# Transporting Alberta's Oil Sands Products:

# Defining the Issues and Assessing the Risks

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## EXECUTIVE SUMMARY

Oil sands are unconventional hydrocarbon deposits that consist of clay, sand, water, and a highly viscous oil known as bitumen. Over the past decade, extracting bitumen from oil sands has become profitable as oil prices have increased and extraction technologies improved. With the rapid growth of oil sands products in Alberta, production is expected to grow from 1.25 million barrels per day (mbl/d) in 2011 to around 3.75 mbl/d by 2030. The majority of oil sands products transported to market will be via existing and proposed pipelines; however, a sharp increase in the use of rail and marine transport can be expected while new pipelines are constructed to match the increasing production of oil sands products.

Alberta bitumen owes its high viscosity and density to its developmental history. These deposits began as standard crude oil reserves but during development the reservoirs never exceeded 80°C, meaning pasteurization did not occur. Therefore, when the conditions were correct, microorganisms began attacking and consuming the smaller molecules leaving only the large molecules that give bitumen its characteristic physical properties. Bitumen densities range from higher than freshwater to lower, making it difficult to conclude whether the substance would sink (higher) or float (lower).

In order to transport bitumen, a diluent must be added to decrease the viscosity. The most commonly used diluent is natural gas condensate, a liquid byproduct of natural gas processing. Typically the mixture of diluent and bitumen (dilbit) consists of 30% diluent and 70% bitumen. The second method is the use of synthetic crude (synbit). Synbit is bitumen that has undergone partial upgrading, which removes larger molecules through coking and hydrolysis. The mixture of synthetic crude and bitumen tends to be 50% synthetic crude and 50% bitumen. Future projections indicate that the use of synthetic crude will increase while the use of natural gas condensate will remain steady resulting from natural gas condensate's high price and decrease in local availability.

Little research is currently available regarding the behavior of oil sands products in water and the process and outcome of weathering after a spill. The only tests that have been conducted were in a laboratory environment so predicting the actual behavior of oil sands products for a range of spills is not currently possible. While the parent bitumen can be denser than water meaning it would sink, after diluent addition, the density decreases to less than water meaning it would float. The environmental conditions present during a spill such as turbidity, water

salinity,, and mixing with sediments can all affect the potential for the oil sands products to float or sink. Responders to the oil sands product spill into the Kalamazoo River reported the presence of floating oil, submerged oil, and sunken oil. Presently there are several research projects in the planning stages addressing the weathering behavior of oil sands products, but only one study has been published to date.

A highly debated topic with oil sands products is the degree of corrosivity with respect to pipeline transport. Oil sands products tend to be higher in sulfur and total acid number than medium and light crude oils, which can contribute to corrosivity. Preliminary conclusions from ongoing research suggest that oil sands products are not more corrosive than standard crude oils and thus do not pose a increased risk for transmission pipeline corrision.

Environmental and human health risks are another concern associated with oil sands development and transportation. The health of the Athabasca River near the oil sands deposits in Alberta serve as background information which will be referenced during future oil spills. Researchers have found raised levels of priority pollutants in the river below oil sands development which exceed those considered safe for aquatic life, but not levels that exceed those listed as safe for human consumption. However, differentiating between river toxicity from bitumen and that from seepage from tailings ponds is difficult. Fish larvae laid on bitumen contaminated substances did have a high rate of death and many of those that survived displayed physical abnormalities including lesions, hematomas, and unusual growths. Poly aromatic hydrocarbons are also present in high levels in the Athabasca River which could contribute to cancer rates although no conclusive evidence has been shown.

If a spill of oil sands products were to occur, responders will have to prepare for both a light, floating oil depending on the diluent used and the potential for a heavy, submerged or sinking oil. Species of concern for floating oil are any that contact the surface of the water frequently, particularly those that may inhale toxic fumes from the oil sands products or the evaporating diluent. Submerged and sinking oil can affect adult fish as well as fish larvae, species that feed on or come into contact with sediments, and benthic habitats such as coral reefs. For responders and citizens living in the vicinity of a spill, it is important to note that during the response to the Kalamazoo spill elevated benzene levels, a known carcinogen, were observed. Also, bitumen tends to be higher in sulfur which could also affect local populations. The diluent, depending on the type, could pose additional problems as it has a low flash point so it can be

highly flammable after evaporation and may collect in depressions, as the gas is heavier than air. After the Kalamazoo spill, 331 people reported adverse effects including nausea, respiratory distress, and headaches although none required hospitalization.

There have been only two major spills of oil sands products. In 2007, synthetic crude spilled in Burnaby, B.C. after a pipeline ruptured. The second, in 2010, was a dilbit spill in Marshall, Michigan. Again, a pipeline rupture led to dilbit spilling into the Kalamazoo River. The spilled dilbit initially floated and then went on to sink to the bottom of the river as well as submerge in the water column. The response efforts in Burnaby B.C. were relatively successful whereas the Kalamazoo spill's response effort was extremely challenging. The clean up effort is still occurring in the Kalamazoo River as of March 2013. In both spills, the failure to follow standard emergency shutdown procedures contributed to the intensity of the oil spill.

Planning response to a spill of oil sands product is difficult as it is not enough data exisit to predict whether it will float, submerge or sink. As of now, the ability to detect, monitor, contain, and recover submerged or sunken oil is limited. In addition, it is difficult to interpret the national or regional capacity to respond to a submerged or sunken oil spill as the equipment lists are missing vital processing information. Research and development is currently being conducted to design equipment for responding to a sinking or submerged oil spill.

Regulations and standards governing oil spills can largely be divided into two related categories—requirements for preparing for oil spills and requirements for responding to oil spills. For oil sands products, a number of gaps in regulations currently exist. Two important gaps are the exemption of oil sands products from an excise tax and the lack of specific information required by facilities and transporters regarding the oil product they are handling. There are additional gaps in policies and regulations that warrant attention as transport of oil sands products increases. The Federal Railroad Administration has traditionally spent little time on the oversight of oil spill planning. Large oil spills in rail transport have not generally been a threat until recent years, during which oil transport via rail has significantly increased. There is also concern that the recently drafted PHMSA contingency plans for pipelines are not well integrated with regional and area plan as required. In addition, while many current regulations give agencies the authority to effectively regulate bitumen products, problems can arise from a lack of resources and experience dealing with potentially non-floating oils.

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## Acronyms

| | |
|---|---|
| ACP | Area Contingency Plan |
| API | American Petroleum Institute |
| ATM | Unit of Atmospheric Pressure |
| Bbl | Barrels |
| BNSF | Burlington Northern Santa Fe |
| BS&W | Water Content Measure |
| CAPP | Canadian Association of Petroleum Producers |
| CN | Canadian National Railway |
| CNOOC | Chinese National Offshore Oil Corporation |
| COFR | Certificates of Financial Responsibility |
| cP | Unit of Viscosity |
| CPR | Canadian Pacific Railway |
| DEP | Maine Department of Environmental Protection |
| DOT | U.S. Department of Transportation |
| EFSEC | Washington's Energy Facility Site Evaluation Council |
| EIA | Energy Information Administration |
| EIS | Environmental Impact Statement |
| EPA | U.S. Environmental Protection Agency |
| ESA | Endangered Species Act |
| EU | European Union |
| FOSC | Federal On-Scene Coordinators |
| FRA | Federal Railroad Administration |
| FRP | Facility Response Plans |
| FWCA | Fish and Wildlife Coordination Act |
| Gal | Gallons |
| GCDWQ | Guidelines for Canadian Drinking Water |
| CDP | Gross Domestic Product |
| GHG | Greenhouse Gases |
| HCA | High Consequence Area |
| IEA | International Energy Agency |
| IM | Integrity Management |
| IRS | U.S. Internal Revenue Services |
| JCP | Joint Marine Pollution Contingency |
| KOH | Potassium Hydroxide |
| LDS | Leak Detection Systems |
| MARPOL | International Convention for the Prevention of Pollution From Ships |
| MLV | Main Line Valve |
| MMBO | Million Barrels of Oil. |
| MPC | Marine Pollution Control |
| MSDS | Material Safety Data Sheets |
| NCP | National Contingency Plan |
| NEB | National Energy Board |
| NEPA | National Environmental Policy Act |
| NRT | National Response Team |

| | |
|---|---|
| NOAA | National Oceanic and Atmospheric Administration |
| NPFC | U.S. Coast Guard National Pollution Funds Center |
| NPRA | National Petrochemical and Refiners Association |
| NRDC | National Resources Defense Council |
| NSFCC | National Strike Force Coordination Center |
| NTSB | National Transportation Safety Board |
| NWACP | Northwest Area Contingency Plan |
| OGJ | Oil & Gas Journal |
| OPA | Oil Pollution Act |
| OPS | Office of Pipeline Safety |
| OSC | On-scene coordinator |
| OSHA | Occupational Safety and Health Administration |
| OSLTF | Oil Spill Liability and Trust Fund |
| PAC | Polycyclic Aromatic Compounds |
| PADD | Petroleum Administration for Defense District |
| PAH | Polycyclic Aromatic Hydrocarbon |
| PHMSA | Pipeline and Hazardous Materials Safety Administration |
| PPE | Priority Pollutants |
| QI | Qualified Individual |
| RAC | Railway Association of Canada |
| RAMP | Regional Aquatics Monitoring Program |
| ROVs | Remotely Operated Underwater Vehicles |
| RRT | Regional Response Team |
| SARA | Superfund Amendments and Reauthorization Act |
| SCA | Site Certification Agreement |
| SCAT | Shoreline Cleanup and Assessment Technique |
| SCP | Subarea Contingency Plans |
| SINOPEC | China Petrochemical Corporation |
| SOLAS | International Convention for the Safety of Life at Sea |
| SOPEP | Shipboard Oil Pollution Plans |
| TAN | Total Acid Number |
| TM | Trans Mountain |
| UC | Unified Command System |
| USCG | U.S. Coast Guard |
| USFWS | U.S. Fish and Wildlife Service |
| USGS | U.S. Geological Survey |
| WRRL | Western Response Resource List |

# 1 BACKGROUND

## 1.1 Introduction to Oil Sands

Oil sands are unconventional hydrocarbon deposits that consist of clay, sand, water, and a highly viscous oil known as bitumen. According to the U.S. Geological Survey (2006), oil sands is a "generic term that has been used for several decades" to describe this type of hydrocarbon deposit." Extracting bitumen from oil sands was previously uneconomical as bitumen is more difficult to extract and transport than conventional crudes due to its thick consistency and the need to dilute the oil for it to flow through pipelines. Over the past decade, extracting bitumen from oil sands has become profitable as oil prices have increased and extraction technologies improved.

The dramatic increase in the extraction of bitumen from oil sands deposits in Alberta is just one part of a larger movement towards development of unconventional oils—those oils not extracted through conventional oil wells. According to the Department of Energy, unconventional oils are those that fall into one of three categories:

1. Petroleum-like material produced through heating the kerogen from oil shale deposits;
2. Bitumen extracted from oil sand deposits;
3. Low gravity crude oil from conventional reservoirs, but require heat for production.

Although conventional oils were historically less expensive to bring to market, extraction technologies have drastically reduced the price of producing unconventional oils—the production of the Alberta oil sands is just one example.

In this report we examine the issues associated with the transport of products from Alberta's oil sands through the U.S., focusing on how this increased activity might change the

spill risks in various ways. We begin with an introduction to oil sands development and transportation, highlighting the economic drivers of that development and the environmental impacts in Alberta. The bulk of the report focuses in on a number of key issues, including a summary of past and projected spills of dilbit and other oil sands products; a detailed outline of where oil sands products are being transported; the chemical and physical properties of oil sands products; an introduction to potential environmental and human health impacts of oil sands products; an outline of risk mitigation approaches in oil transport, planning, and spill response; and a summary of the regulations pertinent to oil transport and spills. We conclude with a section that summarizes the gaps in information, research, and policy that we have uncovered throughout our research related to oil sands transport and oil spills in general, with some recommendations for how policymakers, researchers, and stakeholders might proceed in the future.

| **Common Oil Sands Terms[1]** | |
|---|---|
| **Oil Sands or Tar Sands[2]** | Used synonymously, the combination of bitumen, clay, sand, and water. EIA (2013): "Naturally occurring bitumen-impregnated sands that yield mixtures of liquid hydrocarbon and that require further processing other than mechanical blending before becoming finished petroleum products." |
| **Bitumen** | A semi-solid or solid petroleum deposit. Thick like molasses at room temperature, it must be heated or diluted with lighter hydrocarbons to flow (ENE, 2009). |
| **Diluent** | Any "lighter viscosity petroleum products that are used to dilute bitumen for transportation in pipelines (CAPP, 2012). |
| **Synthetic Crude** | Also syncrude or SCO, according to CAPP (2012), "a mixture of hydrocarbons, similar to crude oil, derived by upgrading bitumen from oil sands." |
| **Dilbit** | Short for diluted bitumen, bitumen combined with any diluent for transport. |
| **Synbit/Dilsynbit** | Bitumen combined with synthetic crude/and synbit combined with a diluent. |
| **Oil Sands Products** | A term we use to describe products derived from oil sands, including bitumen, diluted bitumen, synthetic crude, synbit, and dilsynbit. |

Table 1-1: Common Oil Sands Terms

[1] For a full glossary of oil sands terminology, visit: http://www.energy.alberta.ca/OilSands/1708.asp
[2] Oil sands and tar sands mean the same thing. They are used by different groups in order to frame the issue politically. We chose to use oil sands and oil sands products throughout this report for consistency and because it is more scientifically correct.

### 1.1.1 Reserves

Twenty-three countries have known deposits of oil sands. The largest reserves are located in three major deposits in northern Alberta, Canada—the Athabasca, Cold Lake, and Peace River deposits. The Government of Alberta estimates its total reserves of bitumen at approximately 170 billion barrels (CAPP, 2012). Significant reserves also exist in Venezuela and Russia. U.S. reserves are minimal in comparison but contain twenty-nine accumulations totaling 36,000 MMBO[3] (USGS, 2006).

As of February 2013, bitumen is not being produced at the same quantity, quality, or with the same product specifications anywhere else in the world. However, there are three other countries that are producing products or will soon produce products similar to Canada's dilbit and synbit:

- *Venezuela*: Venezuela has bitumen reserves estimated to be 513 billion barrels of recoverable oil located in the Orinoco Belt (USGS, 2009). Orimulsion is Venezuela's bitumen-based fuel, which consists of bitumen, 30 percent fresh water, and a small amount of surfactant (Rayaprolu, 2013). Orimulsion is not a homogenized mixture and the bitumen drops out of suspension when left undisturbed for an extended period of time (Rayaprolu, 2013). Orimulsion is not being exported to the United States, and Venezuela continues to decrease its orimulsion program due to political volatility (Rayaprolu, 2013).
- *Kazakhstan*: Russian oil company Gazprom Neft purchased a bitumen production facility in Kazakhstan in January of 2013. The facility has an annual production capacity of 280,000 tons (Energy Resources, 2013).
- *Russia*: Russian oil company Gazprom Neft is investing $446 million in renovating the Moscow Oil Refinery to refine bitumen, which is expected to produce up to 1.7 million tons of refined product a year (Moscow Times, 2012).

[3] MMBO, million barrels of oil.

### 1.1.2 Production of Oil Sands Products

Oil sands products are produced in two ways: surface mining and in situ recovery. The method used depends on the proximity of the deposit to the surface. Surface mining is used for deposits within 75 meters of the surface and requires the clearing of trees and topsoil before removing the oil sand deposits using trucks and shovels. After removal, the oil sands are trucked to an on-site processing facility to remove bitumen from sand and clay. Historically, surface mining has been the predominant method, but its share of production will significantly decline in the near future, as nearly 80 percent of reserves are too deep to mine (Energy Information Administration, 2013). The second method of production, in situ recovery, refers to a method where two wells are drilled, one for a steam or solvent injection pipe and another to pump the separated bitumen to the surface. The steam separates the bitumen and also lowers the viscosity making it easier to pump to the surface, where it is blended with a diluent and transported via pipeline to an upgrading facility (NPR, 2012).

#### *1.1.2.1 Extraction and Upgrading*

Extraction separates the bitumen from the oil sands. In-situ extraction uses steam to separate the bitumen while mining requires an additional step at an extraction facility. Here the oil sands are mixed with hot water—creating a slurry—and separated into sand, water, and bitumen and sent to a primary upgrading facility by pipeline (NPR, 2012). According to the Energy Information Administration (EIA), "in order to flow in a pipeline, the bitumen must be diluted with condensate or other light oils or 'upgraded' by complex processing units into a light, sweet 'synthetic' crude oil (SCO). Upgrading is "the process by which heavy oil and bitumen are converted into lighter crude by increasing the ratio of hydrogen to carbon, normally using either

coking or hydroprocessing"—and normally occurs in two steps according to Alberta Energy (2012).

Of all the crude oil and equivalent production in Canada in 2011, roughly 28 percent was synthetic crude oil and 25 percent was non-upgraded crude bitumen" (EIA, 2012). There are currently five upgrading facilities in Alberta where oil sands products were upgraded to synthetic crude oil in 2011, according to Alberta Energy (Alberta Energy, 2012). Maps and information on oil sands deposits, extraction, and upgrading facilities can be found here: http://environment.alberta.ca/apps/osip/

## 1.2 The Economics of Oil Sands Products

The oil industry has long been aware that large reserves of oil sands exist in Canada and parts of the United States. However, production of oil sands products is a more difficult and expensive process than production of conventional crude oils. The profitability of extracting oil sands products depends on a certain, relatively narrow, range of economic conditions. The price of crude oil needs to remain at or above $65/barrel and possibly as high as $95/barrel in order for oil sands products to be profitable (Reuter, Cogan, Sasarean, Lopez Alcala, & Koehler, 2010). As conventional sources of crude oil have become scarcer and extraction technologies for oil sands products improved, the cost-benefit equation has changed and made oil sands products a more attractive commodity.

### 1.2.1 Economic Drivers

According to the International Energy Agency (IEA), the global supply of conventional oil already has or will soon peak, and only a dramatic increase in supply from non-conventional oil or renewable sources will prevent significant leaps in oil prices (IEA, 2012). However, little has been done to actually retool how economic systems work to reduce our dependency on oil,

and until renewable sources are further developed and become commonly available as the status quo, the economic forces driving the extraction and refinement of oil sands remain strong.

The United States and Canada both continue to look for ways to achieve North American energy security and independence. According to Alberta Energy—the ministry that oversees Alberta's non-renewable energy resources—Alberta supplies the U.S. with 1.4 million barrels of oil a day from oil sands products (Alberta Energy, 2012). And, although environmental objections have been fierce, it is appealing in importing oil from a neighboring country that is considered more stable and friendlier to U.S. political and economic interests than potentially volatile OPEC countries[4].

### 1.2.2 Main Economic Players on the Supply Side

According to the EIA, "Canada is one of the world's five largest energy producers and is the principal source of U.S. energy imports (EIA, 2012). [Their] unconventional oil sands products are a significant contributor to the recent and expected growth in the world's liquid fuel supply and comprise the vast majority of the country's proven oil reserves, which rank third globally. According to *Oil & Gas Journal* (*OGJ*), Canada had 173.6 billion barrels of proven oil reserves as of the beginning of 2012. Canada controls the third-largest amount of proven reserves in the world, after Saudi Arabia and Venezuela." (EIA, 2013; Reuter et al., 2010). The Canadian government, on both a national and provincial scale, stands to increase GDP significantly by developing these resources. Canadian oil companies Enbridge, Suncor, and Nexen are all heavily involved in the process (Reuters, 2012). American oil companies Exxon Mobil (Exxon Mobil also owns Imperial Oil and Esso), Shell, Conoco-Phillips, and Chevron are also invested in Canadian oil sands products.

[4] Organization of the Petroleum Exporting Countries

Chinese state-owned oil companies SINOPEC, the China National Petroleum Corp. (parent company of Petro-China), and the Chinese National Offshore Oil Corporation (CNOOC) are increasing their presence in Alberta (The Economist, 2012). Since 2005, CNOOC has been acquiring minority interests in Canadian oil companies, and recently acquired Calgary-based Nexen outright[5] (Reuters, 2012; Armstrong, 2012). The U.S., China, and Canada currently comprise the major industrial stakeholders in Canadian oil sands deposits, but others may emerge on a smaller scale. For a more comprehensive list of the oil sands products major players, see the stakeholder list in Appendix 1.

### 1.2.3 The Main Economic Players on the Demand Side

After extraction, bitumen may be blended with lighter grades of crude oil and is not typically identified as oil sands products when transported (Owens, 2012). However, several major markets are receiving the majority of the oil sands products oil coming out of Canada. The first is the United States. According to Alberta Energy, the U.S. buys 2.5 million barrels of oil from Canada per day (Alberta Energy, 2012). For perspective, those 2.5 million barrels per day accounts for 18.2 percent of total U.S. oil consumption, more than the 11 percent that the U.S. imports annually from Saudi Arabia (Consumer Energy Report, 2012).

The other primary markets for oil sands products oil are in Asia (Gunn, Foschi, & Sexsmith, 2012) and potentially Europe, although these supply lines are still less developed. China has shown interest in Canadian oil development, and has already invested heavily in oil development capacity in Alberta. Additionally, Canada's Prime Minister Harper has spoken openly about diversifying Canada's export of oil to Asian markets, and although it is still a relatively small piece of the total exports, some tankers already carry Canadian oil to china from

[5] Final negotiations went through on 2/ 26. $15.1 billion deal approved.

Canada's west coast (Austen, 2011). As new terminals go online—like the one planned for Kitimat, B.C.—the transport of oil sands products through U.S. and Canadian waters will increase dramatically. According to a presentation given to investors by Ian Anderson, the President of Kinder Morgan's Canada Group, tanker traffic in Port Metro Vancouver alone could increase to 288 annually by 2016, up from only 71 in 2010 (Anderson, 2011). On the U.S. side of the border, tanker traffic in the Strait of Juan de Fuca is predicted by Kinder Morgan to increase from 4 tankers to 6 tankers daily, with a total increase of 500 tankers annually in the region (Kinder Morgan, 2013a). Other sources have also estimated as many as an additional 500 tankers a year moving through Puget Sound[6] (Luk, 2012). While Europe is a major oil importer, the European Union (EU) has been reluctant to open itself to oil sands products (Carrington, 2012). In February 2012, the EU held a vote to determine if oil sands products should be labeled more polluting, which would have made them an infeasible energy source under current climate policies. The vote ended in a stalemate and it seems likely that Canadian lobbyists trying to open trade of oil sands products to Europe will continue to face resistance (Carrington, 2012).

### 1.2.4 Who Benefits?

Oil companies enjoy significant profits from oil sands products. The oil industry, including American oil giants Exxon Mobil, Conoco Philips, and Chevron have already invested significant resources and plan to invest an additional $120 billion over the next decade (Rainforest Action Network, 2012). As conventional crudes become scarcer, there is increased probability that oil prices will rise significantly, which may cause people to pursue alternatives more aggressively. This scenario could equate to massive financial losses and economic

[6] This increase is dependent on the approval and construction of the Enbridge Northern Gateway pipeline. According to some sources it is also contingent on additional new ports that would be built because of the new pipeline system, but according to Kinder Morgan the capacity already exists.

depression if the oil industry cannot adapt (Reuter et al., 2010). Developing Canada's oil sands products reserves is one way that the industry is keeping up with demand and prolonging its ability to provide relatively cheap energy at a profitable level, but its success is not guaranteed.

The Canadian national and provincial governments stand to gain from developing oil sands reserves, something that the current Conservative Party Prime Minister, Stephen Harper has made a national priority. Canada's economy benefits from revenues brought in by becoming a significant oil exporter. At the provincial level, Alberta will reap the majority of the financial rewards, although there have been some disputes between Alberta and British Columbia over potential royalties B.C. would receive for allowing pipelines to cross the province. Twice, in 2010 and again in 2012 B.C. municipal politicians have voted against the Enbridge Northern Gateway pipeline project, expressing feelings that while it may benefit Ottawa and Alberta, B.C. stands to gain little and bears most of the environmental risks (Market Wire, 2010; Huffington Post, 2012). Mining areas like Fort McMurray have also experienced significant economic growth from the development of oil sands products.

Additionally, the United States also stands to benefit from oil sands products development. According to Alberta Energy, for every two jobs created in Canada from oil sands products extraction, a third is created in the U.S. (Alberta Energy, 2012). Alberta Energy claims "oil sands development is projected to generate $521 billion in economic activity in the U.S. over the next 25 years" (Alberta Energy, 2012).

### 1.2.5 Economic Trade-offs

Although the numbers differ depending on the source, it is clear that there are significant economic benefits associated with developing oil sands products. The dramatic increase in production has turned places like Fort McMurray into boom towns, and has had wide reaching

economic impacts through job creation, increased Canadian GDP, and large injections of revenue into the budgets of the federal, provincial, and local governments at a value estimated to be in the billions of Canadian dollars (Timilsina, LeBlanc, & Walden, 2005). However, these monetary gains must be weighed against the negative economic impacts and environmental costs associated with bitumen extraction and potential spills (Skinner & Sweeney, 2012).

## 1.3 Environmental Impact of Oil Sands Products

Development of oil sands products results in a higher number of negative environmental impacts when compared to lighter crude oils. Heavier forms of oil like bitumen require more energy for extraction and processing, resulting in higher greenhouse gas emissions. In addition, oil sands extraction is more disruptive than conventional extraction techniques, leading to significant local impacts in water use, land use, and on wildlife.[7]

### 1.3.1 Greenhouse Gas Emissions

Although all fossil fuel development results in greenhouse gas emissions—primarily carbon dioxide and methane—production of oil sands products has higher emissions intensity. A number of studies have analyzed the overall emissions associated with oil sands products in comparison to other crude oils from a lifecycle perspective.[8] These analyses come in two categories, 'well-to-wheel' and 'well-to-tank'. Well-to-wheel life-cycle assessments consider emissions from extraction, transportation, upgrading and refining, distribution, and combustion while well-to-tank assessments focus on production and extraction. A survey of these studies by

[7] In addition, all crude spills pose potential environmental and health risks. Some organizations have expressed concern over the possible negative impacts of the diluents blended with oil sands in the event of a spill, namely higher exposure to hydrogen sulfide, benzene, and other toxins that affect humans and wildlife. These impacts are discussed below in section 6.

[8] See Alberta Energy Research Institute/Jacobs Consultancy, Life Cycle Assessment Comparison of North American and Imported Crudes, 2009; Alberta Energy Research Institute/TIAX LLC, Comparison of North American and Imported Crude Oil Lifecycle GHG Emissions, 2009; National Energy Technology Laboratory, Development of Baseline Data and Assessment of Life Cycle Greenhouse Gas Emissions of Petroleum-Based Fuels, November 26, 2008; National Energy Technology Laboratory, An Evaluation of the Extraction, Transport and Refining of Imported Crude Oils and the Impact of Life Cycle Greenhouse Gas Emissions, March 27, 2009.

the Congressional Research Service found that Canadian oil sands products emit on average 14-20 percent (well-to-wheel) and 72-111 percent (well-to-tank) more greenhouse gases (GHG) than crudes they would displace in U.S. refineries (Lattanzio, 2012). The higher emissions intensity stems from two sources:

1. *Mining*: mining oil sands products requires more energy-intensive methods and in-situ methods use natural gas to heat steam; and
2. *Extraction and Processing*: extracting oil sands products requires more energy-intensive methods due to bitumen's high viscosity.

### 1.3.2 Water-Use Impacts and Tailing Ponds

One of the most pertinent local environmental concerns is water use and disposal. The extraction and processing of oil sands products requires large quantities of water, particularly in surface mining operations. A barrel of oil requires approximately 3.1 barrels of net fresh water for mining and 0.5 barrels for in-situ (CAPP, 2012). After extraction, bitumen is separated from sand and clay by mixing it with warm water—and the water, clay, sand, and leftover oil (tailings) is moved to large storage ponds (CAPP, 2012). There are concerns around potential negative impacts on aquatic ecosystems from large tailings ponds and removal of water from the watershed (Birn & Khanna, 2010).

Like all mining techniques, surface mining for oil sands generates tailings after separating the bitumen. The tailings—water, sand, clay, and residual bitumen—are sent to a 'tailings pond' to be recycled. The tailings are placed in large pools that allow sediment to settle, which can take years, and the water skimmed off and reused. It is currently estimated that tailings ponds encompass an area of over 130 $km^2$ in Alberta. A number of studies argue that the Government of Alberta's efforts to manage the tailings ponds have been unsuccessful and that leakage, or 'seepage,' of toxic chemicals continues to happen at a high rate. A 2010 study

showed that the oil sands industry "releases 13 elements considered priority pollutants (PPE) under the U.S. Environmental Protection Agency's Clean Water Act, via air and water, to the Athabasca River and its watershed"—seven of which exceeded Canadian standards for an aquatic environment (Kelly et al., 2010).

### 1.3.3 Land-Use and Wildlife Impacts

The Canadian oil sands reserves are located within Canada's boreal forest, part of the largest terrestrial ecosystem in the world. Like water-use, land-use impacts differ based on in situ extraction versus surface mining operations, but both have negative implications for the land. Mining necessitates the removal of vegetation and topsoil; and the topsoil is then stored for later use in the reclamation process. In situ extraction has a smaller footprint but still requires the construction of roads, pipelines, well pads, and facilities. According to the National Energy Board, "the proposed future reclaimed landscape will be significantly different—with 10 percent less wetlands, more lakes, and no peatlands." The government of Alberta requires companies to restore land to at least its previous biological productivity but reclamation requires a long time investment and its long-term success is still the subject of debate.

Wildlife organizations like the National Wildlife Federation argue that oil sands production has disrupted caribou and moose populations, with populations around Fort McKay decreasing 70 percent and 60 percent, respectively (NWF, 2012). For birds, the warm tailing ponds provide an open but harmful body of water during the spring migration season when other bodies of water remain frozen, resulting in large numbers of bird deaths each year (Timoney & Lee, 2009).

## 1.4 Mode of Transporting Crude Oil in North America

The energy sector in North America transports various crude oil, petroleum and natural gas products from source (e.g., wells) to destination (e.g. refineries and industrial complexes). This section briefly describes various modes of transporting oil sands products from source to destination. Canada has been the main supplier of crude oil products to the U.S. since 2010, with the U.S. importing an average of 2.5 million barrels per day (mbl/d) or 27 percent of total U.S. imports (EIA, 2013).

With the rapid growth of oil sands products in Alberta, production is expected to grow from 1.25 million barrels per day (mbl/d) in 2011 to around 3.75 mbl/d by 2030, an average annual growth rate of 11.5 percent (Canadian Province of Alberta [AB], 2012; Canadian Association of Petroleum Producers [CAPP], 2012). The majority of oil sands products transported to market will be via existing and proposed pipelines; however, a sharp increase in the use of rail can be expected while new pipelines are constructed to match the increasing production of oil sands products (CAPP, 2012; CNEB, 2009; CNEB, 2006).

The U.S. Department of Energy has divided the U.S into five regions for planning purposes (Figure 1-1). Each region is called a petroleum administration for defense district (PADD). As of the 3rd quarter of 2012, the U.S. PADD II region was the largest recipient with 1.6 mdl/d (71 percent), followed by PADD IV (11 percent), PADD V (9 percent), PADD I (5 percent) and PADD III (4 percent) (EIA, 2013; CNEB, 2012). The largest markets for synthetic crude oil in the U.S. were PADD II (76 percent) and PADD V (12 percent), while the largest markets for blended bitumen were PADD II (79 percent) and PADD III (10 percent) (EIA, 2013; CNEB, 2012).

Figure 1-1: US DOE EIA: Petroleum Administration for Defense Districts

### 1.4.1 Major Crude Oil Pipeline Networks in North America

#### *1.4.1.1 Existing Networks of Crude Pipelines*

Canada's main pipelines include Enbridge's Mainline, Kinder Morgan's Trans Mountain, and Kinder Morgan's Express pipeline. This pipeline network has a capacity of roughly 3.5 million barrels per day (mbl/d) (Table 1-2) and runs through much of North America, connecting Canadian oil fields to transit ports and refineries in Canada and the U.S. (Figure 1-2) (CAPP, 2012; CNEB, 2009).

The Enbridge system in Canada combined with the Lakehead system in the U.S. is the world's largest crude oil pipeline network (CAPP, 2012; CNEB, 2009). This network is the primary transporter of crude oil from western Canada to markets in eastern Canada and the U.S. Midwest for regional consumption and transfer to the other PADD regions. The system currently delivers about 2.1 mbl/d of crude oil products, including oil sands products, and after future

expansion this capacity could increase to 3.5 mbl/d by 2020 (subject to approval of Keystone XL pipeline in the U.S. Midwest – refer to section 4.1.1.3 for more information). The mainline originates at Edmonton, Alberta and meets with the US Lakehead system at Sarnia, Ontario (CAPP, 2012; CNEB, 2009).

The Kinder Morgan Express pipeline supports refineries in the U.S. West. The Express Pipeline system is a batch-mode, in which the shipper receives the exact blend that it tendered for transport, and is comprised of the Express Pipeline and the Platte Pipeline. It connects Canadian and U.S. crude oil producers to refineries in PADD IV. The pipeline originates at Hardisty, Alberta, and terminates in Casper, Wyoming with capacity of 0.28 mbl/d (CAPP, 2012).

The Kinder Morgan Trans Mountain pipeline system, which directly affects Washington State's energy portfolio, connects Alberta's oil to the Pacific Coast for use by U.S. refineries and export to Asian markets. The Trans Mountain pipeline transports crude oil and petroleum products from Edmonton, Alberta, to Vancouver, British Columbia, and an offshore terminal via the Westridge Docks in British Columbia for customers in U.S. PADD V region and Asian markets, primarily China and Japan with current capacity of 0.30 mbl/d (CNEB, 2009).

A subsection of the Enbridge pipeline network connects Canadian crude oil products from Sarnia, Ontario to Montreal, Quebec and from there to Portland, ME for customers in U.S. PADD I (CAPP, 2012).

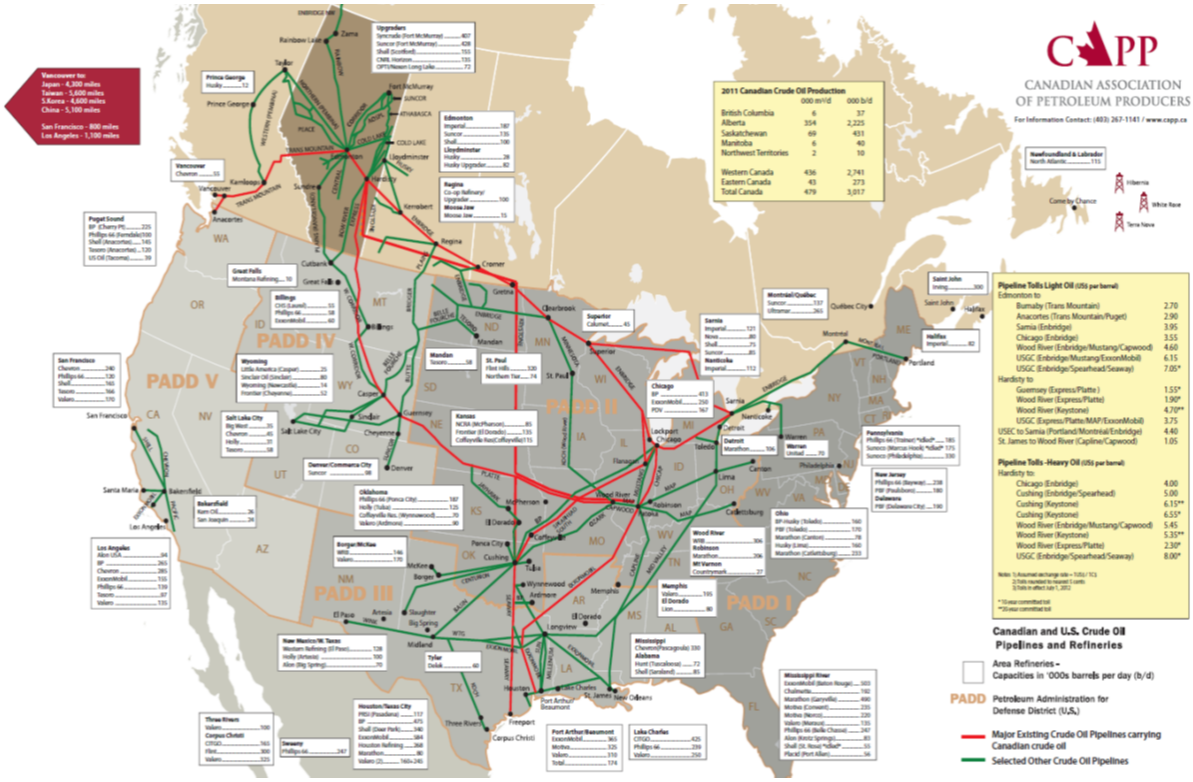


Figure 1-2: Existing North American Crude Oil Pipeline Network

| Pipeline Network | Crude Type | Capacity (mbl/d) | |
|---|---|---|---|
| **Enbridge** | Light | 1.08 | 2.33 |
| | Heavy | 1.25 | |
| **TransCanada** | Light / Heavy (25% / 75%) | 0.59 | |
| **Kinder Morgan Trans Mountain** | Light / Heavy (80% / 20%) | 0.30 | |
| **Kinder Morgan Express** | Light / Heavy (35%/ 65%) | 0.28 | |
| **Total Existing Capacity** | | **3.50** | |

Table 1-2: North America's Existing Crude Oil Pipeline Network

### *1.4.1.2 Proposed Crude Oil and Bitumen Pipelines*

The U.S. and Canadian pipeline industry is currently working on many expansion proposals and construction projects (dotted lines in Figure 1-3) that will increase the current networks capacity by 61 percent to approximately 5.6 mbl/d (Table 1-3). The proposed Enbridge Southern Lights, Enbridge Northern Gateway, and Kinder Morgan Cochin Conversion are

intended to transfer increased Canadian crude oil export to markets in North American and Asia (CAPP, 2012; CNEB, 2009).

Figure 1-3: North American Crude Oil Pipeline – Existing + Proposed

| Pipeline | Crude Type | Capacity (mbl/d) | Origin | Destination | Consumer Markets | Year Active |
|---|---|---|---|---|---|---|
| **TransCanada Keystone XL** | Light / Heavy / Diluent | 0.33 | Hardisty, AB | Steele City, NE | PADD III | 2016 |
| | | 0.55 | Cushing, OK | Nederland, TX | PADD III | 2014 |
| **Enbridge Northern Gateway** | Heavy / Diluent | 0.53 | Kitimat, BC | Edmonton, AB | Asia | 2017 |
| **Kinder Morgan Trans Mountain Expansion** | Heavy | 0.45 | Edmonton, AB | Burnaby, BC | PADD V Asia | 2017 |

| Pipeline | Crude Type | Capacity (mbl/d) | Origin | Destination | Consumer Markets | Year Active |
|---|---|---|---|---|---|---|
| **Enbridge Alberta Clipper & Southern Light Expansion** | Heavy / Diluent | 0.12 | Flanagan, IL | Edmonton, AB | PADD II | 2014 |
| **Enbridge Line 9 Reversal** | Light / Heavy / Diluent | 0.10 | Montréal, Québec | Sarnia, ON | PADD I Europe | 2014 |
| **Kinder Morgan Cochin Conversion** | Diluent | 0.07 | Kankakee County, IL | Fort Saskatchewan, AB | Alberta | 2014 |
| **Total Proposed Capacity** | | **2.15** | | | | |

Table 1-3: North America's Proposed Crude Oil Pipeline Expansion

### 1.4.2 Transport of Oil Sands Products via Rail

Rail is becoming an increasingly larger proportion of the crude oil transportation network because companies can increase their carrying capacity relatively quickly by buying more railcars—and because the freight rail infrastructure is already in place throughout North America. Rail transport of all types of crude oil products has increased roughly 55 percent between March of 2011 and March of 2012 (Table 1-4) (CN, 2012). Rail could provide a short-term alternative to pipelines, as it allows companies to increase production and transportation without investing in significant new infrastructure; however, due to its logistical limitations, it remains to be seen how much of crude oil transport will be done by rail in the long term.

| Date | Rail Cars (#) | Weight (Metric Tons) |
|---|---|---|
| **March-12** | 8,823 | 707,647 |
| **March-11** | 5,602 | 458,696 |
| **Growth Rate** | **57%** | **54%** |

Table 1-4: Growth in use of Rail for Transportation of Crude Oil in North America

Canada's two major rail companies, Canadian National (CN) and Canadian Pacific (CPR), are in position to take advantage of increased oil production in Alberta. Both companies

have track as far north as the Alberta oil sands fields and are already major transporters of mining and in situ extraction supplies for the oil companies. CN and CPR have an extensive North American network that could support transport of crude products from the source to refineries and shipping ports (Figures Figure **1-4**, Figure **1-5**, Figure **1-6**, Figure **1-7**) (CN, 2012; CPR, 2012).

In anticipation of the growth in transportation volume, rail companies are studying several options to reduce their transportation costs and increase the effectiveness of rail transport as an alternate to pipelines. These include (CAPP, 2012):

- Test runs transporting light crude and condensate from California, Texas, and Louisiana.
- The potential of using heated rail cars to transport non-upgraded bitumen that could then be blended to specifications at terminals near the destination refineries. Heated railcars would allow for speedier loading and unloading of high viscosity oil sands products
- The transportation of Alberta oil sands products by electric rail to an existing marine terminal at Valdez, Alaska for Asian markets.

Figure 1-4: Canadian National Rail (CN) Network

Figure 1-5: Canadian National Rail (CN) Northern Alberta Connection

Figure 1-6: Canadian Pacific Rail (CPR) Network

Figure 1-7: Canadian Pacific Rail (CPR) Alberta Connections

### 1.4.3 Transport of Oil Sands Products via Waterways

In anticipation of tremendous growth in the production and transportation of oil sands products and due to uncertainties in development of new pipelines, oil transport companies are

exploring the option of shipping oil sands products via barges through North American waterway networks, specifically the Mississippi River for U.S. PADD II and III markets (Break Bulk I, 2011; Break Bulk II, 2011; Gabriela Alcocer; Seana Lanigan, 2012). The option of using barges in North American waterways would most likely be a viable alternative on the Pacific Coast (e.g., Puget Sound) and the Great Lakes region where waterway distances between crude terminal and refineries are relatively short (Jensen & Pilkey-Jarvis, 2012). There are currently shipments of heavy and extra heavy crude oil products via barges from terminals in British Columbia to Puget Sound refineries in Anacortes and Tacoma (Figure 1-8) (Jensen & Pilkey-Jarvis, 2012).

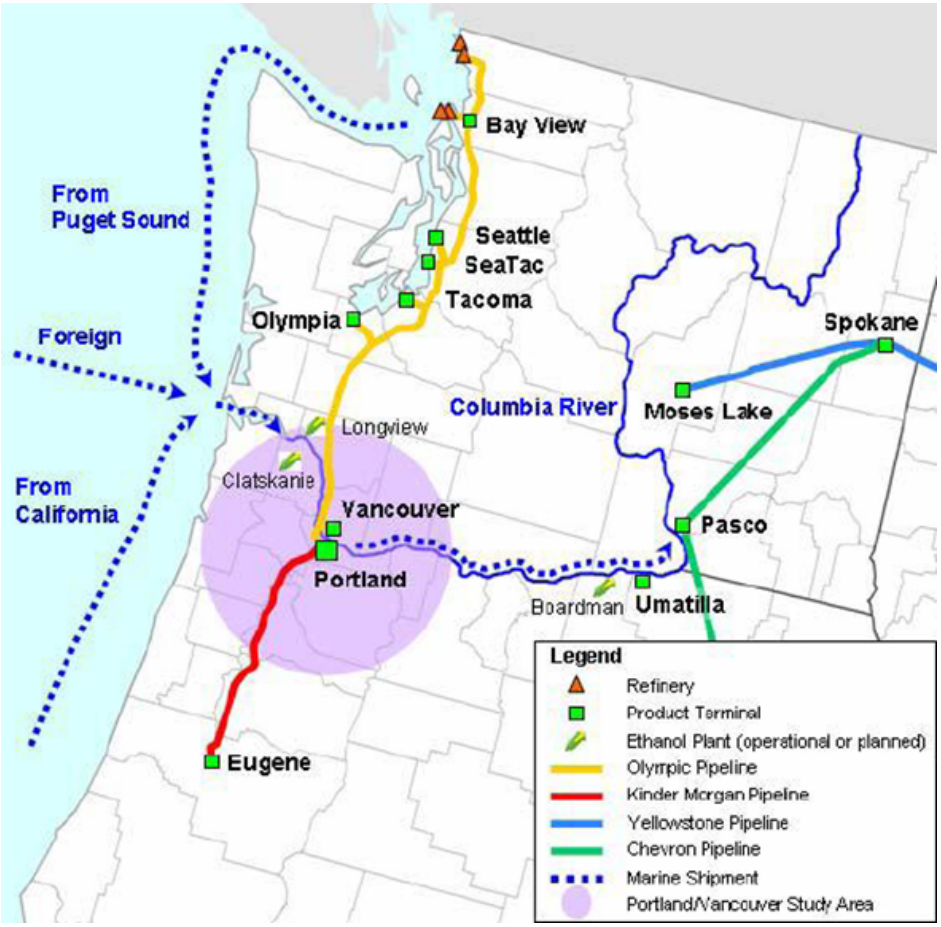


Figure 1-8: WA Department of Ecology: Marine and Pipeline Routes in Puget Sound Region

# 2 SPILLS OF DILUTED BITUMEN

Four significant spills of diluted bitumen have occurred in the U.S. and Canada over the past two and a half years. These include spills on Enbridge pipelines in Michigan and Illinois, a Kinder Morgan Canada pipeline spill in Burnaby, B.C., and one spill at a TransCanada operated Keystone Pipeline pump station in North Dakota. Further information on the Enbridge Michigan and the Kinder Morgan Burnaby spills and response efforts are provided in section 7.2.

## 2.1 Recent Spills of Diluted Bitumen Oil

### 2.1.1 Marshall, Michigan Enbridge Spill

The largest dilbit spill, and largest inland oil spill in U.S. history, occurred on Enbridge's Line 6B pipeline on July 25, 2010 in Marshall, Michigan (Young, 2012). Line 6B is a 293-mile section of the Lakehead system, which originates in Edmonton, Alberta. The rupture was not discovered for more than 17 hours and the total release was estimated to be 20,082 barrels (bbl)[9] of dilbit (NTSB, 2010). The rupture in the line measured 6 feet 8.25 inches in length and 5.32 inches at maximum width (NTSB, 2010). Of the total oil that spilled, 8,033 bbl reached Talmadge Creek and the Kalamazoo River (Enbridge, 2012a).

Notably, Enbridge did not initially report that the pipeline was carrying dilbit, and according to media outlets one Enbridge executive denied that the pipeline was carrying oil sands products (Lydersen, 2010). Disclosure of this information is not required, and thus it took more than a week for federal and local officials to discover they were dealing with a dilbit spill (McGowan & Song, 2010).

[9] 1 barrel (bbl) of oil=42 gallons (gal)

The U.S. Environmental Protection Agency (EPA) mobilized an Incident Management Team in response to the spill that included federal, state, and local agencies. The EPA reports that the spill was contained on July 28, 2010 about 80 miles from Lake Michigan and estimates that 27,359 bbl of oil have been recovered as of October 22, 2012 although the official estimated spill release was reported to be only 20,082 bbl (EPA, 2012; NTSB, 2012). Although large-scale cleanup was ongoing as of this report, the estimated response costs, including the role of the federal government in cleanup, were about $767 million as of October 31, 2011 (NTSB, 2012). Evaluations of air, water, and fish are ongoing. While no impacts on drinking water have been reported and contamination levels of fish were not high enough to trigger fish eating guidelines, an assessment of air contamination is still pending. (MDCH, 2001-2012).

### 2.1.2 Romeoville, Illinois Enbridge Spill

Two months after the spill in Michigan, Enbridge was responsible for another spill on the Lakehead System on Line 6A in Romeoville, Illinois. On September 9, 2010 a rupture resulted in a spill of about 6,095 bbl of dilbit. The spill resulted from a 2.5-inch long puncture on the bottom of the pipeline, likely caused by rocks lodged under the structure, although an official report is yet to be issued (Hood, 2010). As with the Michigan spill, Enbridge press releases describing the pipeline do not explicitly state that it carries dilbit.

The EPA oversaw the spill response with assistance from state and local agencies. The EPA reported the successful completion of its response on October 28, 2010, and transferred the cleanup of contaminated groundwater to the Illinois EPA. In total, the EPA reported in November 2010 that response efforts resulted in about 20,476 bbl of total oily liquids collected—including water and oil (EPA, 2012). Media outlets report that Enbridge cleanup costs for the spill were expected to be $40-$60 million (Huffington Post, 2010).

### 2.1.3 Burnaby, British Columbia, Kinder Morgan

Three years prior to the Enbridge spills in the U.S., there was a spill of approximately 1,400 bbl of synthetic crude oil in British Columbia. On July 24, 2007, a spill resulted from an excavator bucket striking the Westridge Transfer Line in Burnaby, British Columbia during excavation for a new storm sewer line. The pipeline is operated by Kinder Morgan Canada and is owned by Trans Mountain Pipeline L.P. It runs from the Burnaby terminal to the Westridge Dock, where it delivers oil to tankers (TSB, 2008a).

The oil flowed from the ruptured line into Burnaby's storm sewer systems until it reached the Burrard Inlet resulting in damage to the marine environment and affecting 1,200 meters of shoreline (TSB, 2008a). Cleanup took months and cost roughly $15 million and resulted in the recovery of 1,321 bbl of oil (CBC, 2011).

### 2.1.4 Keystone Pipeline Spills

In its first two years of operation, the Keystone Pipeline has experienced 35 spills, 14 of which were in the U.S. (Cornell University, 2012). Although most of these have been small spills, an accident in North Dakota resulted in a 500 bbl spill of dilbit.

#### *2.1.4.1 Ludden, North Dakota, TransCanada*

A failure at a North Dakota pump station resulted in a spill of about 500 bbl dilbit on May 7, 2011 causing the entire pipeline system to shut down for nearly one week. Reports from the North Dakota Public Service Commission assert that the spill was not due to the pipeline itself, but rather resulted from a failed fitting for a valve on the line's discharge piping (Crowl, 2011).

Under the leadership of private contractors and a regional incident management team, clean up and analysis of the spill commenced on May 7. All but approximately five bbl of the

spilled oil were contained within the boundaries of the pumping station. Immediately following this spill, a U.S. Department of Transportation Pipeline and Hazardous Materials Safety Administration (PHMSA) issued a corrective action order requiring operators to replace similar fittings on all Keystone pump stations (USDOT PHMSA, 2011).

# 3 PROJECTIONS OF FUTURE SPILLS

## 3.1 Do Oil Sands Products Increase Pipeline Spills?

Although several studies and reports suggest that pipelines carrying dilbit have a higher frequency of spills than those carrying conventional crude due to the physical characteristics of dilbit, finalized studies as well as those underway suggest this is not the case. Citing PHMSA spill data, a Cornell University report found that between 2007 and 2010 pipelines transporting dilbit experienced three times more spills per mile in the northern Midwest than the national average for conventional crude oil due to the corrosive nature of the material (Skinner & Sweeney, 2012). The added corrosivity of oil sands-derived products is, however, a contested issue. Although the National Resources Defense Council (NRDC) echoed these findings in saying dilbit is "more likely to cause corrosion" in pipelines and tankers (NRDC, 2011); data from several studies suggest that oil sands products are not significantly more corrosive.

Recent studies on dilbit and oil sands products characteristics carried out by Heather Dettman of Natural Resources Canada (NRC) and J. Zhou and J. Been as commissioned by Alberta Innovates. Noting that water content is the paramount factor in pipeline corrosion, Dettman and Zhou and Been use an analysis of sediment content, water content, and other characteristics to assert oil sands products are not significantly different than comparable heavy crudes and are not more highly corrosive enough to be a concern to pipeline operators (Dettman, 2012; Zhou, Been, 2011). For a further discussion of oils sands and pipeline corrosion, refer to section 5.5.

## 3.2 Available Spill Risk Assessments

To determine potential risk of oil spills, public agencies and private consulting firms have carried out assessments on spill predictions for the Keystone, Keystone XL, Enbridge Alberta Clipper, and Northern Gateway pipelines. Assessments to provide spill predictions for the Kinder Morgan Trans Mountain pipeline expansion and the Enbridge Line 9 Reversal in Eastern Canada are respectively planned and underway.

### 3.2.1 Pipelines

Based on U.S. Department of Transportation's statistics, transmission of oil and petroleum products via pipeline is the safest mode in terms of ratio of accidents per amount transported per year (Tables Table **3-1**, Table **3-2**) (Furchtgott-Roth, 2012; Pipeline & Hazardous Materials Safety Administration [PHMSA], 2013).

In compliance with U.S. and Canada governmental requirements to carry out environmental impact assessments, spill risk data are available for the TransCanada Keystone, proposed TransCanada Keystone XL, and Enbridge Northern Gateway pipelines. Assessments are pending for the Kinder Morgan Trans Mountain expansion and Enbridge Line 9 Reversal pipelines. Spill risk data are not available for the Enbridge Lakehead System (Alberta Clipper and Bakken expansions), Kinder Morgan Express, and current Kinder Morgan Trans Mountain pipelines. As U.S. and Canadian reporting and assessment requirements differ and accessibility of documents vary, the amount, source, and presentation of data on spill risk is not consistent across these studies.

| Comparative Statistics for Incident Rates Onshore Transmission Pipelines vs. Road and Railway (2005-2009) | | | |
|---|---|---|---|
| **Mode** | **Billions Ton Miles of Shipment** | **Average Hazmat Incidents per Year** | **Average Hazmat Incidents per Billion Ton Mile** |
| Road | 23 | 14,963 | 650.6 |
| Railway | 35.1 | 718 | 20.5 |
| Hazardous Liquid Pipeline (Onshore) | 584.1 | 354 | 0.61 |
| Gas Transmission Pipeline (Onshore) | 338.5 | 300 | 0.89 |

Table 3-1: Incident Rates Onshore Transmission Pipelines vs. Road and Railway (2005-2009)

| Year | Number | Fatalities | Injuries | Property Damage as Reported ($ million) | Gross Barrels Spilled | Net Barrels Lost | % of Volume Recovery |
|---|---|---|---|---|---|---|---|
| 1993 | 445 | 17 | 111 | $67.3 | 116,802 | 57,559 | 51% |
| 1994 | 467 | 22 | 120 | $160.6 | 164,387 | 114,002 | 31% |
| 1995 | 349 | 21 | 64 | $53.4 | 110,237 | 53,113 | 52% |
| 1996 | 381 | 53 | 127 | $114.5 | 160,316 | 100,949 | 37% |
| 1997 | 346 | 10 | 77 | $79.8 | 195,549 | 103,129 | 47% |
| 1998 | 389 | 21 | 81 | $126.9 | 149,500 | 60,791 | 59% |
| 1999 | 339 | 22 | 108 | $130.1 | 167,230 | 104,487 | 38% |
| 2000 | 380 | 38 | 81 | $191.8 | 108,652 | 56,953 | 48% |
| 2001 | 341 | 7 | 61 | $63.1 | 98,348 | 77,456 | 21% |
| 2002 | 644 | 12 | 49 | $102.1 | 97,255 | 77,953 | 20% |
| 2003 | 673 | 12 | 71 | $139.0 | 81,308 | 50,889 | 37% |
| 2004 | 673 | 23 | 60 | $271.8 | 89,311 | 69,003 | 23% |
| 2005 | 721 | 14 | 48 | $1,246.8 | 138,094 | 46,246 | 67% |
| 2006 | 642 | 21 | 36 | $151.1 | 137,693 | 53,905 | 61% |
| 2007 | 615 | 15 | 50 | $154.9 | 94,981 | 68,941 | 27% |
| 2008 | 662 | 8 | 57 | $565.9 | 102,076 | 69,510 | 32% |
| 2009 | 627 | 13 | 64 | $179.0 | 55,014 | 32,307 | 41% |
| 2010 | 590 | 22 | 109 | $1,465.3 | 174,931 | 123,420 | 29% |
| 2011 | 595 | 14 | 60 | $365.3 | 139,017 | 108,140 | 22% |
| 2012 | 569 | 12 | 56 | $188.4 | 54,061 | 32,401 | 40% |

Table 3-2: National Pipeline Systems –Reported Incidents Summary Statistics: 1993-2012

### 3.2.2 Rail

Concerning the risks associated with transporting dilbit via rail, risk assessments are not conducted according to the specifics of the material being transported. However, an EPA report

does provide rail specific data of on spills of all types of oil in U.S. inland waterways. Between 1980 and 2003, there were 265 spills attributed to rail, which accounted for 0.05 percent of the total number of spills over that timeframe. The average volume per spill was 8,185 gallons (Etkin, 2006). Further discussion on rail transport and regulation are provided in sections 4.2 and 8.3.3.2.

#### 3.2.3 Waterways and Terminals

Regarding spills at coastal terminals and waterways, Enbridge has published spill risk assessments for their pipeline to the Kitimat Terminal and a recent risk assessment was conducted for the Aleutian Islands. These are discussed below. However, risk assessments for other terminals expected to handle oil sands products will not be conducted until upgrades to facilities are underway and regulations require assessments to take place.

### 3.3 Keystone XL Pipeline

The State Department has released two Environmental Impact Statements (EIS) of the Keystone XL, the most recent of which was released in March, 2013 accounts for a re-routed pipeline through Nebraska.

The 2013 draft EIS of Keystone XL reports spill releases as distributed by volume. Basing their figures on historical spill data from PHMSA, the State Department asserts that for all spills along all pipeline components, 79 percent will be less than 50 bbl, 17 percent will be 50-1,000 bbl, and 4 percent will be 1,000-20,000 bbl. Moreover, they predict that there will be .00313 incidents per mile-year of which 21 percent would be greater than 50 bbl. Notably, the final EIS discusses the fact that an undetected leak along a buried section of the pipeline could saturate soil with the potential for the material spilled to reach groundwater. The Final EIS also provides information on pipelines mileage that could affect water bodies. Narrowing their

analysis to water bodies in Montana, South Dakota, and Nebraska, they assess that there are about 355 miles, 129 miles, and 278 miles of pipeline in these respective state that are prone to spills of more than 50 bbl that could affect water bodies (U.S. Department of State, 2013)

The first EIS of the Keystone XL Pipeline provides figures for "significant spills," or those predicted to exceed 50 bbl. Drawing on historical spills from the PHMSA database, the estimated projection for significant spills is 1.18 spills per year (.0007 per mile over 1,682 miles). This equates to nearly 59 spills greater than 50 bbl over the 50-year design life of the pipeline.

The EIS indicates that the maximum spill volume is 66,666 bbl, which, due to topographic conditions, is only possible along less than 1.7 miles of the proposed route. Taking factors such as shutdown time, structural failure, flow rate, and line drainage volumes into account; for about 50 percent of the proposed pipeline route the maximum spill volume would be about 16,000 bbl , which could result from a "complete structural failure of the pipeline" (U.S. Department of State, 2011). The EIS also asserts that spill volumes would be much lower at river crossings because main line valves (MLVs) occur on either side of each river crossing (U.S. Department of State, 2011).

Two additional assessments of the Keystone XL pipeline provide different figures. An assessment carried out by TransCanada contractor DNV consulting, found the likelihood of significant spills (greater than 50 bbl) to be .21 (.00013 per mile) or about 11 spills over 50 years. John Stansbury of the University of Nebraska argues that these figures are "highly questionable" because the firm failed to take into account the historical PHMSA spill data that accounts for 23 percent of historical pipeline data (Stansbury, 2011). Taking the PHMSA data into account and using dilbit's increased acidity and sulfur rates to substantiate his claims of the

material's increased corrosiveness and abrasiveness, Dr. Stansbury's spill prediction for Keystone XL is 1.83 (.00109 per mile) or 91 significant spills over 50 years (Stansbury, 2011). However given data showing that dilbit is not more corrosive than other crude oils, Dr. Stansbury's results might be overstated.

Dr. Stansbury also provides worst-case spill scenarios for major Keystone XL river crossings and the Sandhills region of Nebraska. At the Missouri River Crossing, his worst-case spill prediction is 122,867 bbl. For the Yellowstone River, the worst-case prediction is 165,416 bbl. At the Platte River crossing, the worst-case prediction is 140,950 bbl (Stansbury, 2011).

Keystone Pipeline

A DNV Energy analysis carried out for TransCanada provides estimates for spills greater than 50 bbl on the Keystone pipeline. Providing data specifically for spills of diluted bitumen, DNV states in a section on uncertainties that their estimates assume failure causes are identical to crude oil (DNV Energy, 2011). The DNV estimates are 0.094 and 0.151 spills per year respectively for the mainline and the mainline plus the Cushing extension (DNV Energy, 2011). Over a fifty-year period, this equates to 4.70 and 7.55 spills respectively.

Regarding worst-case spills, Dr. Stansbury uses Keystone figures to support his analysis of Keystone XL. He asserts that TransCanada estimated worst case spills for the Keystone pipeline (at Hardisty Pumping Station) to be 41,504 bbl, while Stansbury's estimate is closer to 88,000 bbl (Stansbury, 2011). The principal difference in arriving at these estimates is the assumed shut-down time, 19 minutes for TransCanada and two hours for Stansbury (Stansbury, 2011).

## 3.4 Northern Gateway Pipeline

Enbridge provides data on spill risks for their Northern Gateway pipeline, the Kitimat Terminal, and associated waterways in a 2011 General Oil Spill Response Plan (Enbridge, 2011). The estimated spill frequency data in the report is provided in spill return years (number of years per spill). Converting these figures to yearly spill likelihoods, the company predicts there will be about 0.036 spills per year greater than 62.8 bbl on the pipeline in the region between Alberta and Kitimat. The maximum spill volume along the pipeline is predicted to be 49,060 bbl at kilometer point (KP) 165 near Mayerthorpe. The assessment also states that the pipeline is designed to limit spill volumes at watercourse crossings to less than 12,579 bbl. For spills at the Kitimat Terminal involving a tanker at berth, there will be an estimated 0.002 spills greater than 62.8 bbl per year. A separate, third party assessment carried out by University of British Columbia engineering professors puts the estimated spill rate per year at 0.014 (Gunn, Foschi, & Sexsmith, 2012) The maximum spill volume at the terminal is predicted to be 10,063 bbl. And for waterway spills associated with tanker traffic, there will be an estimated 0.003 spills per year of any volume and 0.002 spills per year greater than 31,449 bbl. The maximum spill volume for a waterway spill is predicted to be 226,433 bbl.

## 3.5 Unimak Pass

An assessment of worst case spills in the Aleutian Islands is relevant to the report given the likelihood that oil sands products will be shipped via great circle routes through the islands and Unimak Pass for export to Asia. Data presented here comes from The National Fish & Wildlife Foundation, U.S. Coast Guard, and State of Alaska Department of Environmental Conservation multi-phase risk assessment of maritime transportation in the Bering Sea and the Aleutian Archipelago. Providing baseline and future accident estimate predictions for all vessels

(8.67 for 2008/2009 and 9.61 for 2034), a summary report of the assessment estimates that collisions with crude oil tankers along this route would result in a spill of 428,080 bbl (Aleutian Islands Risk Assessment Management Team, 2011).

# 4 TRANSPORTATION METHODS

As stated in section 1.4 pipelines, rail, barges and tankers are the primary modes of transporting crude oil products from source to markets in North America. Canada produced roughly 1.2 billion barrels in 2012 (approximately 3.5 mbl/d), 55 percent of which were oil sands products (upgraded bitumen and non-upgraded bitumen) (CNEB, 2012). As of 2011, 65 percent of Canadian crude oil production was destined for the U.S (CNEB, 2012; EIA, 2012). The most widely used mode of exporting Canadian crude oil to the U.S. is the use of pipelines. Canada exported 89 percent of its crude oil via pipelines, 10.8 percent via marine transportation and 0.2 percent via rail (CNEB, 2012). However, due to environmental and political challenges to pipeline expansion, the use of rail is rapidly growing (EIA, 2013; CNEB, 2012). From 2007 to 2011, the use of pipelines grew by only 5.3 percent yearly and use of marine (tankers and barges) shrank by 2.4 percent yearly, while use of rail has increased by over 7000 percent yearly (EIA, 2013; CNEB, 2012). The rapid growth in use of rail stems from the facts that almost no crude oil was transported via rail in 2007 and 2008 (EIA, 2013; CNEB, 2012).

The U.S. accounts for 97 percent of Canadian crude oil export (CNEB, 2012). In 2012 Canada's crude oil export to the U.S. included conventional light (30 < API), conventional medium (25 < API < 30), conventional heavy (API < 25), synthetic (upgraded bitumen or upgraded heavy crude oil of any API), and blended bitumen (bitumen blended with light hydrocarbons and/or synthetic crude oil) (CNEB, 2012). As of the 3$^{rd}$ quarter of 2012, oil sands products were the largest type of crude oil product exported to the U.S. (31 percent), followed by conventional heavy (24 percent), synthetic (24 percent), conventional light (18 percent) and conventional medium (3 percent) (CNEB, 2012). This makes the U.S. consumer of 99 percent of the Canadian oil sands crude products destined for export (CNEB, 2012).

There are major policy and research gaps related to transportation of oil sands products (pipelines, rail or marine) that must addressed in order for both the policy makers and governmental organizations to assess ecological, environmental, social and economic risks and uncertainties surrounding integration of oil sands products into the global economy. Sections 8.8 and 9 outline major gaps in both policy and research.

## 4.1 Pipelines

Pipelines are the primary mode of transportation for oil products in North America. Approximately 71 percent of crude oil and petroleum products (including crude oil and post refining products) are shipped via pipelines on the ton-mile basis (mass in tons * distance in miles) (Bureau of Transportation Statistics [BTS], 2012). Tanker and barge traffic account for roughly 23 percent of oil shipments, and rail about 3 percent (Table 4-1) (BTS, 2012). By focusing on the crude oil products, including all types of crude oil, the numbers swing even more towards pipelines. In 2009 roughly 80 percent of all crude oil transport in ton-miles in North America was via pipelines, while tankers and barges accounted for 19 percent and rail 0.3 percent respectively (Table 4-1) (BTS, 2012).

| **Crude Oil and Petroleum Products Transported in the United States by Mode (billions)** | | | | | | |
|---|---|---|---|---|---|---|
| | **2008** | | | **2009** | | |
| | **Tonne-Kilometers** | **Ton-Miles** | **%** | **Tonne-Kilometers** | **Ton-Miles** | **%** |
| **Crude oil, total** | **543.1** | **372.0** | **100.0%** | **490.6** | **336.0** | **100.0%** |
| Pipelines | 447.2 | 306.3 | 82.3% | 391.6 | 268.2 | 79.8% |
| Water carriers | 92.3 | 63.2 | 17.0% | 95.0 | 65.1 | 19.4% |
| Motor carriers | 2.5 | 1.7 | 0.5% | 2.5 | 1.7 | 0.5% |
| Railroads | 1.0 | 0.7 | 0.2% | 1.5 | 1.0 | 0.3% |
| **Refined petroleum products, total** | **709.4** | **485.9** | **100.0%** | **692.2** | **474.1** | **100.0%** |
| Pipelines | 437.1 | 299.4 | 61.6% | 438.3 | 300.2 | 63.3% |
| Water carriers | 191.0 | 130.8 | 26.9% | 177.7 | 121.7 | 25.7% |
| Motor carriers | 48.8 | 33.4 | 6.9% | 47.0 | 32.2 | 6.8% |

| Crude Oil and Petroleum Products Transported in the United States by Mode (billions) | | | | | | |
|---|---|---|---|---|---|---|
| | **2008** | | | **2009** | | |
| | **Tonne-Kilometers** | **Ton-Miles** | **%** | **Tonne-Kilometers** | **Ton-Miles** | **%** |
| Railroads | 32.6 | 22.3 | 4.6% | 29.1 | 19.9 | 4.2% |
| **Combined crude and petroleum products, total** | **1,252.5** | **857.9** | **100.0%** | **1,182.7** | **810.1** | **100.0%** |
| Pipelines | 884.3 | 605.7 | 70.6% | 829.8 | 568.4 | 70.2% |
| Water carriers | 283.2 | 194.0 | 22.6% | 272.7 | 186.8 | 23.1% |
| Motor carriers | 51.2 | 35.1 | 4.1% | 49.5 | 33.9 | 4.2% |
| Railroads | 33.6 | 23.0 | 2.7% | 30.5 | 20.9 | 2.6% |

Table 4-1: Crude Oil and Petroleum Products Transported in the US by Mode

There are three major types of pipeline systems that support transfer of oil from its source to destination; they are for gathering, crude oil, and refined products, with sizes ranging from 2 inches to 42 inches in diameter (Figure 4-1) (BTS, 2012). The U.S. has a network of 175,000 miles of these pipelines for the purpose of onshore and offshore transmission of crude oil and petroleum products (BTS, 2012). Gathering pipeline systems gather crude oil from production wells, crude oil pipeline systems transport crude oil from the gathering systems to refineries, and refined products pipeline systems transport refined products such as gasoline, kerosene and many industrial feedstock petrochemicals from refineries to the end user or to storage and distribution terminals (BTS, 2012).

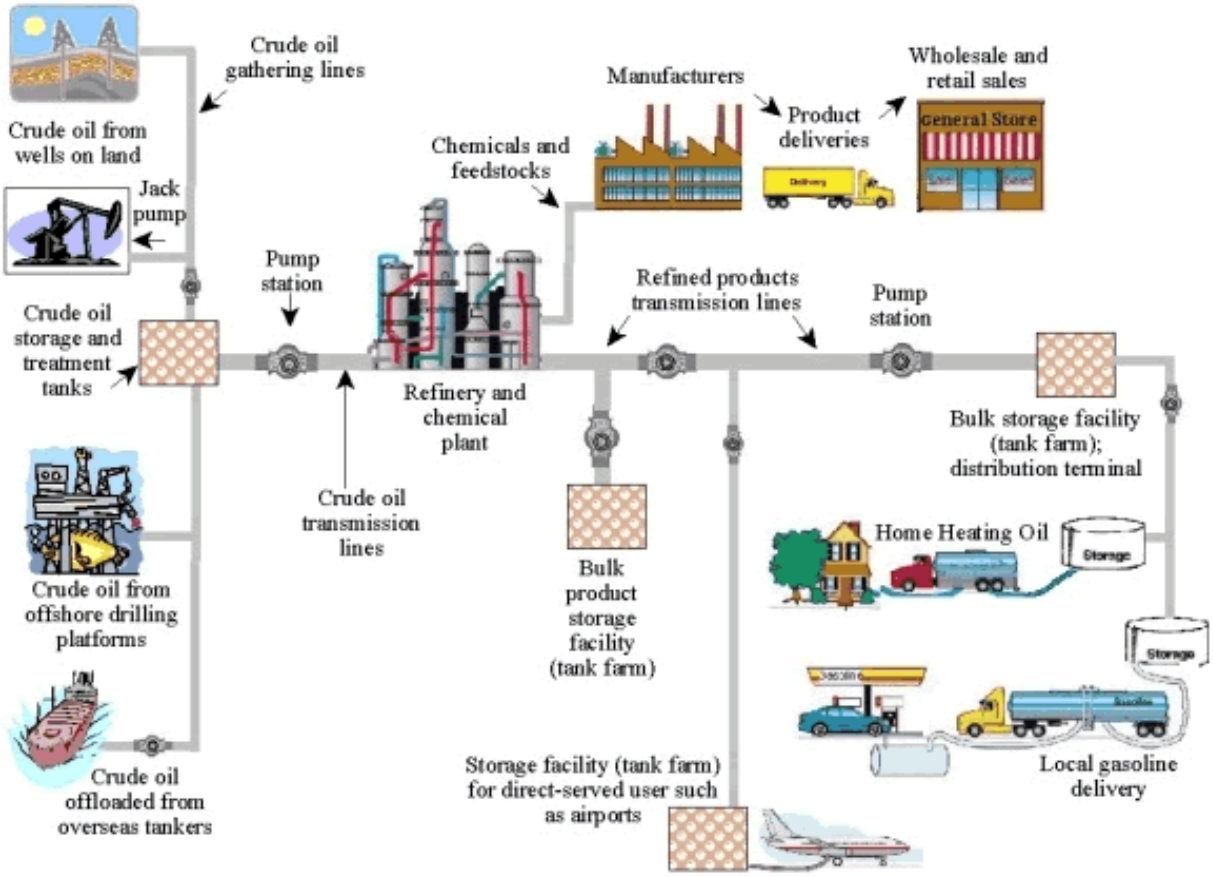


Figure 4-1: US DOT, PHMSA's Petroleum Pipeline Systems

### 4.1.1 Networks of Crude Pipelines in North America

As stated in section 1.4.1, there are four major networks of crude pipelines in North America that carry crude products from the source (wells and mines) to the destination (refineries and offshore drop off terminals for tanker shipment) with an average capacity of 3.5 mbl/d (CAPP, 2012; CNEB, 2009).

It is worth mentioning that Canadian heavy-crude prices have declined relative to their U.S. and international benchmarks due to lack viable transportation mechanism to transfer the increased production capacity to market (Olson & van Loon, 2013). According to Bloomberg News, Western Canada Select, a blend refined from oil-sands bitumen, had fallen over 20

percent during the past six months amid uncertainty over approvals for Keystone XL, Enbridge's Northern Gateway and Kinder Morgan Energy Partners LP (KMP)'s TransMountain pipelines (Olson & van Loon, 2013).

#### *4.1.1.1 Enbridge Mainline Pipeline System*

The Enbridge pipeline system delivers crude oil and other refined products from western Canada, Montana, and North Dakota to markets in western Canada, the U.S. PADD II (**Error! Reference source not found.**), and Ontario (CAPP, 2012; CNEB, 2009). The system connects to a number of regional pipelines in the U.S. PADD II region, such as the Minnesota Pipeline at Clearbrook, MN and Spearhead South at Flanagan, IL (CAPP, 2012; CNEB, 2009). The Enbridge system has the capacity of 2.3 mbl/d (CAPP, 2012; CNEB, 2009; CNEB, 2006).

The Enbridge network is currently being expanded through upgrades to two of its main pipelines, Alberta Clipper and Southern Access (CAPP, 2012; CNEB, 2009). By 2014, when the expansion projects are completed, the Alberta Clipper will have an additional 0.12 mbl/d capacity and the Southern Access with have an addition 0.16 mbl/d capacity (CAPP, 2012; CNEB, 2009; CNEB, 2006).

#### *4.1.1.2 Kinder Morgan Express and Trans Mountain Pipeline Systems*

Kinder Morgan Canada, Inc. is the parent company of both Kinder Morgan and Trans Mountain Pipelines (CAPP, 2012; CNEB, 2009). The Trans Mountain system originates in Edmonton, Alberta and transports crude oil and petroleum products to delivery points in British Columbia, which include the Westridge dock for offshore exports to final destinations that include the U.S. PADD V (primarily CA and WA) and Asia (CAPP, 2012; CNEB, 2009; CNEB, 2006).

The system also includes the Express Pipeline system, which is comprised of the Express Pipeline and the Platte Pipeline (CAPP, 2012; CNEB, 2009). This system connects Canadian and U.S. crude oil producers to refineries in the U.S. PADD II and PADD IV (CAPP, 2012; CNEB, 2009). The Express Pipeline originates at Hardisty, Alberta and ends at the Casper, WY facilities on the Platte Pipeline with a capacity of 0.280 mbl/d (CAPP, 2012; CNEB, 2009; CNEB, 2006). The Platte Pipeline runs from Casper, WY to refineries and interconnecting pipelines in Wood River, IL with the capacity of 0.15 mbl/d (CAPP, 2012; CNEB, 2009).

#### *4.1.1.3 TransCanada Keystone Pipeline System*

The existing Keystone pipeline system runs from Hardisty, Alberta to terminals in Wood River and Patoka, IL (CAPP, 2012; CNEB, 2009). The latest extension to the Keystone pipeline is the Cushing Extension, which runs from Steele City, NE to Cushing, OK (CAPP, 2012; CNEB, 2009). The system has a capacity of 0.591 mbl/d to either Wood River or Cushing depending on market requirements (bidirectional) (CAPP, 2012; CNEB, 2009; CNEB, 2006).

TransCanada's future expansion plan includes the Keystone XL pipeline. The purpose of this pipeline will be to transfer oil sands products from Alberta to refineries on the Gulf Coast (PADD III), and from there to international markets. The initial routing plan faced fierce objections from a variety of stakeholders, including several state governments and environmental groups (Avok, 2011). A new revised route has been selected to address the environmental concerns related to the original routing in state of Nebraska. This new route proposal resulted in NE governor approving the passage of pipeline through his state (Gardner & Quinn, 2013). On March 1, 2013, the U.S. State Department issued a revised environmental impact statement for the Keystone XL pipeline. The statement, although, "made no recommendation about whether the project should be built, it presented no conclusive environmental reason that it should not be"

(Broder, 2013). Thus, the report raised the possibility of final approval by the U.S. government (Broder, 2013). The approval of the proposal now depends on President's Obama's decision. TransCanada will begin the construction of the pipeline in the first half of 2013 with a targeted in-service date of 2015 if the project is approved (TransCanada; Gardner & Quinn, 2013). The Keystone XL would originate at Hardisty, Alberta and end at Steele City, NE (TransCanada). The proposal has the transfer capacity of 0.83 mbl/d and its primary function would be to transport synthetic crude oil and dilbit from the Athabasca oil sands region to multiple destinations in the U.S. PADD II, III and IV (CAPP, 2012; CNEB, 2006).

### 4.1.2 Regional Crude Pipelines in the U.S.

Table 4-2 lists all major crude pipelines connecting Canadian sources to various regions of the U.S. The table is divided into multiple U.S. PADD regions (CAPP, 2012; CNEB, 2009; CNEB, 2006).

| **Summary of Crude Oil Pipelines to the U.S. East Coast - U.S. DOE PADD I** | | | | |
|---|---|---|---|---|
| **Pipeline** | **Originating Point** | **Destination** | **Status** | **Capacity (mbl/d)** |
| Enbridge Line 9 | Sarnia, ON | Montréal, QC | Operating | 0.24 |
| Enbridge Line 9 Reversal | Montréal, QC | Sarnia, ON | Changed Direction – 1999 | |
| Portland-Montreal | Montréal, QC | Portland, ME | Operating | 0.60 |
| TransCanada East Coast Pipeline Project | Montréal, QC | Saint John, NB | Proposed – 2015 | 0.63 |
| **Summary of Crude Oil Pipelines to the U.S. Midwest & Rocky Mountain - U.S. DOE PADD II & PADD IV** | | | | |
| **Pipeline** | **Originating Point** | **Destination** | **Status** | **Capacity (mbl/d)** |
| Minnesota Pipeline | Clearbrook, MN | Minnesota refineries | Operating | 0.47 |
| Enbridge Mainline | Superior, WI | Multiple delivery points | Operating | 1.56 |
| Spearhead North Expansion | Flanagan, IL | Spearhead North Chicago, IL | Proposed – 2014 | 0.10 |
| Enbridge Spearhead | South Flanagan, IL | Cushing, OK | Operating | 0.19 |
| Enbridge Flanagan South | Flanagan, IL | Cushing, OK | Proposed – 2014 | 0.59 |
| Enbridge Mustang | Lockport, IL | Patoka, IL | Operating | 0.10 |

| | | | | |
|---|---|---|---|---|
| Kinder Morgan Express-Platte | Guernsey, WY | Wood River, IL | Operating | 0.15 |
| Trans Canada Keystone to Patoka or Wood River | Hardisty, AB | Patoka, IL | Operating | 0.59 |
| Trans Canada Keystone to Cushing | Steele City, NE | Cushing, OK | Operating | |
| **Summary of Crude Oil Pipelines to the U.S. Gulf Coast - U.S. DOE PADD III** | | | | |
| **Pipeline** | **Originating Point** | **Destination** | **Status** | **Capacity (mbl/d)** |
| ExxonMobil Pegasus | Patoka, IL | Nederland, TX | Operating | 0.10 |
| Seaway Reversal Phase 1 | Cushing, OK | Freeport, TX | Operating – May 2012 | 0.15 |
| Seaway Reversal Phase 2 | | | Proposed – Early 2013 | 0.25 |
| Seaway Twin Line | | | Proposed – Mid 2014 | 0.45 |
| TransCanada Gulf Coast | Cushing, OK | Nederland, TX | Proposed – Mid 2014 | 0.55 |
| **Summary of Crude Oil Pipelines to the West Coast - U.S. DOE PADD V** | | | | |
| **Pipeline** | **Originating Point** | **Destination** | **Status** | **Capacity (mbl/d)** |
| Kinder Morgan Trans Mountain | Edmonton , AB | Burnaby, BC | Operating | 0.30 |
| Kinder Morgan Trans Mountain Expansion | | | Proposed – 2017 | 0.45 |
| Enbridge Northern Gateway | Bruderheim, AB | Kitimat, BC | Proposed – 2017 | 0.53 |

Table 4-2: Major Crude Pipelines Connecting Canadian Sources to the U.S. Destinations

### 4.1.3 Diluent Pipelines

Table 4-3 summarizes the proposed pipelines for transport of diluent in reverse direction to the where oil sands upgrading occurs. These pipelines will address the potential demand by western Canadian oil sands producers for additional diluent supply needed to transport growing volumes of bitumen-derived products (CAPP, 2012; CNEB, 2009; CNEB, 2006).

| **Summary of Diluent Pipelines** | | | | |
|---|---|---|---|---|
| **Pipeline** | **Originating Point** | **Destination** | **Status** | **Capacity (mbl/d)** |
| Enbridge Southern Lights | Flanagan, IL | Edmonton, AB | Operating | 0.18 |
| Enbridge Northern Gateway | Kitimat, BC | Edmonton, AB | Proposed – 2017 | 0.19 |

| Summary of Diluent Pipelines | | | | |
|---|---|---|---|---|
| **Pipeline** | **Originating Point** | **Destination** | **Status** | **Capacity (mbl/d)** |
| Kinder Morgan Cochin Conversion | Kankakee County, IL | Fort Saskatchewan, AB | Open Season – Ends May 2012 | 0.08 |
| Portland-Montreal Bitumen Expansion | Montréal, QC | Portland, ME | Proposed – 2017 | |

Table 4-3: Summary of Major Diluent Pipelines

## 4.2 Rail Transportation

The increase in production of crude products in North America and the costly and lengthy process of obtaining permits for new pipelines have made rail the transport mode of choice for crude oil products, especially at new crude production sites (Black, 2013). The number of crude oil carrying rail cars tripled to more than 200,000 units between 2011 and 2012, and is expected to continue to grow in the foreseeable future (Black, 2013). Furthermore, an analysis conducted by the U.S. Department of State indicated that with modest expansion and upgrades to the existing infrastructure, railroad networks in the U.S. can handle all new oil produced in western Canada through 2030 (Efstathiou, 2012; U.S. Department of State [DOS], 2013).

The biggest players in transport of crude products via rail in North America are Canadian National Rail (CN), Canadian Pacific Rail (CPR) and Burlington Northern Santa Fe (BNSF). These companies, along with other rail companies and major oil car manufacturers in North America, foresee continuous growth in their sector for a foreseeable future due to the slow process of granting permits for new pipelines (Vanderklippe, 2013).

Since trains haul commodities by their weight (typically in tons or carloads) and pipelines move oil products by the barrels/day, comparison of the two modes of transport is difficult (Furchtgott-Roth, 2012; Vanderklippe, 2013). Despite that, studies have been conducted to compare the two modes of transporting oil products (Furchtgott-Roth, 2012; Vanderklippe,

2013). A report by the Manhattan Institute aggregated data from U.S. Department of Transportation and looked at risks associated with the transport of crude oil and petroleum products via pipelines, rail, trucks, and ships. The study found that the average hazmat incidents per billon-ton mile were 0.61 spills for pipelines, 20.5 for rail and 650.6 for road (trucks and etc.) (Furchtgott-Roth, 2012). Comparing pipelines vs. rail, that is a spill rate 34 times higher for rail (Furchtgott-Roth, 2012). The American Association of Railroads (AAR), however, disputes that analysis. According to AAR's internal study, there is a much smaller spill ratio of 2.6 times the pipeline rate (Association of American Railroads [AAR], 2013). AAR's study also determined that trains on average leak smaller amounts than pipelines (AAR, 2013). It must be noted that AAR's claims have not been independently assessed and verified. The association website said "railways spill less of their hazardous liquid product than do pipelines, 9 percent less per billion barrel miles over the 20-year period 1990-2009 and 35 percent less over the 2002-2009 period" (AAR, 2013).

The Railway Association of Canada (RAC) also claims that unlike pipelines, oil sands crude, which they refer to as "bitumen" can be moved by train without dilution (Vanderklippe, 2013). Because of bitumen's physical characteristics, in the case of a spill due to derailment, "it's like molasses in January coming out. So you're not going to have a huge problem," said Michael Bourque, president of the RAC in an interview with the Globe and Mail (Vanderklippe, 2013). It is worth mentioning that Mr. Bourque's claim has not been independently assessed and verified.

Putting aside the apparently conflicting statistics presented by the rail and pipeline industries, both means of transporting crude oil have experienced accidental spills in recent years. For example, CN trains leaked roughly 4,400 barrels of Bunker C in Lake Wabamun,

Alberta in 2005 and a derailment and explosion near Rockford, IL lost 7,700 barrels in 2009 (Vanderklippe, 2013). Pipelines are also subject to spills as discussed in Section 2.

Rail will be used to ship oil sands products from Alberta to U.S. markets. According to TransCanada's president, Alex Pourbaix, even if all of the proposed pipeline were delayed, oil-sands development would continue because of the possibility of crude exports by rail even though shipping oil by rail is about two to three times more costly than by pipeline (Olson & van Loon, 2013).

## 4.3 Marine Shipment

Shipment of crude and petroleum products via barges across North America and tankers to Asia and other consumer markets is expected to grow dramatically (International Energy Agency, 2012). It is expected that tanker traffic will increase primarily in Puget Sound, the Gulf of Mexico, and Maine if the proposed Enbridge Gateway (West Cost), TransCanada's Keystone XL (Gulf Coast) and Kinder Morgan Trans Mountain Expansion of Portland-Montreal's Bitumen Expansion (East Coast) are approved (CAPP, 2012).

Due to the limited availability of data for other regions, the remainder of this section will focus on increased vessel traffic in Pacific Northwest, especially in Puget Sound, Strait of Juan de Fuca and Unimak pass and Aleutian Islands.

### 4.3.1 Puget Sound Waters – British Columbia to Washington

The increased traffic in the Puget Sound Area would be primarily due to barges that carry crude oil products from British Columbia to refineries in Washington State, with most barges transiting from Vancouver, BC to refineries in Cherry Point and Tacoma (Jensen & Pilkey-Jarvis, 2012).

### 4.3.2 Strait of Juan de Fuca – British Columbia to Western U.S. States and Asia

The Pacific Northwest also serves as a shipping point for crude oil export from Vancouver, BC, Grays Harbor, WA, and Tacoma, WA to markets in California and across the Pacific region, primarily Asia through Puget Sound and Strait of Juan de Fuca (Figure 4-2) (Jensen & Pilkey-Jarvis, 2012). This potential increase in tanker traffic in the Strait has caused multiple stakeholders in the region, including the Makah Tribe and Puget Sound Partnership, to commission a risk study from a team of scientists at George Washington University called the Vessel Traffic Risk Assessment (VTRA). The purpose of VTRA is to develop a geographic profile for oil spill risk simulation using 2010 vessel traffic data (Hass, 2013; van Dorp, 2013). The study's final report will describe the analysis results of the geographic profiles of 2005 and 2010 oil spills by vessel type and location stated in Table 4-4. The study will analyze the increased traffic due to Gateway and Kinder Morgan's pipeline proposals to ship Canadian crude oil products from British Columbia to Asian markets as well as the increased re-shipment inside Puget Sound waters by barges (Hass, 2013). The study's initial report is due in August 2013.

| LOCATION | VESSEL TYPE |
|---|---|
| Cherry Point Area | Tug without Barge |
| Puget Sound South | Tug ATB's or ITB's |
| Strait of Juan de Fuca East | Tug Pushing Ahead |
| Strait of Juan de Fuca West | Container |
| Puget Sound North | Tanker |
| Saddle Bag Area | Bulk carrier |
| Rosario Strait | Freighter |
| Haro Strait \ Boundary Pass | Passenger vessel |
| Guemes Channel | Service vessel |
| | Public vessel |
| | Fishing Vessel |
| | Tug Towing Astern |
| | Recreational Vessel |

Table 4-4: Scope of the VTRA Study Commissioned by Makah Tribe and Puget Sound

The Government of British Columbia and environmental organizations, such as Natural Resources Defense Council, Pembina Institute and Living Oceans Society, also conducted analyzed increased social, economic, and environmental risks resulting from vessel traffic growth in Puget Sound and the Strait of Juan de Fuca waters, especially the rapid growth in tanker traffic (Government of British Columbia [Gov. BC], 2012; Swift, Lemphers et al., 2011). The report categorized risks into four major areas that include:

- "Compromising the lifestyles of First Nations who depend on the region's lands and waters for their livelihoods, culture, and health"
- "Threatening the economic well-being of the communities of British Columbia that depend on fisheries and forests"
- "Potential devastation from a major oil spill from the pipeline or an oil supertanker, which could destroy economically important salmon habitat, as well as the habitat of Spirit Bears and grizzlies, and whales, orcas, and other marine life that depend on these rich coastal waters"
- "Harm from an oil spill to the Great Bear Rainforest that the province and First Nations have worked hard to protect from unsustainable forestry practices and to shift to a conservation-based economy (Swift, Lemphers et al., 2011)."

Figure 4-3 is the graphical depiction of response processes devised by the Government of British Columbia in case of a major marine spill. The flow of these processes was developed to address some of the concerns raised during that government's assessment of rapid growth in tanker traffic in Strait of Juan de Fuca (Gov. BC, 2012).

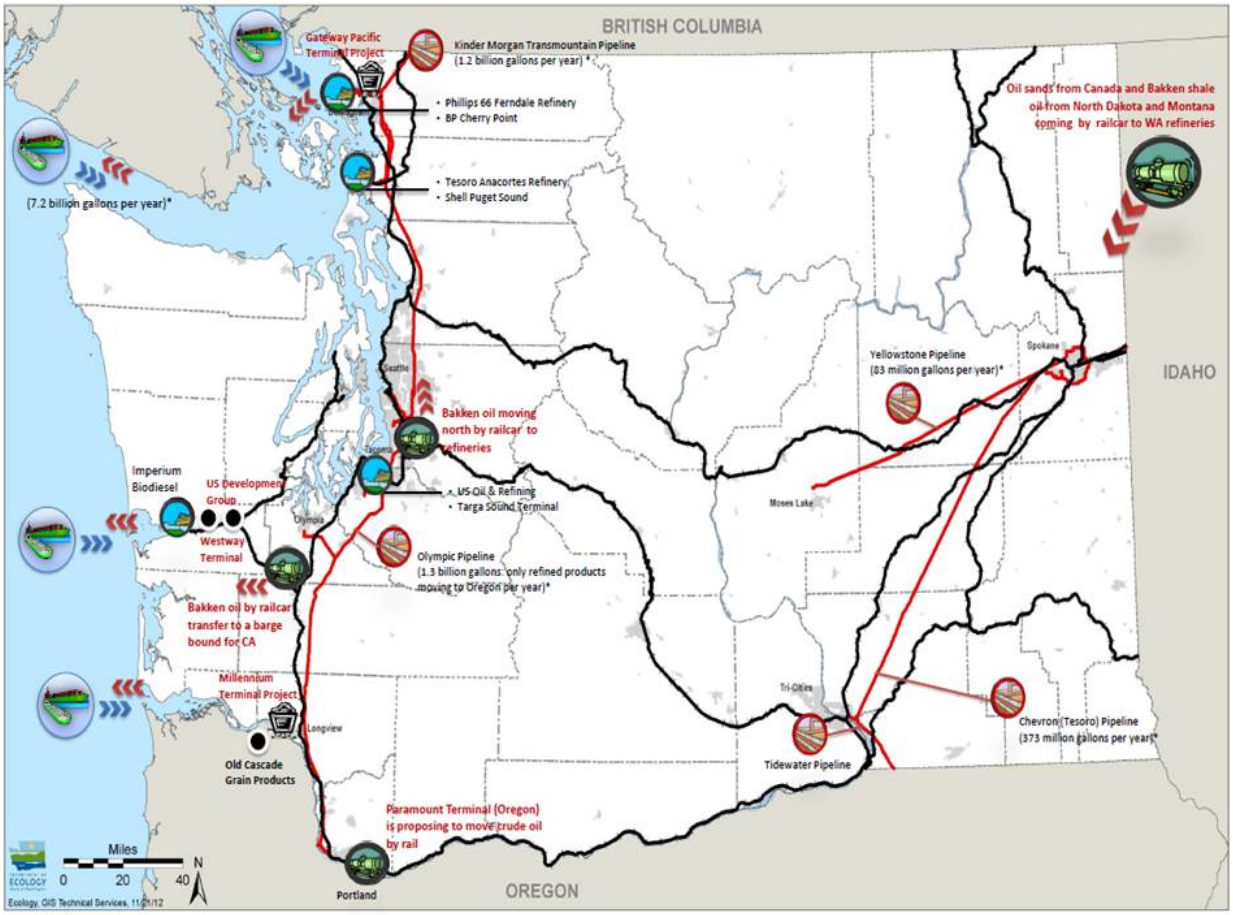


Figure 4-2: Map of Crude Oil Transport in Washington State (WA Dept. of Ecology)

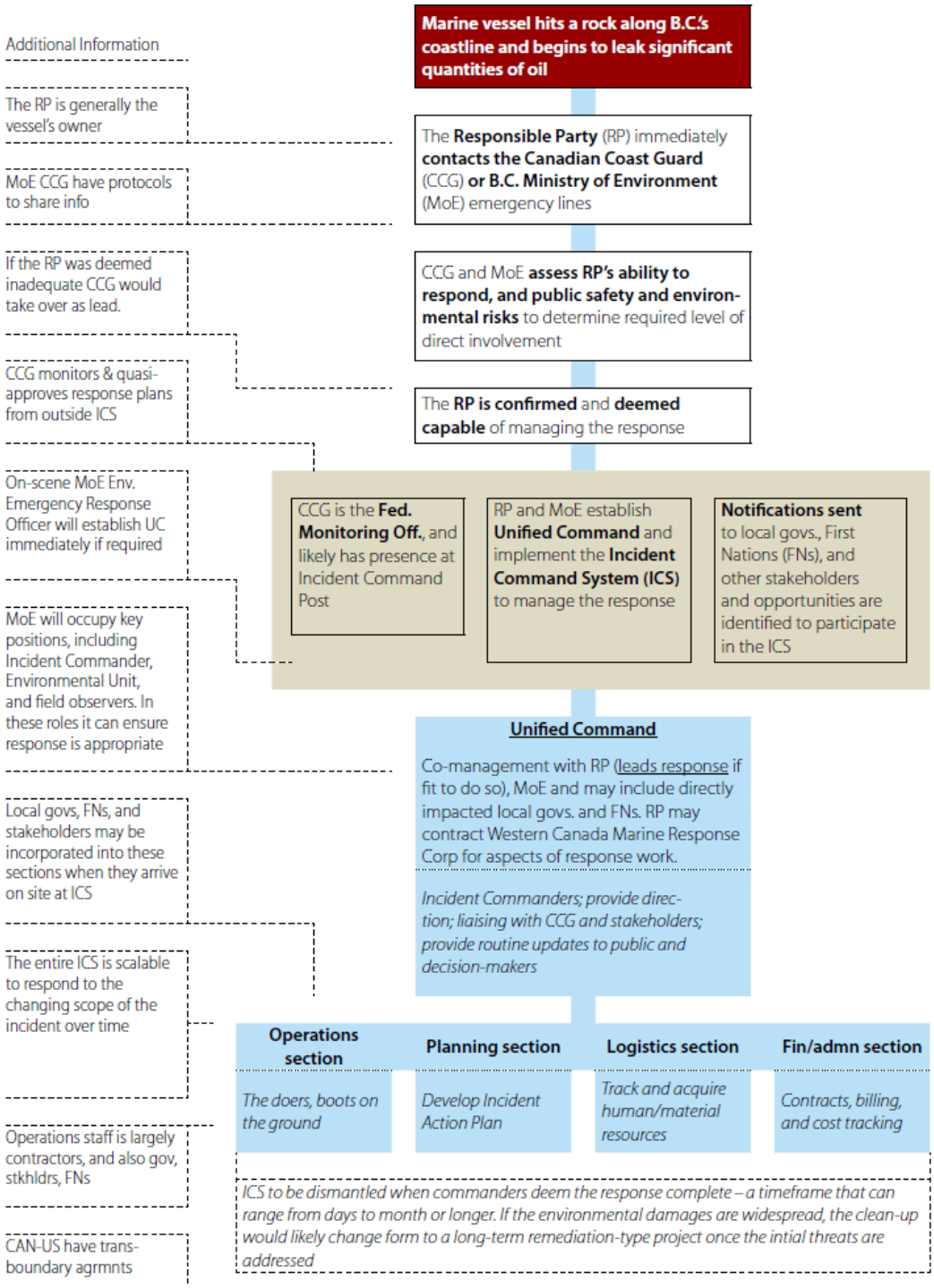


Figure 4-3: Response Plan for a Major Spill in the Marine Environment - Canadian North Pacific

### 4.3.3 Unimak Pass and the Aleutian Islands – British Columbia to Asia

Upon approval of Enbridge's Northern Gateway pipeline to Kitimat, BC, there will be dramatic surge in tanker traffic from Kitimat to Asian markets through the Aleutian Islands (Hass, 2013). This increase in tanker traffic coupled with dramatic growth in overall transpacific

traffic, due to advancement of trade relations across Asia and North America, has amplified the risk of accidents and spills in waters off the coast of the Aleutian Islands (Transportation Research Board of the National Academies [TRB], 2009). The Aleutian Islands' abundant natural resources are quite unique to that region and the main source of that region's economic vitality (TRB, 2009). Any accidents involving these ships cold result in oil spills with serious ecological, environmental, social and economic consequences. To study the risks and put forth recommendations to mitigate them, the U.S. Coast Guard (USCG) commissioned the Transportation Research Board (TRB) within the National Academies conduct a study (TRB, 2009). The final report was called, "Risk of Vessel Accidents and Spills in the Aleutian Islands: Designing a Comprehensive Risk Assessment" that was publishes in 2009.

The primary recommendation of the report was for a more comprehensive long-term study of vessel accident risks around the Aleutian Islands, but it also offered USCG some interim risk mitigation steps:

- "USCG to take appropriate action to expand the AIS tracking network along the Aleutian chain and covering the southern North Pacific Great Circle Route"
- "USCG to investigate the possible structure and costs of a Vessel Traffic Information System within and near Unimak Pass and Dutch Harbor (TRB, 2009)"

Data gathered through the interim steps should also assist with more comprehensive risk assessment study, information about this ongoing work can be found at: http://www.aleutiansriskassessment.com.

# 5 PROPERTIES, FATE, AND BEHAVIOR OF OIL SANDS PRODUCTS

## 5.1 Definition of Terms

Specific gravity and API (American Petroleum Institute) gravity are both measures of density relative to water. Although specific gravity is a more common measurement in the broader scientific community, API gravity is standard when comparing the densities of petroleum products.

- **Specific Gravity** in calculated based directly on a material's density and uses pure water as the benchmark, assigning it a specific gravity of 1.0. Anything with a specific gravity greater than 1.0 is denser than water and will sink while anything with a specific gravity less than 1.0 will float.
- **API Gravity** also uses pure water as the benchmark, but assigns it a value of 10.0. The other key difference between the two measurements is that API gravity is an *inverse* measure of relative density compared to water, so as a substance's API value increases, it is getting *less* dense compared to water. Thus, in theory anything with an API gravity of greater than 10.0 will float on pure water, and anything with an API gravity of less than 10.0 will sink. The API gravity for saltwater is ~6, so anything with API gravity greater than 6.0 will float in saltwater and anything with an API less than 6.0 will sink in saltwater. API is expressed mathematically as: $°API = (141.5/SG) – 131.5$.
- **Total Acid Number (TAN)** measures the composition of acids in a crude oil, which can gauge its potential for corrosion of pipes or other equipment during transportation or refining. TAN value is measured as the number of milligrams (mg) of potassium hydroxide (KOH) needed to neutralize the acids in one gram of oil. Crude oils with a TAN greater than 0.5 are considered to be potentially corrosive due to the presence of naphthenic acids (Ramseur, Lattanzio, Luther, Parfomak, and Carter, 2012). However, while increased TAN values do increase the potential for corrosion, according to some experts water content in the oil may be the *key* factor that leads to corrosion in a pipeline (Dettman, 2012).

- **Miscible & Non-Miscible vs. Soluble & Non-Soluble** refers to the ability of one substance (the solute) to mix completely with another substance (the solvent) and become homogeneous. Miscible refers to the mixing of two liquids, whereas soluble refers to a solid dissolving into solution in a liquid.

## 5.2 Chemical and Physical Differences between Raw Bitumen and Other Crudes

### 5.2.1 Formation of Oil Sands

Alberta oil sands most likely formed from a standard crude oil deposit that underwent a significant amount of biodegradation (USGS, 2007; Shuqing et al., 2008). The lighter, shorter chain alkanes were subject to degradation by microorganisms leading to the predominance of large molecules. The biodegradation occurred because the bitumen reserves never exceeded 80° C, meaning pasteurization didn't occur (Shuqing et al., 2008). The conditions needed for biodegradation are: a low reservoir temp, the presence of an electron acceptor such as water, an oil-water contact, microorganisms, and nutrients (Shuqing et al., 2008). For more in-depth discussion on development of bitumen reserves in Alberta see Shuqing et al. (2008). The amount of biodegradation that may occur after a spill of oil sands products will be dependent on the extent to which the material was degraded prior to extraction. Therefore, bitumen that has undergone a high degree of biodegradation will probably undergo little biodegradation after a spill (Dettman, 2013). However, there are no experimental data available to fully evaluate the biodegradation potential oil sands products spilled into fresh or salt water systems.

### 5.2.2 Bitumen Chemical Properties

Biodegradation of oil leads to a relative increase in sulfur, resins, asphaltenes, and metals (Shuqing et al., 2008). In biodegradation, microorganisms initially attack small, organic compounds leaving large compounds behind. Biodegradation of crude oil, in situ, leads to

bitumen containing a lower proportion of paraffins (saturated hydrocarbons without rings) and naphthenes (saturated hydrocarbons with rings), and a higher proportion (>50 percent) of aromatics (hydrocarbons with one or more aromatic nuclei), which leads to the increased viscosity and density characteristics of bitumen (USGS, 1990). Netzer et al. (2006) found that aromatics made up 37 percent of the total weight of Athabasca bitumen with resins being second (25.7 percent), followed by saturates and asphaltenes (both 17.3 percent). Yang et al. (2011) found, through gas chromatography, that Alberta bitumen is characterized by large, unresolved compounds (n-$C_{10}$ to n-$C_{40}$) and a near absence of n-alkanes. Souraki et al. (2012) found that $C_{39}$ and larger molecules made up 56.96 percent of the weight of Athabasca bitumen. See Table 1 in *Heavy Oil and Natural Bitumen Resources in Geological Basins of the World* (USGS, 2007) for a numeric breakdown of many of the chemical properties of bitumen.

### 5.2.3 Bitumen Physical Properties

Finding information on the physical properties of Alberta oil sands products can be problematic as some of the specific data about physical properties is considered proprietary business information. For this reason it has been difficult for regulators and others in the scientific community to access (Jensen & Pilkey-Jarvis personal communication, 2012).

Bitumen is generally characterized as being denser than standard crude oils (USGS, 2007; Shuqing et al., 2008). The density of bitumen, when compared to water, depends on the specific reservoir and temperature of the source material. Athabasca bitumen tends to be denser than freshwater but less dense than saltwater under standard conditions of 15.56°C and 20 bara/19.74 ATM (Netzer, 2006; Souraki et al., 2012). Between 25 and 40°C, Athabasca bitumen becomes less dense than water (Mochinaga et al. 2006). Cold Lake bitumen is denser than freshwater below ~40°C but not denser than saltwater (Mehrotra & Svercek, 1988). Barrufet &

Setiadarma (2003) found that bitumen is less dense than water at ambient temperature although they do not specify from which reservoir the sample was obtained. As temperature increases, the viscosity and density decrease. Bitumen is orders of magnitude more viscous than conventional oils. At 25°C, the viscosity of conventional crude is ~13.7 cP, while for bitumen it is >1,000,000 cP (USGS, 2007). Athabasca bitumen must exceed 150°C and approach 200°C before its viscosity is similar to standard crude oil viscosity at ambient temperatures (Souraki et al., 2012). Cold Lake bitumen must exceed 120°C before its viscosity is similar to standard crude viscosity at ambient temperature (Mehrota & Svrcek, 1988). See Table 1 in USGS (2007), for a more in depth comparison of the physical properties of bitumen to heavy, medium, and conventional oils.

See below for a comparison of Bitumen to other common crude oils and gas condensates. API values for crude oils range from approximately <22-42. An overview of crude oil and other petroleum product densities is as follows.

- Gas Condensates – ≈ 42 to 55°API
- Light Crude Oils – ≈ 31 to 42°API - varies
- Medium Crude Oils – ≈ 22 to 31°API
- Heavy Crude Oils – ≈ <22°API
- Alberta Bitumen – ≈ 8°API prior to being mixed with diluent
- Water (≈10°API); Gasoline (≈63°API); Fuel Oil #2(≈30-38°API)

See Appendix 2 for more data values and ranges for the relevant oil sands products being exported from Canada (Environment Canada, 2013; USGS, 2007; USDOT PHMSA, 2012).

## 5.3 API, Specific Gravity, Acidity, and Other Data for Oil Sands Products

### 5.3.1 Floating, Sinking, and Submerged Oil

#### *5.3.1.1 Floating Oil*

Most crude and refined oil products float when spilled. Spill response agencies are most familiar with and best equipped to handle floating oil spills.[10] However, depending on the environment, a spill of a very light conventional crude oil does not always float. In the Deepwater Horizon spill in the Gulf of Mexico, small droplets of light oil released below the surface were kept submerged by the movement of the ocean water despite having API gravity greater than 10, because the turbulence was enough to overcome the buoyancy of the small particles of oil (Joint Analysis Group, 2012). While this oil would have behaved differently had it not been a subsurface release, it demonstrates the variability of oil's fate based on the circumstances under which it is spilled and the environment into which it is spilled.

#### *5.3.1.2 Sinking Oil*

Some oils, including Group V (defined as having a specific gravity greater than 1.0) can sink, sometimes reaching the ocean floor or riverbed (National Research Council, 1999). However, specific gravity as used in the regulatory definition of Group V oils, does not adequately characterize all oil types and weathering conditions that produce non-floating oils, which has led to the "non-floating" or "submerged oil" definition below.

#### *5.3.1.3 Non-floating and Submerged Oil*

Non-floating oils behave differently and have different environmental fates and effects than floating oils. The resources at greatest risk from spills of floating oils are those that use the

[10] See Section 7 for more on response technology.

water surface and the shoreline. Floating-oil spills have fewer impacts on water-column and benthic resources. In contrast, non-floating oil spills can pose an increased threat to water-column and benthic[11] resources (National Research Council, 1999). This includes Group IV oil, which has a specific gravity of slightly less than 1.0 and "might mix into the water column and sink to the seabed after weathering and interaction with sediments" (National Research Council, 1999). This can make effective recovery difficult if not impossible, because skimmers and other surface technologies as well as ROVs that would be able to recover oil from the bottom are both rendered ineffective (Goodman, 2006).[12] Oils that have density values very close to that of water can become neutrally buoyant, and remain suspended in the water column when they interact with the environment in a variety of ways, including:

- Picking up particles of suspended sediment from turbid water, especially in rivers during flood stage, estuarine waters, or any other water carrying sediment (National Research Council, 1999).
- Turbulence in the water can move neutrally buoyant oil—or oil with a density very close to that of the surrounding water—vertically in the water column. During the Kalamazoo spill response, turbulence along the river bottom caused sunken oil to resurface (Muller, 2013).
- When oil is spilled and enters the environment there is the potential for it to change temperature. Any decreases in temperature will cause the oil's density to increase, further increasing the chance of becoming submerged.

### 5.3.2 Implications of Physical Properties in Spill Scenarios

#### *5.3.2.1 Saltwater*

Due to the salt content, saltwater is denser than fresh water with an API gravity value of approximately 6.0 (specific gravity ranging from 1.02-1.03) (Glencoe, 2002). Raw, undiluted

[11] The term benthic refers to organisms living on or in sea or lake bottoms.
[12] See Section 7 for more on response technology.

bitumen produced from oil sands products can have API gravity below 10 (specific gravity of 1) depending on the reservoir, meaning that it would sink in fresh water. Dilbit and synbit being transported in pipelines and by rail, which have been blended with lighter petroleum in the form of diluents or processed into "synthetic crude", have higher API densities (Environment Canada, 2013). This addition of lighter material may change the density enough to allow the product to initially float if spilled in fresh or saltwater. Although other sources listed above show dilbit being lighter that water, the Keystone XL Draft EIS released by the State Department on March 1, 2013 lists specific gravity values for dilbit that range on either side of water. This may be related to the specific samples they were using (U.S. Department of State, 2013). Additionally, having an API density close to 10 means that smaller variations in density due to temperature or other environmental factors could change the way the product acts or reacts in a spill. The density of fresh oil also changes as a result of weathering and biodegradation. For example, as diluents and other lighter molecules begin to evaporate, the remaining material become denser. No experimental data are available to evaluate how oil sands products will behave when spilled in saltwater environments. Of particular interest is whether oil sands products will sink or submerge after weathering, interaction with sediments, or other interactions with the environment.

#### *5.3.2.2 Freshwater*

The most well documented example of a dilbit spill into freshwater is the Enbridge spill into Michigan's Kalamazoo River, which included both Cold Lake Blend and Western Canadian Select crude oil condensate mixtures. These dilbit blends have a reported specific gravity of 0.65 to 0.75 (NTSB, 2010). According to responders and damage assessors who worked on-scene monitoring and advising the response effort from its early stages, the spill presented unique

challenges not typical in traditional crude oil spills (Jessica Winter personal communication, 2012; Laurie Muller personal communication, 2013). Because oil begins to weather as soon as it enters the environment, some of these unique challenges are a direct result of the specific environment in which the spill occurred. An additional difficulty is determining definitively what role the physical properties of Cold Lake Blend and Western Canadian Select played in the ultimate fate of the oil spilled. Responders from the EPA, NOAA, and the NTSB report state that containment and cleanup efforts required responding to floating, submerged and sunken oil (NTSB, 2010; Jessica Winter personal communication, 2012; Laurie Muller personal communication, 2013). Initially there was a visible sheen of oil on the water surface, and during the course of the cleanup, responders also found "blobs" of oil moving in the water column and sunken oil on the river bottom (Jessica Winter personal communication, 2012; Laurie Muller personal communication, 2013). Flood conditions, turbidity, and the velocity and volume of the river at the time of the spill all influenced the behavior of the oil once it was spilled (NTSB, 2010). Oil sands products could be particularly challenging in this type of dynamic fresh water environment because the lighter diluents evaporate, leaving the heavy ends of the product behind. If these heavy ends are sufficiently dense—and especially if they mix with sediment—the oil can become submerged or sunken.

#### *5.3.2.3 Estuarine Water and Puget Sound*

Estuarine water presents its own set of unique challenges when trying to model or predict the behavior, weathering, and fate of spilled oil. Influx of fresh water from rivers with differing temperatures, salinity, and density can cause the water column to become stratified. In Puget Sound specifically, it is this influx of riverine water that is the primary cause and control of stratification (Climate Impacts Group, 2005). Because this mixing with fresh water dilutes the

salinity, estuarine water is less dense than oceanic saltwater. In addition, because it is less dense, the less salty riverine water tends to stay in the top layers, meaning that heavy oil spilled into estuarine water like that in Puget Sound is more likely to become submerged or sunken than the same oil spilled in the open ocean. This is especially a concern in the waters around potential terminal sites like Grays Harbor, WA and Kitimat, B.C., where major rivers flow into the system. Predicting and preparing for a spill of oils sands product in Puget Sound or other estuarine environments requires taking into account these varying factors that affect water density.

#### 5.3.3 Information Gaps for Physical Properties

- The API values listed on the Environment Canada website may be out of date. At least some of the values there were originally published in 1983.
- Physical properties of oil sands derived products fluctuate based on season, customer requirements, and other factors (Dettman, 2013).
- It is difficult to say how realistic it is to expect that pipeline operators will know what is in the pipeline at the location of a release (Dettman, 2013).
- The lack of experimental data on oil products weather significantly limits the ability of spill response organizations to understand and predict the behavior and fate of oil sands products in freshwater, estuarine, and saltwater environments.

## 5.4 Diluents

#### 5.4.1 Diluents and Synthetic Crude

The diluents being used are light hydrocarbons usually with a density between 0.6-0.775 g/ml, with a maximum weight by percent of 0.5 percent for sulfur, and max viscosity of 2.0 cST (7.5°C) according to Enbridge (2010) specifications. Natural gas condensate, a liquid under standard, ambient conditions that contains pentanes and heavier hydrocarbons produced from processing natural gas, is currently the most commonly used diluent (Bott, 2011). Additional

pipelines are being proposed to supply diluent to Alberta and counter the increasing demands but decreasing supply of diluents in Canada (CAPP, 2011). Another approach to upgrading bitumen is to blend it with synthetic crude to make a product called Synbit. Synbit is a mixture of bitumen with synthetic crude, which is bitumen that has undergone upgrading through coking and hyrdrolysis to remove the larger molecules and decrease viscosity (Yui, 2008; Héraud, 2011; U.S. Department of State, 2013). See Yui (2008) for a simplified schematic of the synthetic crude upgrading process. Currently, this method is less expensive than mixing with diluent (Héraud, 2011). Projections are that the use of synthetic crude as a diluting agent will increase over the next decade while the use of natural gas condensate will remain steady (Héraud, 2011). The exact physical characteristics of the diluent will vary depending on the diluent being used. See Crude Quality Inc. (2013) for an in depth list of the physical and chemical properties of multiple diluents.

### 5.4.2 Dilbit/Diluent and Synbit Composition for Transport

The composition of dilbit tends to be between 25 and 30 percent diluent and 70-75 percent bitumen depending on the viscosity of the bitumen and the density of the diluent (Héraud, 2011). The ratio can be as high as 40 percent diluent for denser bitumen (Bott, 2011). The diluent required for mixture can be decreased if asphaltenes are removed from the parent bitumen (Rahimi & Gentzis, 2006). Because the diluent and bitumen are both hydrocarbon based, the two are completely miscible (Dettman, 2013). For synbit, the mixture is typically 50 percent synthetic crude and 50 percent bitumen (Héraud, 2011).

### 5.4.3 Gaps in Diluents

The diluent properties will differ depending on the exact diluent being used as they can range from high to low in sulfur content. They have highly variable boiling points so determining at what temperature it will become gas in the event of a spill is difficult.

## 5.5 Weathering of Dilbit in the Environment

### 5.5.1 Weathering of Oil Sands Derived Products Compared to Conventional Heavy Crude Oils

Currently, there is very little information about how oil sands products will weather in the environment. A few studies have been conducted at the laboratory level, and covered specific oil sands products rather than looking at the whole range of oil sands products being transported out of Canada (SL Ross, 2012). One of these studies, conducted by SL Ross Environmental Research Limited tested MacKay River Heavy Bitumen and Cold Lake Bitumen that were diluted with synthetic crude (Suncor Synthetic Light) and condensate (CRW condensate), respectively. The study found that oil subjected to weathering tests was measured to have an ultimate density that approached but did not surpass that of the water. At the end of the tests approximately 15 percent of the recovered oil was collected from the tank walls 10 cm below the water surface. The majority (approximately 85 percent) of the oil was recovered from either the surface or stuck to the side walls within 10 cm of the surface. At no point was oil found to submerge, sink, and stick to the bottom of the flume (SL Ross, 2012).[13] It is important to remember that the results SL Ross found represent only one possible weathering scenario, were limited by the experimental conditions, and could vary with different products or experimental environments. Although some more comprehensive studies are being conducted,[14] publically

[13] A complete description of their methods and findings can be found in the report SL Ross published, cited in the references section.

[14] According to a webinar talk given by Kinder Morgan on February 13th 2013 they have engaged O'Brien's Response Management and Polaris to study fate of oils sands products. They have completed the literature review, gap analysis and research plan, and are scheduled to do research March 2013 and issue final report by April 2013. They intend to include tests of

available data are currently limited to what can be gleaned from the response efforts of the few well-documented dilbit spills (See section 7.2 Response Efforts). What is known is that dilbit, synbit, and other bitumen-based products contain more "heavy ends" or large hydrocarbon molecules than conventional crude oils. Additionally, part of the weathering process of conventional crude oil is due to biodegradation by microorganisms, and because oil sands products have already undergone partial biodegradation, there is some question as to whether any further biodegradation would occur in the environment after initial weathering of the diluent portion of the mixture.[15]

### 5.5.2 Potential Weathering Patterns in the Environment

Anytime oil is spilled into the environment it begins to "weather" due to physical, chemical, and biological conditions of the environment. Effectively modeling the weathering patterns of any oil—including oils sands products—requires knowing the particular properties of that product, including density, pour point, and distillation curves. While environmental agencies, regulators, and responders tend to have good data on the properties of conventional crude oils, less is known or understood about the properties of oils sands products. The current state of knowledge is only useful for predicting the weathering of a specific product—Cold Lake Blend specifically for example—but not any of the other bitumen diluent blends or synbits being produced in the region. Gathering the information necessary to model weathering behavior may be particularly difficult for oil sands products. The physical properties of crude oil from conventional reservoirs typically changes slowly over years making them easier to predict at any given time. In contrast, physical composition of the oil sands products being transported out of

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typical oil sands products under ambient conditions similar to those of the Salish Sea. Tests on API by the National Academy of Science on diluted bitumen are also currently underway.

[15] See section 5.1 for more on biodegradation and the history of Canada's oil sands deposits.

Alberta can vary greatly. Not only do the physical properties of bitumen deposits vary across the region, but what enters the transmission lines after being upgraded and or diluted can vary on a weekly basis. Each oil sands product entering a pipeline differs based on specifications from the refineries processing the product at the other end of the line (Dettman, 2013). All crude oils contains a spectrum of hydrocarbons, and each segment of the spectrum is used to make different products—i.e. gasoline, asphalt, plastics, etc. Refineries change the mix they request based on demand for specific products.

There is some evidence that because oil sands products are heavier and more viscous than conventional crude oils, they are likely to be more difficult to clean up. In the event of a spill on land, "the heavier and more viscous components (i.e., the asphaltenes) would likely remain trapped in soil pores above the water table. It is also likely that the lighter constituents would partly evaporate and not be transported down through the soil with the heavier components." (Ramseur, et al, 2012). These properties can also make clean up challenging in the event of a spill into water. The potential for the lighter diluent to evaporate quickly, leaving the heavier bitumen behind equates to an increased risk that responders will be dealing with oil not only on the surface, but also sunken oil or oil submerged in the water column. These predictions are consistent with the experience of responders at the Kalamazoo spill (Jessica Winter personal communication, 2012; Laurie Muller personal communication, 2013).

### 5.5.3 Information and Policy Gaps for Modeling Weathering

- Regulatory and response agencies may lack sufficient information about what product is being transported through a pipeline at any given time, and lag time associated with getting accurate data from the producer or pipeline operator can cause delays to the repose and cleanup efforts.

- Experimental and field data on the potential for further biodegradation of spilled oil sands products.

## 5.6 Corrosiveness of Oil Sands Products

### 5.6.1 Overview of Existing Research on Pipeline Corrosion

A recurring theme throughout the debate over the risks of transporting oils sands via pipelines has centered on corrosion, and the potential for oil sands products to be more corrosive than traditional crude oil. Several research reports exist on the subject of oil sands products corrosiveness (see the "Key Sources of Information" below), and although not entirely conclusive, the data suggest that in general oil sands products are not significantly more corrosive than other heavy crude oils. A brief overview of the findings includes the following points:

- Sulfur content of Alberta oil sands products tends to range between 2-5 (weight percent). There are conflicting reports regarding how these sulfur levels compare to other heavy crude oils. The report by Zhou and Been found oil sands products to be generally comparable to other heavy crudes, with the exception of a few specific products (Zhou, Been, 2011). However, a USGS study reports higher sulfur content as a fundamental difference between natural bitumen and conventional crude oils as a result of in situ biodegradation (USGS, 2007).
- TAN values of Alberta oil sands products ranged from .5-2.5 (mgKOH/g), which is comparable to many conventional heavy crudes. Products with TAN values higher than 0.5 are generally considered "potentially corrosive" (Ramseur et al, 2012), but in lab testing the oil sands products were not found to be significantly different than comparable heavy crudes and not corrosive enough to be a concern to pipeline operators (Dettman, 2012), (Zhou, Been, 2011).
- Water content (BS&W) in oil sands products is comparable to other crudes, required maximum allowable threshold is set by pipeline operators (Dettman, 2012), (Owens, 2012).

- Sediment content in dilbit crudes was found to be lower than or comparable to that of conventional crudes, with the exception of one dilsynbit blend that was found to have more than double the solids content of most other crudes (Zhou, Been, 2011). The data, however, only indicates the total amount of sediments and does not provide information on the size distribution. It is unknown how the solids in the conventional crudes compare to those in dilbits (Zhou, Been, 2011).
- Sediment build-up in low or high spots in the pipeline interior can lead to corrosion (Dettman, 2012; NTSB, 2010).
- According to some, water is still the most important factor in the potential for pipeline corrosion (Dettman, 2012).

Our research does not indicate that oils sands products are significantly more corrosive than other heavy crude oils. A National Academy of Sciences study currently underway and scheduled to be complete by the end of 2013 will analyze whether transportation of dilbit by transmission pipeline has an increased likelihood of release compared with pipeline transportation of other crude oils. The National Academy study will primarily be a review of existing literature and will not include any original research. PHMSA data presented to the National Academy show that since 2002 there have been no releases of oil caused by internal corrosion from pipelines carrying dilbit (API, 2012). However, this does not mean that corrosion is not a concern. Together, internal and external corrosion account for 37 percent of non-small pipeline accidents for crude oil (PHMSA, 2012c).

### 5.6.2 Water and Sediment Content

After being mined from the ground, oil sands go through a series pipelines called “gathering lines” and “feeder lines” during initial extraction and processing. During these early stages the product can have diluent mixed with it, and can also have elevated levels of sediment and water. Consequently, these gathering and feeder lines are more prone to corrosion, and are

maintained every three months. Once the product enters the larger "transmission lines" that transport the oil sands products out of Alberta, the sediment and water has been reduced and corrosion is less likely (Dettman, 2012).

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## Key Sources: Properties, Fate, and Behavior of Oil Sands Products

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Comparison of the Corrosivity of Dilbit and Conventional Crude, By Zhou and Been. Commissioned by Alberta Innovates

Congressional Research Service Report: Oil Sands and the Keystone XL Pipeline: Background and Selected Environmental Issues

Crude Monitor: http://www.crudemonitor.ca/

Environment Canada Oil Properties Database: http://www.etc-cte.ec.gc.ca/databases/OilProperties/oil_prop_e.html

Heather Dettman, Petroleum Research Scientist at Natural Resources Canada.

Presentation: National Academy of Sciences Transportation Research Board Study of Pipeline Transportation of Diluted Bitumen Pipeline and Hazardous Materials Safety Administration Briefing

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# 6 ENIVRONMENTAL AND HUMAN HEALTH EFFECTS OF OIL SANDS PRODUCTS

## 6.1 Environmental Impacts

### 6.1.1 Species at Risk During Floating and Sinking Phase

Spills can have both immediate ecosystem impacts as well as long-term consequences resulting from continued chronic exposure (Peterson et al., 2003). Spills of oil sands products impacts include those from the partitioning of diluent into the air and water as well as the components of the source bitumen that could differentially partition into the water column and sediments.

#### *6.1.1.1 Species at Risk During Floating Phase*

During floating oil spills, species that contact the water's surface frequently are at highest risk. This can include aquatic and semi-aquatic mammals, sea birds and waterfowl, turtles, and aquatic insects. Aquatic and semi-aquatic mammals, depending on species, can suffer acute mortality through hypothermia from loss of insulation, oil ingestion, and inhalation of toxic fumes (EPA, 1999). Mammals that rely on fur for insulation appear to be most affected (USFWS, 2010). Sea otters, river otters, beavers, and fur seals, are particularly vulnerable resulting from their frequent contact with the water's surface and their reliance on fur for insulation (EPA, 1999). Seabirds and waterfowl are also subject to acute mortality through loss of insulation and oil ingestion. These species at risk would be the same as the species which would be at risk during any similar floating oil spill.

#### *6.1.1.2* Species at Risk During Submerged and Sinking Phase

Fish eggs laid on bitumen contaminated sediments in lab studies showed frequent death or physical abnormalities including spinal deformities, lesions, hematomas, and eye defects

(Colavecchia et al. 2004; Colavecchia et al., 2006; Colavecchia et al., 2007). Therefore, if a spill occurs during spawning periods, fish eggs and larvae may be adversely affected (Peterson et al., 2003). Coral communities may also be adversely affected by submerged oil (White et al., 2012[a], White et al. 2012[b]). Oil can continue to affect marine mammals through ingestion especially in species which have contact with sediments or feed on bivalves (Peterson et al. 2003). Shellfish can be adversely affected if oil sinks or becomes concentrated near shorelines (USFWS, 2010). Through gill uptake or ingestion of oil or contaminated prey, fish may be subject to adverse health impacts (USFWS, 2010). The continued presence of polyaromatic hydrocarbons (PAH) after oil spills are toxic to certain fish species' larva including pink salmon and herring (Peterson et al. 2003).

#### *6.1.1.3 Species at Risk From Diluent*

According to the Material Safety Data Sheet for sour natural gas condensate from ConocoPhillips (2012), condensates can cause lasting effects in aquatic environments and are considered to be toxic to aquatic organisms. In general, natural gas condensate is moderately to highly toxic via inhalation and thus could pose problems for all species which breath at or near the surface. As the diluent is liquid under ambient conditions, it could mix with water having detrimental effects for fish and aquatic insects.

### 6.1.2 Athabasca River

Fish which had contact with tailings associated water had adverse immunological effects (McNeill et al. 2012). Fish eggs laid on bitumen contaminated sediments showed either adverse physical abnormalities including spinal deformities, lesions, hematomas and eye defects or death (Colavecchia et al., 2004; Colavecchia et al., 2006; Colavecchia et al., 2007). While fish physical

abnormalities have been reported downstream of oil sands development (Schindler, 2010), a direct causal link is yet to be established. Kelly et al. (2010) found increased levels of the 13 elements considered priority pollutants in either melted snow or water samples from near or downstream of development. Seven of these pollutants—cadmium, copper, lead, mercury, nickel, silver, and zinc—all surpassed either Canada's or Alberta's guidelines for the protection of aquatic life (Kelly et al., 2010). PAH's are also significantly higher downstream of oil sands development, 10 to nearly 50 fold higher, when compared to areas not subject to land disturbance (Kelly et al., 2009). Some of the values exceeded that which were toxic to fish embryos. It is possible during spring snowmelt that PAH values could exceed toxicity levels for both aquatic and terrestrial organisms (Kelly et al., 2009). Changes in mercury levels in fish populations in the vicinity and downstream of oil sands products development is contested. Timoney & Lee (2009) found an increase in mercury levels in fish from 1976-2005, while Evans & Talbot (2012) found a decrease in mercury levels in fish species from 1981-2011. The reason for the conflicting results may be attributable to research methodology (Evans & Talbot, 2012).

### 6.1.3 Gaps in Environmental Impacts

Current water, snowpack, and air monitoring for toxic outputs near oil sands development are not sufficient (Kelly et al., 2009; Schindler, 2010). A new testing scheme or organization responsible for monitoring needs to be implemented. The Regional Aquatics Monitoring Program (RAMP) is currently in charge of monitoring water quality and fish populations in the Athabasca River but recent literature has elucidated several problems with the current monitoring program (Kelly et al., 2009; Schindler, 2010; Royal Society of Canada, 2010; Jordaan, 2012). Ongoing monitoring of potential fish tainting may also be an important component of an overall monitoring program to determine the impact of oil sands development (Tolton et al., 2012).

## 6.2 Human Health Impacts

### 6.2.1 Human Health Concerns Near Oil Sands Products Development

No solid evidence currently exists suggesting people who live in the vicinity or downstream of oil sands sites near the Athabasca River are subject to increased health concerns (Royal Society of Canada, 2010). Two studies have noted that cancer is tied to PAH's and therefore increased PAH levels could cause increases in cancer downstream, but a conclusive link between increased PAH's in the Athabasca river and cancer cases has not been made (Royal Society of Canada, 2010). A higher number of cancer cases than would be expected have been observed 250km downstream from oils sands development in Fort Chipewyan, but this could be due to chance and no connection to oil sands development have been made (Chen, 2009; Royal Society of Canada, 2010). When compared to the values laid out in the Guidelines for Canadian Drinking Water Quality (GCDWQ), antimony, arsenic, cadmium, chromium, copper, lead, mercury, selenium, and zinc did not exceed the recommended values at or below oil sand development sites near the Athabasca River (Kelley et al. 2010; Royal Society of Canada, 2010). Refer to *Environmental and Health Impacts of Canada's Oil Sands Industry* (Royal Society of Canada, 2010) for a more in depth discussion of human health risks in the areas near oil sands products development sites.

### 6.2.2 Safety of Cleanup Crew and Citizens in the Spill Vicinity

The responders to the dilbit spill in Kalamazoo reported elevated levels of benzene above those recorded at spills of standard crude oils (Lori Muller, 2013). Also, bitumen is characterized as being richer in sulfur (Shuqing et al., 2008). Bitumens tend to be lower in mercury than conventional oil but higher in lead content (USGS, 2007). The added diluent could pose problems due to its low flash point; meaning combustion could be a problem from the

evaporation of diluent. Evaporation of diluent could pose an inhalation risk to responders. The MSDS for ConocoPhillips (2012) and Gibsons (2012) natural gas condensate lists the product as extremely flammable. ConocoPhillips (2012) further warns that condensate is toxic and potentially fatal if inhaled resulting from the hydrogen sulfide gas content. The MSDA for Hess (2012) lists sweet natural gas condensate as only marginally toxic through inhalation probably because of lower hydrogen sulfide levels. Benzene, a known carcinogen, is also present in natural gas condensate, which could pose a risk to spill responders. The MSDS for Hess (2012), ConocoPhillips (2012), and Gibsons (2012) recommend spill responders wear air supplied respirators, protective clothing, and eye protection. The MSDS for natural gas condensate for Oneok (2009) warns that condensate, being heavier than air, will accumulate in depressions. These MSDS are for natural gas condensate alone, so the risks from natural gas condensate after blending to form dilbit could be different. After the Enbridge spill in Kalamazoo, MI, 320 community members and 11 spill responders reported adverse health effects which included headaches, nausea, and respiratory issues (Michigan Department of Community Health, 2010; NTSB, 2010). Refer to the report *Acute Health Effects of the Enbridge Oil Spill* (2010) produced by the Michigan Department of Health for a list and statistical breakdown of the observed adverse health effects.

### 6.2.3 Gaps in Human Health Impacts

Resulting from the unknown specifications of the diluent, impacts to private citizens living in the vicinity of the spill and to responders is unknown because of the potential variability in the diluent and bitumen specifications. Additionally, the evaporation rate of the diluent is often unspecified, so it is not possible to predict whether responders and citizens would face pockets of evaporated natural gas condensate.

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# 7 RISK MITIGATION

The U.S. government has in place a number of systems that are meant to mitigate the risks associated with the transportation of oil. In this section, we will look at three issues:

1. The siting process of pipelines at the state and international level;
2. Systems to detect pipeline leaks; and
3. Spill response equipment with the ability to handle heavy oil spills.

These three issues are important in the oil sands debate as they provide insight in the ability and capacity for the U.S. government, as well as private companies, to prepare for and respond to spills of oil sands products.

## 7.1 Risk Mitigation Techniques

### 7.1.1 Pipeline Siting

The federal government, through the U.S. State Department, approves or rejects the construction of pipelines whenever the proposed route crosses a U.S. border (Parfomak *et al.,* 2013). However, the federal government is not involved in the siting of any intrastate or interstate pipelines.[16] In both cases, state law determines the appropriate regulatory agency that approves the siting and construction of large energy infrastructure projects. The procedures and regulatory agency in charge of siting pipelines varies from state to state (Parfomak *et al.*, 2013).

[16] The Federal Energy Regulatory Commission (FERC) is in charge of approving construction of interstate natural gas pipelines, however, this authority does not extend to oil pipelines. FERC's involvement with interstate pipeline includes regulating the rates and practices of oil pipeline companies, establishing equal service conditions to provide shippers with equal access to pipeline transportation, and the establishment of reasonable rates for transporting petroleum and petroleum products by pipeline (FERC, 2013).

In this section, we will review the factors that the U.S. State Department considers when making pipeline approval decisions and also examine the state requirements in Washington.

#### *7.1.1.1 Presidential Permit Application*

Pipeline operators constructing an international pipeline must apply for a Presidential Permit through the U.S. State Department (the "Department"). The Department has a considerable amount of discretion in its decision-making process, however, its main goal is to determine if the project is within the "national interest" (Parfomak *et al.*, 2013). To accomplish this, the Department looks at (Parfomak *et al.*, 2013):

- Environmental impacts of the proposed project;
- Potential for the proposed project to diversify U.S. energy supplies and meet demand;
- Security of the pipeline at the border crossing, specifically in relation to other modes of transport;
- Stability in the relationship of trading partners;
- Impact of the proposed project on foreign policy goals;
- Economic benefits of the project; and
- Proposed project's impacts on U.S. goals of reducing fossil fuel dependence.

The Department must also take into account any potential impacts the proposed pipeline may have on the National Historic Preservation Act, the Endangered Species Act, the National Environmental Policy Act, and Executive Order 12898 which addresses environmental justice concerns (Parfomak *et al.*, 2013). Of these policies, the National Environmental Policy Act (NEPA) traditionally is the most discussed. NEPA requires federal agencies to consider the environmental impacts of proposed projects and provides a forum for stakeholders to express their concerns (Caldwell, 1998).

NEPA requires the completion of an Environmental Impact Statement (EIS). EISs occur in two stages: a draft stage and a final stage. When a draft EIS is submitted to the State Department, it is then made available to the public for a mandated comment period. The final EIS must incorporate the comments from the public by either explaining why the concern was not considered or by explicitly addressing the concern in the final draft (Caldwell, 1998). The U.S. Environmental Protection Agency (EPA) must publically comment on the draft EIS and evaluate both how well the EIS analyzes the environmental impacts of the alternatives (adequacy) and the level of environmental impact of the proposed action (impact) (EPA, 2012c).

Based on the EPA's ratings of the draft EIS and the public's comments, the project proposer either revisits the draft proposal or incorporates the comments to create a final EIS. After the final EIS is submitted to the State Department, there is a final 90-day review period where the Department gathers information from relevant agencies and stakeholders to determine if the project is within the national interest (Parfomak *et al.*, 2013).

#### *7.1.1.2 Washington State Requirements*

In Washington State, all intrastate pipelines carrying crude, refined, or liquid petroleum products must be approved by Washington's Energy Facility Site Evaluation Council (EFSEC). The EFSEC is responsible for evaluating applications and ensuring that all environmental and socioeconomic impacts are considered before a pipeline is approved. Applicants must address over 60 environmental and socioeconomic impact objectives (including measures to mitigate impacts), submit an environmental impact statement, and defend themselves at public hearings before their projects can be approved. After evaluating the application, EFSEC will submit its recommendation to Washington's Governor. If the Governor approves the project, a Site Certification Agreement (SCA) is issued and construction can begin (EFSEC, 2012). EFSEC is

also the regulatory agency that provides oversight during the construction and operation of the facility. It has the right to levy fines or halt construction if it deems that the project is violating state laws or the conditions of the SCA (EFSEC, 2012).

#### *7.1.1.3 Stakeholders and other factors in pipeline siting*

In order to increase the political feasibility of a large infrastructure project, such as the siting of a pipeline, there are a number of factors that should be taken into account beyond economic and environmental benefits or concerns. These include (Nussbaum, 2012):

- Wildlife management areas, including all parks, national forests, and public lands;
- Other pipelines and utilities that cross the proposed route;
- Roads, railroads, and water crossings;
- Jurisdictional boundaries of states, counties, and cities;
- Native American or First Nation ownership or interests;
- Federal and State threatened or endangered species' habitat;
- Wetlands and other environmentally sensitive properties; and
- Private land.

The proposed pipelines mentioned below have faced opposition and been delayed due a number of these factors. For example, the Enbridge Northern Gateway pipeline is being opposed by First Nations because the proposed route crosses their land, whereas the Keystone XL pipeline has been delayed for multiple years because its proposed route crossed environmentally sensitive areas in Nebraska and because of the additional regulations imposed on pipelines that cross U.S. borders.

**Key Sources: Pipeline Siting**

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#### *7.1.1.4 Status of Each Proposed Pipeline*

Four major pipelines are being planned to increase the transport of oil sands products from Alberta to consumer markets. These pipelines include Enbridge's Northern Gateway pipeline, Kinder Morgan's Trans Mountain (TM) Expansion, TransCanada's Keystone XL, and Enbridge's Line 9 Reversal. Enbridge's Northern Gateway and Line 9 Reversal and Kinder Morgan's TM Expansion[17] are within Canadian borders, whereas the Keystone XL crosses the U.S. – Canadian border. The status of each pipeline, as of March 2013, is as follows:

[17] Note that Kinder Morgan's expansion is occurring between Edmonton, Alberta and Burnaby, B.C. The expansion does not include the segment of the pipeline that crosses the U.S. border, which is why it does not require State Department approval.

| Pipeline | Regulatory Status | Start of Construction[18] | Operational | Major Opposition |
|---|---|---|---|---|
| ***Northern Gateway*** | • Began Joint Review Panel on 8/3/2012 to assess environmental impacts, public comments, Aboriginal concerns, and gather information.<br>• Hearings will continue through May 2013 (NEB, 2013a). | Mid-2014 (Enbridge, 2013) | 2017 (Enbridge, 2013) | • Fear for Fraser and Skeena River Salmon populations (WCEL, 2012).<br>• Stanch opposition from First Nation Groups, with over 130 Nations signing the "Save the Fraser Declaration" (McKnight, 2012).<br>• Sixty percent of B.C. residents oppose the pipeline (Flegg, 2012) |
| ***TM Expansion*** | • Toll application was submitted in 2012.<br>• Plan to file facilities application in late 2013.<br>• Expect decision from the National Energy Board (NEB) in 2014 (Kinder Morgan, 2013b) | 2016 (Kinder Morgan, 2013b) | 2017 (Kinder Morgan, 2013b) | • Largest opposition is from local groups in Vancouver that are concerned with the lack of additional marine safety procedures for the harbor.<br>• Traverses Jasper National Park in the Canadian Rocky Mountains and some of Canada's most productive farmland in the Fraser Valley (Lee, 2013) |
| ***Keystone XL*** | • Denied Presidential Permit in 2/2012.<br>• Reapplied in 5/2012 with a new route in Nebraska that avoids the environmentally sensitive Sand Hills region.<br>• Decision is expected in early 2013 (TransCanada, 2013).<br>• All states directly affected by the Pipeline have expressed support (Jones, 2013; Olson 2013).<br>• Received approval from Canada's NEB in 2010 (TransCanada, 2012). | Southern section from Oklahoma to Texas is already under construction. The second section, from Alberta to Nebraska, is expected to begin in mid-2013 (TransCanada, 2012) | Late 2014 or early 2015; Southern section, late 2013 (TransCanada, 2013) | • Main opposition is from environmental groups and landowners.<br>• The largest delay was the opposition from the State of Nebraska, which just recently approved the pipeline route (NPR, 2012). |
| ***Line 9 Reversal*** | • Hearing completed in 5/2012.<br>• Approval to reverse the 9A pipeline was obtained in 7/2012 (NEB, 2013b).<br>• NEB is currently reviewing the request to reverse and expand Line 9B from Ontario to Quebec (Enbridge, 2012b). | No construction (Enbridge, 2012b) | Early 2014 (Enbridge, 2012b) | • Since this isn't a new pipeline, the major opposition has been to the transportation of oil sands products.<br>• To bring the oil to the Atlantic, the Portland/Montreal pipeline will also have to be reversed in the future (Nelson, 2012) |

[18] Pending Approval

### 7.1.2 Pipeline Modes of Failure and Leak Detection Technologies

There are four main categories of pipeline failure (Chris, 2007):

- Pipeline corrosion and wear, caused by corrosive products, atmospheric effects, external corrosion, or leaving a pipeline partially full for a period of time;
- Operation outside design limits;
- Unintentional third party damage; and
- Intentional damage.

The most common source of pipeline failure is from external corrosion, specifically caused by water eroding the outside coating of the pipeline (Dettman, 2013). This may have been a contributing factor in the Kalamazoo spill as there were high floodwaters at the time of the rupture and significant external corrosion was found at the rupture site (Dettman, 2013; NTSB, 2010).

#### *7.1.2.1 Types of Spill Detection*

Pipeline operators use a number of techniques to detect pipeline leaks. Spill detection methods are not meant to prevent spills, but to alert operators of spills so they can respond in a timely manner. Traditionally, leak detection methods can be broken down into three different categories (Zhang, 1996):

- *Traditional methods*: using personnel to walk or fly the line and visually inspect unusual patterns on the pipeline route, such as discolored vegetation;
- *Hardware-based methods:* localized leak detection that identifies changes in temperature, noise, presence of gas, and negative pressure at specific points; and
- *Software-based methods or Leak Detection Systems:* various computer programs that monitor the changes in flow, pressure, temperature, and other hydraulic data. The most successful software-based method involves dynamic modeling, which attempts

to mathematically model the flow within the pipeline and detect discrepancies between calculated and measured values.

#### *7.1.2.2 Leak Detection Systems*

Currently, software-based methods or Leak Detection Systems (LDS) are the only method of spill detection that offers real-time, continuous monitoring down the length of the pipeline (Song, 2012). LDS work by sensing abrupt changes in the flow rates and pipeline pressure and then triggering an alarm when discrepancies occur.

When analyzing the success of LDS, it is important to consider the ability of the system to detect the location of the leak, the extent of the leak, and the possibility of a false alarm (Jiang *et al.,* 2009). Positives of using LDS include (Song, 2012):

- High success rates in detecting large spills and ruptures;
- 24/7, 365 day monitoring; and
- In theory, these systems can detect a spill and shut down the flow of oil in the affected pipeline segment within 10 minutes.

#### *7.1.2.3 False Alarms and Leak Detection Systems*

One of the main issues with LDS is that controllers have to decide whether an alarm is in an actual leak or a false alarm. The more sensitive a system is to the loss of hydrocarbons, the higher the rate will be of false alarms (Shaw, et al., 2012). If a system is sensitive to the loss of hydrocarbons and false alarms are commonplace, it could condition controllers to assume that the majority of alarms are false alarms. This can in turn lead to controllers losing confidence in the system and ignoring real warnings, as was the case in the Kalamazoo spill (Zhang, 1996; Shaw, et al., 2012; NTSB, 2010).

One aspect of pipeline operation that contributes to false alarms is the occurrence of column separation. Column separation, or “slack flow,” is the breaking of liquid columns in a

fully filled pipeline (Bergant *et al.*, 2006). This occurs when the pressure in the pipeline becomes low enough to allow the light ends of the oil to vaporize within the pipeline, creating a sort of "bubble." When the pressure of the pipeline naturally rises, the bubble can collapse which will cause the pressure in the pipeline to surge. This phenomenon may occur at high elevation points or when there are large changes in elevation and is common in all crude oil pipelines, not just dilbit (Dettman, 2013). The issue with column separation is that the pressure surges will register a "leak" with an LDS and indicate a false alarm (NTSB, 2010).

#### *7.1.2.4 Criticisms of Leak Detection Systems*

Other than the high occurrence of false alarms, there are a number of criticisms about relying on LDS to detect spills. According to a study commissioned by PHMSA (Song, 2012):

- LDS detected only 5 percent of the nation's pipeline spills between 2002 and 2012. The general public detected 22 percent of the spills and on scene employees detected 62 percent.
- LDS are not effective at identifying smaller spills, especially those that leak slowly. Smaller spills of this kind are much more common among pipeline infrastructure.
- Pipelines with variable flow rates, such as the Keystone XL, make it difficult to estimate how much oil is supposed to be in the pipeline at a given time.
- Pipeline companies' procedures have allowed alarms to be ignored by controllers, assuming that the alert is a false alarm instead of a real threat.

Two recent spills document the dangers of relying on LDS to detect spills. In both cases, human error, specifically hesitation in shutting down the system after an alarm sounded, led to excess oil spilling into the natural environment:

- *Kalamazoo Spill:* Enbridge claimed that their spill detection sensors would remotely detect and shut down a rupture in eight minutes. After the initial alarm sounded it took 17 hours for the pipeline operators to confirm the spill and shut down the pipeline segment. The controllers assumed that the alarm was due to column

separation and not a leak. As a result, the controllers restarted the line and pumped more oil through the pipeline in order to "fix" the problem. The safety board concluded that the workers had not been sufficiently trained to recognize a spill alarm, which was the primary contributor to the intensity of the spill (NTSB, 2010).

- *Yellowstone Spill:* In 2010, over 1,500 barrels of Exxon Mobil crude oil (not dilbit) was released into the Yellowstone River. The rupture was detected in the control room and the pipeline was partially isolated seven minutes after recognizing failure. However, as Exxon employees were trying to figure out next steps, crude continued to flow into the river for 48 minutes, until the upstream valve was closed and the pipeline segment was fully isolated. Human delay resulted in approximately 6.2 times more crude spilling into the river than if the upstream valve was closed upon the initial alarm (DOT, 2012).

#### *7.1.2.5 Expected Use of LDS with New Pipelines*

Both Enbridge and TransCanada have released statements about using LDS to detect spills on their proposed pipelines. In public discussions about LDS, the two companies have made clear that they are aware of the potential failures of relying on LDS and indicated that it will be one of many tools used to detect spills. Regardless of this submission, the two companies continue to use LDS to address citizen concerns regarding spill detection.

TransCanada states that the Keystone XL will have the best LDS technology in the world (TransCanada, 2013). The company estimates that with their LDS they will be able to detect spills at or above 1.5 percent of the pipeline's flow. This translates to spills of 12,450 barrels or larger (Song, 2012). To detect spills smaller than the 1.5 percent threshold, TransCanada states that they will use static pressuring. However, this method does require TransCanada to periodically shut down operations for testing (Song, 2012). TransCanada has also agreed to adopt 57 measures that will hold them accountable to go beyond the legal minimum requirements in risk reduction methods. These conditions include burying the pipeline deeper

underground than mandated, installing a higher number of data sensors and remote controlled shut-off valves, and increasing inspections and maintenance (TransCanada, 2013). TransCanada will also conduct aerial patrols every two weeks (TransCanada, 2013). Enbridge stated that it will use multiple approaches for leak detection that include computational pipeline monitoring, controller monitoring, line balance calculations, and aerial patrols at least once every two weeks (NEB, 2012).

Kinder Morgan has not indicated its use of LDS beyond general, nonspecific information on its website (Kinder Morgan, 2012). This may be because Kinder Morgan's Trans Mountain Expansion's projected completion date is further in the future than TransCanada's and Enbridge's projects and therefore may be subject to less scrutiny than the other two companies at this point in time.

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**Key Sources: Pipeline Modes of Failure & LDS**

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### 7.1.3 Gaps in Risk Mitigation Factors

In this section, two major risk mitigation methods were discussed: the process of approving the construction of pipelines at the federal and state level and the use of leak detection systems to detect leaks. Three main information and knowledge gaps exist in this discussion:

- In this report, we did not discuss the siting process of interstate pipelines due to time constraints. One main question remains regarding this topic: do pipeline companies need to pursue separate approval processes in every state that the pipeline will cross or is there a separate regulatory agency, or certain states, that are in charge of approving the construction of interstate pipelines?
- There are many criticisms of relying on leak detection systems to detect spills. TransCanada and Enbridge have stepped forward to describe how leak detection systems will be used in their risk mitigation strategies. However, a gap still remains in understanding how much the pipeline operators are relying on leak detection systems to detect spills and if this dependence is providing a false sense of security.
- There is doubt about the ability of operators to differentiate between false and real threats when interpreting leak detection systems' alarms. It is unknown if the training these pipeline companies are providing is adequate to create a reliable detection system.

## 7.2 Response Efforts

There have been two water-based spills of oil sands products in recent history: the Kalamazoo Spill in Marshall, Michigan (dilbit) and the Burnaby Harbor Spill in Burnaby, British Columbia (synthetic crude). Both spills occurred in unique situations, so our ability to extrapolate how oil sands products will behave in a spill and the success of response efforts and equipment is limited. Due to the small number of case studies, this section will also examine the Wabamun Lake Spill, a railcar derailment that spilled Bunker C oil, a heavy fuel oil, into Lake Wabamun in Alberta, Canada.

### 7.2.1 Kalamazoo Spill

Two types of dilbit oil were spilled during the Kalamazoo spill: Cold Lake and McKay River Heavy (Miskolzie, 2012). The dilbit initially floated in the fresh water. However, after mixing with sediments and the evaporation of the light hydrocarbons, some oil became heavy

and sank (Miskolzie, 2012). As a result, the dilbit simultaneously was floating, submerged in the water column, and on the bottom of the river. Beyond the characteristics of the oil, the water temperature, the presence of sediments, and the speed of the river affected oil recovery (Miskolzie, 2012). See section 2.1.1 for more information about this spill.

#### *7.2.1.1 Technologies Used in Recovery*

The most important consideration for oil removal efforts during the Kalamazoo spill was the fast moving water of the Kalamazoo River and Talmadge Creek (NTSB, 2010). Recovering oil in fast moving water is difficult, as oil tends to flow under booms and skimmers necessitating quicker and more efficient responses (USCG, 2001). In these situations, the United States Coast Guard (USCG) recommends installing underflow dams, overflow dams, sorbent barriers, or a combination of these techniques (NTSB, 2010).

Enbridge responders, along with personnel from Terra Contracting and the Baker Corporation, used:

- *Oil booming and sorbent booming* at 33 oil spill containment-and-control points. At the most heavily boomed location, 176,124 feet of boom was deployed (NTSB, 2010).
- One *Gravel-and-earth underflow dam* at the meeting of the contaminated marsh and Talmadge Creek. This site was chosen because it was accessible to heavy equipment. Responders did not have the traditional materials for adjustable underflow dams on site and had to construct one out of surplus materials and therefore were late deploying the technology (NTSB, 2010).
- Three *vacuum trucks* were used to recover oil at the underflow dam. Nine other vacuum tracks were deployed at other sites (NTSB, 2010).
- *Oil skimmers* were also used to recover oil (NTSB, 2010).
- On 25 acres, *dredging* was used to recover oil (NTSB, 2010). This method was the most successful in terms of the amount of oil recovered (Muller, 2013).

- Responders considered plugging the steel culvert pipe under Division Drive with earth to contain the oil upstream, but the quick water flow prohibited attempting this method (NTSB, 2010).

At peak deployment, 2,011 personnel engaged in oil spill recovery (NTSB, 2010). As of March 2013, the cleanup efforts are still ongoing. In October 2012, EPA asked Enbridge to dredge approximately 100 more acres of the Kalamazoo River as oil continues to accumulate in three areas (EPA, 2012d). The main concern with the presence of this oil is that during a flood, the pools of oil could remobilized and contaminate parts of the river that have already been cleaned (Hasemyer, 2012). EPA chose to move forward with dredging because it was deemed the most effective method during the original recovery efforts (EPA, 2012d). Enbridge is fighting EPA's assessment saying that further dredging would do more harm than good to the Kalamazoo River ecosystem (Adams, 2012).

#### *7.2.1.2 Lessons Learned regarding Recovery Efforts*

Three main issues are of concern in regards to Enbridge's recovery efforts:

1. *Communication* –The spill occurred during the night and initial responders were not aware of the severity of the spill or the type of oil spilled (Muller, 2013), which led to poor decision-making (NTSB, 2010). Responders had no estimate of a volume release when the first round of containment methods was deployed (NTSB, 2010).
2. *Lack of resources* – Originally, Enbridge responders did not have the resources to contain or control the flow of oil into the surrounding bodies of water (such as materials for underflow dams). Also, Enbridge initially brought in contractors from Minnesota, a 10-hour drive away from the site, which slowed down recovery time (NTSB, 2010). The EPA on-scene coordinator had to provide Enbridge with the contact information for local contractors to keep recovery efforts moving forward (NTSB, 2010).

3. *Lack of Training* – During the initial response, Enbridge personnel placed the containment booms too far downstream to be effective and also used booms that were incompatible with fast-moving water (NTSB, 2010). This had to do both with lack of training and also the lack of communication and knowledge regarding the severity of the spill.

### 7.2.2 Burnaby Harbor Spill

#### *7.2.2.1 Spill Summary*

On July 24, 2007, approximately 1,400 barrels of synthetic crude leaked from the Westridge Transfer Line in Burnaby, British Columbia. After the oil was spilled, it flowed in Burnaby's storm sewer systems until it reached the Burrard Inlet (TSB, 2008a). In total, eleven houses were sprayed from the rupture, fifty properties were affected, 250 residents voluntarily left, and the Burrard Inlet's marine environment and 1,200 meters of shoreline were affected by the spill (TSB, 2008a).

Five minutes after the rupture, the pipeline operator shut down the Westridge Pipeline and the Westridge dock delivery valves were closed. However, the Burnaby Terminal is at a higher elevation than the rupture site, so gravity continued to intensify the release of the oil. Twenty-four minutes after the rupture, the Burnaby Terminal and the Westridge Pipeline were fully isolated. Kinder Morgan established a unified command with the British Columbia Ministry of Environment and the NEB to coordinate the response. The initial failure to fully shutdown the Westridge Pipeline was contrary to Kinder Morgan's standard shutdown procedures (TSB, 2008a). Cleanup took months and cost roughly $15 million and resulted in the recovery of approximately 1,321 barrels of oil (CBC, 2011).

In 2011, three companies – two contracting companies and Trans Mountain Pipeline L.P. – pleaded guilty to violating the Environmental Management Act for introducing pollutants into

the environment and will each pay a $1,000 fine and donate $149,000 to the Habitat Conservation Trust Foundation (CBC, 2011). Trans Mountain Pipeline L.P. will be required to pay an additional $100,000 to fund training and education programs (CBC, 2011). See section 2.1.4 for more information on this spill.

#### *7.2.2.2 Technologies Used in Recovery*

Kinder Morgan primarily relied on contractors to recover the oil (Ministry of the Environment, 2007). The contractors used three distinct methods to recover the oil which were based on the oil's location (Penner & Sinoski, 2007):

1. *Residential areas*. Peat moss was used successfully to absorb oil on land.
2. *Storm Sewers*. Oil in the storm sewers was vacuumed up. Much of the oil was collected in the pump station.
3. *Burrard Inlet*. The responders were able to set up floating booms outside the storm sewer tunnels to collect oil that made it to the Inlet. To treat the oil that had adhered to the shoreline, responders successfully used the chemical shoreline cleaner Corexit 9580 (Shang *et al.,* 2012).

#### *7.2.2.3 Lessons Learned*

The recovery effort during the Burnaby Harbor spill was relatively successful. Because the synthetic crude traveled on a predictable path through the storm sewer system, the responders were able to set up booms in a quick and efficient manner. We were not able to find any reports of the oil sinking or being submerged in the water column. Extrapolating the oil behavior in this case to other potential synthetic crude spills is difficult because most of the oil was able to be collected in the storm sewer systems and on land.

The main issue in this case study was the lack of communication between city contractors and Kinder Morgan during the excavation process. Also, by failing to follow standard emergency

procedure after a spill was detected, more oil was released into the natural environment. As with the Kalamazoo spill, failure to follow administrative procedures significantly increased the amount of oil spilled.

### 7.2.3 Wabamun Lake Spill

#### *7.2.3.1 Spill Summary*

Forty-three Canadian National Railway (CN) freight railcars derailed on August 3, 2005 by Lake Wabamun, just west of Edmonton, Alberta. The derailment resulted in 4,400 barrels of Bunker C oil and 554 barrels of a pole treating oil being spilled with approximately 1235 barrels[19] of the oil entering the temperate Lake Wabamun (Fingas, 2010; TSB, 2008b). The spill was caused by a faulty train track that had a least 13 undetected defects (CBC, 2007). Though Bunker C is not an oil sands product it is known to have a density near that of water, which could be similar to that of some kinds of undiluted bitumen. In this case, the oil began to sink with limited amounts of weathering and sedimentation (Goodman, 2006).

CN used an oil response contractor to recover the spilled oil. However, after the contractor's initial efforts, it became clear that they were not experienced in oil spills of this magnitude or of this type of oil. As a result, they were not able to contain the spill and CN eventually had to contract out the cleanup to a more experienced response organization (TSB, 2008b). The response contractors began by using the Shoreline Cleanup and Assessment Technique (SCAT) and then moved to cleaning up individual shore segments (Goodman, 2006). They also cut a number of reed beds because the reeds became a continuing source of surface contamination (Goodman, 2006). In total, approximately 1076 barrels of oil was recovered and the response effort was completed in October 2005 (Severs, 2005).

[19] The amount of oil that entered Lake Wabamun is debated and varies greatly depending on the source. This estimate is an average of the most commonly cited amounts.

During the clean up, there was strong public perception that the government failed to do its job, citing that the recovery efforts were more concerned with getting the track up and working again than any ecological effects. This was compounded by the delay in beginning cleanup efforts due to lack of available equipment (Goodman, 2006). As a result, the Alberta Ministry of the Environment established the Environmental Protection Commission in August of 2005 after the spill (Goodman, 2006) and First Nations sued CN and were awarded $10 million. CN spent approximately $132 million in cleanup costs and paid $1.4 million in fines, as well as made changes to its spill procedures and equipment requirements (Goodman, 2006).

#### *7.2.3.2 Technologies Used in Recovery*

Two main elements were taken into consideration during spill response: weather and the type of oil spilled. Both of these elements affected the behavior of the spilled oil, such as when the oil submerged and entered the water column or when the oil sank to the bottom (Fingas, 2010). Responders used the following technologies:

- *Sorbent and containment booms* were the first technologies deployed at the site. Sorbent booms were ineffective in containing the Bunker C oil and there were not enough containment booms to stop the spread of oil due to high winds (Goodman, 2006). Additional equipment had to be brought in from across Canada and the United States (TSB, 2008b).
- *Dykes* were successfully built to stop the flow of oil into the lake. Once the ditches and dykes were completed, no further oil made it to the lake (TSB, 2008b).
- *Vacuum trucks* helped recover the oil (TSB, 2008b).
- *Hand shoveling and skimmers* were relatively successful (TSB, 2008b).
- *Sorbent pads* were used to probe the bottom of Lake Wabamun in order to detect oil that had settled on the bottom. The Bunker C oil had formed a skin and did not adhere to the pads, making this technology ineffective (Goodman, 2006).

- *Video cameras for detection* were only successful in some shallow water situations due to the dispersed nature of the oil (Goodman, 2006).
- *Nets of ten millimeters* were ineffective. Responders had to move toward very fine netting, which inhibited water flow. Ten-millimeter nets were tried due to the success this size of net has had in collecting bitumen (Goodman, 2006).
- Responders had very limited success recovering oil once it reached the bottom (Goodman, 2006).

It is important to note that it was not until much later on August 3rd that responders realized that the pole treating oil had been spilled as well. The pole treating oil being transferred was mixed with other chemicals and is used as a wood preservative. This type of substance may contain toluene, benzene and its derivatives, naphthalene and its derivatives, phenyls, and polycyclic aromatic compounds (PACs) (TSB, 2008b). As a result, the workplace hazard associated with the chemical was neither recognized nor communicated until days later (TSB, 2008b).

#### *7.2.3.3 Lessons Learned from Spill*

The spill response effort at Wabamun Lake was not efficient particularly due to management decisions (TSB, 2008b). An emergency operations center under the unified command system (UC) was not set up. Under UC, response agencies collaborate on the response effort. Its main purpose is to provide guidelines for multiple agencies to work together efficiently (TSB, 2008b). This was the Transportation Safety Board of Canada's (2008b) main criticism of CN's response efforts. Other factors to consider during the response effort include:

- *Limited amounts of response equipment in close proximity to the spill.* This was problematic as it led to both negative public relations as citizens saw the oil spreading without an adequate response, as well as responders missing crucial time in containing the spill (Goodman, 2006). Later, it was determined that some response

equipment in the region was not made available because it was held in reserve in case of a concurrent environmental disaster (TSB, 2008b).

- *The need for contingency planning.* CN implemented its Dangerous Goods Emergency Response Plan but failed to install a unified command (TBS, 2008b). The lack of a central structure led to considerable confusion in the early stages of recovery as more responders arrived on scene and there was no organizational structure to rely on (Goodman, 2006). Also, the contingency plan CN had in place was generic and had no specific guidelines for the Wabamun Lake area. The plans had not been tested recently and there had been little contact with response groups in the area (Goodman, 2006).
- *Lack of information regarding the behavior of heavy oil when spilled.* In this case, the lack of information regarding the interaction of oil and fine sediments and how the changes in surface water temperature affects submerged oil, tar ball formation, and the long-term fate of submerged oil in marine and fresh water ecosystems affected clean-up efforts (Goodman, 2006).
- *Limited number of tested and effective oil detection technologies.* Response crews lacked appropriate technology for detecting oil once it reached the bottom of the lake (Goodman, 2006).

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## Key Sources: Response Efforts

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NTSB. (2010). *Enbridge Incorporated, Hazardous Liquid Pipeline Rupture and Release, Marshall, Michigan, July 25, 2010.* National Transportation Safety Board, Pipeline Accident Report. Washington D.C.: NTSB.

Goodman, R. (2006). *Wabamun: A Major Inland Spill.* Innovative Ventures Ltd. Cochrane: IVL.

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#### 7.2.4 Gaps in Response Efforts

This section concentrated on past response efforts for oil sands products spills and one case of a heavy oil spill. Due to the small number of case studies, a number of research and information gaps remain. One research gap stands out based on the above discussion:

- As the Kalamazoo spill suggests, weathering and sedimentation may lead to the oil being overwashed by water, suspended in the water column, or sinking to the bottom. There is a gap in understanding how oil sands products are affected by the weathering and sedimentation processes and also the time frame when these processes will affect the success of spill response.

The three case studies discussed above also have similarities in the ineffectiveness of management during the spill response. This leads to the question:

- Are the current plans, training procedures, and equipment resources adequate in preventing significant amounts of oil from entering the natural environment?

## 7.3 Effectiveness of Current Equipment on Sunken and Submerged Oil Spills

#### 7.3.1 Assumptions

The below analysis is based on the assumption that oil sands products will remain on the surface for several hours or days when spilled into saltwater, but as sedimentation and volatilization occurs, some of the oil will submerge or sink (Counterspil Research, 2011). This assumption is further backed up by Enbridge's technical data reports that were released in conjunction with the proposed Northern Gateway pipeline project. The report suggests that in a

marine spill scenario 80 percent of the oil will remain on the surface for 120 hours under summer conditions (will not easily sink) but it "will be easily overwashed with water" (Counterspil Research, 2011). Due to the lack of available case studies on oil sands product spills, this analysis looks at equipment effectiveness in past heavy oil spills, where the oil was submerged in the water column or sank. This is relevant to the oil sands discussion as oil sands products may behave like non-floating oils after weathering and other interactions with the environment.

### 7.3.2 Common Oil Spill Recovery Technologies and Anticipated Effectiveness

#### *7.3.2.1 Detection and Monitoring of Submerged and Sunken Oil*

Based on U.S. Coast Guard research, multi-beam and imaging sonars are the most effective technologies for conducting wide area detection surveys and looking for large pools of subsurface oil. They are most effective in detecting subsurface pools if they are deployed before the oil breaks up. However, the resolution of these devices is still relatively low, impairing their effectiveness. Laser systems and narrower beam sonars are better suited to narrow areas and determining the amount of oil present (Hansen *et al.*, 2009). A summary of other detection and monitoring technologies are provided in the table below. For a full analysis of detection and monitoring equipment, see Appendix 3.

| Technology | Analysis |
|---|---|
| ***Snare Sampler*** | • Specifically used to detect oil at various depths in the water column<br>• Produces time-series data<br>• Time and labor intensive (Counterspil Research, 2011; Michel, 2006) |
| ***Vessel-Submerged Oil Recovery System (V-SORS)*** | • Can detect both pooled and mobile oil moving along the bottom<br>• Relatively efficient<br>• Time and labor intensive<br>• Susceptible to snagging on bottom (Counterspil Research, 2011; Michel, 2006) |
| ***Side-scan sonar data*** | • Provides good spatial coverage and visualization of large accumulations and bottom features<br>• Effectiveness diminishes as the oil spreads and the water becomes rough<br>• More successful in detecting the trenches and other bottom features that contain pooled oil instead of the oil itself (Counterspil Research, 2011; Michel, 2006) |
| ***RoxAnn*** | • Used to differentiate seafloor bottoms (Michel, 2006; Counterspil Research, 2011) |
| ***Remotely-operated underwater video*** | • Successfully provides estimates of frequency and size of oil accumulations<br>• Cannot always determine exact oil position<br>• Effective with visibility exceeding 0.5 meters, but it does not generate a wide view (Counterspil Research, 2011) |
| ***Sorbents attached to weights*** | • Ineffective (Counterspil Research, 2011) |
| ***Sorbent drops and sediment cores*** | • Not effective for mobile oil in the water column (Michel, 2006) |
| ***Snare Sentinels*** | • Too time and labor-intensive for widespread use (Counterspil Research, 2011; Michel, 2006) |
| ***Airborne Hyperspectral fluorescent LiDar*** | • Successful in detecting oil suspended in the top few meters below the water surface |
| ***RESON Sonar System*** | • Positively identifies 87 percent of sunken oil targets.<br>• Has a false alarm rate of 24 percent (Hansen *et al.*, 2009) |
| ***EIC Fluorosensor*** | • Can be attached to ROVS or other platforms<br>• GIS input fluctuates and direct mapping is not possible (Hansen *et al.*, 2009) |
| ***Side-looking Airborne Radar, UV, & IR*** | • Unable to penetrate water |

#### *7.3.2.2 Containment of Submerged and Sunken Oil*

Containment of submerged oil is still mostly in the conceptual stage. To the extent that the below technologies have proven effective, it has only been in low-flow zones or depressions (Counterspil Research, 2011).

| Technology | Analysis |
|---|---|

| | |
|---|---|
| ***Trenching and Berming*** | • Does not work if the oil is suspended |
| ***Pneumatic barriers (air bubbles)*** | • Limited information on this method<br>• May aerate oil, which would change the density and reduce the oil's tendency to sink.<br>• Effective at "protecting a water intake at currents of less than 0.75 knots" (Counterspil Research, 2011) |
| ***Deep-skirted booms*** | • Developed to contain Orimulsion<br>• May be effective, but have limited information (Counterspil Research, 2011) |
| ***Bottom booms, filter fense, trenches, and booms*** | • Can be coordinated with recovery and are quick and easy to deploy<br>• Highly dependent on bottom conditions<br>• Seabed booms for sunken oil have not been tested in a real situation (Counterspil Research, 2011) |
| ***Trawl nets*** | • Have proven effective (other than fine mesh nets)<br>• Made specifically for heavy oil recovery (Counterspil Research, 2011) |
| ***Sorbent barrier/fence*** | • Never tested<br>• Engineering design inadequate to assure it would function properly<br>• If manipulated, it can be easily fabricated to meet site-specific contexts (Michel, 2006) |

#### *7.3.2.3 Removal of Submerged and Sunken Oil*

If oil is suspended in the water column there can be little done other than detecting the oil (Counterspil Research, 2011). During the DBL-152 heavy oil spill, hydraulic submersibles that featured open impeller chambers, such as the MPC model KMA axial/centrifugal pump, and directed by divers proved to be most successful in removing sunken oil (Counterspil Research, 2011). The U.S. Coast Guard's research suggests that a hopper dredge or large duck-bill system has the highest potential for use in recovery efforts based on timing, operational limits, recovery efficiency, remobilization, cost, and safety (Michel, 2006).

| **Technology** | **Analysis** |
|---|---|
| ***Hydraulically-driven submersible dredge pump with a diver-directed suction hose*** | • Recovered 900 gallons of submerged, pooled oil from small trench during M/T Athos<br>• Diver directed hoses led to a slow recovery, especially since the oil was moving (Counterspil Research, 2011) |
| ***Centrifugal Pump*** | • Resulted in droplet formation<br>• Used with a lower rpm Foilex TDS-150 Archimedes screw pump as well as a 4-stage decanting system to effectively reduce water content (Counterspil Research, 2011) |

| | |
|---|---|
| ***Clamshell dredges*** | • Successful when oil solidifies (Counterspil Research, 2011) |
| ***ROVs and mini-subs*** | • Potential to recover oil from greater depths<br>• Marine Pollution Control has been testing a mini submarine mounted with a suction recovery system (Counterspil Research, 2011) |
| ***Nets*** | • Messy and largely ineffective (Counterspil Research, 2011) |
| ***Dredging*** | • Effective<br>• Generally limited to 50 meters water depth<br>• Pneumatic dredgers can operate in greater depths<br>• Fastest method of recovering sunken oil but generates a large volume of sediment and water that needs to be stored<br>• Also need to consider the benefits of removing oil against seabed disturbance (Counterspil Research, 2011) |

Based on the current state of recovery technologies, five problem areas need to be refined and addressed for heavy oil or oil sands products cleanup (Counterspil Research, 2011):

1. Nozzle design of hoses to reduce the water intake during underwater pumping;
2. Diver-directed vacuum systems to increase the pumping rate;
3. Remotely-operated vehicles (not divers) development for safe pumping;
4. Dredges modified to minimize water and sediment uptake; and
5. Improvement in oil separation and water decanting technology.

#### *7.3.2.4 Transfer of Viscous Oil*

Overall, the transfer of viscous oil should not be a limiting factor in heavy oil or oil sands products recovery. Many modifications to existing technology have already been made to process heavy oils (Counterspil Research, 2011).

| **Technology** | **Analysis** |
|---|---|
| ***Pharos Marine GT185 Skimmer*** | • Main component of the Canadian Coast Guard recovery inventory.<br>• Unable to recover and pump floating bitumen. Similar with USCG stock equipment, need modifications to process heavy oils (Michel, 2006; Counterspil Research, 2011) |
| ***Annular water injection*** | • Modified pump developed and tested in Denmark, Sweden, Norway, and Finland seems to be successful (Counterspil Research, 2011) |

**Key Sources: Effectiveness of Current Equipment on Sunken and Submerged Oil Spills**

Counterspil Research. (2011). *A Review of Countermeasures Technologies for Viscous Oils that Submerge.* Counterspil Research Inc. West Vancouver: Counterspil Research Inc.

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Michel, J. (2006). *Assessment and recovery of submerged oil: Current state analysis.* Research Planning, Inc. Groton: USCG.

### 7.3.3 Regional Response Capacity – Heavy Oil Spills

To obtain project approval from governing bodies, companies exploring, transporting, producing, and refining oils are mandated to submit a contingency plan in case of a spill. The majority of oil companies choose to enlist an oil spill cooperative to satisfy oil spill response needs (Allen, 1981). The United States Coast Guard (USCG) does not have the equipment to respond to a submerged oil spill scenario (Hansen, 2013). Nationally, there are two oil spill cooperatives that have a large capability in recovering heavy oil that sits on the bottom of bodies of water: Marine Pollution Control (MPC), based in Detroit, Michigan, and BISSO Marine, based in Houston, Texas (Hansen, 2013). Other cooperatives do have capabilities that include divers that can respond or other special equipment used for recovery of oil inside of vessels.

Currently, there is no uniform method of reporting a region's oil spill response equipment availability. As seen below, the Pacific Northwest and the New England area aggregates its equipment lists into a regional list, which includes publically and privately owned equipment

available in multiple states. The Great Lakes Region concentrates on equipment owned and operated by state governments.

In addition, many response organizations publish their equipment lists, but they may not report all the necessary information to determine how the equipment can be used in an oil spill. For example, a response organization may report that it has a sonar in its inventory, but will not include the frequency it is operating at or other vital processing information (Hansen, 2013). This makes it difficult to assess a region's capacity to respond to a heavy oil spill or a spill of oil sands products.

#### *7.3.3.1 Response Capacity in Washington State*

In the Pacific Northwest, all equipment maintained by spill response cooperatives in the area is listed at: http://www.wrrl.us. However, this list does not capture all the equipment that may be available to a responder during a spill because it only lists equipment that is geographically close to the spill. This means that oil spill response organizations outside of the Pacific Northwest that are contracted with oil companies operating in the region will not report available equipment to the WRRL. For example, Kinder Morgan theoretically could contract with BISSO but because BISSO's equipment is located in Texas it is not accounted for in the WRRL.

The WRRL contains response equipment that is both dedicated to spill response and those that are not. A considerable proportion of the equipment is not dedicated to spill response. For example, WRRL lists a number of private fishing boats that could be used during a spill response effort. This means, there is a possibility that a piece of equipment listed may not be available during a spill (OSAC, 2009).

#### *7.3.3.2 Response Capacity in the Great Lakes*

Through various laws and regulations, the U.S. and Canada have a formal relationship in regards to oil spill preparedness and response programs. This is expanded on further in section 8.4.

The ability for response organizations to respond to a spill in the Great Lakes Region may be hindered significantly during winter conditions. With icy or snowy conditions, access to remote locations may be difficult and some facilities may operate with reduced personnel (Emergency Preparedness Task Force, 2012). The states in the region do not have a large inventory of response equipment (Emergency Preparedness Task Force, 2012). For a full list of equipment available during a spill, broken down by state see Appendix 4.

#### *7.3.3.3 Response Capacity in Maine*

As part of Maine's contingency planning, the Department of Environmental Protection created a directory of all spill response equipment located in the New England area. This includes oil response cooperatives, such as Marine Spill Response Corporation, U.S. and Canadian regulatory agencies, U.S. and Canadian Coast Guard contacts, and citizen volunteers who may choose to lend their boat or aircraft to spill response. This document can be found at: http://www.maine.gov/dep/spills/emergspillresp/documents/appendices.pdf. Again, this does not necessarily reflect the response capacity of the region as individual companies may contract with oil cooperatives outside of the area.

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**Key Sources: Regional Response Capacity**

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Hansen, Kurt. (2013 11-February ). US Coast Guard. Personal Communication.

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### 7.3.4 Gaps in Effectiveness of Current Equipment on Dilbit Spills

There are multiple gaps in policy and research in terms of equipment and mandated response capacity:

- The regional and national equipment lists are missing vital processing information about available oil spill response equipment, which makes it difficult to assess how a particular piece of equipment can be used effectively during a spill response scenario.
- There is a lack of real world testing and experience with equipment on dilbit spills, hindering our ability to assess whether or not a region has equipment that will be effective in an oil sands products recovery effort.
- When an oil spill occurs, the responsible party must respond within a specific period of time. If there is an oil sands products spill, the responsible party will be in compliance with oil spill response requirements as long as they have personnel on the site performing recover efforts, e.g. divers, not necessarily with the appropriate equipment to the specific type of oil spilled. This could mean that the responsible party would have to wait up to 72 hours for the appropriate equipment to reach the site if the spill is in Washington but the needed equipment is in Detroit or Houston.
- Clean up regulations require oil cooperatives to prove that they possess the equipment and can respond to a spill during a specified time period. However, policy does not require them to demonstrate the effectiveness of the equipment on specific oils. As we saw in the case studies, this may affect oil spill response effectiveness.
- Material Safety Data Sheets (MSDS) (discussed further in Section 8.5.1) do not require the properties of the specific type of oil spilled to be noted. In the case of the Kalamazoo Spill, responders were given an MSDS that listed “crude” oil as the material spilled, not dilbit. This affected the responders’ ability to plan their response efforts.
- There is a lack of information and ability to employ oil spill detection and recovery methods when the oil reaches the bottom of a body of water or when the oil is suspended in the water column.

# 8 SIGNIFIGANT POLICIES AND REGULATIONS

## 8.1 Introduction

Regulations and standards governing oil spills can largely be divided into two related categories—requirements for preparing for oil spills and requirements for responding to oil spills. The U.S. Coast Guard (USCG), the Environmental Protection Agency (EPA), and the Department of Transportation (DOT) oversee oil spill planning, response, and transportation—and are the primary regulatory actors relevant to the transport of oil sands products. These regulatory categories can overlap and are administered and enforced by multiple federal and state agencies. In this section, we outline:

- Spill planning and response rules derived from the National Contingency Plan and the Oil Pollution Act;
- The primary federal agencies responsible for rulemaking and enforcement in oil spill planning and response, noting any efforts to address the transport of oil sands products (focusing on the USCG, EPA, and DOT);
- The role of states and regions in oil spill response planning, including some recent efforts to address the increase in oil sands products and additional legislation that could relate to oil sands products indirectly; and
- Initial gaps in transportation and spill response and preparedness policies related to oil sands products.

## 8.2 Contingency Planning and Spill Response Background

In general, contingency plans are protocols detailing the steps responsible parties and government agencies must follow before, during, and after an oil spill and determine who should respond (EPA, 1999). The National Oil and Hazardous Substances Pollution Contingency Plan, commonly referred to as the National Contingency Plan (NCP), outlines the federal

government's procedures for oil spill contingency planning and response coordination (40 CFR 300). The NCP's scope has been expanded several times since its original publication in 1968, with the most recent revisions in 1994 following the passing of the Oil Pollution Act (OPA). The NCP has created a multilayer National Response System for coordination of local, state, and federal agencies, industry, and other actors to ensure effective response to spills (EPA 2013). The NCP system is defined by a few key components (40 CFR 300):

- *National Response Team*—established the NRT to plan and coordinate responses to major discharges of oil and to provide guidance to Regional Response Teams (RRTs)
- *Regional Response Team*—established RRTs to coordinate, plan, and respond at the regional level and includes representatives from federal agencies that are members of NRTs plus local and state officials.
- *Federal On-Scene Coordinators(FOSCs)*—established to coordinate federal efforts with local, state, and regional groups with four key responsibilities: assessment of a spill and resources needed, monitoring of responsible parties, federal response assistance if necessary, and evaluation of response actions overall.
- *Unified Command*—established a unified command structure to coordinate personnel and resources of federal and state officials as well as the responsible party.

For federal agencies this regulatory structure requires planning for coordination during oil spills and oversight of response plans. The regulatory framework for responding to a spill was solidified through the OPA amendments, which consolidated all federal spill response laws under one program (Ramseur 2012). The notable oil response provisions of the NCP include establishing (40 CFR 300.15):

- The general responsibilities of FOSCs and authorizing FOSCs to direct response activities at spill site;
- The general pattern of response of FOSCs in determining the threat, classification, size, and type of the release;
- Authorization of FOSCs to determine if a spill poses a threat to public health or welfare;

- Requirements of FOSCs to notify the National Strike Force Coordination Center (NSFCC)[20] in the event of a worst-case discharges, defined as "the largest foreseeable discharge in adverse weather conditions;"
- Provision of funding for oil spill responses under the Oil Spill Liability Trust Fund if certain criteria are met.

The NCP and OPA give responsibility for designating a FOSC to the EPA or the U.S. Coast Guard (USCG) depending on the location of the spill. USCG has the authority to "evaluate, coordinate and direct clean-up" of spills in coastal waters and the Great Lakes and the EPA has the authority for inland spills (US Coast Guard Gulf Strike Team, 2008).

### 8.2.1 Discharge of Oil Regulation

The Discharge of Oil regulation, commonly known as the "sheen rule," sets the standard for deciding whether or not a spill should be reported to the federal government (Discharge of Oil, 1996). Broadly, under the Clean Water Act, the sheen rule mandates that an oil spill should be reported if the spill poses a threat to public health or U.S. welfare. The rule specifically states that any spills with the following characteristics should be reported:

1. Spills resulting in a discoloration or a sheen on the surface of a body of water;
2. Spills that violate pertinent water quality standards;
3. Spills that cause sludge or emulsion to be deposited beneath the surface of the water or on adjoining shorelines.

## 8.3 Federal Contingency Planning

The NCP framework has resulted in a web of federal agency responsibilities related to contingency planning and response requirements. This section outlines the main federal agencies that lead contingency planning: the USCG for vessels, the EPA for non-transport-related inland

[20] According to the USCG website, "the National Strike Force (NSF) provides highly trained, experienced personnel and specialized equipment to Coast Guard and other federal agencies to facilitate preparedness for and response to oil and hazardous substance pollution incidents in order to protect public health and the environment… The NSFCC provides support and standardization guidance to the Atlantic Strike Team (AST), Gulf Strike Team (GST) and Pacific Strike Team (PST)."

spills, and the DOT in rail and pipeline transportation. We then discuss the role of regional and state plans and other potentially relevant laws governing increased transport of oil sands products. Throughout, we discuss if and how agencies have thought about the transportation of oil sands products.

Oil spill prevention planning requirements are determined by the potential source of the spill, which for oil sands products primarily includes vessel, facility, pipeline, and rail. The USCG, EPA, and DOT play the most important role in establishing and implementing spill response procedures for operators. The designated federal agency must assess the capacity of the responsible party to effectively respond to a spill, which may include providing oversight of response plans, maintaining contingency plans at various levels, and personnel training (Ramseur 2012).

### 8.3.1 USCG

The USCG plays a key role in both spill response and clean up, and in spill prevention and preparedness. As the FOSC for maritime oil spills, the USCG is given the authority to ensure an effective response to oil spills in U.S. waters subject to the tide, the Great Lakes, and other specified waters (40 CFR 300.5).[21] USCG jurisdiction in oil spill preparation and planning covers vessels, onshore facilitates with transportation-related activities, and deepwater ports (Ramseur 2008). Contingency plans for maritime oil spills in the U.S. are established at the national and regional level to ensure that for oil transported through Canadian waters, the U.S. is prepared to engage in cleanup if a spill has the potential to cross into U.S. waters or affect U.S. coastlines.

[21] 40 CFR 300.5 provides a full definition of coastal zone as: "all United States waters subject to the tide, United States waters of the Great Lakes, specified ports and harbors on inland rivers, waters of the contiguous zone, other waters of the high seas subject to the NCP, and the land surface or land substrata, ground waters, and ambient air proximal to those waters."

Under OPA and an international treaty, MARPOL 73/78[22], owners and operators of vessels carrying oil must submit Shipboard Oil Pollution Plans (SOPEP) to ensure tanker crews have a plan to respond to an array of oil spill scenarios (Ramseur 2008). Annex 1, Regulation 37 of MARPOL requires that oil tankers weighing 150 tons gross tonnage or more carry an approved SOPEP (IMO 2013). Although other vessels are required to carry SOPEPs depending on tonnage (400 tons gross or more), oil tankers have specific plans given the large quantities of oil they hold. For U.S. ships, 33 CFR 151.27 requires the Coast Guard to 'review and approve' a vessel plan (USCG 1995). Among other things, a SOPEP contains:

- General information about the ship,
- Procedures to contain a discharge of oil,
- Reporting procedures in case of a spill,
- Drawings of fuel lines,
- Descriptions and locations of oil tanks, and
- Action plans for all crew members at the time of a spill.

A list of the vessel contents are also required, but in the case of vessels carrying oil sands products above an API of 10, a SOPEP would only be required to list "crude oil" instead of the specific product (see section 8.3.4 on Group V oils).

An update to the USCG's FRP requirements went into effect in February 2011. Aimed at improving response preparedness for facilities carrying or handling oil on U.S. navigable waters, the new regulation updated requirements for oil-spill removal equipment, added requirements for plan holders to use new response technologies, and amended procedures for spill response. The new rule applies to facilities already required to hold response plans under the FRP rules (Removal Equipment Requirements and Alternative Technology Revisions, 2009).

[22] MARPOL 73/78's full name is the International Convention for the Prevention of Pollution From Ships, created in the years 1973 and 1978.

### 8.3.2 EPA

EPA's main responsibility relevant to oil spills is its responsibility as FOSC for inland oil spills, but it also regulates non-transport related spill planning. EPA provides oversight over Facility Response Plans (FRP), which are required under OPA. A FRP is required for certain facilities that store and use oil and include detailed plans for responding to a worst case discharge. As appropriate, FRPs also outline responses to small and medium discharges. The EPA has created regulations for what facilities must prepare and submit FRPs and what the plans must contain (US EPA, 2002).

OPA requires that "substantial harm" facilities develop FRPs. These include facilities that could cause substantial harm to the environment or navigable waters if a discharge occurred. The specific regulation on "substantial harm" criteria is found in 40 CFR 112.20 and 112.21, appendices B through F. Under the rule, a facility falls in the category if it meets at least one of the following criteria (Facility Response Plans, 2005):

- The facility has a total oil storage capacity greater than or equal to 42,000 gallons and performs overwater oil transfers to or from vessels; or
- The facility has a total oil storage capacity greater than or equal to one million gallons, and meets one of the following conditions:
    - The facility does not have secondary containment for each aboveground storage area; or
    - The facility is located such that a discharge could cause injury to an environmentally sensitive area; or
    - The facility is located such that a discharge would shut down a public drinking water intake; or
    - The facility has had, in the past five years, a reportable spill greater than or equal to 10,000 gallons.

### 8.3.3 DOT: Pipelines (PHMSA) and Rail (FRA)

The DOT houses two agencies that oversee the transportation of oil via pipeline and rail—the Pipelines and Hazardous Materials Safety Administration (PHMSA) and the Federal Railroad Administration (FRA). Pipeline transport of oil is heavily regulated beginning with pipeline siting, construction, and maintenance and continuing during the planning for potential oil spills and recovery efforts. Regulations for rail transport of oil are less developed. With increased transport of oil sands products from Alberta and crude from the Bakken region, closer oversight of rail transport may be necessary.

#### *8.3.3.1 Regulating Oil Transportation by Pipeline*

The Natural Gas Pipeline Safety Act of 1968 and the Hazardous Liquid Pipeline Act of 1979 established the DOT as the federal agency responsible for oversight of pipeline safety in the U.S (Parfomak 2013). The Clean Water Act (as amended by the Oil Pollution Act of 1990) requires regulations that establish oil spill planning requirements, plan review, and plan approval. In 1991, Executive Order 12777 ordered PHMSA to develop regulations that require operators to submit spill response plans and review and approve plans for onshore pipelines (PHMSA 2012). PHMSA's Office of Pipeline Safety now oversees these two primary regulatory areas, along with safety regulations of the design, construction, and maintenance of pipelines (49 CFR Part 195), and response plans for onshore oil pipeline spill response plan requirements (49 CFR Part 194).

Safety

The 1994 Pipeline Safety Act combined the two previous pipeline safety statutes, giving PHMSA authority to maintain the safe and reliable operation of the Nation's pipeline infrastructure. The Office of Pipeline Safety developed prescriptive regulations for pipeline

design, inspection in the manufacturing and construction processes, and maintenance and operation oversight through the life of the pipeline. Tools for enforcement included warning letters and compliance orders followed by civil penalties—which are used alongside various information-sharing programs (PHMSA 2012a).

The prescriptive regulations before legislation in the early 2000s largely followed an inspection checklist approach. Accidents led to additional prescriptive requirements and also the inclusion of management-based mandates to analyze risk, identify spill prevention options and evaluate programs. The Pipeline Safety Improvement Act of 2002 established requirements for risk analysis and integrity management (IM) programs for operators (Parfomak 2013). Called the Liquid IM Rule, the program outlined how operators should 'identify, prioritize, assess, evaluate, repair, and validate the integrity of hazardous liquid pipelines that could, in the event of a leak or failure, affect High Consequence Areas (HCAs) with the United States" (PHMSA 2012b). The rules defined HCAs as population centers, ecologically sensitive areas, and commercially navigable waters—and required operators to explore how pipeline risks would impact HCAs.[23] Finally, The Pipeline Inspection, Protection, Enforcement, and Safety Act of 2006 developed rules on corrosion, public awareness, and qualifications for operators and rules on pipeline control room management (Parfomak 2013).

Spill Response

PHMSA reviews contingency plans for pipelines where a major leak could cause harm to the environment. Requirements for an onshore pipeline spill response plan must (PHMSA 2012a):

- Maintain consistency with National and Area Contingency Plans;

[23] Full name: "Liquid Pipeline Integrity Management in High Consequence Areas for Hazardous Liquid Operators" found in 49 CFR Parts 195.450 and 195.452

- Identify the qualified individual (QI) with authority to respond;
- Identify private personnel and equipment necessary to remove a worst case discharge—and ensure their availability;
- Describe training, testing, drills; and
- Be updated periodically and after major changes.

PHMSA and Oil Sands Products

A number of recent events led to changes at PHMSA that are directly or indirectly relevant to the transportation of oil sands products. The Enbridge spill in Kalamazoo and other pipeline accidents led to The Pipeline Safety Act in late 2011.[24] The legislation had a number of relevant components. First, it increased civil penalty authority for PHMSA for safety and compliance violations. Second, it required DOT to evaluate areas of technology that could increase safety and detect leaks and required PHMSA to evaluate if integrity management requirements should be expanded to more areas. Finally, it led to a study by the Transportation Research Board of the National Academies, which will determine if regulations are sufficient for facilities transporting dilbit (Parfomak 2013). The study will analyze:

1. Dilbit risks to pipelines to determine if dilbit increases the frequency of spills compared with other liquid petroleum products; and
2. If the committee finds that dilbit presents an increased risk, it will review regulations to determine if current rules are sufficient to address the risk.

All tasks are to be completed by December 2013. Recent presentations by PHMSA officials suggest that they found spill risks similar to other U.S. crude oils for corrosiveness or abrasiveness (PHMSA 2012a).

Additional changes at PHMSA have resulted from recent spills (PHMSA 2012a):

- More staff are now dedicated to plan-reviewing;

[24] Full name: The Pipeline Safety, Regulatory Certainty and Job Creation Act of 2011. See www.gpo.gov for the full text.

- The Office of Pipeline Safety (OPS) initiated an internal audit of plan review activities;
- PHMSA continues to revise its plan review criteria and procedures. Previously, only the response plan preparer was involved in the review process whereas now PHMSA includes operator compliance official(s) into reviews;
- During the review process, an operator's history is now considered. This includes incident and accident history; and
- Increased participation in drills by operators.

Moving forward, PHMSA's strategic plan is to integrate OPS, target and expand safety inspections based on the most serious risks, and focus pipeline safety research on methods to identify defects.[25] In addition, PHMSA is also planning to review NTSB's findings and recommendations on response plans, examine opportunities for better alignment with EPA and USCG plan standards, and integrate spill plan responsibilities and the Pipeline Safety Inspection Program (PHMSA 2012b).

*8.3.3.2 Regulating Oil Transportation by Rail*

The boom in rail transportation of oil in Canada and the U.S. due to increases in supply in Alberta and the Bakken crudes has increased concern over the relative lack of regulatory oversight in rail transport. The Federal Railroad Safety Act of 1970 established the Federal Railroad Administration's (FRA) role in overseeing the safety of rail transport in general, including the safe transport of hazardous materials (GAO 1998). Under 49 CFR 130, the FRA is required to oversee contingency plans for operators carrying 'any liquid petroleum oil in a packaging having a capacity of 3,500 gallons or more." Response plans must follow the general pattern dictated by the NCP; operators must:

- Outline the response procedure for potential discharges,

[25] Also see PHMSA Onshore Oil Pipeline Fact Sheet http://www.eaovt.org/sbcap/pdf/FS19PipelineTransfer.pdf

- Consider the maximum potential discharge,
- Identify 'private personnel and equipment available to respond to a discharge', and
- Identify relevant agencies to be contacted.

The FRA regulates safety in railcar construction and inspections of rail cars are required by DOT before loading operations begin and again once the car has been loaded. According to the EPA's rules, railroad cars often present an issue of jurisdiction between DOT and EPA:

> "DOT regulates railroad cars from the time the oil is offered for transportation to a carrier until the time that it reaches its destination and is accepted by the consignee. DOT jurisdiction includes railroad cars that are passing through a facility or are temporarily stopped on a normal route. EPA regulates railroad cars after the transportation process ends; that is, when the railroad cars are serving as non-transportation-related storage at an SPCC-regulated facility (EPA 2005)."

In addition, the USCG has regulatory involvement relative to transfers of oil from rail to barges and vice versa.

Due to the relative lack of large-scale oil transport by rail, the Federal Railroad Administration, unlike PHMSA's Office of Pipeline Safety, has no known program to specifically address potential spills of crude oil let alone heavy oils or oil sands products. With expected substantial increases in rail transport throughout North America and the many waterways along rail routes, increased oversight of planning and response to oil spills from train transport should be considered.

### 8.3.4 Federal Planning Regulations Specific to Group V Oils

At least three federal contingency planning regulations apply specifically to Group V oils, two of which are of particular interest: 40 CFR 112 Appendix E, an appendix to the EPA's oil

pollution prevention plans, and 33 CFR Section 155.1052, USCG vessel requirements under the FCP.

1. *40 CFR 112 Appendix E*—sets standards for facility owners or operators dealing with Group V Oils. Owners or operators must have contractual agreements that confirm access to response resources, including things such as sonar and oil locating sampling equipment. Notably, these resources "shall be capable of being deployed (on site) within 24 hours of discovery of a discharge" (Determination and Evaluation of Required Response Resources for Facility Response Plans, 2011).
2. *33 CFR Section 155.1052*—sets 'response plan development and evaluation criteria for vessels carrying group V petroleum oil as a primary cargo.' Owners and operators of vessels must include specific information about the availability of equipment for response 'capable of operating in the conditions expected in the geographic area(s) in which the vessel operates.'

These regulations, as well as contingency plan requirements in the state of Washington, require operators to plan specifically for carrying group V oils as a primary cargo. These regulations do not apply to oil sands products (normally classified as group IV when a diluent is used) even though they have the potential to be non-floating oils when spilled.

## 8.4 Regional and State Roles in Contingency Planning and Response

### 8.4.1 Plans for U.S.-Canada Contingent Waters

The Canada-U.S. Joint Marine Pollution Contingency Plan (JCP) is the coordinated system to plan, prepare, and respond to spills of oil and other harmful substances in contiguous waters of the U.S. and Canada. The JCP supersedes previous joint contingency plans and maintains consistency with provisions of Article 10 of the 1990 *International Convention on Oil Pollution Preparedness, Response, and Co-operation* and Annex 9 of the 1972 *Agreement between Government of Canada and the Government of the United States on Great Lakes Water*

*Quality.* The principle purpose of the JCP is to establish a coordinated system for planning, preparedness, and response to "incidents" of "harmful substances" in contiguous waters by supplementing existing national plans and ensuring cooperative bilateral response planning at the local and national levels (Canada-United State Joint Marine Pollution Contingency Plan, 2003). The JCP also facilitates the coordination of response activities for the parties responsible for a spill and establishes consultation procedures between parties responding to a spill.

Additionally, the JCP includes geographic annexes for five regions to better coordinate localized response efforts. Each geographic annex, referred to as a bilateral plan, serves to strengthen and coordinate the pollution response systems in order to facilitate an efficient cross-border spill response. Each geographic annex defines the roles of that region's response team and is tested and updated through ongoing exercises. These five geographic annexes, each of which is pertinent to the transportation of oil sands products are as follows:

- *CANUSLANT*: joint pollution response for Atlantic marine boundary between Canada and the U.S. This includes the Gulf of Maine and the Bay of Fundy. Relevant due to the potential of oil sands products passing through Portland, Maine.
- *CANUSLAK*: joint pollution response for Great Lakes boundary between Canada and the U.S. Relevant due to oil sands products passing through the region via pipeline and rail, as seen in the Kalamazoo spill in 2010.
- *CANUSPAC*: joint pollution response for Pacific water boundaries between Canada and the U.S. Relevant due to oil sands products passing through the Strait of Juan de Fuca region.
- *CANUSDIX*: joint pollution response for Dixon Entrance water boundary between Alaska and British Columbia. Relevant due to potential for oil sands products to be transported to Valdez, Alaska via rail.

### 8.4.2 Regional Contingency Planning

Contingency plans specifically targeted for specific U.S. regions include USCG area contingency plans and the region-specific joint plans with Canada. In addition to the NCP discussed above, OPA requires that area committees are established by region as designated by the President of the United States. Area committees are composed of federal and state agencies that coordinate response actions with the private sector, local governments, and tribal communities. Federal On-Scene Coordinators in each area direct the committees, which are primarily tasked with developing Area Contingency Plans (ACPs), and work with responders to develop procedures to increase the efficiency of decision making for response actions. RRTs, as established in the NCP, are responsible for regional planning and preparedness prior to a response and each of the 13 RRTs maintain a Regional Contingency Plan. During a response, RRTs in each region support FOSC and State On-Scene Coordinators (SOSCs). The principal purposes of ACPs in an oil spill are to:

1. Detail orderly and effective response actions to protect human health, property, and natural resources,;
2. Promote the coordination and strategy for a unified response from federal, state, tribal, local, responsible party, and community actors; and
3. Provide guidance for facility and vessel response planners (Northwest Area Contingency Plan, 2013).

As it concerns the transport of Alberta oil sands products, the following provides a brief overview and links to more information on ACPs in the Pacific Northwest, the Great Lakes Area, the area encompassing Maine, and Alaska. The RRTs that operate in coordination for these regions are:

- Northwest: RRT, Region 10
- Maine: RRT, Region 1

- Great Lakes: RRT, Region 5
- Alaska: RRT Alaska

*8.4.2.1 The Northwest Regional Contingency Planning*

The Northwest Area Contingency Plan (NWACP) covers the coastal and inland zones of Idaho, Oregon, and Washington. Regarding the ports and coastal waters surrounding Washington State in particular, the NWACP serves as the state's Oil and Hazardous Substance Spill Prevention and Response Plan and applies to all public agencies that manage oil and hazardous substance spills. The Washington State Department of Ecology is Washington's lead agency in overseeing the response, containment, and cleanup of oil spills in state waters.

In December 2012, the Washington State Department of Ecology added a new provision to the Oil Spill Contingency Plan requiring more detail on the type of oil handled to be included in a Material Safety Data Sheet (MSDS) or SOPEP. This new rule requires that responsible parties disclose the name of all oils handled on vessels and at facilities including pipelines as well as the density, gravity, API, oil group number, and sulfur content (Oil Spill Contingency Plan, 2012).[26]

Regarding non-floating oils, a Washington State standard effective January, 2013 requires those plan holders that are "carrying, handling, storing, or transporting" Group V Oils to hold contracts with primary response contractors (PRCs) that "maintain the resources and/or capabilities necessary to response to a spill of Group 5 Oils." This includes sonar, sampling equipment to locate suspended oil, and dredges, among other pieces of cleanup and detection equipment (Planning standards for Group 5 Oils, 2013).

Also notable in the Northwest region is legislation requiring the USCG to conduct a risk assessment regarding the transportation of Canadian oil sands products. Established via H.R.

[26] NWACP website: http://www.rrt10nwac.com/

2838, the Coast Guard and Maritime Transportation Act of 2012 requires the USCG to "assess the increased vessel traffic in the Salish Sea (including Puget Sound, the Strait of Georgia, Haro Strait, Rosario Strait, and the Strait of Juan de Fuca), that may occur from the transport of Canadian oil sands products (Coast Guard and Maritime Transportation Act of 2012, 2012),.[27] More specifically, the assessment must identify:

- The extent to which vessels traffic (for barge, tanker, and supertanker) will increase due to the development of Canadian oil sands products;
- Whether or not transport from the Canadian oil sands products will require navigation through U.S. territorial water;
- The regulations that restrict supertanker traffic and the amount of oil that tankers and barges can transport in U.S. waters as well as whether there are ways to bypass these rules ;
- The spill response capability throughout shared U.S. and Canadian waters including spill response requirements for vessels transiting through the waters of the other nation; and
- Whether oil sands products have different properties from other types of oil, including toxicity and other properties, that may require different maritime clean up technologies.

#### *8.4.2.2 Maine*

In the Northeast region, there is an ACP covering Maine and New Hampshire as well as a Maine Department of Environmental Protection (DEP) Marine Oil Spill Contingency Plan. The Maine and New Hampshire ACP was last updated in 2010. Maine law requires DEP to set up a state-specific Marine Oil Spill Contingency Plan to coordinate Maine's response to oil spills. The DEP plan focuses on prevention, preparedness, timely response, and restoration and disposal. Recognizing the development of other contingency plans that apply to Maine, DEP affirms that

[27] The bill can be accessed here (section 722) http://www.govtrack.us/congress/bills/112/hr2838/text/eah

the Marine Oil Spill Contingency Plan does not supersede any other plan and is intended to be carried out in coordination with other contingency plans (Maine DEP, 2011).[28]

#### *8.4.2.3 Great Lakes*

For the Great Lakes region, there is series of ACPs and Subarea Contingency Plans (SCPs) that cover the Eastern Great Lakes and Lake Michigan. These include the EPA Region 5 Regional Contingency Plan, the Eastern Great Lakes Area Contingency Plan, and the Sector Lake Michigan Area Contingency Plan.[29]

#### *8.4.2.4 Alaska*

In addition to the Alaska-specific RRT, the state has a State Preparedness Plan for Response to Oil and Hazardous Substance Discharges/Releases (the Unified Plan) as well as ten SCPs. These SCPs, in coordination with the Unified Plan, describe the federal, state, and local response strategies for oil spills. The SCP most pertinent to the transportation of oil sands products is the Prince William Sound Subarea Contingency Plan for Oil and Hazardous Substance because of its inclusion of the waters and coastlines near Valdez, a possible terminal for dilbit carrying trains. This plan contains guidelines for operations in the event of an oil spill or discharge of other hazardous material.[30]

## 8.5 OSHA: Spill Response Planning Safety

In addition to the contingency plans coordinated with EPA, USCG, state agencies, and PHMSA, at national and sub-national levels, the Occupational Safety and Health Administration (OSHA) also participates in oil spill planning and response. In an effort to protect workers in a

[28] EPA Region 1 RRT website: http://www.rrt1.nrt.org/production/NRT/RRT1.nsf/AllPages/rrt1.html
Maine DEP Contingency Plan: http://www.maine.gov/dep/spills/emergspillresp/documents/contplan.pdf
[29] Great Lakes RRT website: http://www.rrt5.org/acp/
[30] Alaska RRT website: http://alaskarrt.org/
Prince William Sound Subarea Contingency Plan website: http://dec.alaska.gov/spar/perp/plans/scp_pws.htm

spill response scenario, OSHA focuses on exposure to toxic chemicals, training, job-specific safety hazards, heat stress, injuries, and illnesses. In order to assess worker exposure and safety, OSHA has set sampling strategies in place to monitor for air pollutants and respond with protective equipment as necessary (OSHA). In order for OSHA to effectively respond to a dilbit spill, it is imperative that the characteristics of the bitumen and the diluents be readily available.[31]

### 8.5.1 Material Safety Data Sheets (MSDS)

The IMO requires that vessels carrying oil or oil fuel have a MSDS prior to loading, similar to the contents disclosure required in SOPEPs. An MSDS requires the disclosure of "general categories of materials" that would be considered hazardous in the case of exposure, but does not specify the specific type of material (International Maritime Organization, 2009). MSDSs are required by a 2009 amendment to The International Convention for the Safety of Life at Sea (SOLAS) and are also required under the OSHSA Hazard Communications Standard in title III of the 1986 Superfund Amendments and Reauthorization Act (SARA). An MSDS for a vessel carrying oil sands products would list "crude oil" on the sheet and would not have to specify the type of crude.

## 8.6 Liability

OPA unified oil spill liability statutes hold the responsible party liable for any discharge of oil from a vessel or facility and all cleanup costs incurred by government entities, private parties, injury to natural resources, and loss of personal property.

[31] OSHA Oil Spill website: http://www.osha.gov/oilspills/index.html

### 8.6.1 USCG National Pollutions Funds Center and the Oil Spill Liability and Trust Fund

Related to the liability issue, Title I of OPA authorized the Oil Spill Liability and Trust Fund (OSLTF). OSLTF makes available up to $1billion per incident to assist the responsible party in oil removal and otherwise uncompensated damages (USCG 2013). Administration of OSLTF, handled by the USCG National Pollution Funds Center (NPFC), ensures funding for a federal response to oil spills and recovers costs from liable parties. The NPFC was established specifically in 1991 with a mandate of implementing Title I of OPA and is committed to protecting the U.S. environment through certifying that oil-carrying vessels have the financial capacity to contribute in the case of a spill.

The OSLTF is split into two major components: the Emergency Fund for response to oil discharges and initial natural resource damage assessment and the Principal Fund to pay claims and fund appropriations by Congress that administer OPA provisions and support research and development. The Principal Fund has five sources of revenue, the largest of which is an eight-cent-per-barrel excise tax collected from the oil industry on petroleum imported to or produced in the United States. Notably, as a result of an Internal Revenue Services (IRS) exemption, dilbit and synthetic crude derived from oil sands are exempt from paying this barrel tax, although spills of oil sands products are covered by the OSLTF (IRS, 2011). See policy gaps section below for further information on the exemption.

Ensuring responsible parties have the funds to be held accountable, the NPFC issues Certificates of Financial Responsibility (COFR), which demonstrates that vessels can pay for damage and cleanup up to OPA's required liability limits. With few exceptions, vessels weighing more than 300 gross tons must have a valid COFR before navigating U.S. waterways. The NPFC

also recovers costs from responsible parties, provides quick response funding, and compensates claimants for costs and damages (US Coast Guard, 2012).

## 8.7 Other Pertinent Regulations

In addition to the policies and regulations discussed above, three additional federal regulations are pertinent to the transport and discharge of bitumen and dilbit. These include the Fish and Wildlife Coordination Act, Marine Mammal Protection Act, and the Endangered Species Act.

### 8.7.1 Fish and Wildlife Coordination Act (FWCA)

Intended to minimize the adverse impact on fish and wildlife resources and habitat, the FWCA requires federal agencies to consult with the US Fish and Wildlife Service, the National Marine Fisheries Service, and State wildlife agencies for all activities that affect, control or modify any streams or bodies of water ((Fish and Wildlife Coordination Act). This consultation is generally incorporated into the permitting process or licensing requirements required during the construction of pipelines that cross water bodies and for upgrades to shipping terminals.

### 8.7.2 Marine Mammals Protection Act

The Marine Mammals Protection Act (MMPA), enacted in 1972, serves to protect all marine mammals in U.S. waterways from harm, capture, and harassment. The act was passed due to several findings including the potential risk of extinction or depletion that some marine mammals may face as a result from human action, the fact that marine mammal species must not be permitted to fall below optimum levels for sustainable population, and the understanding that measures should be taken to replenish these species (Marine Mammal Protection Act, 1972). Given the rise in transportation through, over, and adjacent to U.S. waterways resulting from the

oil sands industry; this act is important in considering transportation routes and measuring impacts on aquatic organisms.

### 8.7.3 Endangered Species Act (ESA)

In an effort to conserve endangered and threatened species and their habitats, the ESA mandates that federal departments and agencies ensure that any authorized, funded, or implemented action is "not likely to jeopardize the continued existence of listed species or modify their critical habitat." NOAA and USFWS are responsible for publishing lists of endangered and threatened species. The ESA would apply to the construction of dilbit transport infrastructure and must also be considered in spill response scenarios (Endangered Species Act, 1973).

## 8.8 Policy Gaps and Analysis

The outline of regulations governing oil spills and their prevention above has suggested potential gaps in regulations when it comes to increased transport of oil sands products out of Alberta. The two most obvious gaps are the exemption of oil sands products from an excise tax and the lack of specific information required by facilities and transporters regarding the oil product they are handling. However, there are additional gaps in policies and regulations that warrant attention as transport of oil sands products increases. The Federal Railroad Administration has traditionally spent little time concerned with the oversight of oil spill planning as large oil spills in rail transport have not generally been a threat until recent years, during which oil transport via rail has increased. Further, there is a concern that the recently drafted PHMSA contingency plans for pipelines are not well integrated with regional and area plan as required. In addition, while many current regulations give agencies the authority to

effectively regulate bitumen products, problems can arise from a lack of resources and experience dealing with potentially non-floating oils.

### 8.8.1 Dilbit Excise Tax Exemption

As mentioned above, an IRS memorandum exempted dilbit and synthetic crude derived from oil sands from being subject to an eight-cent-per-barrel excise tax that would otherwise go into the Oil Spill Liability Trust Fund. The July 2011 IRS memorandum stated: "tar sands imported into the United States are not subject to the excise tax on petroleum imposed by § 4611 of the Internal Revenue Code" (IRS, 2011). Notably, this fund can be drawn upon to cover spills of oil sands products. "Tar Sands" in this context refers to two materials:

1. *Dilbit*: described in the memo as "bitumen extracted from tar sands and blended with a diluent or other liquid that enables the bitumen to be transported through a pipeline"
2. *Synthetic Crude*: described as "an upgraded oil stream which is a synthetic crude oil derived from tar sands."

The exemption was made at the request of an anonymous company that was referenced only as "Company" in the IRS memorandum.[32]

### 8.8.2 Disclosing Oil Type and Characteristics

The majority of oil spill contingency plans do not require responsible parties to disclose specific information on the type of oil that could be handled in a spill. As discussed above, this became problematic during the Enbridge pipeline spill in the Kalamazoo River when responders were not informed that they were handling oil sands products until nearly one week after the spill. Further complicating the matter, when regulations do require disclosure of oil types, oil sands or oil sands-derived products are not listed among the types of oils to disclose. For example, the Washington Department of Ecology adopted rules for transferring oil over water

[32] Available online at: http://www.irs.gov/pub/irs-wd/1120019.pdf

that require the delivering facility to submit an Advance Notice of Oil Transfer (ANT) 24 hours prior to transfer. In addition to other reporting requirements, the ANT must provide information on the oil product type and quantity (Advance Notice of Transfer, 2006). However the data available for reporting is based on the Puget Sound/British Columbia (PS/BC) Oil Spill Task Force data dictionary, which does not currently include oil sands products.

Regulators in Washington State are working to close these reporting gaps. As mentioned, Washington State passed a provision to the state's Oil Spill Contingency Plan in 2012 requiring responsible parties to provide the names and physical characteristics of all oils handled by vessels and facilities (Spill Contingency Plan, 2012). Given the unique characteristics of bitumen and dilbit, Washington can be seen as an early actor. Contingency plans, at the national, regional, and state level could build similar provisions into their contingency planning requirements.

### 8.8.3 Planning for Response to Group V Oils

Linked to the matter of contingency planning and oil type disclosure, there is a concern that in certain scenarios oils sands products could have the characteristics of group V—or non-floating—oils. Oil sands-derived products are normally classified as group IV oils based on physical characteristics once blended with a diluent or a synthetic crude. The contingency planning requirements for group V oils outlined in section 8.3.4 therefore do not apply to oil sands-derived products. However, if diluents were to flash off after a dilbit spill or if unblended bitumen were to be transported via railcar as has been suggested, the material at the spill site could potentially be a non-floating oil based on API levels reported for unblended bitumen. In failing to suggest that bitumen-products could potentially meet the characteristics of group V oils, contingency plans are underestimating the risks and response needs in the case of a spill of oil sands products.

### 8.8.4 Assessing Risks of Transportation Oil Sands Products

As discussed above, a recent bill will require an assessment of the waterway transportation routes through the Salish Sea as they concern the Canadian oil sands products. This bill also requires an assessment to discern the different properties between Canadian oil sands products and other types of oil. There are not similar efforts underway to assess the risks of transporting Canadian oil sands products in East Coast and Gulf of Mexico waterways, across major river crossings, and near the Great Lakes via rail and pipeline.

### 8.8.5 Inconsistencies in Contingency Planning: PHMSA

Section 8.3.3 outlines the efforts that DOT and PHMSA have taken to better plan for the transport of oil sands products in light of the Michigan Enbridge pipeline spill. One of the requirements for PHMSA pipeline contingency plans is to ensure consistency with regional and national plans. However, a reported lack of coordination between RRTs and PHMSA raises the concern that the PHMSA plans are not integrated into regional and area plans and vice versa. The fact that RRTs might not have access to PHMSA plans and cannot integrate them accordingly into their plans, could result in inconsistencies between plans and a compromised response effort in the case of a spill. RRT 10 has reported a plan to draft a memorandum of understanding with PHMSA to gain access to pipeline contingency plans, which would potentially solve this problem and set an example for other RRTs as well as national planners (Chris Field personal communication, 2013).

### 8.8.6 Increased Transport of Oil by Rail

The increase in transport of oil sands products and other oils by rail has raised concern that regulations of rail transport are inadequate. While the Department of Transportation regulations cover the basic contingency planning requirements, the ability of the Federal Railroad

Administration to oversee this dramatic increase in transport is unclear. The Federal Railroad Administration, unlike PHMSA's Office of Pipeline Safety, has no known program to address potential spills of crude oil let alone heavy oils or oil sands products.

## Key Sources: Important Policies and Regulations

EPA, Office of Emergency and Remedial Response. (1999). *Understanding oil spills and oil spill response.*

PHMSA. (2012a). Oil Spill Response Plans: A History Lesson. *PHMSA Presentation.* Alan Mayberry. July 12, 2012.

Parfomak, Paul (2013). Keeping America's Pipelines Safe and Secure: Key Issues for Congress. *Congressional Research Service,* Report R41536.

Ramseur, J. L. (2012). Oil Spills in U.S. Coastal Waters: Background and Governance. *Congressional Research Service*, Report RL33705.

# 9 GAPS IN REGULATIONS AND TECHNICAL INFORMATION

This section summarizes the gaps in information, research, and policy that we have uncovered throughout our research related to oil sands transport and oil spills in general. There are still many questions to be answered associated with the development and transportation of oil sands products. Listed below are the main areas of concern that we have identified, as well as our recommendations for the most efficient ways to address the gaps:

## 9.1 Policy

Currently, a limited number of policies exist that explicitly address the transportation of oil sands products in the U.S. Below are a number of areas where we find this lack of preparation concerning, categorized by planning, transportation, and response requirements:

### 9.1.1 Planning

**Pipeline spill plans are not consistently integrated with the regional and area contingency planning process.** Currently, EPA is in charge of regulating area plans and PHMSA is the ultimate authority on pipeline spill plans. Although PHMSA requires that contingency plans maintain consistency with area and regional plans, PHMSA's role in spill planning varies from state to state, making it difficult to have a consistent relationship with EPA. As a result, in at least some regions, there are no agreements in place for PHMSA to provide EPA access to pipeline spill plans to ensure consistency.

*Recommendation:* pipeline spill response plans should be made available to Regional Response Teams (RRTs) and incorporated into the regional and area contingency plans.

**Companies transporting oil sands products are not subject to the eight-cent-per-barrel excise tax that supports the Oil Spill Liability Trust Fund.** However, a spill of oil sands products would still be covered by the fund, bringing into question the long-term viability of the fund if an oil sands product spill occurred.

*Recommendation:* the tax exemption for oil sands products should be removed. An oil sands product spill would still require significant recovery efforts comparable to if not exceeding a spill of conventional crude that is subject to the tax. The scale of the Kalamazoo spill response and ongoing cleanup efforts support this.

**Current preparedness and training requirements do not appear adequate for minimizing the amounts of oil from spilling during a pipeline leak.** As demonstrated by the majority of cases discussed, human error caused more oil than necessary to enter into the environment than would have occurred if spill response protocols had been properly followed. This is especially apparent in pipeline operators' inability to differentiate between a false and real alarm.

*Recommendation:* Enbridge implemented a number of mandated training exercises for its personnel after the Kalamazoo spill that could be required or encouraged at the national level. First, Enbridge increased the number of emergency response simulator sessions that operators were required to attend from one per year to two per year. Two additional training sessions were mandated that looked into human factors that contribute to a response failure and hydraulics. Additional training was also provided on column separation. More recommendations can be found in the NTSB (2010) report under section 1.14.3, Enbridge Actions.

**Regulations do not require risk assessments related to water terminals until construction is taking place.** Risk assessments are not required for terminals that are expected to handle oil sands products until upgrades to facilities are underway.

*Recommendation:* risk assessments should be required before permits are granted to ensure that new risks are factored into the decision to expand a terminal's capacity.

### 9.1.2 Transportation

**Rail regulations specific to the transport of crude oil are undeveloped.** Although the FRA has plans in place to handle spills of hazardous materials, these do not directly address oil spills in general or oil sands products specifically. The ability of the FRA to oversee and regulate the increase in oil sands products being transported by rail is unclear.

*Recommendation:* more research needs to be done to understand the regulations that rail companies must adhere to as they transport oil sands products.

**Policies do not require pipeline operators to provide information to regulatory authorities on the type of product being transported in a pipeline.** The lag time associated with regulatory and response agencies getting accurate data from the pipeline operator may affect their ability to plan for and respond to a spill.

*Recommendation:* require operators to track the type of oil present in each batch as the material is transported through the pipeline. Regulatory and response agencies will have access to this information at the time a spill is reported. This will allow pipeline operators, regulatory, and response agencies to know what product is spilled when the response is initiated.

### 9.1.3 Response

**The responsible party does not have to demonstrate ability to have appropriate oil spill equipment on site within the mandated time.** If there is a spill of oil sands products, the responsible party is in compliance with oil spill response requirements if they have implemented a response effort, but it is not necessary that they have the appropriate equipment on site to deal with oils that my submerge or sink over time. Initial response time with product appropriate equipment could be especially critical with a spill of oil sands products, given the uncertainty of weathering and the potential for the oil to submerge over time.

*Recommendation:* contingency planning requirements could be expanded to require companies to demonstrate their ability to get the appropriate equipment to a potential spill site based on the type of product they are transferring.

**Oil spill response regulations require oil cooperatives to prove that they can deploy the equipment in their inventory, but not demonstrate the equipment's effectiveness.** As we saw in the Wabamun Lake case, this significantly impacted the response effort's ability to contain the oil.

*Recommendation:* while assessing inventories, regulators should require a demonstration to illustrate the ability to deploy and effectively use the equipment.

**MSDSs are not required to disclose the specific type of oil being transported.** As we saw in the Kalamazoo spill, the MSDS noted that "crude oil" had been spilled and did not specify that dilbit was the actual product in the pipeline. This affected the clean up crew's response and resulted in public and environmental health concerns.

*Recommendation:* adopt the Washington regulation discussed in Section 8.4.2.1 as national requirment.

**Response plans do not address the potential for oil sands products to act as non-floating oils in the case of spill.** There is a concern that in certain scenarios oil sands products could have the characteristics of group V—or non-floating—oils. However, the contingency planning requirements for group V oils outlined in section 8.3.4 do not apply to oil sands products.

*Recommendation:* regional and area response plans should reflect the fact that in the case of a spill of oil sands products, there is the potential for the material to sink or be suspended in the water column unless there is sufficient laboratory or field data to demonstrate otherwise.

**Our regional and national capacity to respond to a oil sands products spill is unknown as most equipment lists are missing vital processing information that would allow us to understand how a piece of equipment can be used in a spill.**

*Recommendation:* require oil spill response organizations to list their inventory, as well as necessary performance information on a national list, to understand how the equipment can be used in a spill.

## 9.2 Research

In general, there is a lack of published independent oil sands related research . There are a number of studies under way, but the results have not been published. Research is needed in three categories: the physical properties and behavior of oil sands products, the increased risk associated with transporting oil sands products, and the effectiveness of current oil spill

equipment on an oil sands products spill. For each gap, we recommend conducting independent research that will look into the missing information. Specifically:

### 9.2.1 Physical Properties & Behavior of Dilbit

**The properties, behavior, and potential public health concerns of the diluent have not been adequately addressed at this point.** The health risks for responders may differ depending on the exact diluent being used. Therefore, there is a gap in research regarding the properties of the diluent and also a gap in policy requiring the diluent to be named on an MSDS or be made available during a spill response. Also, because the flash point of diluents can differ by type, the rate of evaporation could be difficult to predict during a spill.

**There are unknowns regarding how weathering and sedimentation may lead to oil sands products being overwashed by water, suspended in the water column, or sinking to the bottom.** Importantly for spill response, the timing of when the oil may potentially leave the surface is unknown.

**Research regarding how oil sands products will further biodegrade in the environment is not sufficient.** This has implications for response efforts during an oil sands products spill because the degree to which the product has already biodegraded will affect how much biodegradation the oil sands products are subject to.

**When research is conducted, a variety of bitumen products should be tested.** Bitumen properties vary both by deposit as well as over time within the same deposit. Therefore, there is a need to test a number of different samples to assess the true range of properties.

### 9.2.2 Transportation Risks

**The risks associated with increased waterborn transport oil sands products are unknown.** There is at least one study planned assessing the risk associated with an increase of traffic through the Salish Sea, however, there are no studies as of March 2013 that examine potential increases in tanker or rail traffic in or near East Coast and Gulf of Mexico waterways, major river crossings, or the Great Lakes. There is a risk assessment planned for transport through the Aleutian Islands, but it does not specifically address the transport of oil sands products.

*Recommendation:* conduct risk assessments examining the increased traffic in the Aleutian Islands, East Coast and Gulf of Mexico waterways, major river crossings, the Great Lakes, and other waterways that could see increased transportation of oil sands products. Each risk assessment should explicitly look at the potential increases in oil sands products transport.

### 9.2.3 Response Effectiveness

**There is a lack of real world testing and experience with recovery equipment on oil sands products.** This hinders our ability to determine whether or not a region will be prepared to handle an oil sands products spill and which equipment will be effective.

*Recommendation:* controlled experiments looking at current equipment's effectiveness on oil sands products should be conducted. A range of oils should be used to test the equipment including different product types (dilbit, synbit, synthetic crude, etc.) and different sources (Cold Lake, McKay River Heavy, etc.).

**Information is lacking on the ability to recover oil when it sinks or is suspended in the water column.**

*Recommendation:* continue the U.S. Coast Guard's work in researching and developing new methods of detecting, monitoring, containing, and recovering sunken or submerged oil.

### 9.2.4 Other Gaps

**LDS are not predicting a significant portion of the spills.** More research and development should be dedicated to improving the accuracy of LDS. Additionally, more training may be necessary for pipeline operators to help them determine the difference between a real and false alarm.

**Some of the API values listed in this report are based on research completed in the 1980s.** If possible, these values should be updated in order to have a more reliable understanding of where oil sands products fit on the spectrum of API values.

# 10 APPENDICES

## 10.1 Appendix 1

| Oil Sands Major Players List* | | |
|---|---|---|
| **Individual/ Organization** | **Description of Involvement** | **Additional Information** |
| **Energy Companies** | | |
| BP Canada Energy Trading Company | BP uses in situ extraction at three jointly owned mines: Sunrise oil sands (50% owner, Husky Energy operator); Pike oil sands (50% owner, Devon Energy operator); Terre de Grace oil sands (75% owner and operator). These projects have not begun producing yet, but the first is expected to go online in 2014. BP also signed a long-term contract with Kinder Morgan's (KM) Trans Mountain Pipeline and has both downstream and upstream facilities. | http://www.bp.com/sectiongenericarticle.do?categoryId=9036695&contentId=7067648<br><br>http://www.transmountain.com/news-releases/trans-mountain-updates-customer-commitments-for-proposed-expansion-project |
| Canadian Natural Resources | Canadian Natural Resources is the operator and owner of the Kirby, Grouse, and Primrose and Wolf Lake In Situ Oil Sands Projects. It also signed a long-term contract with KM's Trans Mountain Pipeline and is a strong supporter of the Enbridge Line 9 Reversal project. | http://www.cnrl.com/operations/north-america/north-american-crude-oil-and-ngls/thermal-in situ-oilsands/<br><br>http://www.transmountain.com/news-releases/trans-mountain-updates-customer-commitments-for-proposed-expansion-project |
| Cenovus Energy Inc. | Cenovus owns and operates two in situ extraction sites in Foster Creek and Christina Lake in conjunction with ConocoPhillips (50% share). It jointly owns two refineries in the U.S., with a 50% interest in ConocoPhillip's Wood River and Borger refineries. Cenovus signed a long-term contract with KM's Trans Mountain Pipeline. | http://www.cenovus.com/operations/index.html |
| Chevron | Chevron jointly owns the Muskeg River Mine in Alberta which went online in 2011. Its current capacity is approximately 255,000 barrels per day (b/d). | http://www.chevron.com/deliveringenergy/oilsands/ |

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| China National Petroleum Corp. (parent company of Petro-China) | In 2007, CNPC was the first Chinese company to win mineral rights to mine bitumen. In August 2009, CNPC bought 60% of the development rights of Athabasca Oil Sands Corp.'s Mackay River and Dover projects. In 2012, this was extended so that CNPC was the owner and operator of the MacKay River oil sands project. In 2005, the company signed a Memorandum of Understanding (MOU) with Enbridge supporting a western pipeline that would help carry crude to China via tankers (Northern Gateway). | http://www.cnpc.com.cn/en/cnpcworldwide/canada/<br><br>http://www.scmp.com/article/598721/cnpc-wins-right-work-oil-sands-alberta<br><br>http://www.theglobeandmail.com/news/politics/chinas-oil-sands-deal-will-have-lasting-impact/article1357620/ |
| Chinese National Offshore Oil Company (CNOOC) | CNOOC is a Chinese state owned multinational oil company that operates in Canada and the U.S. In July of 2012 CNOOC announced plans to buy Canadian oil firm Nexen for $15 billion. It was recently approved by the U.S. Committee of Foreign Investment (Nexen owns assets in the Gulf of Mexico) and the deal officially closed on 2/25/2013. It also owns a 17% stake in MEG Energy, an Alberta oil sands project developer. In 2011, CNOOC acquired equity interest in OPTI, a Canadian oil sands producer. | http://www.cnoocltd.com/encnooclt d/AboutUs/zygzq/Overseas/132.shtml<br><br>http://www.cnbc.com/id/100454779/CNOOCNexen_Deal_Wins_US_Approval_Its_Last_Hurdle<br><br>http://business.financialpost.com/2013/02/25/cnooc-completes-contentious-15-1-billion-acquisition-of-nexen/?__lsa=5f87-ac2a |
| ConocoPhillips | ConocoPhillips holds approximately 1 million net acres of land in northeastern Alberta. Its main operations occur at the Surmont oil sands project, southeast of Fort McMurray where the company employs in situ extraction techniques. The Surmont project is a 50/50 joint venture project with Total E&P Canada Ltd and has the capacity to produce 110,000 b/d. ConocoPhillips is also in a 50/50 partnership with Cenovus Energy. This partnership operates the Foster Creek and Christina Lake projects as well as the proposed Narrows Lake project. The partnership has a total capacity of 428,000 b/d. Most of its oil sands product is piped through the Keystone pipeline to U.S. refineries, specifically the Phillips 66 Wood River Refinery. | http://www.conocophillips.com/EN/oilsands/assets/Pages/index.aspx<br><br>http://www.conocophillips.com/EN/oilsands/overview/Pages/transportation.aspx |
| Exxon Mobil/Imperial Oil Ltd./Esso | ExxonMobil Canada and Imperial Oil jointly own the Kearl oil sands project, which is one of Canada's largest open-pit mining operations north of Fort McMurray. Its current capacity is 345,000 b/d. The project is assessing its refining options and will most likely integrate with North American refineries owned by Imperial Oil and ExxonMobil. Enbridge's Line 9A Reversal project was pursued due to a request from Imperial Oil. | http://www.imperialoil.ca/Canada-English/operations_sands_kearl_overview.aspx<br><br>http://www.enbridge.com/ECRAI/Line9ReversalProject.aspx |

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| Flint Hills Resources/Koch Industries | Flint Hills Resources, which is operated by Koch Industries, is an oil refinery company in the U.S. Its St. Paul, Minnesota refinery is rumored to be refining over 320,000 b/d of oil sands products. | http://www.fhr.com/refining/canada.aspx<br><br>http://www.sustainablebusiness.com/index.cfm/go/news.display/id/22112 |
| Husky | Husky energy has been exploring oil sands since 1973 and is one of the top holders in oil sands reserves in Alberta. Its Sunrise reservoir alone is estimated to hold 3.7 billion barrels of bitumen as of 12/2011. It jointly owns a refinery near Toledo, Ohio. | |
| Marathon | Marathon Oil has a 20% share of the Muskeg River and Jackpine mine as well as the Scotford Upgrader. It also has the rights to over 216,000 acres of potentially mineable land in the Alberta region. Marathon owns interests in in situ oil sands leases near Fort McMurray. It is also one of the largest oil refinery companies in the United States. | http://www.marathonoil.com/Global_Operations/Canada/Operations/ |
| Nexen Marketing Inc. | Nexen has an interest in over 300,000 acres in the Athabasca region. It's the 65% owner and operator of the Long Lake reserve, where they use in situ extraction to produce synthetic crude on site. Nexen also has begun developing the Kinosis area and the extracted bitumen will be upgraded at Long Lake. It has a 7% interest in Syncrude's oil sands mining and upgrading facilities and has a 15% non-operating interest in Hangingstone, an extraction project developed by Japan Canada Oil Sands. Nexen signed a long-term contract with KM's Trans Mountain Pipeline. As mentioned before, Nexen was recently purchased by CNOOC. | http://www.nexeninc.com/en/Operations/OilSands/OurOilSandsBusinesses.aspx |
| PBF Energy | PBF Energy owns nearly 1/3 of U.S. East Coast refining capacity and is expected to refine oil sands products. | http://www.ubs.wallst.com/ubs/mkt_story.asp?docKey=1329-L1E8MQ61A-1&first=0 |
| Shell Oil | Through Shell's Athabasca Project, where it is the majority owner (60%, with Chevron at 20% and Marathon at 20%), Shell both mines and upgrades bitumen and converts it to synthetic crude. It is the joint owner of two mines (the Muskeg River Mine and the Jackpine Mine) and the joint owner of one upgrader (Scotford Upgrader) in Alberta. It currently has the capacity to produce 255,000 b/d of synthetic crude. | http://www.shell.com/global/aboutshell/our-strategy/major-projects-2/athabasca.html |

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| SINOPEC | SINOPEC is a Chinese state owned company that bought a 9% stake in Alberta's Syncrude Canada Ltd. in 2010. It first became involved in Canadian oil sands in 2005 when it formed a joint venture with Canada-based Synenco Energy to form the Northern Lights oil sands project. SINOPEC continues to look for ways to grow its business in Canada. | http://business.financialpost.com/2012/12/12/sinopec-still-keen-to-invest-in-canada-as-long-as-theres-money-to-be-made/?__lsa=5f87-ac2a<br><br>http://english.caixin.com/2010-04-13/100134471.html |
| Statoil Canada Ltd. | Statoil uses in situ to extract bitumen from its Leismer Demonstration Project. It also signed a long-term contract with KM's Trans Mountain Pipeline. | http://www.statoil.com/en/environmentsociety/relevanttopics/oilsandincanada/pages/default.aspx |
| Suncor Energy | Suncor was the original oil sands producer in the Athabasca region. It uses mining and in situ operations to extract bitumen and has two upgrading facilities on site in Fort McMurray and a third upgrader in Edmonton. Suncor has signed a long-term contract with KM's Trans Mountain Pipeline. | http://www.suncor.com/en/about/242.aspx |
| Syncrude (Majority owner: Canadian Oil Sands, Ltd.) | Syncrude is one of the original oil sands producers and began extracting bitumen in 1973. Currently, its Syncrude Project leases three mines near Fort McKay and it extracts bitumen deposits using in situ and open pit mining extraction techniques. It sends its product by pipeline to three Edmonton area refinieries and to refineries in Canada and the U.S. Through its majority owner, Canadian Oil Sands, Ltd., Syncrude signed a long-term contract with KM's Trans Mountain Pipeline. | http://www.syncrude.ca/users/folder.asp?FolderID=5753 |
| Tesoro Refining & Marketing Company | Tesoro is an oil refiner with seven refineries in the Western United States, including one in Anacortes, WA. Tesoro signed a long-term contract with KM's Trans Mountain Pipeline. | http://www.tsocorp.com/TSOCorp/ProductsandServices/Locations/RefineryLocations/index.htm |
| Total E&P Canada Ltd. | Total E&P Canada extracts bitumen at its Surmont, Joslyn, Fort Hills, and Northern Lights reserves and upgrades the bitumen at its own Voyageur Upgrader. E&P also has assets unexplored at this time, known as Asphalt Creek and Griffon. It has signed a long-term contract with KM's Trans Mountain Pipeline | http://www.total-ep-canada.com/upstream/upstream.asp |
| Valero | Valero is the world's largest independent petroleum refiner. It has committed to taking on at least 100,000 b/d from the Keystone XL. | http://www.nationaljournal.com/energy/u-s-oil-giants-poised-to-gain-on-keystone-pipeline-20110804 |
| **Pipeline Operators** | | |

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| Enbridge | Enbridge's oil sands pipeline infrastructure connects six producing oil sands projects. It also operates contract storage facilities for oil sands products. Enbridge is currently sending oil sands products into the U.S. through its Line 6B pipeline and has proposed to increase its capacity through the construction of the Northern Gateway Project and the Line 9 Reversal. | http://www.enbridge.com/MediaCentre/News/regionaloilsandsAAG.aspx<br><br>http://www.reuters.com/article/2012/05/17/enbridge-idUSL4E8GH0H820120517 |
| Kinder Morgan | Kinder Morgan is a Texas-based pipeline operator that is poised to expand its Trans Mountain pipeline from Alberta to Vancouver in order to increase its capacity to transport oil sands products. | http://www.kindermorgan.com/investor/presentations/013013_KMCanada.pdf<br><br>http://www.kindermorgan.com/business/canada/tmx_expansion.cfm |
| TransCanada | TransCanada is the Keystone pipeline operator and is bidding to expand the Keystone pipeline from Alberta, Canada to Houston, Texas. It currently delivers to refineries in Wood River and Patoka, Illinois and Cushing, Oklahoma. Its current capacity is 590,000 b/d. | http://www.transcanada.com/100.html |
| **Rail Companies** | | |
| Canadian National Rail | Canadian National Rail (CN) has a rail yard in Fort McMurray, giving them direct access to northern Alberta oil sands products. Their network has direct access to Peace River and Cold Lake deposits. | http://www.cn.ca/en/shipping-north-america-alberta-oil-sands.htm |
| Canadian Pacific Rail | Canadian Pacific Rail (CPR) directly serves the Edmonton/Fort Saskatchewan area. They have a direct route to the pipeline injection/terminating points at Hardisty and Edmonton. CPR also brings diluent to the pipeline terminal facilities at these locations. | http://www.cpr.ca/en/ship-with-cp/where-you-can-ship/oil-sands/Pages/default.aspx |
| Burlington Northern Santa Fe (BNSF) | Owned by Warren Buffet, BNSF is taking advantage of the delay in pipeline construction by becoming a more politically stable way to transport oil sands to refineries and beyond. BNSF is currently allowing CNR and CPR to use their tracks to transport oil sands products into the U.S. | http://www.bloomberg.com/news/2012-01-23/buffett-s-burlington-northern-among-winners-in-obama-rejection-of-pipeline.html |
| Union Pacific | Union Pacific Railroad operates in 23 states across the Western two-thirds of the U.S. Its network is currently set up to handle oil sands products and to deliver oil sands crude to refineries in Texas and Oklahoma. | http://www.uprr.com/customers/chemical/attachments/crude/crude_map.pdf |
| CSX Transportation | CSX has an extensive rail network in the Eastern U.S. Although it currently is not transporting oil sands products, it is in the position to do so if pipeline construction is further delayed. | http://www.csx.com |
| **Industry Associations** | | |

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| API | The American Petroleum Institute (API) is an American trade association that represents all aspects of the oil and natural gas industry. It also provides information to the general public about oil sands products and their uses. | http://www.api.org/oil-and-natural-gas-overview/exploration-and-production/oil-sands.aspx |
| CAPP | The Canadian Association of Petroleum Producers (CAPP) represents companies that explore, develop, and produce natural gas or oil throughout Canada. It provides information and resources to its member organizations and also to the general public. | http://www.capp.ca/canadaIndustry/oilSands/Energy-Economy/Pages/default.aspx |
| CEPA | The Canadian Energy Pipeline Association (CEPA) works with its members on the many issues associated with moving oil by pipeline. Specifically, CEPA makes information available on the corrosivity of diluted bitumen in pipelines. | http://www.cepa.com/5-more-facts-to-know-about-diluted-bitumen |
| COSIA | Canada's Oil Sands Innovation Alliance (COSIA) is an alliance of oil sands producers that focuses on accelerating the pace of improvement in environmental performance in Canada's oil sands through collaborative action and innovation. | http://www.cosia.ca |
| OSDG | The Oil Sands Developers Group (OSDG) is an industry-funded nonprofit that represents oil sands operators and developers. Its members work in cooperation with other stakeholders to address issues related to oil sands development and to communicate information on oil sands activity. | http://www.oilsandsdevelopers.ca |
| **U.S. Regulatory Agencies** | | |
| U.S. Coast Guard | The U.S. Coast Guard (USCG) is in charge of facilitating all spill response efforts in coastal waters and the Great Lakes. With the proposed increase in oil sands transport, the USCG is concerned with increases in oil tanker traffic in British Columbia and Washington. Washington State has five major petroleum refineries which could receive oil sands products. As a result, the USCG will study the risk of transporting oil through the Salish Sea waters. This is mostly in response to the proposed Kinder Morgan Trans Mountain pipeline expansion. | http://www.cbc.ca/news/canada/story/2013/01/06/bc-oil-tanker-traffic-review.html |
| Alaska Department of Environmental Conservation | If the Northern Gateway pipeline were approved, Alaska would see an increase in oil tankers coming through its coastal waters. It also has the potential to see oil sands products traveling to Valdez by rail. The Alaska Department of Environmental Conservation is the agency in Alaska that works to prevent, prepare, and respond to oil spills. | http://www.dec.state.ak.us/spar/index.htm |

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| Federal Railroad Administration | Under the DOT, the Federal Railroad Administration (FRA) is in charge of regulating all railcars traveling throughout the U.S. Since this is likely method of transport for oil sands products, FRA is a pertinent regulatory agency in the oil sands discussion. | http://www.fra.dot.gov/ |
| Maine Department of Environmental Protection | There is a strong possibility that oil sands products will/is being transported to Maine's oil refineries. Maine's Department of Environmental Protection is in charge of enforcing the state's environmental laws. Therefore, it has a stake in understanding how the transport of oil sands products could potentially affect Maine's natural resources. | http://www.maine.gov/dep/spills/index.html |
| U.S. EPA | The U.S. Environmental Protection Agency (EPA) is in charge of responding to all inland spills and is also the regulatory agency commenting on TransCanada's Keystone XL Environmental Impact Statement. EPA was the key regulatory agency involved in the Marshall, Michigan spill in 2010. | http://yosemite.epa.gov/oeca/webeis.nsf/(PDFView)/20100126/$file/20100126.PDF<br><br>http://www.epa.gov/region05/cleanup/kalproject/index.htm |
| U.S. PHMSA - Office of Pipeline Safety | The U.S. Pipeline and Hazardous Materials Safety Administration, a subagency within the U.S. Department of Transportation (DOT), is in charge of regulating pipelines in the U.S. | http://phmsa.dot.gov/about |
| U.S. State Department | The U.S. State Department approves pipelines that cross international borders. This means that the Keystone XL will not be constructed without the State Department's approval. | http://www.keystonepipeline-xl.state.gov |
| Washington's Department of Ecology | The Washington State Department of Ecology (DOE) is mostly concerned with the potential increase in tanker traffic in Washington waters due to increased production of oil sands products and the potential for these products to be shipped out of British Columbia. The DOE estimates that about 11% of the gasoline that is refined and consumed in Washington is a derivative of oil sands. | http://www.ecy.wa.gov/programs/spills/about_us/SPPR%202012-2013%20Program%20Plan%20(final).pdf<br><br>http://www.ecy.wa.gov/climatechange/docs/fuelstandards_112009_presentation.pdf<br><br>http://dep.ky.gov/Pages/Spills.aspx |
| **Canadian Governmental Bodies** | | |
| Alberta Energy | Alberta Energy oversees Alberta's non-renewable resources. Specifically, it operates the Oil Sands Division, which provides administrative and regulatory services for the Oil Sands Royalty Regulations, Oil Sands Tenure Regulation, and Crown and individual agreements to ensure that Alberta receives appropriate royalties and rentals from oil sands development. | http://www.energy.alberta.ca/ourbusiness/oilsands.asp |

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| Canada's Federal Government | Oil sands development adds employment opportunities and contributes to Canada's economic growth. As a result, conservative Prime Minister Stephen Harper has made developing oil sands a national priority and has publically expressed his support for the Northern Gateway pipeline and the Trans Mountain (TM) expansion. | http://www.vancouversun.com/business/Northern+Gateway+pipeline+vital+Canada+interests+Stephen/7053312/story.html |
| Canada's National Energy Board | The National Energy Board (NEB) regulates pipelines, energy development, and trade at the interprovincial and international level. Therefore, NEB's approval is required for any oil pipeline that crosses into the U.S. (Keystone XL) or crosses provincial boundaries (Northern Gateway, TM Expansion, Line 9). | http://www.neb-one.gc.ca/clf-nsi/rthnb/whwrndrgvrnnc/rrspnsblt-eng.html |
| Environment Canada | Environment Canada's mandate is to preserve the quality of the natural environment and coordinate environmental policies and programs at the federal level. It is currently the main resource for scientific research performed on the behavior of oil sands. | http://www.ec.gc.ca/inre-nwri/default.asp?lang=En&n=D974A85E-1 |
| Government of Alberta | Given that the oil sands reserves are for the most part contained in Alberta, the Alberta Government is integral in the management and development of oil sands. | http://www.oilsands.alberta.ca |
| Government of British Columbia | The Northern Gateway pipeline and Kinder Morgan's TM Expansion affect British Columbia residents. There is a large constituency in the province that oppose both the pipelines. However, the Premier Christy Clark sees the export of oil sands products from B.C. ports as a potential economic boost and a source of significant employment opportunities. | http://www.vancouversun.com/business/Clark+likens+potential+Alberta+oilsands/7698187/story.html |
| **Environmental Groups** | | |
| Forest Ethics | Forest Ethics is working to reduce the demand for oil sands products in the U.S. Specifically, the organization is focusing its work on the communities surrounding U.S. oil sands refineries. | http://forestethics.org/tar-sands |
| Living Ocean Society | The Living Ocean Society is an environmental group in Canada that is concerned with marine conservation issues. They have been vocal about their concerns regarding the state of response technologies that could potentially clean up a bitumen-related spill. | http://ecowatch.org/2012/condemns-announcement/ |
| NRDC | The NRDC is leading the charge against the import of oil sands products into the United States. Particularly, they have produced a number of anti-Keystone XL reports. | http://www.nrdc.org/energy/tarsandssafetyrisks.asp |

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| NWF | The National Wildlife Federation (NWF) is mostly concerned with the methods used to extract bitumen and the potential for adverse wildlife impacts if a spill occurs. | http://www.nwf.org/What-We-Do/Energy-and-Climate/Drilling-and-Mining/Tar-Sands.aspx |
| Sierra Club | The Sierra Club has helped organize a number of anti-oil sands demonstrations in Canada and is specifically working with First Nations to bring their concerns to the table. | http://www.sierraclub.org/dirtyfuels/tar-sands/default.aspx |
| The Pembina Institute | Oil sands, specifically the greenhouse gases associated with development, is one of the Pembina Institute's focus areas. It has produced a number of reports regarding the responsible development of oil sands in Alberta. | http://www.pembina.org/oil-sands |
| Other Environmental Groups addressing oil sands development include, but are not limited to: | Greenpeace Canada, Sierra Club Canada, David Suzuki Foundation, Alberta Wilderness Association, Environmental Defense Canada, Dogwood Institute, West Coast Environmental Law, Indigenous Environmental Network, Oil Change International, 350.org, Energy Action Coalition, Climate Action Network Canada, Equiterre, Respecting Aboriginal Values and Environmental Needs (RAVEN), SumOfUs, LeadNow.ca, Ecojustice, DeSmogBlog.com | |
| **First Nations & Native American Tribes** | | |
| Chipewyan | The Chipewyan's lands sit in the heart of the Alberta oil sands. The Chipewyan launched a constitutional challenge based on Treaty 8 against Shell Canada, which is looking to expand their Jackpine oil sands mine into the Chipewyan's traditional territories. The Chipewyan are arguing that Shell failed to adequately consult them, violating treaty rights. The Chipewyan also state that they are experiencing adverse health effects as a result of living downstream from the oil sands. | http://indiancountrytodaymedianetwork.com/article/athabasca-chipewyan-launch-treaty-8-challenge-to-shell-canada-over-oil-sands-137632<br><br>http://www.tarsandswatch.org/depth-fort-chipewyan |
| Cree | The Beaver Lake Cree Nation hunts and fishes in and around the Athabasca River. The Cree Nation argues that oil sands development is destroying the habitat that the animals and fish they hunt depend on. They are currently in a legal battle with the Alberta Government with a trial date set for early 2015. | http://www.raventrust.com/beaverlakecree.html |
| Dene | The Dene Nation is downstream from Alberta's oil sands and depends on the Athabasca River as part of its livelihood. They oppose any new pipelines and expansion of oil sands development because of the potential negative effects it may have on its traditional way of life. | http://www.nnsl.com/northern-news-services/stories/papers/oct21_11pip-nwt.html |

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| Haida | The Haida Nation is opposed to the Northern Gateway pipeline and was part of the NEB hearings in Edmonton. The pipeline route would go through Haida land. | http://www.qciobserver.com/Article.aspx?Id=5631 |
| Haisla | Enbridge's Northern Gateway pipeline would cross Haisla's land. The Haisla Nation is opposed to the pipeline, resulting in legal questions about whether Enbridge will be able to build the pipeline through Haisla's land. | http://www.theglobeandmail.com/report-on-business/industry-news/energy-and-resources/oil-sands-pipeline-hits-its-highest-hurdle/article1357847/ |
| Lakota | The Lakota Nation actively opposes the transport of oil sands products through its lands. For example, in 2012 the Lakota created a human blockade to stop oil sands pipeline trucks from entering their territory. | http://colorlines.com/archives/2012/03/lakota_indians_block_keystone_xl_pipeline_trucks_from_entering_reservation_in_six-hour_standoff.html |
| Makah | The Makah Nation is active in oil spill preparedness and is concerned with the potential tanker traffic increase in the Strait of Juan de Fuca. The Makah Nation also provided George Washington University (GWU) data for GWU's vessel traffic risk assessment. | http://www.uscg.mil/proceedings/spring2010/articles/51_Bowechop_MakahTribalCouncilOfficeOfficeOfMarineAffairs.pdf<br><br>http://www.eisgatewaypacificwa.gov/sites/default/files/content/files/Makah_Tribal_Council.pdf |
| Métis | The Métis community sits in the heart of the next wave of oil sands development in Northern Alberta. They recently signed a deal with Cenovus Energy that will give 300 community members benefits estimated to be worth $40 to $60 million over the next 40 years. | http://www.aawgecdev.ca/deal-between-metis-community-oils-sands-firm-a-turning-poin.html |
| Nisga'a | Though the pipeline will not run through Nisga'a land, the Nisga'a Nation opposes the pipeline due to concerns over increased tanker traffic. | http://www.cbc.ca/news/canada/british-columbia/story/2012/02/17/bc-cullen-enbridge-hearing.html |
| Sioux | The Yankton Sioux Reservation is located in South Dakota. The Sioux Nation hosted the historical event, “Gathering to Protect the Sacred From the Tar Sands and Keystone XL," where those attending signed an international treaty to block the Keystone XL. | http://www.ienearth.org/tribes-and-allies-gather-on-yankton-sioux-reservation-to-oppose-the-tar-sands-and-keystone-xl-pipeline/ |
| Squamish | The Squamish protested the Kinder Morgan expansion in 2012 by canoeing from Ambleside to Cates Park to showcase the sanctity of the ocean. | http://dirtyoilsands.org/news/article/squamish_and_tsleil_waututh_paddle_to_protest_kinder_morgan_pipeline |
| Wet'suwet'en | The Wet'suwet'en is opposed to oil sands products being transported over their land. Recently, the Wet'suwet'en have reaffirmed their declaration of "No Enbridge Northern Gateway Pipeline on Wet'suwet'en Territory." | http://www.wetsuweten.com/media-centre/news/information-clarification-around-the-proposed-northern-gateway-pipeline |

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| Coastal First Nations | Coastal First Nations is an alliance of First Nations on British Columbia's North and Central Coast and Haida Gwaii. The Coastal First Nations include Wuikinuxv Nation, Heiltsuk, Kitasoo/Xaixais, Nuxalk Nation, Gitga'at, Metlakatla, Old Massett, Skidegate, and Council of the Haida Nation. In March 2010, the Coastal First Nations signed the Coastal First Nation Declaration, which bans oil sands pipelines and tankers on the North Coast. | http://wcel.org/sites/default/files/First%20Nations%20that%20have%20declared%20opposition%20to%20proposed%20Enbridge%20tanker%20&%20pipeline%20project.pdf<br><br>http://www.coastalfirstnations.ca/sites/default/files/cfn-files-public/oil%20tanker%20impacts_1.pdf |
| **Other Stakeholders** | | |
| Landowners in South Dakota, Montana, Kansas, Oklahoma, Nebraska, and Texas | Landowners along the proposed Keystone XL route have mixed opinions about the pipeline being routed through their land. | http://billingsgazette.com/news/state-and-regional/montana/landowners-have-mixed-views-of-keystone-xl/article_1031db2c-fd18-5c8d-8250-e1c473ac5ee9.html |
| Regional Aquatics Monitoring Program (RAMP) | RAMP is currently engaged in the creation of a new monitoring system for the Athabasca oil sands. | http://athabasca.riverawarenesskit.org/ramp/news.aspx?nid=25 |
| The Prince William Sound Regional Citizens Advisory Council (RCAC) | RCAC is an independent non-profit corporation that promotes the environmentally safe operations of the Alyeska Pipeline marine terminal in Valdez. It has an OPA mandate to build trust and provide citizen oversight of environmental compliance by oil terminals and tankers. With the increase in oil sands transportation, the RCAC will have an interested in the increased tanker activity in their region. | http://www.pwsrcac.org/about/index.html |
| **Note: This is not an exhaustive list, but it hopefully reveals the range of stakeholders participating in the oil sands debate* | | |

## 10.2 Appendix 2

| Known Characteristics and Data Ranges for Alberta Oil Sands Products | | | | | | | |
|---|---|---|---|---|---|---|---|
| **Product:** | **API Gravity** | **Density (g/cm^3)** | **Viscosity (cP;Temp)** | **Sulfur Content (weight %)** | **TAN** | **Pour Point** | **Benzene (ppm)** |
| Athabasca Bitumen | 7.7-9 | 1.011-1.0133 (15.56C) | 19000->300000(15C) | 4.41-5.44 | 3 | | |
| Cold Lake Bitumen | 9.8-13.2 | 0.977-1.002(15C) | 235000 | 4.11-6.9 | 0.97 | (-4)-9 | |
| Cold Lake Blend | 22.6 | 0.9172-0.9177(15C) | 150(15C) | 3.6-4.72 | 0.8 | (-45)-(-46) | 1510 |
| Cold Lake Diluent | 69.3 | 0.704(15C) | 1(15C) | 0.25 | | < -75 | 11600 |
| Enbridge Diluent Specs | | 0.6-0.8(15C) | max = 2(7.5C) | 0.5 | | | 1.17 |
| Bitumen | 5.4 | | 1290254.1(25C) | 4.4 | | 72.9 | |
| Heavy Oil | 16.3 | | 100947(25C) | 2.9 | | 19.7 | |
| Medium Oil | 22.4 | | 34(25C) | 1.6 | | 8.6 | |
| Conventional oil | 38.1 | | 13.7(25C) | 0.4 | | 16.3 | |
| **Product:** | **Pour Point** | **Benzene (ppm)** | **Total VOC (ppm)** | **Oil/Salt Water Interfacial Tension (mN/m)** | **Oil/Fresh Water Interfacial Tension (mN/m)** | **Aqueous Solubility (mg/L)** | |
| Athabasca Bitumen | | | | | | | |
| Cold Lake Bitumen | (-4)-9 | | | | | | |
| Cold Lake Blend | (-45)-(-46) | 1510 | 10500 | 28.1 at 0 °C, 16.3 at 15 °C. | 28.3 at 0 °C, 21.7 at 15 °C. | 28 at 25 °C (distilled water) | |
| Cold Lake Diluent | < -75 | 11600 | 68080 | 7.5 at 0 °C, 6.8 at 15 °C. | 8.3 at 0 °C, 8.3 at 15 °C. | 58 at 25 °C (distilled water) | |
| Enbridge Diluent Specs | | 1.17 | | | | | |
| Bitumen | 72.9 | | | | | | |
| Heavy Oil | 19.7 | | 4891.1 | | | | |
| Medium Oil | 8.6 | | 8209.2 | | | | |

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|---|---|---|---|---|---|---|---|
| Conventional oil | 16.3 | | 15996.3 | | | | |
| **Sources: Environment Canada and the Congressional Research Service report (Ramseur et al, 2012), (Environment Canada, 2013).** | | | | | | | |

## 10.3 Appendix 3

| ANALYSIS OF DETECTION & MONITORING EQUIPMENT | |
|---|---|
| **Technology** | **Analysis** |
| ***Snare Sampler*** | • Used in M/T Athos 1 incident where Bachaquero Venezuelan crude oil spilled<br>• Approximately 100 snare samplers were deployed to measure the spread of oil<br>• Specifically used to detect oil at various depths in the water column<br>• Produces time-series data<br>• Many were lost due to strong currents, rough seas, and vandalism<br>• Time and labor intensive<br>• No calibration of the efficacy of sampling and how it might change over time (Counterspil Research, 2011; Michel, 2006) |
| ***Vessel-Submerged Oil Recovery System (V-SORS)*** | • Deployed V-SORS in M/T Athos 1 and DBL-152 spills<br>• Difficulties with precise locations<br>• Could detect both pooled and mobile oil moving along bottom<br>• Relatively efficient<br>• Provides spatial data on extent of submerged oil<br>• Can be used in vessel traffic lanes<br>• Good positioning capability with onboard GPS<br>• Time and labor intensive<br>• Susceptible to snagging on bottom<br>• Requires use of white snare, which has to be special ordered (Counterspil Research, 2011; Michel, 2006) |
| ***Side-scan sonar data*** | • Used in DBL-152 and M/T Athos 1<br>• Provided good spatial coverage and visualization of large accumulations and bottom features<br>• Effectiveness diminished as the oil spread and the water became rough<br>• Slow turn around time (days) to validate oil location<br>• Can be used to identify areas of potential accumulation<br>• More successful in detecting the trenches and other bottom features that contained the pooled oil instead of the oil itself (Counterspil Research, 2011; Michel, 2006) |
| ***RoxAnn*** | • Used during DBL-152 with the purpose of differentiating seafloor bottoms<br>• Limited use due to its narrow detection range in relation to the patchiness of submerged oil and the large search size<br>• Less accurate in muddy substrates (Michel, 2006; Counterspil Research, 2011) |
| ***Remotely-operated underwater video*** | • Used in DBL-152<br>• Successfully provided estimates of frequency and size of oil accumulations<br>• Provides a record for review by others<br>• Could not always determine exact position<br>• Effective with visibility exceeding 0.5 meters, but it does not generate a wide view<br>• Small survey swath because of visibility issues (Counterspil Research, 2011) |
| ***Sorbents attached to weights*** | • Ineffective<br>• Weight of the device pushed the oil away, as seen in the M/T Athos spill (Counterspil Research, 2011) |

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| ***Sorbent drops and sediment cores*** | • Results can be used immediately<br>• Low tech solution<br>• Not effective for mobile oil in the water column<br>• Very slow and labor intensive<br>• Rough water conditions restricted vessel operations<br>• Could not safely work in active vessel traffic lanes (Michel, 2006) |
| ***Snare Sentinels*** | • Effective in the DBL-152 spill, but were determined to be too time and labor-intensive for widespread use<br>• High loss rates (Counterspil Research, 2011; Michel, 2006) |
| ***Airborne Hyperspectral fluorescent LiDar*** | • Used in Deepwater Horizon spill<br>• Proved successful in detecting oil suspended in the top few meters below the water surface |
| ***RESON Sonar System*** | • Tested by Coast Guard.<br>• Positively identified 87% of sunken oil targets.<br>• Had a false alarm rate of 24% (Hansen, Fitzpatrick, Herring, & VanHaverbeke, 2009) |
| ***EIC Fluorosensor*** | • Tested by Coast Guard.<br>• Can be attached to ROVS or other platforms<br>• GIS input fluctuated and direct mapping was not possible. (Hansen *et al.*, 2009) |
| ***Side-looking Airborne Radar, UV, & IR*** | • Unable to penetrate water |

## 10.4 Appendix 4

| State | Stated Capacity (Personnel & Equipment |
|---|---|
| ***Illinois*** | • EPA Personnel located in Springfield, Collinsville, and Des Plaines |
| ***Indiana*** | • On Scene coordinators (OSC) in Evansville and South Bend<br>• Six OSC in Indianapolis<br>• Each OSC is supplied with booms and pads<br>• One equipment trailer<br>• One Command trailer<br>• Three zodiac-style boats<br>• One Airboat<br>• Four boats that patrol Lake Michigan<br>• Intra-red equipment |
| ***Michigan*** | • Personnel located in Lansing, Warren, Jackson, Kalamazoo, Grand Rapids, Bay City, Cadillac, Gwinn, Detroit, Gaylord, Newberry, Crystal Falls, and Calumet |
| ***Minnesota*** | • Relies on two major spill response contractors and several smaller contractors<br>• All major contractors have headquarters in Duluth with some response equipment<br>• Duluth Fire Department and Duluth Safety Department of the U.S. Coast Guard also have response equipment |
| ***New York*** | • Maintains approximately 100 Spill Response vehicles located in nine regions |
| ***Ohio*** | • EPA personnel are equipped with testing kits, booms, pads, and other sorbents |
| ***Ontario*** | • Government agencies in Ontario do not maintain equipment to perform spill recovery operations<br>• Largest spill cleanup response organization is ECRC<br>• ECRC will most likely be deployed during a spill in the Great Lakes |
| ***Pennsylvania*** | • Three vehicles dedicated to emergency response<br>• Emergency response members have safety gear and limited containment supplies |
| ***Québec*** | • Specialized equipment<br>• Flammable gas detectors<br>• PHD Ultra mulitgas detectors. |

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| ***Wisconsin*** | • 8 containment booms along Lake Michigan, Lake Superior, and the Mississippi River<br>• Department of Natural Resources has zone contracts with private companies to respond to all types of hazardous material spills<br>• 2 FLIR Units (infrared detection) |

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# Oil Spills in Washington State: *A Historical Analysis*

WASHINGTON STATE DEPARTMENT OF ECOLOGY

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# Department of Ecology
# Spill Management Program

# *Oil Spills in Washington State: A Historical Analysis*

April 1997, Publication #97-252

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**Cover Photo:**
*The tank vessel Mobil Oil grounded on Warrior Rock in the Columbia River on March 20, 1984. Rudder failure from improper maintenance was the cause of the accident. After losing 200,000 gallons of heavy oil, this photo shows how other vessels were used in an attempt to lighten and refloat the tanker.* *Photo by Jon Neel*

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# Introduction

Twenty-two years have elapsed since the Department of Ecology first proposed establishing a comprehensive oil spill prevention and response program in Washington State. The 1975 legislative proposal was prompted after the state suffered major oil spills. Another concern at that time was that the brand new Alyeska pipeline would dramatically increase oil tanker traffic in the Puget Sound. Although the Alaskan pipeline spurred major refining activity in Washington, the proposed environmental protection program never materialized due to lack of funding. Even though no one wanted spills to occur, the full public cost of oil spills was not placed completely on the shoulders of those responsible for transporting oil. The oil spills kept occurring.

It took a series of major oil spills in Washington and Alaska in the late 1980s and early 1990s before Washington's innovative spill prevention and response program was finally put into place by the Legislature. These major spills include:

- The 1985 *ARCO Anchorage* tanker spill in which 239,000 gallons of crude oil was released into marine waters at Port Angeles;
- The 1988 *Nestucca* barge spill which released 231,000 gallons of fuel oil into waters along the coast of Grays Harbor ;
- The disastrous 1989 *Exxon Valdez* spill in Alaska which unleashed 11 million gallons of crude oil into Prince William Sound;
- The 1991 Texaco refinery spill at Anacortes which released 130,000 gallons of crude oil, of which 40,000 gallons went into Fidalgo Bay; and
- The 1991 spill at the U.S. Oil refinery in Tacoma which involved 600,000 gallons of crude oil, most of which was stopped from entering state waters.

How these and other major oil spills accelerated state and federal oil spill prevention, preparedness and response legislation is outlined in **Appendix 2**. This outline shows how the major preventable spills between 1985 and 1992 resulted in innovative legislation which holds potential spillers accountable for preventing and cleaning up spills.

Washington's oil spill prevention and response program has been in place for six years. This report is an examination of the history of oil transportation and the resulting trends in oil spills. This analysis is the first step toward measuring the level of success that industry, government and the public are having on preventing oil spills. This report is also intended to help Washington determine how to best provide the "best achievable protection" from the effects of oil spills while assuring that federal and state programs complement each other.

This report provides partial answers to the following fundamental questions:

- What fundamental forces have shaped state policy regarding oil transportation and spills?
- Has Washington's additional attention to oil spill prevention and response paid off?
- Given Washington's recent increased refinery production, increased pipeline traffic and expanded Pacific Rim trade: How does our state's record of recent spills compare with national and international trends?
- Should the state make any adjustments in its program as a result of these trends?

# Chapter 1: Washington State Energy Policy and Oil Spill Initiatives

Washington's unique physical geography coupled with its abundance and diversity of natural resources has been the driving force behind how the state has provided for its energy needs and how much importance the state has placed on preventing and responding to environmental threats, especially oil spills.

Located at the northwest corner of the continental United States, Washington's rugged mountain terrain and distance from traditional energy sources prompted the state to develop its own energy reservoirs. Since the 1930s, Washington has exploited its hydroelectric resources and these dams have, in many ways, become the region's energy backbone.

The Puget Sound is also the closest national port in the lower 48 states for vessels carrying crude oil out of Valdez, Alaska. For more than 25 years, tankers laden with Alaskan crude oil have brought their precious cargo into Washington. Even though the state produces none of its own oil, Washington has the fifth highest refining capacity of any state in the nation. The waters of Washington State are also one of North America's primary water-borne transportation avenues for Pacific Rim commerce. A visitor to one of Washington's busy ports will see many ships flying flags from Russia, China, Japan, Korea, Malaysia and a variety of other nations.

At the same time, Washington's waters and shorelines contain highly sensitive and valuable natural resources. State marine waters contain critical commercial resources including fishing, crabbing, shrimping and shellfish industries. Washington is also blessed with abundant and diverse fish and wildlife resources which are a driving force in state tourism and provide recreational opportunities for residents. The seabird colonies along Washington's outer coast are among the largest in the United States. In addition, 29 species of marine mammals — including whales, dolphins, seals, seal lions and sea otters — breed in or migrate through the state. The Olympic Coast is the least disturbed major section of coastline in the continental lower 48 states and, according to the Office of Marine Safety and U.S. Coast Guard, it is also the area in Washington that is at greatest risk of experiencing a major vessel oil spill.

Given the importance of preventing spills, this report explores the important connection between historical oil spill information and spill trends, and identifies general areas where non-regulatory approaches for spill prevention might be viable. Effective spill prevention can best be attained through the right mix of regulatory and voluntary compliance initiatives. As state regulatory programs have matured, Ecology has been shifting its focus to educational initiatives. The information on spill trends in this report is part of this effort.

Measuring the effectiveness of state spill prevention endeavors is very complex. Most experts agree that while human factors of one type or another underlie most incidents, spills occur from a wide variety of specific sources and causes. Specific technological or procedural changes must be developed and implemented to eliminate or minimize the occurrence of these incidents. If we are to continue making good progress in preventing spills, it is imperative that we gather better information on actual spills to understand these incidents. This report is also an effort to obtain and disseminate this information.

## State Oil Spill Policy: A Historical Overview

Prior to the mid-1940s, most Washington communities discharged raw sewage into state water bodies, most industrial wastes went untreated and small oil spills were accepted as part of doing business. As a result of continued population growth, state harbors, rivers, lakes and streams quickly became polluted. In March 1945, the Legislature established the Pollution Control Commission. In order to give the commission real authority, lawmakers also passed legislation prohibiting the pollution of any waters of the state and established specific penalties for violations.

In 1955, the Legislature passed a new law which required that any "commercial or industrial operation of any type which results in the disposal of solid or liquid waste material into the waters of the state shall procure a permit" from the Pollution Control Commission. This state act preceded the federal Water Pollution Control Act by 10 years. In several instances, Washington State environmental laws have been models for federal pollution laws.

**Growth of Washington Oil Industry**

Prior to 1950, there were no refineries and very little crude oil was transported into Puget Sound. In 1953, the Trans-Mountain Pipeline Company and Mobil Oil announced their plan to construct an oil pipeline from British Columbia into Washington. A year later, the state received its first delivery of Canadian crude oil. Most of Washington's refineries were constructed in the 1950s, including:

- 1954 — Mobil Oil refinery, Ferndale (now owned by Tosco);
- 1955 — Shell Oil refinery, Anacortes;
- 1957 — US Oil refinery, Tacoma; and
- 1958 — Texaco refinery, Anacortes.

In 1958, a high tariff imposed by Canada on the Trans-Mountain Pipeline resulted in a 12-18 month embargo on oil imports from British Columbia. This and other events led to concerns about the long-term stability of the Canadian supplies. In order to improve the oil transportation system, the Olympic Pipe Line Company built its pipeline in 1966 and began delivering petroleum products from the refineries in the north part of the state to consumers in Seattle, Tacoma and Olympia in Washington, and to Portland and Eugene in Oregon.

**Developments Related to Alaskan Oil**

In 1968 and 1969, the Alaska North Slope oil fields were discovered at Prudhoe Bay. In anticipation of the movement of Alaskan oil into Washington and other pressing environmental concerns, the Legislature passed a series of environmental and spill-related laws.

In 1970, the Washington State Legislature established the Department of Ecology, followed quickly by the passage of the 1971 Washington Oil Pollution Act which:

- Established unlimited liability for oil spills;
- Provided for state cleanup capability; and
- Specifically clarified that the discharge of any oil into state waters was illegal.

That same year, Governor Dan Evans requested an oil risk analysis report concerning the transportation of oil into Puget Sound. Also in 1971, ARCO built its Cherry Point refinery near Ferndale. This move put state production of petroleum products well ahead of in-state consumption. It also greatly increased tanker traffic into Puget Sound.

Construction of the Trans Alaska Pipeline System (TAPS) began in 1973 after the U.S. Congress passed the Trans Alaska Pipeline Act. However, in October 1973 the Organizations of Petroleum Exporting Countries (OPEC) placed an embargo on oil exports to the United States. The resulting shortage placed additional national attention and reliance on Alaskan North Slope oil.

In Washington, one of the results of the embargo was that in 1975 the Northern Tier Pipeline Company proposed constructing a major oil pipeline originating in Cherry Point near Ferndale and terminating in Minnesota. In January 1976, Northern Tier changed its proposed point of origin from Cherry Point to Port Angeles.

Also in 1975, the Legislature passed the Washington Tanker Safety Act which prohibited tankers exceeding 125,000 dead weight tons from entering Puget Sound, and required tug escorts and pilots for certain other tankers. In 1978, the U.S. Supreme Court invalidated this "supertanker" ban in the case of *ARCO vs. Governor Ray*. The court found that federal law pre-empted Washington from banning large tankers, but affirmed the right of the state to establish tug escort and other requirements. U.S. Senator Warren Magnison later re-established supertanker limits through federal legislation.

In the 1970s, the Department of Ecology completed a number of shoreline sensitivity studies focused on the San Juan Islands in anticipation of the influx of Alaskan oil. The studies were undertaken in order to establish a "baseline" so that any environmental changes precipitated by a major oil spill could be more readily quantified. In both 1972 and 1975, Ecology proposed creating a state spill prevention and response program but could not secure funding from the Legislature for the effort. It took a series of major spills in the late 1980s and early 1990s to provide the impetus to establish and fund a state comprehensive spill prevention, preparedness and response program (see **Appendix 2**).

In June 1976, a federal Coastal Zone Management law placed a partial prohibition on the expansion of existing oil terminals. However, this provision may be superseded by other federal laws. That same year, Washington also established the Energy Facility Site Evaluation Council (EFSEC) whose mission was to oversee the siting and permitting of energy facilities such as pipelines, refineries and nuclear power plants. The council held extensive hearings on the Northern Tier Pipeline proposal. The pipeline project was not approved.

**Recent Developments**

During the late 1970s, EFSEC certified the siting and construction of five Washington Public Power Supply System (WPPSS) nuclear power plants. Three developments — the subsequent demise of four of these five plants, the WPPSS bond default and the shut down of the federal "N" reactor at the Hanford Nuclear Reservation — assured the state's continued reliance on hydropower and fossil fuel resources, including oil and coal for use in the Centralia power plant.

In 1990, the Trans Mountain Pipeline Company proposed constructing an oil terminal at Low Point east of Port Angeles on the Olympic Peninsula. The proposal included two single-point mooring buoys, a tank farm at Low Point, and a pipeline which would be located under Puget Sound and connect the Low Point facility with refineries located at Anacortes and Ferndale. The project would have eliminated most tanker traffic coming into Puget Sound beyond Port Angeles, but was eventually withdrawn as a result of public environmental concerns and lack of support from the oil industry.

Even with the state's relative isolation from continental U.S. energy supplies, its oil markets are not immune to the market effects of Mideast oil supply volatility as seen during the 1973 OPEC embargo. On Dec. 11, 1996, the United Nations again allowed the sale of Iraqi oil on the international market as a result of humanitarian pressures. This action is expected to lower the consumer price of refined petroleum products throughout the United States.

## Current Regulatory Framework

Ecology has been involved in preventing and responding to spills since the agency was formed in 1971. The agency's spill response capability prior to 1989 consisted of a team of employee volunteers in each of the four regional offices whose main area of expertise lay in other program areas. There was little centralized management of spill activities. As a result of the drawbacks associated with this decentralized response system and the identification of additional funding, Ecology centralized the spill organization in 1990.

These changes and the legislation which passed from 1989 to 1992, resulted in the state spill program which continues to evolve to this day with centralized management systems and regional service delivery. Ecology is now responsible for:

- Preventing spills at oil handling facilities;
- Managing the state's preparedness efforts;
- Responding to oil and hazardous material spills statewide; and
- Coordinating state natural resource damage assessment activities.

The U.S. Congress passed the Oil Pollution Act in 1990 (OPA 90). This statute created new national standards for oil spill prevention and response in the wake of the Exxon Valdez spill. Congress delegated responsibility for implementing most of OPA 90's provisions to the Coast Guard, Environmental Protection Agency, Department of Transportation's Office of Pipeline Safety, National Oceanic and Atmospheric Administration and the Minerals Management Service.

The Washington State Office of Marine Safety (OMS) was created in 1991 by the Legislature to provide further assurance that frequency of oil spills would be reduced. OMS is responsible for preventing vessel oil spills through vessel inspections, investigation of marine casualties, enforcement of state maritime standards and by approving vessel spill contingency plans.

**State and Federal Relationships**

Washington's role in the current state-federal framework for regulating the oil industry is complicated because each major federal regulatory agency views the role of the state differently. Some independent legal analysts believe that the U.S. Coast Guard attempts to promote uniformity by establishing "ceilings" for regulatory requirements, while the U.S. Environmental Protection Agency uses federal environmental laws to set "floors" which allow states to set more stringent requirements if they are necessary for regional considerations. Major oil pipelines are regulated by the U.S. Department of Transportation's Office of Pipeline Safety. This agency generally sets ceilings. However, unlike the EPA and Coast Guard, the Office of Pipeline Safety delegates some of their spill prevention authority to states that have established effective regulatory programs.

Some of these federal agency policy differences concerning state program consistency can be traced to concerns for interstate uniformity regarding transportation systems such as vessels, trucks and airlines. However, these interstate concerns may not be valid when states establish regional standards for fixed facilities and do not impede interstate commerce. Questions remain regarding EPA and the Coast Guard delegation of programs to states and why fixed interstate pipelines should not be subject to state spill prevention standards if interstate commerce is not impeded. These issues are particularly relevant when the current congressional view of states rights' seems to be reducing federal regulatory programs in favor of state control. However, at this time federal law does not provide a mechanism for state delegation.

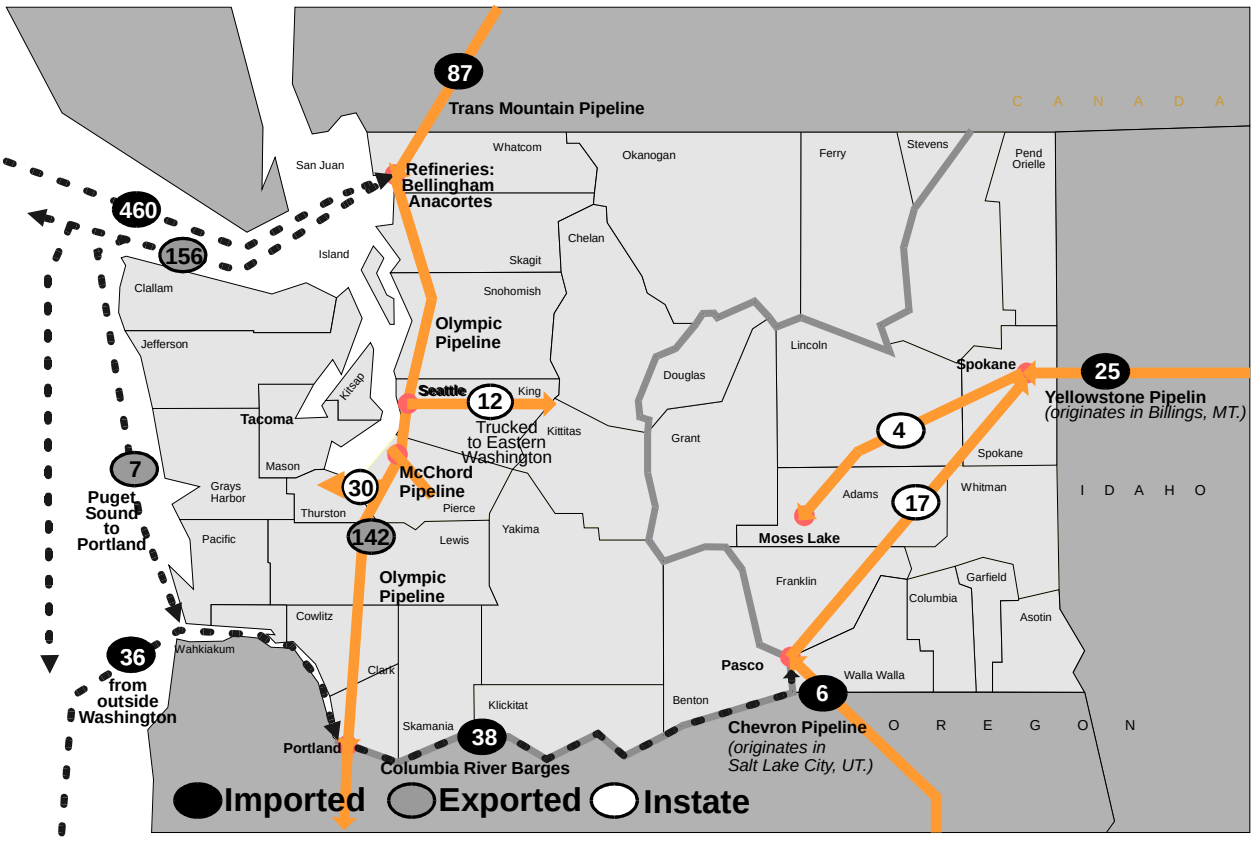
These differences in regulatory approach do not apply to spill preparedness and response. EPA and the Coast Guard have established strong and effective cooperative mechanisms with respect to state co-management of spill responses while minimizing duplication.

## Current Oil Transportation Patterns and Related Spill Risks

As one of North America's major gateways to Pacific Rim trade, Puget Sound is one of the busiest waterways in the world with vessel traffic going to several busy ports in Washington State and to major facilities in Vancouver, British Columbia. More vessel tonnage moves through the Strait of Juan de Fuca than through the combined ports of Los Angeles and Long Beach, California.

Washington is also one of the nation's primary petroleum refining centers. Refined products are exported from Washington to other western states, such as Oregon and California, primarily through pipelines, barges and tankers. There are five major pipelines in Washington: Trans Mountain, Olympic, McChord, Chevron and Yellowstone. The primary transportation routes and quantities of oil transported are shown in **Figure 1**. The map shows the enormous quantities of crude oil and refined products which are transported through our coastal areas, Puget Sound and the Columbia River by tankers and barges.

**Figure 1 — Oil Movement in Washington State** (figures in thousands of barrels a day)




The vessels in-bound to Puget Sound are primarily moving crude oil to Washington's refineries. Large quantities of crude oil also come into our refineries through the Trans Mountain Pipeline. Refined petroleum products are moved to in-state consumers primarily by pipelines and trucks. These transportation corridors constitute the areas at greatest risk of major spills. Significant elements of major spill risk which are not indicated on the map include: cargo and passenger vessels in Pacific Rim trade; large facilities with piping and storage tanks; and rail/tanker truck traffic.

Production in the Alaskan North Slope oil fields has declined over the last few years as the proven reserves are drawn down. However, it is not clear at this time whether this trend will continue, as projected recently by the Oil and Gas Journal, or whether new finds and improved production techniques will stabilize production as believed by some industry analysts. The long-

term effect of changes in Alaskan oil production on Washington refineries remains to be seen. One of the current effects of the reduced North Slope oil supply is that oil importation from Canada through the Trans Mountain Pipeline has dramatically increased in recent years. The Office of Marine Safety data indicates that the number of individual tankers moving oil into Washington waters was:

- 907 in 1993;
- 908 in 1994;
- 723 in 1995; and
- 804 in 1996.

This data includes tank ships bound through Washington waters to Puget Sound ports, the Columbia River, Canadian ports and Grays Harbor.

# Chapter 2: Oil Spill Data Sources

The spill related information in this report is divided into two sections for the purpose of presenting a clear analysis. ***Chapter 3: Major Oil Spills in Washington*** deals with well documented facility, pipeline, vessel and surface transportation spills greater than 10,000 gallons that have occurred since 1970. ***Chapter 4: Recent Trends in Oil Spills*** takes a closer look at all oil spills between 25 and 10,000 gallons that have occurred in the last four years — with the exception of surface transportation (railroad and truck) spills.

Ecology began consistently keeping records of oil spills only after the Legislature provided dedicated funding for the program in 1991. Prior to this time, readily accessible records are incomplete. Fortunately, the agency has institutional memory and information relating to larger spills, particularly those exceeding 10,000 gallons. In preparing this report, a range of sources were reviewed to fill in data gaps. With respect to recent spills (discussed in **Chapter 4**), the information should be accurate given the careful data collection efforts of Ecology's spill and damage assessment team for spills of over 25 gallons reaching surface waters. Spill information is stored in the agency's Environmental Report Tracking System (ERTS) database and a small "stand alone" database for major spills.

Information on specific spills in this report could contain inaccuracies. For example, there is often a tendency by those responsible for a spill to under report the amount of product spilled. No potential systematic errors in the data have been identified other than the possible under reporting of spill volume. Accurate information on the root cause of past spills was also difficult to obtain. Therefore, a smaller data set was used to evaluate spill causes.

Data for land transportation (truck and rail) spills has not been included in the analyses of recent spills because of a lack of complete information about this industry segment. However, land transportation spills do represent a serious threat. Staff from Ecology's regional office located in Yakima have reported that tanker truck accidents have resulted in multi-thousand gallon spills with some regularity over the years. These tanker truck spills pose a significant threat to public health and safety in addition to environmental damage. These inland fuel spills can contaminate drinking water, create dangerous fumes, pose a fire threat and result in fresh water fish kills.

Unless otherwise noted, the figures in this report do not include information on leaking underground storage tanks (LUST) or from spills of animal or vegetable oil.

Ecology intends to use the information contained in this report as environmental quality indicators to help measure the state's success in preventing spills. The information will also help the agency target its facility spill prevention efforts. The agency will continue tracking and reporting spill information and appreciates receiving additional information regarding spill history and trends from all sources.

# Chapter 3: Major Oil Spills in Washington

This section evaluates information on major spills of 10,000 gallons or more which have occurred in Washington since 1970.

## Distribution of Major Spills

The historical trends in the annual volume of oil spilled each year from major incidents are a key indicator of the state's success in preventing major spills. According to the *Oil Spill Intelligence Report*, the annual average volume of oil spilled worldwide from oil spills greater than 10,000 gallons during the five year period 1987-91 was 53 million gallons (excluding the 1991 Persian Gulf war related causalities). However, the annual average volume of oil spilled at major oil spills during the four year period 1992-95 was 75 million gallons worldwide — a 41 percent increase.

The "1995 International Oil Spill Statistics" compiled by the *Oil Spill Intelligence Report* concluded that despite the considerable efforts to reduce spills, a downward trend in the number of large spill incidents worldwide "is probably not occurring."

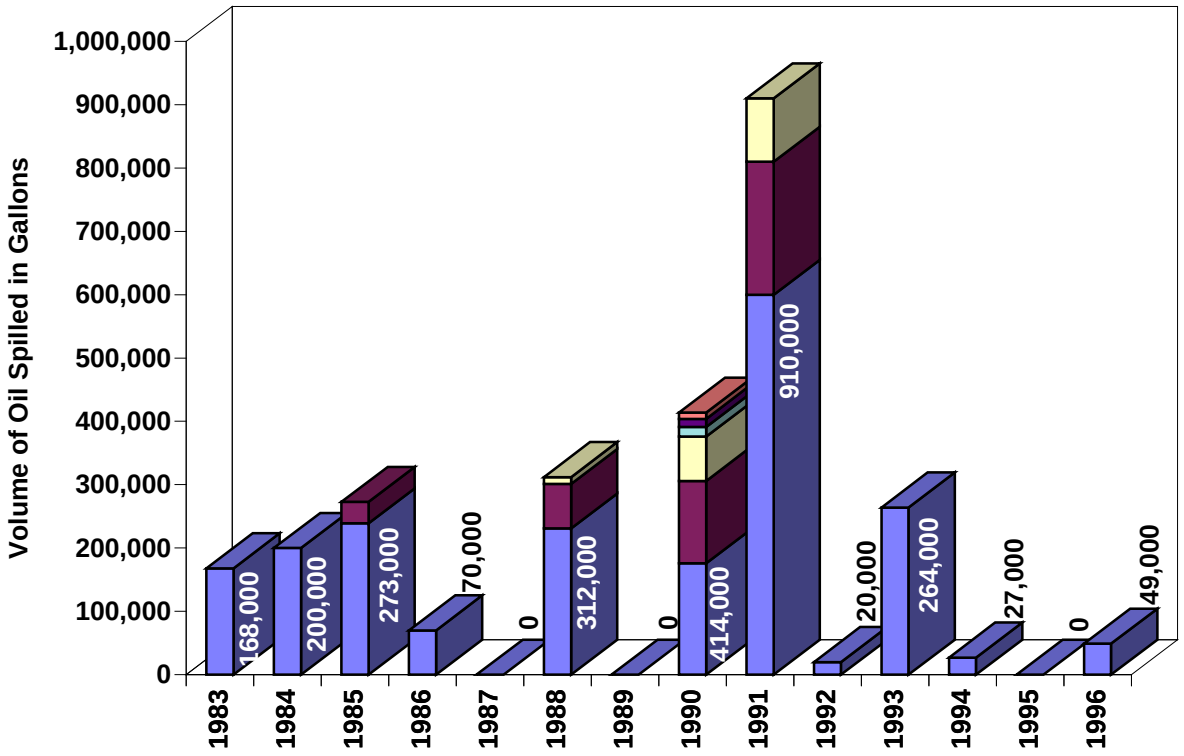
The data in **Figure 2** displays the annual amount of oil spilled in Washington State from spills larger than 10,000 gallons. As seen in this figure, the amount of oil spilled per year as a result of major incidents appears to be declining in Washington during the last five years. Although there is not enough data to evaluate the trends statistically, it does appear that the volume and incidence of major spills in Washington State may be declining more abruptly than that indicated by national and international trends.

The year Washington passed its major oil legislation (1991), we experienced 3 major spills over 10,000 gallons. During this apparently anomalous year, incidents resulted in the loss of 100,000 gallons from the Tenyo Maru; 600,000 gallons from US Oil and Refining; and 210,000 gallons from Texaco refining.

The annual average volume of oil spilled in Washington State from petroleum oil spills greater than 10,000 gallons during 1987-91 was 327,000 gallons. The volume of oil spilled during the five-year period from January 1992 through June 1996 was 72,000 gallons — a 78 percent reduction. Both Ecology and the state Office of Marine Safety's spill prevention and response efforts were fully funded and staffed by June 1992. However, one should be cautious when interpreting the significance of these trends in relation to the effectiveness of the state's program given:

- The highly variable nature of the data (especially spills during 1991);
- The fact that spill incidents have a higher probability of being reported in more recent years;
- The fact that spill volumes are more accurately reported now; and
- The regulatory programs of the Coast Guard and EPA under the federal Oil Pollution Act of 1990, while not visibly affecting national trends may have had a regional effect.

**Figure 2 — Major Oil Spills in Washington State Over 10,000 Gallons: Volume of Spills Per Year in Gallons**




The cause and effect of such broad trends cannot easily be determined in a complex milieu such as spill prevention. Factors which weigh heavily in determining outcomes include human considerations such as legal liability, criminal liability and corporate philosophy. Non-human considerations include weather patterns, environment and sea conditions. Furthermore, a single catastrophic spill such as the *Exxon Valdez* can significantly skew the data.

However, with these limitations in mind, Ecology attributes this apparent decline in the volume of oil spilled in Washington from major incidents to a broad effort by industry, the public sector and public interest groups to prevent these incidents. In addition to the efforts by state agencies:

- The major oil refineries and marine terminals have enhanced corporate policies, developed more effective spill prevention and response plans, improved personnel training and dedicated more resources to equipment maintenance among other initiatives;
- Oil tanker and regional tank barge operators have invested heavily in clean-up equipment and personnel improvements — including procedures, training, crew rotation and spill response equipment;
- The domestic cargo vessel industry has placed a much higher priority on spill prevention than in the past;
- The Coast Guard has enhanced the vessel traffic system;
- In the Northwest, the Coast Guard and EPA have been very active in implementing the federal Oil Pollution Act of 1990; and
- The efforts by local government, tribes and environmental groups have been particularly important in keeping private and public sector stakeholders focused on effective prevention measures.

While this data relates to volume, it does appear to be consistent with trends identified in national spill statistics by American Petroleum Institute (API). API concluded that during the decade ending in 1994, the *frequency* of large spills declined by 57 percent.

## Source of Major Spills

**Figures 3** and **4** display the number of vessel, facility and transmission pipeline spills in the database. As previously mentioned, data on spills from surface transportation modes, such as rail and truck, has not been consistently collected and therefore was not included in the statistics.

**Figure 3 — Major Oil Spills Over 10,000 Gallons: Number of Spills by Source**

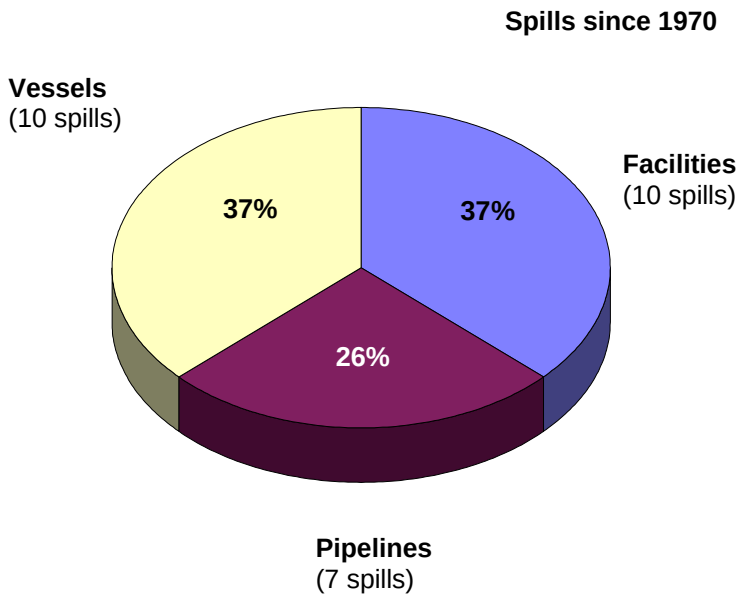
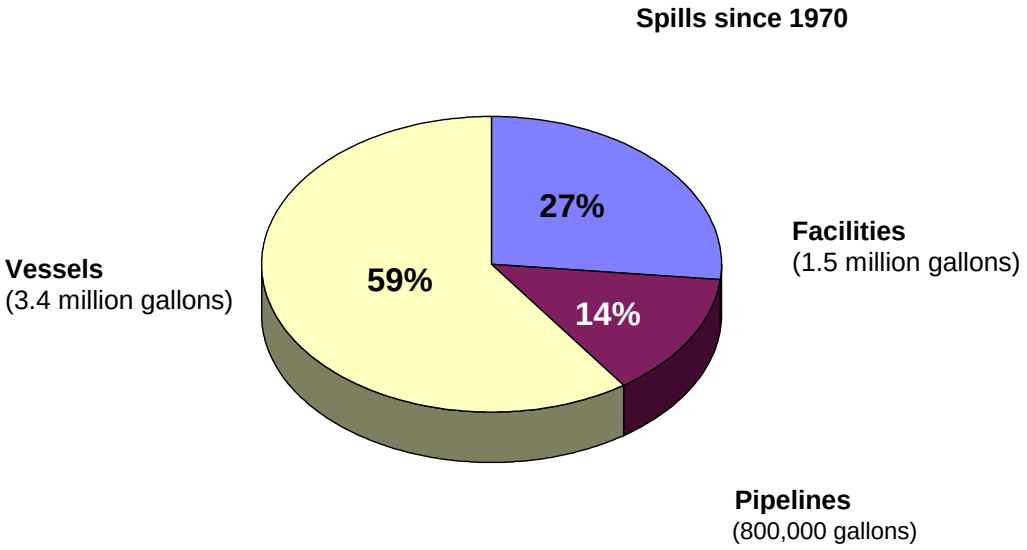


**Figure 4** shows the volume of oil spilled from the marine industry (3.4 million gallons) is larger than that spilled by facilities and pipelines (2.3 million gallons). The two figures combined indicate that the size of major vessel spills exceeds that of facility and pipelines. This data is heavily influenced by several large volume marine accidents which have occurred on the coast and in the Strait of Juan de Fuca.

The data indicates that major pipeline spills are generally smaller than major vessel or major facility spills. However, as discussed later in this report, there has been a recent series of major pipeline spills.

The American Petroleum Institute has concluded that "large spills of 10,000 gallons or more accounted for nearly 90 percent of the total oil spilled during the last decade." State data appears to support this conclusion.

**Figure 4 — Major Oil Spills Over 10,000 Gallons: Total Volume of Oil Spilled by Source**



## Types of Oil Spilled

**Figures 5** and **6** display information on the number and volume of oil spilled by product type. The figures show that heavy fuel and crude oils, which are the most environmentally damaging types, are the largest amount of oil spilled in the state. These viscous "black" oils have a tendency to smother animals such as birds and mammals, often killing them. These oils are also highly persistent and create residues which are resistant to natural physical and biological degradation processes.

**Figure 5 — Major Oil Spills Over 10,000 Gallons: Number of Spills by Type**

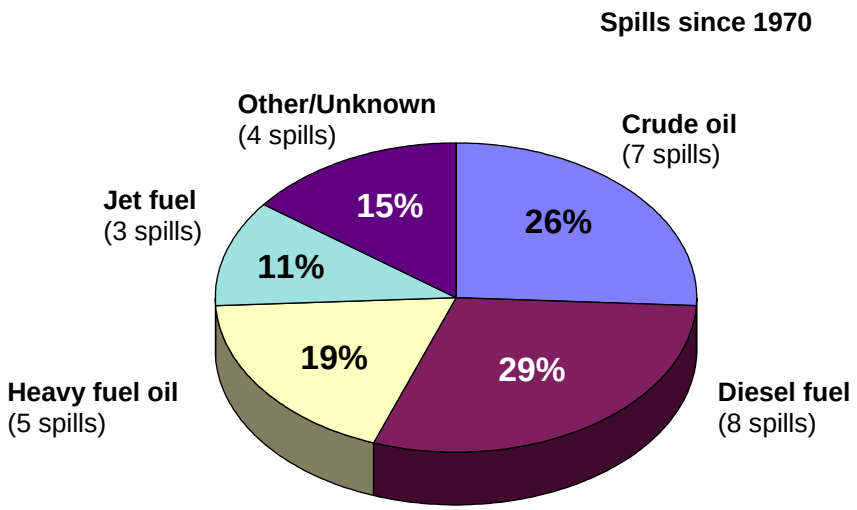
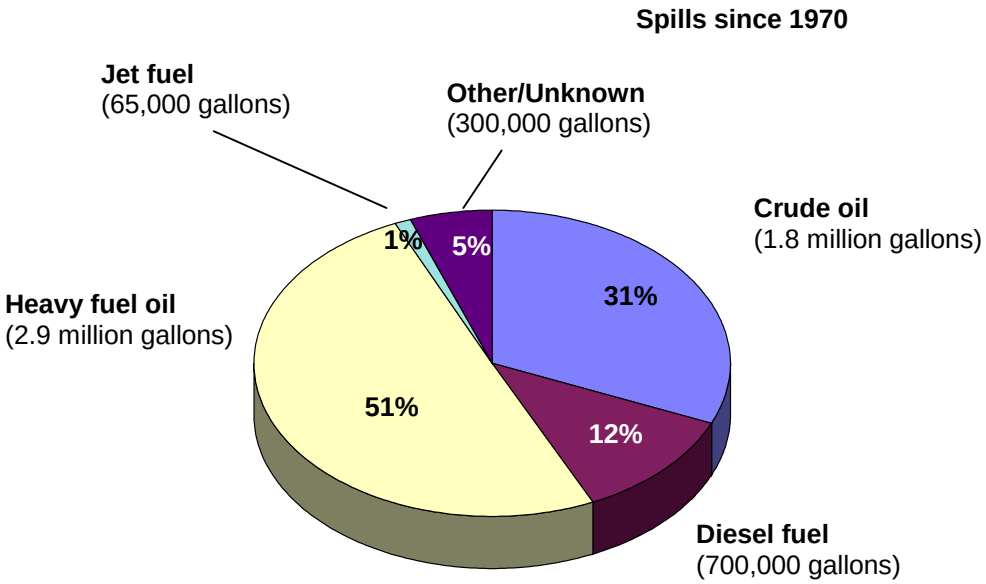


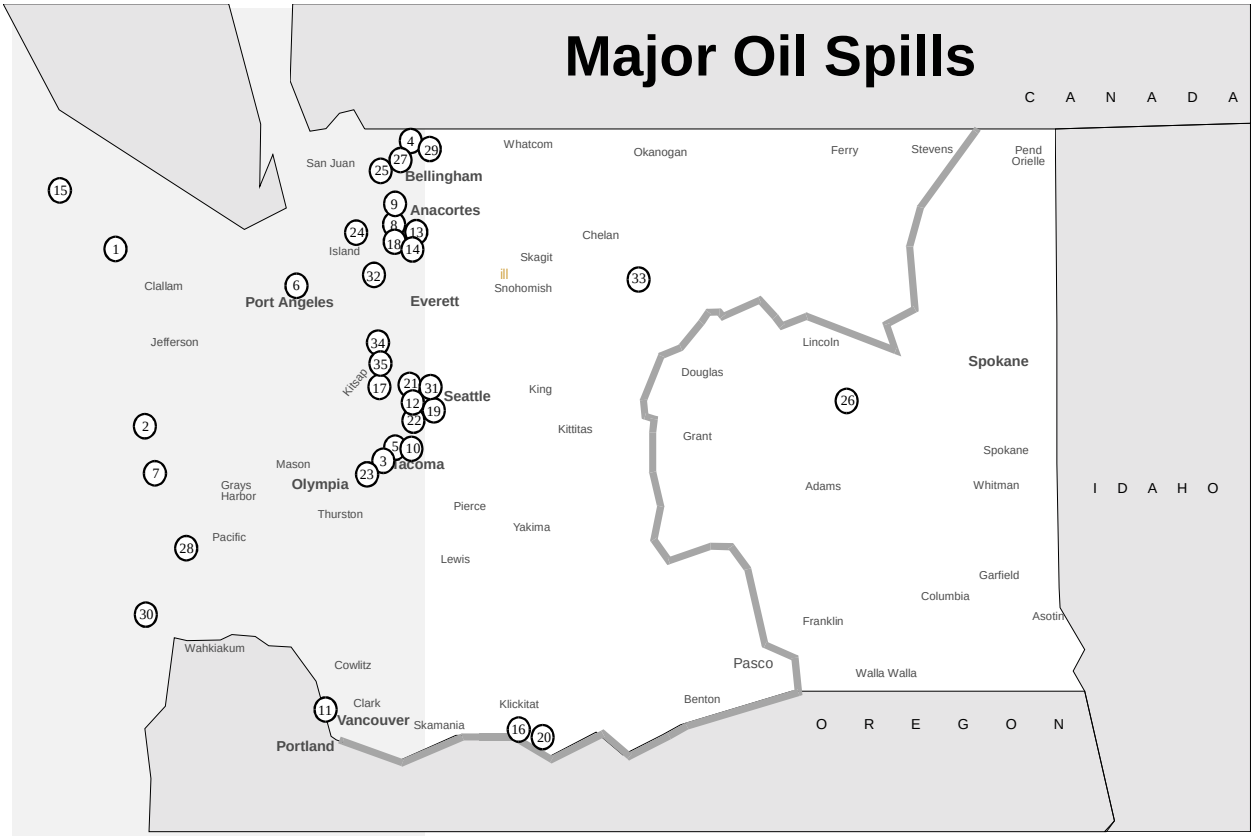

**Figure 6 — Major Oil Spills Over 10,000 Gallons: Volume of Oil Spilled by Type**



## Geographical Distribution

**Figure 7** is a map of the state showing the locations of the major spills, and includes additional spills not analyzed in **Figures 2-10**. The additional spills are noted in **Appendix 4**. The map shows a clustering of large spills in Puget Sound and dispersed along the coast and Strait. **Appendix 4** provides a detailed list of these spills.

**Figure 7: Location of Major Oil Spills Over 10,000 gallons**



**Figures 8** and **9** show the distribution of the number and volume of major oil spills in Ecology's four regional offices. A map depicting the jurisdictional boundaries of each regional office is found in **Appendix 5**. More oil was lost from major spills in the agency's southwest regional office than the three other regions combined. This is likely due to this region's long marine shoreline which encompasses all of the state's Pacific coast line, the Strait of Juan de Fuca and much of Puget Sound.

**Figure 8 — Major Oil Spills Over 10,000 Gallons: Number of Spills by Regional Office**

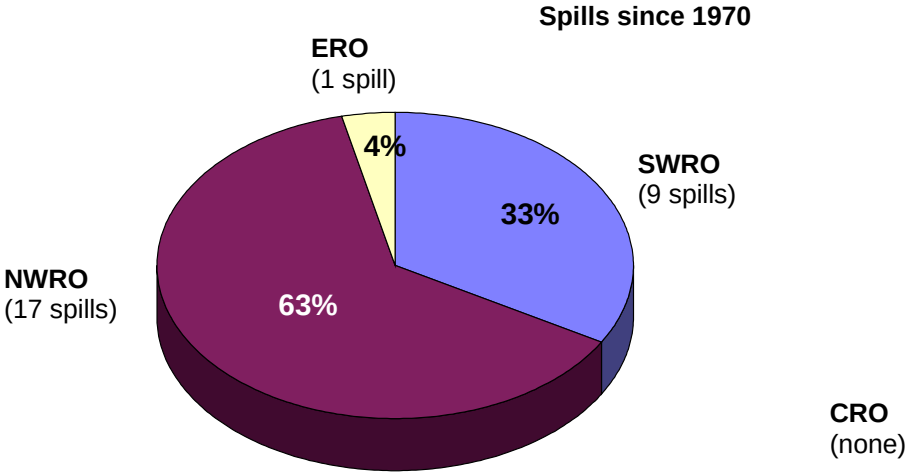
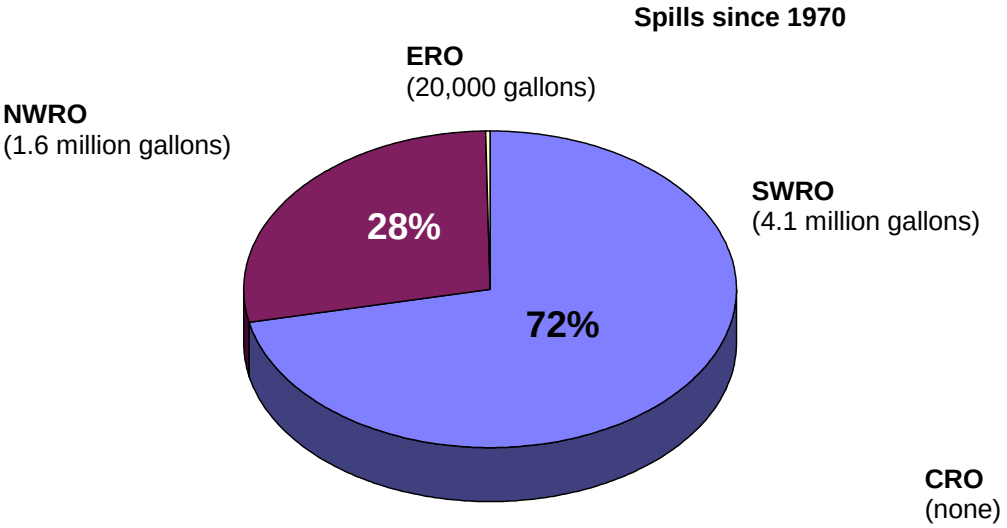



**Figure 9 — Major Oil Spills Over 10,000 Gallons: Volume of Spills by Regional Office**

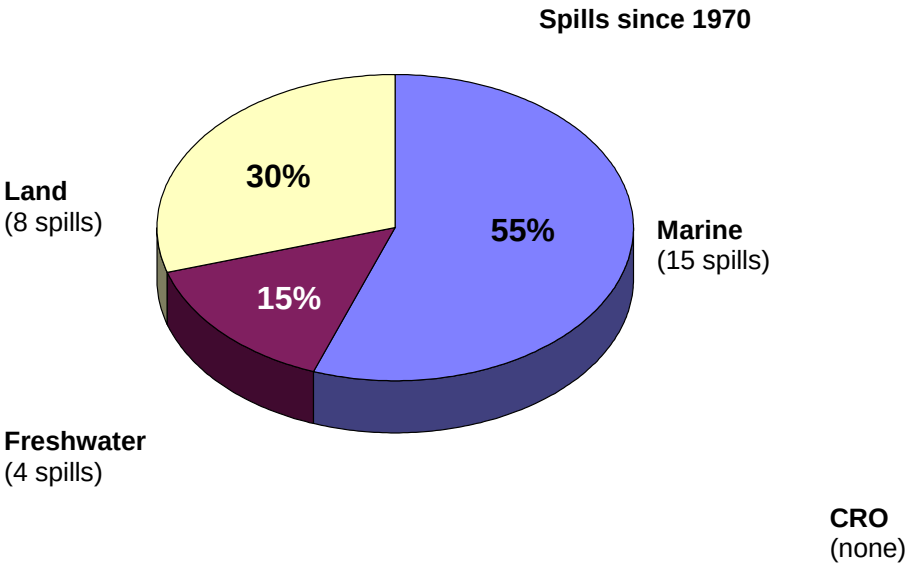


While the largest spills occurred in the SWRO, the northwest regional office (NWRO) actually received more spills greater than 10,000 gallons. This is due to the large population and activity levels centered in Seattle, Bremerton and, to a lesser extent, the northern refineries.

The data probably under represents the volume and number of spills in the Central (CRO) and Eastern (ERO) regions because surface transportation incidents were not included in the analysis. CRO has reported the greatest number of multi-thousand gallon petroleum product spills from tanker truck rollovers. Winter mountain pass conditions undoubtedly contribute to the number of truck accidents.

**Figure 10** shows the distribution of spills by receiving environment. Slightly over half of the spills effected the marine environment. In 45 percent of the major spills, impacts were primarily limited to freshwater habits and the land. While land spills often have a lower degree of impact on the environment they can have serious consequences upon public health if they affect drinking water wells, and to public safety if gasoline fills buildings with explosive and/or toxic vapors.

**Figure 10 — Major Oil Spills Over 10,000 Gallons: Number of Spills by Impacted Medium**



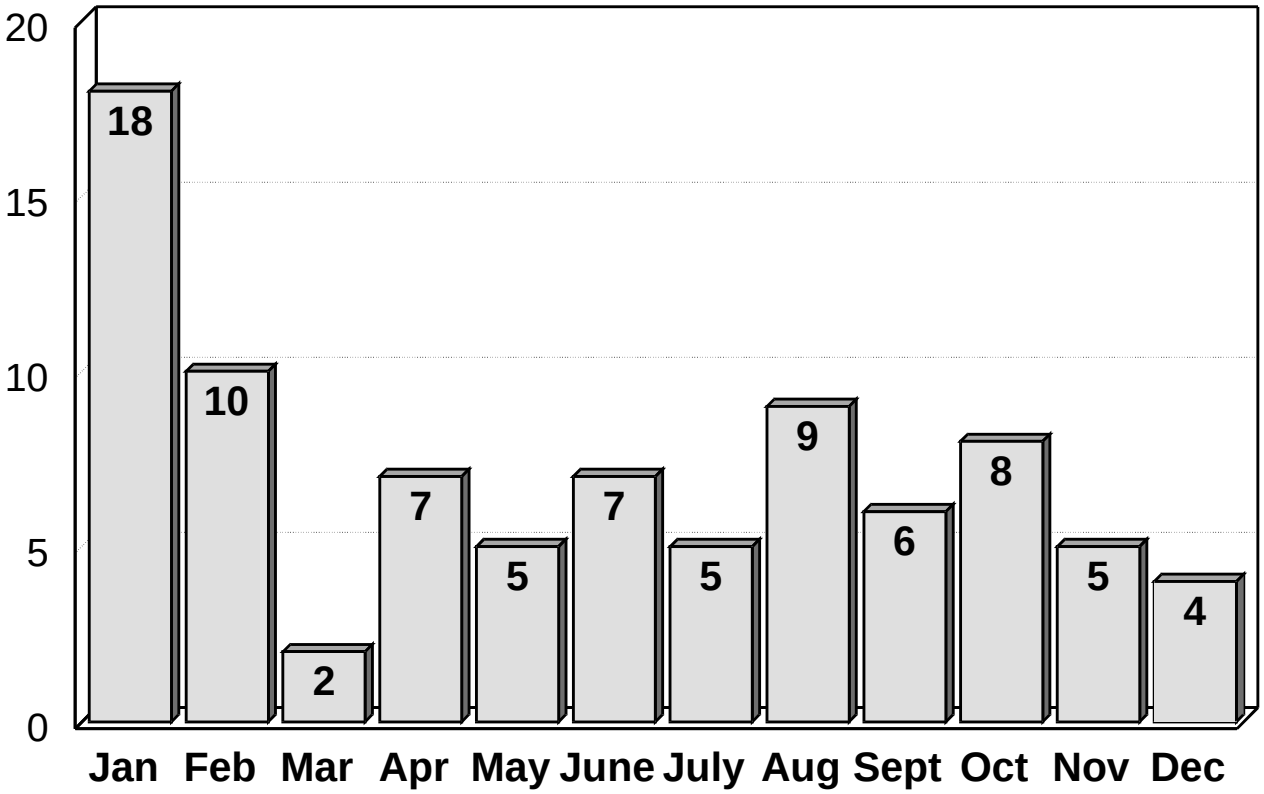
# Chapter 4: Recent Trends in Oil Spills

This section evaluates information on spills between 25 and 10,000 gallons which have occurred between June 30, 1992, and July 1, 1996. The spills included in this data set include 86 vessel and facility spills and six pipeline spills where at least 25 gallons of oil reached water or at least 250 gallons was spilled on land. Truck and train transportation incidents are not included in this data.

## Distribution of Recent Spills

**Figure 11** compresses the most recent four years of facility and vessel spill data into a single 12 month bar chart. While we must be careful in not over interpreting the graph given the relatively few data points in each month, it does appear that spill frequency peaks during January. This phenomena has been observed by others and may be explained by probability of human error increasing during cold, dark climatic conditions and the holiday season.

**Figure 11 — Distribution of Oil Spills Over Time: Number of Vessel and Facility Spills by Month**
(pipelines not included)



## Source of Recent Spills

As shown in **Figures 12** and **13**, our information indicates that for these medium sized spills, the number of vessel incidents is significantly larger than the number of facility and pipeline incidents combined. The volume of oil spilled from the marine industry is also large compared with facilities and pipelines.

**Figure 12 — Recent Spills 25 to 10,000 Gallons: Number of Oil Spills by Source**

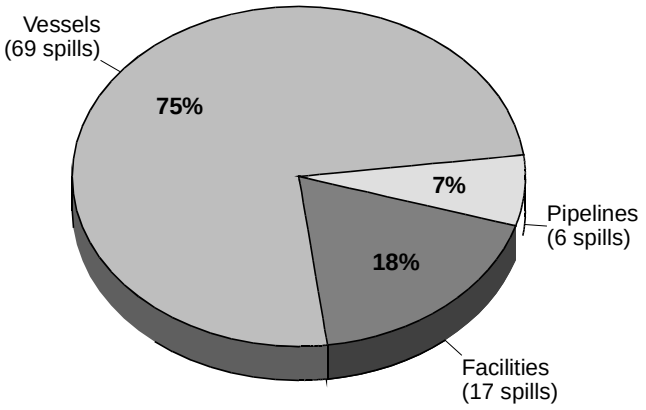
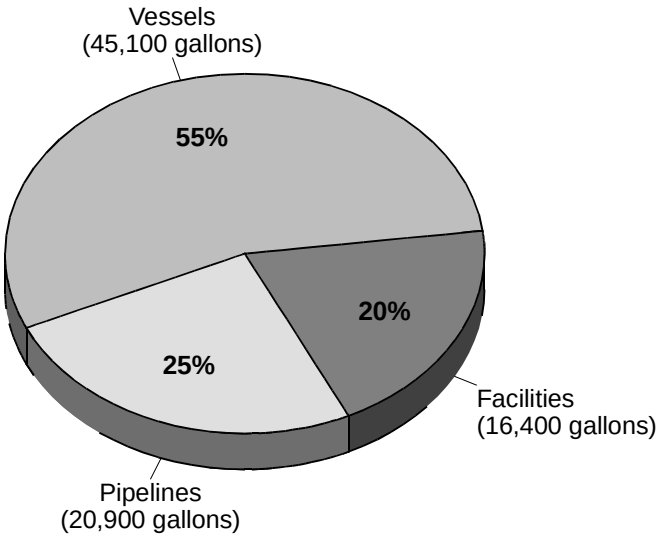



**Figure 13 — Recent Spills 25 to 10,000 Gallons: Volume of Oil Spilled by Source**




Overall, there are a relatively large number of medium sized vessel diesel fuel spills. However, another observation is that pipeline spills tend to be larger than vessel or facility spills (see **Figure 13**) for this data set. While pipelines account for only seven percent of the spill incidents, they resulted in 25 percent of the volume of spilled oil.

## Types of Oil Spilled

**Figures 14** and **15** describe the number and volume of oil spills by product type. In contrast to the major spills which were dominated by heavy fuels and crude oil, diesel spills dominate the number and volume of recent medium-sized spills. In this data set, crude oil spills are relatively infrequent while heavy fuel oil spills contributed to the total volume of spilled oil. In general the heavy fuel oil spills were larger than other incidents. This is due to the occurrence of relatively large vessel bunkering spills. Had rail and truck incidents also been included, they would have further increased the number and volume of diesel and gasoline spills.

**Figure 14 — Recent Spills 25 to 10,000 Gallons: Number of Spills by Oil Type**

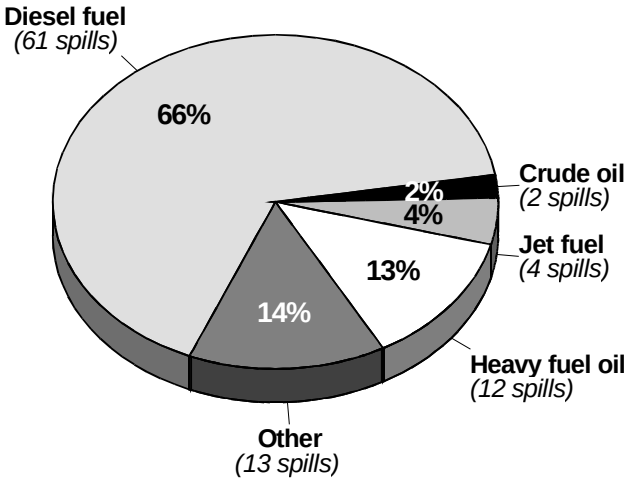
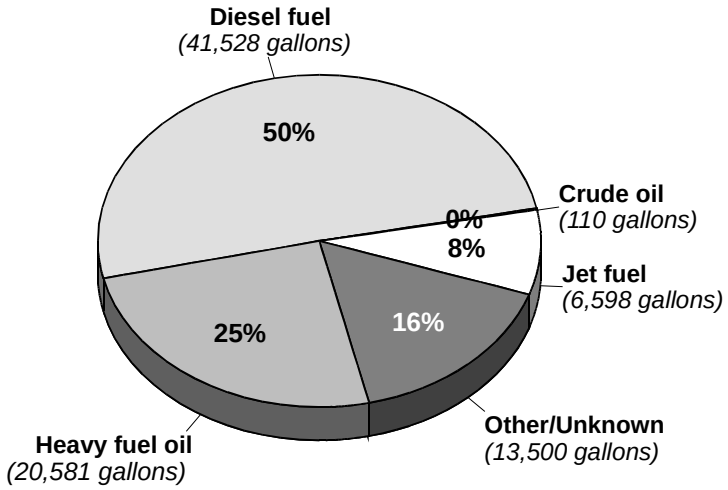


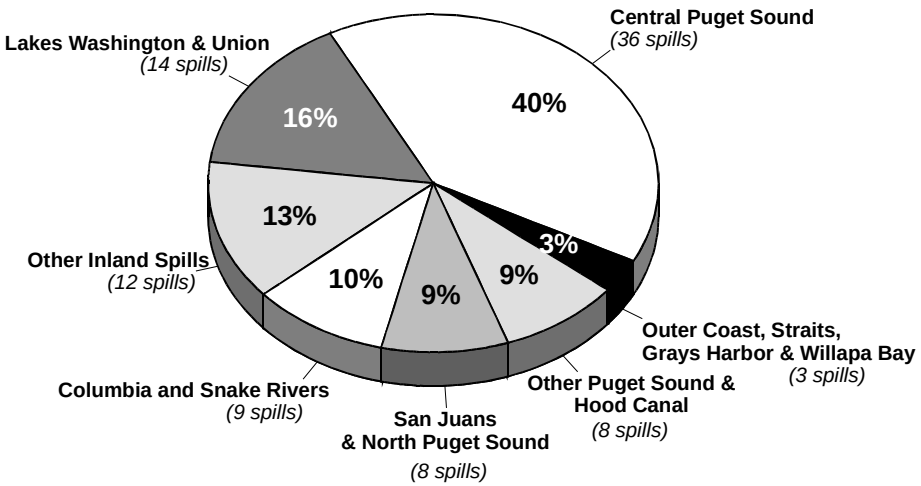

**Figure 15 — Recent Spills 25 to 10,000 Gallons: Volume of Spills by Oil Type**



## Geographical Distribution

**Figure 16** shows the distribution of spills among the Northwest Area Committee's Geographic Response Plans (GRP). More than half of the spills (50) occurred in the Central Puget Sound GRP and in Lakes Washington and Union. This area includes the state's largest population center, the Seattle/Tacoma metropolitan area. Other areas experiencing large numbers of spills included the San Juan Island/North Puget Sound area and the Columbia River.

**Figure 16— Recent Spills 25 to 10,000 Gallons: Spill Distribution by GRP**




**Figures 17** and **18** show the distribution of spills among Ecology's regional offices. The northwest regional office (NWRO) experienced more spills than any other region. However, the amount of oil spilled in the southwest region (SWRO) was approximately equal to that of the more populated northerly region. Interestingly, over both spill size distributions discussed in this report (spills greater than 10,000 gallons discussed in **Chapter 3** and the data in this chapter), spills in SWRO were larger than NWRO. This data again probably under represents the volume and number of spills in the central and eastern regions because surface transportation incidents (rail and truck) were not included in the analysis.

**Figure 17 — Recent Spills 25 to 10,000 Gallons: Number of Spills by Ecology Region**

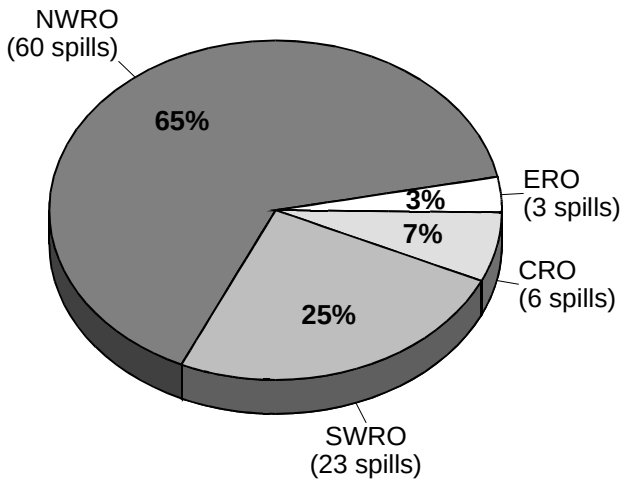
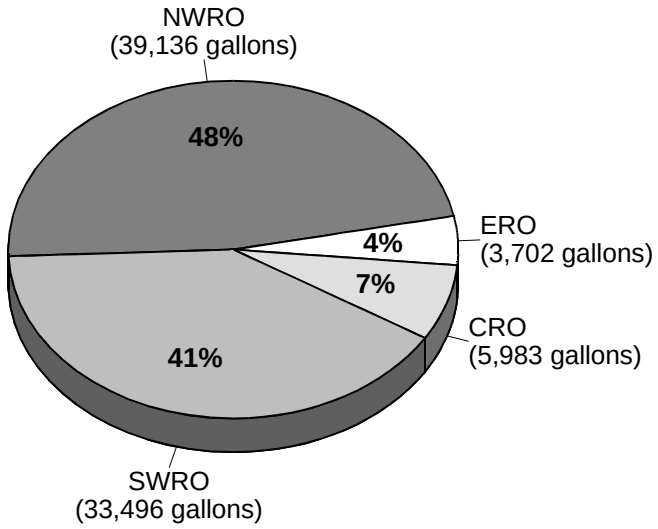



**Figure 18 — Recent Spills 25 to 10,000 Gallons: Volume of Oil Spilled by Ecology Region**



**Figures 19** and **20** show that similar to the major spills discussed earlier in the report, recent medium-sized oil spills have had a significant impact on the marine waters compared with freshwater and land environments. However, primarily as a result of pipeline spills, land spills which represent only nine percent of the spills by number resulted in 29 percent of spills by volume.

**Figure 19 — Recent Spills 25 to 10,000 Gallons: Number of Spills by Impacted Medium**

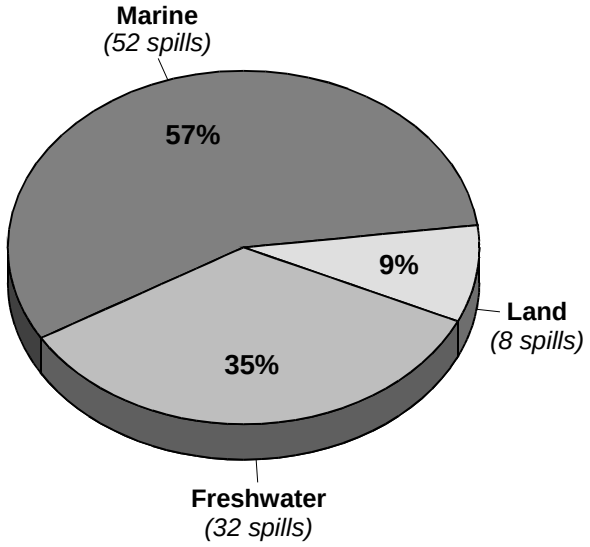
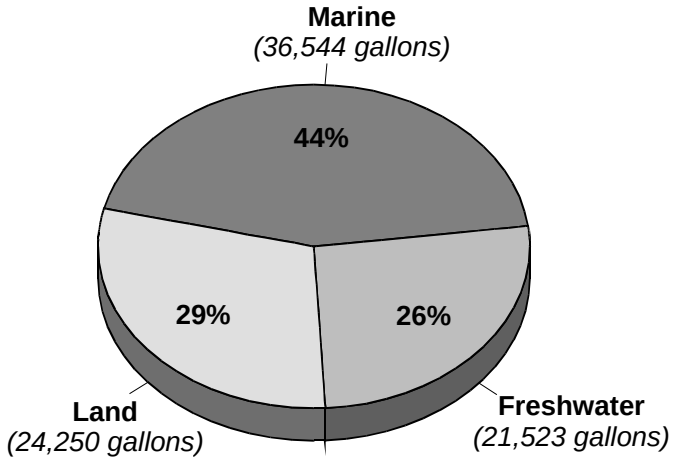



**Figure 20 — Recent Spills 25 to 10,000 Gallons: Volume of Spills by Impacted Medium**



## Comparison with Coast Guard Data

The U.S. Coast Guard maintains a national data base which can be used to evaluate both national and regional trends in oil spills. Spill data from 1991-1995 currently under review by the Coast Guard's District XIII staff in Seattle, seems to confirm the general trends shown in **Figure 13.** This data for the Puget Sound Marine Safety office indicates that 62 percent of the volume of oil spilled came from vessels, 34 percent came from facilities and four percent from another source.

National trends identified by the Coast Guard's "Marine Environmental Protection Performance Indicators" indicates that major and medium sized oil spills may be trending downward. This potential trend appears to be consistent with **Figure 2** of this report. Ecology will continue to work closely with our federal partners to track and report on trends as they emerge.

## Cause of Recent Spills

The analysis and understanding of the causes of major spills is not as simple. There are a myriad of reasons for this, including:

- **Most major spills are difficult to analyze** given that they are often the result of a series of complex factors and conditions coming together at a particular moment in time. The factors may include both failures which are preventable, and conditions which are not within human control. Often a major incident would not have occurred if any one of the factors or conditions had been absent. Therefore, it is often difficult to boil an incident down to a single primary/root cause with identified contributing factors.

- **There is a lack of a consistent framework** for systematically analyzing and categorizing incidents. This is a problem both nationally and in Washington State.

- **There is lack of consistently collected reliable information** on spill causes. This is partially due to the scarcity of highly trained staff resources in the investigating agencies, the reluctance of industry to fully disclose information for liability reasons and the lack of agency funding to hire independent experts to conduct professional investigations.

- **There is also a reluctance on the part of many investigators** to directly place blame because of liability concerns, sympathy for an individual or organization who has already been affected by an incident, and concern that an employee who may have contributed to an incident may lose their livelihood. The result is that some investigations identify the cause of an incident as equipment failure or a natural event, even when an easily preventable human error (individual or organizational) occurred.

However, there is a consensus that most major spills are caused by some form of human error and are therefore preventable. In order to provide additional insight into the types of human error, this report further distinguishes between individual human factors and management/organizational factors. The terms used in this report are defined as follows:

- **Management/Organization** — The failure of an organization to provide the necessary policies, procedures, equipment, personnel, supervision, training or time to safely design and operate a system which could potentially cause a spill. In order to prevent spills, an organization may be expected to go beyond currently accepted industry practices.

- **Human Factor** — The diminished ability (over which the organization has relatively little control) of an individual to safely complete a task. Examples include poor communication, drugs/alcohol, improper equipment use, inaccurate computation, inattention, procedural error, complacency, not following training procedures, fatigue, illness or sabotage/intentional.

- **Equipment** — A mechanical, structural or electrical failure not attributable to a human error-related design, material specification, manufacture/construction, installation, operation or maintenance deficiency. An example which would not qualify for this category as an "equipment failure" would be a failure from normal wear and tear as a result of lack of maintenance. This would be either a management/organization or human factor caused spill.

- **External** — Natural phenomenon such as earthquakes, floods, storms, tsunami, fog, ice, lightning, tidal conditions, sea state and landslides which occur with a magnitude outside of reasonably anticipated design or operating limits. An example of an external cause could be any act caused by Mother Nature.

For the reasons stated earlier, Ecology's data on spill cause is somewhat limited. Ecology is working to improve the systems for collecting, analyzing and maintaining spill cause data. Current initiatives include the development of an investigator training curriculum, hiring independent experts on major spills and the States/BC Oil Spill Task Force's project to provide a consistent methodology for collecting and sharing spill data on the entire West Coast.

**Figures 21** and **22** show the distribution of spill causes for 41 recent spills in Washington (Note: incident cause was not identified in 51 of the other spills analyzed in this section). Based on the limited information available to Ecology, it appears that "human error" at the levels of the organization and individual predominate. Of the four cause definitions, organizational failure is the primary cause of recent spills in terms of both number of incidents and total volume of oil spilled. Human factors are the second most predominant cause of these spills.

The conclusion that human error is the primary cause of most spills is supported by findings by the Washington State Office of Marine Safety, the California Lands Commission, the U.S. Coast Guard, the Alaska Department of Environmental Conservation and most industry analysts. The definitions used in this report are identical with those being developed by the States/British Columbia Task Force for the purpose of consistently collecting cause data in the future on the West Coast.

**Figure 21 — Recent Spills 25 to 10,000 Gallons: Number of Spills by Cause**

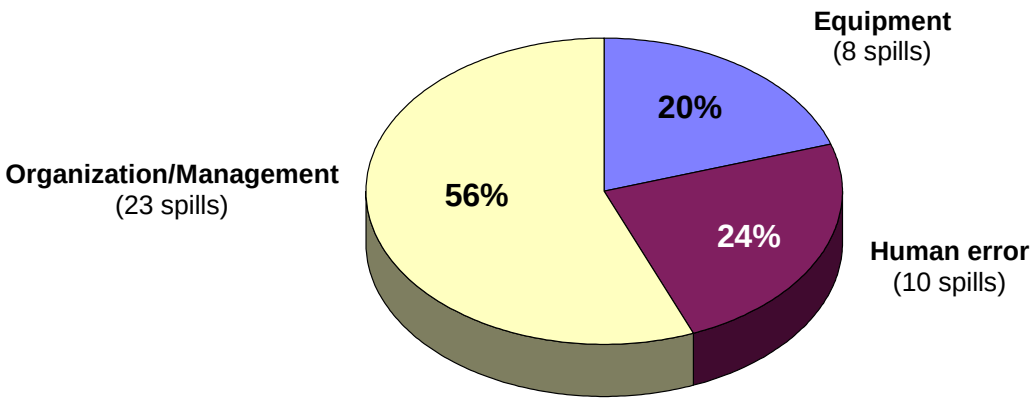
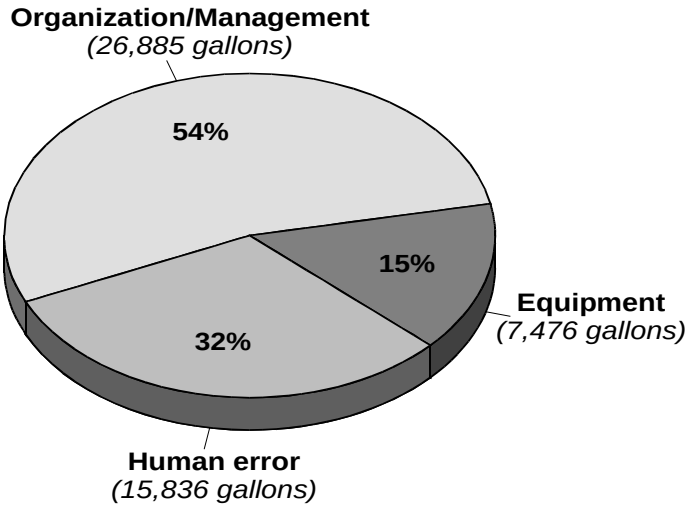



**Figure 22 — Recent Spills 25 to 10,000 Gallons: Volume of Oil Spilled by Cause**



# Chapter 5: Near Miss Incidents

This report's **Appendix 1: Significant Vessel Casualties and Near Miss Incidents** is a list of important vessel-related incidents where there was either a major system failure or actual external damage to a vessel that occurred between 1984-96. Those incidents which did not result in the release of oil are considered to be close calls. When they are properly investigated, as much can be learned about spill prevention from these incidents as from actual spills. The state Office of Marine Safety (OMS) is currently working with other stakeholders to put a system in place which would collect information on more of these vessel incidents.

If these collisions, groundings, allisions (collision with a fixed object) and losses of power were plotted on the map outlining Washington's major oil spills **(Figure 7)**, they would largely parallel the locations where major spills have actually occurred.

Given the difficulty in agreeing on what constitutes a "near miss," the lack of incentives for reporting these incidents and the liability concerns of facility owners, it would be difficult to establish a reporting system for major non-spill incidents at marine facilities and transmission pipelines. However, Ecology will continue to follow progress by OMS and the marine industry to determine if similar discussions should be initiated with the industry segments which Ecology regulates.

# Chapter 6: Lessons Learned From Recent Pipeline Spills

Over the last few years pipeline spills have occurred nationally with a frequency and environmental consequence that have raised significant concerns from the National Transportation Safety Board and others. The potential for similar major oil spills exists in Washington State. For example, two past pipeline spills involved the release of 460,000 and 168,000 gallons. These incidents show how much oil can be spilled by pipelines before the leak is detected, the system is shut down and residual drain out is controlled.

In Washington State, the major oil transportation pipelines spill only a very small portion of the products they transport. However, because of the large amount of oil which can be spilled before a spill incident is identified and controlled, they have the potential to cause serious environmental damage. Spill events during 1996 have demonstrated the need for Ecology to review current spill prevention measures for the state's major oil transportation pipelines. During 1996, the following incidents occurred:

- **On March 23, 1996, an estimated 1,560 gallons of diesel fuel** spilled from the Olympic Pipe Line into a tributary to Spencer Creek in Cowlitz County. The spill was caused by damage to the pipeline as a result of ground slumping in unstable soil in the area surrounding the pipeline.

- **On June 16, 1996, at least 1,000 gallons of gasoline and diesel fuel spilled** from a small crack in the Olympic Pipe Line into an unnamed slough near Everett. The cause of the spill may have been due to construction damage during original installation in 1972.

- **On Dec. 6, 1996, approximately 49,000 gallons of unleaded gasoline spilled** at the GATX oil storage facility on Harbor Island in Seattle. The spill resulted from a pipeline coupling failure at the plant during a product transfer from the Olympic Pipe Line. The specific cause of the spill is still under investigation and has not been determined.

It is often difficult to determine the quantity of oil lost during pipeline spills. For instance, the two Olympic Pipe Line spills went undetected for a significant period of time while oil entered soils and state waters. Ecology will continue to review the cause of these and other similar events with industry to gain a better understanding of how these spills can be prevented. This review is particularly important at this time, given the proposal for a major cross-Cascades petroleum pipeline. The state has a responsibility to assure that any new or repaired pipeline sections are constructed and operated in an optimal manner to minimize the opportunity for spills.

As a result of recent pipeline spills, Ecology is evaluating the need for industry to put in place additional protection measures. However, at this time Ecology does not have resources to institute a transmission pipeline spill prevention effort.

# Conclusions

We have reached a number of conclusions after reviewing the information presented in this report. These conclusions were not based on a statistical analysis but were developed by inference after evaluating the data. The conclusions presented below are arranged by category, not priority.

## Data Collection and Analysis

- **Resources needed for data collection:** Readily accessible historical data on major spills prior to the mid-1980s is incomplete. Ecology will continue to improve the collection of this information in order to better analyze the cause of significant oil spills and help the agency target its prevention efforts. This needed improvement will require Ecology to continue current efforts to improve investigator training and commit additional resources to information management. There is also a need to improve truck and rail data in particular, given the gap in this report.

## Important Trends in Spills

- **Human error causes most spills:** Ecology's spill cause data indicates that most recent spills (about 80 percent) were the result of some type of human factor and were, therefore, preventable. It also appears that organization/management is responsible for significantly more incidents than the failure of an individual. These conclusions are consistent with the findings of other researchers at the national level and have important implications for spill prevention.

- **Spills occur most frequently in January:** During the last four years, the annual incidence of significant oil spills was highest during January. While we need to better understand the reasons for this seasonal influx, one factor suggests the importance of addressing the human factors component in oil spills.

- **Spills over 10,000 gallons are source of most oil:** The overall quantity of oil spilled is dominated over time by large spills greater than 10,000 gallons. The state should continue to target prevention activities for potential major spill sources. However, this report did not evaluate non-point source oil inputs to the environment, which are seldom reported to environmental agencies and can add up to large volumes. Non-point sources include leaking motor vehicle crank cases, parking lot run-off, improper disposal of used motor oil and other similar sources.

- **"Black" oil is a serious threat:** Crude and heavy fuel oils have constituted about 82 percent of the total oil released from spills over 10,000 gallons. These forms of "black" oil are among the most persistent and environmentally damaging types of oil and are very difficult to clean up. Future spill prevention efforts should continue to address vessel

spills which were responsible for about 59 percent of the total volume of oil lost from major spills and many of the incidents involving black oil.

- **Biggest risk is associated with marine transportation corridors:** The outer coast, the Strait of Juan de Fuca and the vicinity surrounding the state's major refineries are the areas at greatest risk of major spills.

- **Transmission pipelines present significant risk:** During the last four years, the volume of oil released per spill from pipeline incidents was relatively large compared with routine vessel and facility spills. With the continued occurrence of these spills, industry and Ecology should place additional emphasis on prevention of spills from major transmission pipelines.

## Effectiveness of Existing Spill Prevention Measures

- **Big spill incidents may be dropping:** While it is difficult to clearly attribute the long-term trend in spills over 10,000 gallons to any specific measure, it does appear that since 1983 the number and volume of major spills in Washington has gone down (see **Figure 2**). Furthermore, this apparent decline may be occurring more rapidly than national rates. If this is true, it has good implications for the effectiveness of the state/federal and industry spill prevention partnerships which have been developed in Washington since the passage of the state's spill prevention legislation in 1991. However, the state must guard against complacency and losing focus on spill prevention.

- **Land-based spills continue to pose risk:** Washington has information on 15 petroleum oil spills of over 100,000 gallons since 1964. These major spills have included tanker and barge accidents, refinery accidents and major transmission pipeline releases. While vessel spills may present the greatest risk for catastrophic spills, refinery and transmission pipeline operations have resulted in four of the last five spills over 10,000 gallons. These facilities should continue to be the primary focus of Ecology's spill prevention efforts.

## State Spill Policy

- **Effect of spills on state legislation:** As indicated in **Appendix 2**, there is a strong connection between the incidence of oil spills and subsequent legislative expansion of state responsibilities for spill prevention and response. We can expect that the future occurrence of major spills will trigger additional public expectations for improved spill prevention measures.

- **Washington has a unique energy policy setting:** Washington State has not depended solely on federal rules for the protection of its natural resources, but has established its own stringent oil spill prevention and response program. The primary factors which have influenced state policy in this area (other than actual spill events) include: the high sensitivity and value of Washington's aquatic resources; the large volume of Pacific rim trade; and the state's reliance on external crude oil resources.

- **Petroleum products exported from Washington are subject to a tax credit:** Washington State refines large volumes of petroleum products. A significant portion of the refined products are exported to Oregon and California. While our state is exposed to the spill risks associated with the importation, processing, storage and export of those products, Washington's spill prevention and response programs do not receive tax revenue from petroleum which is exported.

# Appendices

**Appendix 1 —** Significant Vessel Casualties and Near Misses

**Appendix 2 —** Major Oil Spills and Related Legislative Action

**Appendix 3 —** Selected Spills in Washington State

**Appendix 4 —** Legend for Map:  Spills Over 10,000 Gallons

**Appendix 5 —** Ecology's Regional Offices Map

## Appendix 1 — Significant Vessel Casualties and Near Misses

- **August 12, 1996, Grounding** — A loaded grain ship, the *Ossolineum* grounded along the banks of the Columbia river. The vessel, which was outbound, was carrying 350,000 gallons of fuel in its tanks when it ran aground upstream from three wildlife refuges and estuaries. Luckily no oil was spilled.

- **July 11, 1996, Loss of Power** — The oil tanker *Kenai* lost power off Port Angeles. The tanker was headed toward Valdez when it stopped at Port Angeles to have its radar fixed and to refuel for the voyage. Fortunately, an escort tug was near by when the vessel lost power and was able to bring the vessel back to Port Angeles without incident.

- **July 6 1996, Shipboard Fire** — The cruise ship *Golden Princess* was headed to Vancouver, British Columbia, when a fire in the engine room caused the engines to shut down. The vessel also lost electrical power. A tug boat arrived on scene in three hours to tow the vessel to Vancouver for repairs. The vessel was carrying over 600,000 gallons of fuel when it lost power.

- **October 1994, Grounding** — The empty tanker *Keystone Canyon* broke all of her mooring lines in high winds while moored in Astoria, Oregon. The ship drifted across the Columbia River and struck the Astoria-Megler Highway Bridge. Fortunately, damage to the ship and the bridge was minimal. No oil was spilled although an empty tank was breached. A combination of weather conditions and lack of procedures lead to the grounding.

- **July 1994, Loss of power** — The 32,671 bulk carrier *Verbier* was outbound from Vancouver, British Columbia, when it lost power 2.5 miles from shore in the Strait of Juan de Fuca. After an unsuccessful attempt to be towed to port by a small tug, a second larger tug was dispatched. After several hours of towing, the tow line parted. The tug made-up again, and successfully towed the vessel to Port Angeles with the final assistance of tow other tugs. Lack of proper owner and operator oversight and support contributed to the accident.

- **July 1994, Collision** — The Chinese bulk freighter *Tian Tan Hai* collided with the fully laden tank barge *Cascades* approximately 30 miles west of the Columbia River entrance. The *Cascades* was being towed by the tug *Fairwind* and was carrying 2.4 million gallons of oil. Fortunately no oil was spilled because the collision did not rupture any cargo tanks on the barge or fuel tanks on the freighter. The barge was double-hulled. Lack of communication and adherence to regulations and policy contributed to this collision.

- **November 1993, Explosion** — The tanker *Sea River Philadelphia* suffered an explosion in her Inert Gas compartment while moored in Anacortes. Fortunately no one was injured and no oil was spilled. Inadequate maintenance procedures and possible inadequate design contributed to the explosion.

- **July 1993, Poor Vessel Condition —** The tanker *Altair* was boarded and briefly detained in Victoria, British Columbia, by the Canadian Coast Guard. The ship was in poor condition. Two months later, the *Altair* blew up and sank in the South China Sea.

- **June 1991, Grounding** — The laden tanker *ARCO Texas* ran aground at Ediz Hook in Port Angeles, Washington. No release of oil occurred.

- **September 1989, Loss of power** — The tanker *Exxon San Francisco* lost power while outbound in the Strait of Juan de Fuca. The vessel returned to Port Angeles without further problems.

- **April 1989, Loss of power** — The tanker *Exxon Philadelphia* lost power and was adrift off the mouth of the Strait of Juan de Fuca with a load of 23 million gallons of Alaska crude oil. Approximately five hours later, a tug reached the tanker and towed the ship to Port Angeles.

- **April 1988, Grounding —** The tanker Matsukaze grounded at Crescent Bay west of Port Angeles causing extensive damage to the vessel but no loss of product.

## Appendix 2 — Major Oil Spills and Related Legislative Action

**1964**

- United Transportation Barge, Grays Harbor Co. (3/64) — 1,200,000 gallons diesel fuel

**1969**

- Extensive oil spill legislation was passed in 1969-1972

**1971**

- United Transportation Barge, Skagit Co. (4/71) — 230,000 gallons of diesel/gasoline

**1972**

- *General M.C. Meiggs* (U.S. Navy), Clallam Co. (1/72) — 2,300,000 gallons of fuel oil

**1973**

- Trans Mountain Pipeline, Whatcom Co. (1/73) — 460,000 gallons of crude oil

**1983**

- Olympic Pipe Line Co., Allen Pump Station (9/83) — 168,000 gallons of diesel fuel

**1984**

- *Tanker SS Mobil Oil*, Columbia River (3/84) — 200,000 gallons of fuel oil

**1985**

- Olympic Pipe Line, King Co. (11/85) — 34,000 gallons of jet fuel
- *ARCO Anchorage*, Port Angeles (12/85) — 239,000 gallons of crude oil

**1986**

- Concurrent Legislative Resolution 19 established an oil spill advisory committee
- Olympic Pipe Line, King Co. (5/86) — 70,000 gallons of oil

**1988**

- *Barge MCN#5* (Olympic Tug & Barge), Skagit Co. (1/88) — 70,000 gallons of heavy oil.
- *Nestucca Barge* (Sause Towing), Grays Harbor Co. (12/88) — 231,000 gallons of fuel oil.

**1989**

- HB 2242 — Established financial responsibility requirements for vessels.
- SB 6701 — Washington State Maritime Commission (WSMC) established.
- HB 1853 & 1854 — Natural Resource Damage Assessment methodology.
- *Exxon Valdez* grounding, AK (3/89) — 11,000,000 gallons of crude oil. This spill resulted in significant legislative changes in Washington, as well as other U.S. states and Canada.

**1990**

- HB 2494 — Broad spill preparedness & contingency planning legislation
- HB 6528 — Pilotage legislation
- OPA 90 — Passage of the Federal Oil Pollution Control Act of 1990
- Navy Supply Depot, Kitsap Co. (2/90) — 70,000 gallons of diesel fuel
- Texaco, Skagit Co. (3/90) — 130,000 gallons of diesel fuel
- Chevron Richmond Beach, King Co. (8/90) — 176,000 gallons of asphalt
- PNW Terminals, Pierce Co. (11/90) — 200,000 gallons of tallow

**1991**

- HB 1027 — Broad legislation with a spill prevention focus
- US Oil Tacoma, Tacoma (1/91) — 600,000 gallons of crude oil
- Texaco Refinery, Anacortes (2/91) — 210,000 gallons of crude oil
- *Tenyo Maru* (COSCO Shipping), Canadian waters at entrance to Strait of Juan de Fuca (7/91) — 100,000 gallons of diesel & heavy oil

**1992**

- HB 2389 — Amendments to 1991 legislation
- Chevron Pipeline, Lincoln Co. (11/92) — 20,000 gallons of jet fuel

**1993**

- HB 1144 — Established OMS vessel inspection program
- US Oil Refinery, Tacoma (10/93) — 264,000 gallons of crude oil
- *M/V Nosac Forest* (Barber International), Tacoma (4/93) — 6,260 gallons of fuel oil
- *M/V Central* (Azuero Shipping), Columbia River (6/93) — 3,000 gallons of fuel oil

**1994**

- ESHB 1107 — Marine Oversight Board Abolished
- HB 1407 — Washington State Maritime Commission privatized
- Crowley Barge 101, Rosario Strait (12/94) - 26,900 gallons diesel of fuel
- An Ping (Shanghi Hai Xing Shipping), Columbia River (1/94) - 2,771 gallons of fuel oil

**1995**

- ESHB 2080 — Merged OMS with Ecology, legislation was struck down by superior court action

**1996**

- Initiative 188 fails — Bans off-shore drilling; eliminates OMS merger; adjusts spill funding
- GATX, Harbor Island Seattle (12/96) — 49,000 gallons of unleaded gasoline

# Appendix 3 — Selected Spills in Washington State
## (Arranged by date)

| Incident Date | Incident Name | Total Quantity Spilled (Gallons) | Product Type |
|---|---|---|---|
| 03/10/1964 | V-UNITED TRANSPORTATION BARGE | 1,200,000 | DIESEL FUEL |
| 04/26/1971 | V-UNITED TRANSPORTATION BARGE # U | 230,000 | DIESEL FUEL |
| 01/01/1972 | V-GENERAL M.C. MEIGGS | 2,300,000 | HEAVY FUEL OIL |
| 06/04/1972 | V-WORLD BOND | 21,000 | CRUDE OIL |
| 01/10/1973 | P-TRANS-MOUNTAIN PIPELINE | 460,000 | CRUDE OIL |
| 01/01/1978 | V-BARGE | 100,000 | DIESEL FUEL |
| 12/31/1980 | F-WHATCOM CREEK PENTA SPILL | 20,000 | OTHER OIL |
| 05/01/1981 | V-ST. ANTHONY | 2,000 | CRUDE OIL |
| 09/23/1983 | P-OLYMPIC PIPELINE | 168,000 | DIESEL FUEL |
| 03/20/1984 | V-SS MOBIL OIL TANKER SPILL | 200,000 | HEAVY FUEL OIL |
| 11/28/1985 | P-OLYMPIC PIPELINE | 34,000 | JET FUEL |
| 12/20/1985 | F-CHEVRON BULK STORAGE TERMINAL | 1,440 | HEAVY FUEL OIL |
| 12/21/1985 | V-ARCO ANCHORAGE | 239,000 | CRUDE OIL |
| 01/31/1988 | V-MCN#5 BARGE | 70,000 | HEAVY FUEL OIL |
| 12/23/1988 | V-NESTUCCA BARGE | 231,000 | HEAVY FUEL OIL |
| 02/25/1990 | F-MANCHESTER NAVAL SUPPLY DEPOT | 70,000 | DIESEL FUEL |
| 03/27/1990 | F-TEXACO REFINERY | 130,000 | DIESEL FUEL |
| 07/14/1990 | F-PNW TERMINALS | 30,000 | OIL OTHER, TALLOW |
| 08/10/1990 | F-CHEVRON RICHMOND BEACH PARK | 176,000 | OTHER OIL |
| 11/17/1990 | F-PNW TERMINALS TALLOW SPILL | 200,000 | OIL OTHER, TALLOW |
| 01/06/1991 | F-US OIL AND REFINING COMPANY | 600,000 | CRUDE OIL |
| 01/15/1991 | P-TRANS MOUNTAIN | 3,025 | OTHER OIL |
| 02/22/1991 | F-TEXACO REFINERY | 210,000 | CRUDE OIL |
| 02/28/1991 | V-HANJIN CONTAINER | 210 | DIESEL FUEL |
| 07/22/1991 | V-TENYO MARU | 100,000 | HEAVY FUEL OIL AND DIESEL |
| 12/11/1991 | P-TRANS MOUNTAIN PIPELINE | 3,528 | CRUDE OIL |
| 03/07/1992 | P-TRANS MOUNTAIN PIPELINE | 2,100 | CRUDE OIL |
| 06/30/1992 | V-SUN ROSE | 850 | HEAVY FUEL OIL |
| 07/04/1992 | T-TWIN CITY FOODS | 100 | DIESEL FUEL |
| 07/17/1992 | V-SAMSON TUG | 70 | GASOLINE |
| 08/22/1992 | F-WASHINGTON WATER POWER | 370 | DIESEL FUEL |
| 10/11/1992 | V-ARCTIC ALASKA | 30 | DIESEL FUEL |
| 11/03/1992 | P-CHEVRON PIPELINE | 20,000 | JET FUEL |
| 12/15/1992 | V-ARCTIC ALASKA FISHERIES | 500 | DIESEL FUEL |
| 01/07/1993 | V-ARCTIC ALASKA FISHERIES | 800 | DIESEL FUEL |
| 03/02/1993 | V-F/V ROVER | 495 | DIESEL/LUBE OIL |
| 04/15/1993 | V-USS CAMDEN | 5,400 | HEAVY FUEL OIL |
| 04/25/1993 | F-PORT OF PORT TOWNSEND | 900 | DIESEL FUEL |
| 04/25/1993 | V-NOSAC FOREST | 6,260 | HEAVY FUEL OIL |
| 05/04/1993 | V-DUTCHIE C | 60 | DIESEL FUEL |
| 06/01/1993 | F-PENINSULA FUEL | 35 | DIESEL FUEL |
| 06/03/1993 | V-M/V CENTRAL | 3,000 | HEAVY FUEL OIL |
| 08/03/1993 | V-GREAT PACIFIC | 100 | DIESEL FUEL |
| 08/05/1993 | V-F/V EXCELLENCE | 2,995 | DIESEL FUEL |
| 08/05/1993 | V-ARCTIC ALASKA | 50 | DIESEL FUEL |
| 08/08/1993 | PACIFIC N. OIL | 80 | HEAVY FUEL OIL |
| 08/13/1993 | V-F/V RADIO | 360 | LUBE OIL |
| 09/06/1993 | V-STORMY SEA | 30 | DIESEL FUEL |
| 10/14/1993 | V-TIDEWATER SPILL | 3,295 | DIESEL FUEL |
| 10/15/1993 | V-F/V ANELA | 50 | DIESEL FUEL |
| 10/18/1993 | F-US OIL | 264,000 | CRUDE OIL |
| 11/23/1993 | V-WA D.O.C. | 25 | DIESEL FUEL |
| 11/25/1993 | F-U.S. NAVY | 560 | DIESEL FUEL |
| 12/22/1993 | V-USS NIMITZ | 308 | JET FUEL |
| 01/07/1994 | V-ISLAND TUG | 40 | DIESEL FUEL |
| 01/10/1994 | V-AN PING 6 | 2,771 | HEAVY FUEL OIL |
| 01/25/1994 | F-FOSS MARITIME | 300 | DIESEL FUEL |
| 01/30/1994 | V-F/V TRIAL | 40 | DIESEL FUEL |
| 02/01/1994 | V-USS CAMDEN | 30 | DIESEL FUEL |
| 02/15/1994 | V-TUG DAUB | 483 | DIESEL FUEL |
| 02/15/1994 | F-NORTHWEST ENVIRO SERVICES | 5,500 | DIESEL FUEL |

| Incident Date | Incident Name | Total Quantity Spilled (Gallons) | Product Type |
|---|---|---|---|
| 05/10/1994 | V-GOLDEN DAWN | 85 | DIESEL FUEL |
| 06/06/1994 | V-USS SACRAMENTO | 200 | DIESEL FUEL |
| 06/14/1994 | V-MATTHEW | 50 | GASOLINE |
| 06/29/1994 | F-L.U. DRYDOCK | 1,000 | DIESEL FUEL |
| 07/18/1994 | V-JOE C | 700 | DIESEL FUEL |
| 08/09/1994 | V-USS ARCADIA | 325 | DIESEL FUEL |
| 09/11/1994 | V-OMAR | 200 | LUBE OIL |
| 09/22/1994 | V-J. MICHELLE | 100 | HYDRAULIC OIL |
| 10/15/1994 | V-TYSON SEAFOOD | 25 | DIESEL FUEL |
| 10/15/1994 | V-BRENEVA | 500 | DIESEL FUEL |
| 10/27/1994 | V-USS SACREMENTO | 3,700 | JET FUEL |
| 11/05/1994 | V-F/V SITKOF | 100 | DIESEL FUEL |
| 11/13/1994 | V-NOAA | 80 | DIESEL FUEL |
| 12/17/1994 | V- JUPITER | 50 | DIESEL FUEL |
| 12/31/1994 | V-CROWLEY BARGE 101 | 26,900 | DIESEL FUEL |
| 01/11/1995 | F-BAINTER RANCH | 300 | DIESEL FUEL |
| 01/20/1995 | V-POLAR CUB | 200 | DIESEL FUEL |
| 01/25/1995 | V-U.S. NAVY | 2,520 | JET FUEL |
| 01/25/1995 | F-JOHNSON CONTROL | 50 | HYDRAULIC OIL |
| 01/26/1995 | V-TRIPOLI | 30 | DIESEL FUEL |
| 01/27/1995 | F-WEYERHAEUSER, LONGVIEW BUNKER SP | 1,000 | HEAVY FUEL OIL |
| 01/30/1995 | V-DAPHNE | 400 | DIESEL FUEL |
| 02/10/1995 | V-IMCO CONST. | 37 | DIESEL FUEL |
| 02/17/1995 | V-NX PRESSION | 250 | DIESEL FUEL |
| 02/20/1995 | TACOMA SCHOOL DISTRICT | 50 | HEAVY FUEL OIL |
| 02/23/1995 | V-CATHERINE | 200 | DIESEL FUEL |
| 02/26/1995 | V-USS-NIMITZ | 100 | DIESEL FUEL |
| 04/22/1995 | V-MARTINIQUE | 55 | DIESEL FUEL |
| 05/24/1995 | V-A. KOLLONTOY | 100 | DIESEL FUEL |
| 06/02/1995 | V-N. VICTOR | 30 | DIESEL FUEL |
| 07/16/1995 | V-BETTY JEAN | 25 | DIESEL FUEL |
| 07/18/1995 | V-RYBAKCAUTOKY | 100 | DIESEL FUEL |
| 08/09/1995 | V-GASTELLO | 50 | HEAVY FUEL OIL |
| 08/13/1995 | F-DISTINCTIVE PROPERTIES | 30 | DIESEL FUEL |
| 08/19/1995 | V-PELICAN | 40 | GASOLINE |
| 09/14/1995 | V-DAVID R. RAY | 50 | DIESEL FUEL |
| 09/14/1995 | V-SEA NEST | 75 | DIESEL FUEL |
| 09/29/1995 | V-DIANE | 50 | DIESEL FUEL |
| 10/21/1995 | F-SR 509 'D' STREET POND | 50 | HEAVY FUEL OIL |
| 10/31/1995 | F-TOSCO | 85 | CRUDE OIL |
| 11/12/1995 | V-OMAR | 120 | DIESEL FUEL |
| 01/04/1996 | V-MUSKRAT | 30 | HYDRAULIC OIL |
| 01/05/1996 | V-COMMODORE | 241 | DIESEL FUEL |
| 01/06/1996 | F-U.S. OIL | 25 | CRUDE OIL |
| 01/14/1996 | F-SNOQUALMIE PASS OIL TANK | 200 | HOME HEATING FUEL |
| 02/06/1996 | V-TANKER NEPTUNE | 378 | DIESEL FUEL |
| 02/21/1996 | V-REBEL | 50 | DIESEL FUEL |
| 02/28/1996 | V-BERNERT BARGE | 308 | DIESEL FUEL |
| 03/23/1996 | P-OLYMPIC PIPELINE | 1,561 | DIESEL FUEL |
| 03/25/1996 | V-NORTHERN LADY | 450 | DIESEL FUEL |
| 04/16/1996 | V-POLAR QUEEN | 37 | DIESEL FUEL |
| 04/20/1996 | T-WIND RIVER TRAIN DERAILMENT | 65,000 | DIESEL FUEL |
| 04/21/1996 | F-ROCK ISLAND SPILL | 700 | OTHER OIL |
| 04/22/1996 | V-ISSWAT | 35 | DIESEL FUEL |
| 05/06/1996 | F-WAPATO RANCH | 4,000 | HOME HEATING FUEL |
| 05/15/1996 | V-EXPEDITIONS 3 | 100 | DIESEL FUEL |
| 06/11/1996 | V-U.S. NAVY | 70 | JET FUEL |
| 06/17/1996 | P-OLYMPIC PIPELINE | 1,500 | DIESEL FUEL |
| 12/06/1996 | F-GATX HARBOR ISLAND | 49,000 | GASOLINE, UNLEADED |

This table lists all spills analyzed in this report. Also included are additional spills which included non-petroleum products or for which agency data is incomplete.

# Appendix 4 — Legend for Map: Spills Over 10,000 Gallons

**(Ranked by spill size)**

| | Incident Date | Incident Name | Total Quantity Spilled (Gallons) | Product Type |
|---|---|---|---|---|
| 1 | 01/01/1972 | V-GENERAL M.C. MEIGGS | 2,300,000 | HEAVY FUEL OIL |
| 2 | 03/10/1964 | V-UNITED TRANSPORTATION BARGE* | 1,200,000 | DIESEL FUEL |
| 3 | 01/06/1991 | F-US OIL AND REFINING COMPANY | 600,000 | CRUDE OIL |
| 4 | 01/10/1973 | P-TRANS-MOUNTAIN PIPELINE | 460,000 | CRUDE OIL |
| 5 | 10/18/1993 | F-US OIL | 264,000 | CRUDE OIL |
| 6 | 12/21/1985 | V-ARCO ANCHORAGE | 239,000 | CRUDE OIL |
| 7 | 12/23/1988 | V-NESTUCCA BARGE | 231,000 | HEAVY FUEL OIL |
| 8 | 04/26/1971 | V-UNITED TRANSPORTATION BARGE # U | 230,000 | DIESEL FUEL |
| 9 | 02/22/1991 | F-TEXACO REFINERY | 210,000 | CRUDE OIL |
| 10 | 01/17/1990 | F-PNW TERMINALS TALLOW SPILL** | 200,000 | OIL OTHER, TALLOW |
| 11 | 03/20/1984 | V-SS MOBIL OIL TANKER SPILL | 200,000 | HEAVY FUEL OIL |
| 12 | 08/10/1990 | F-CHEVRON RICHMOND BEACH PARK | 176,000 | OTHER OIL |
| 13 | 09/23/1983 | P-OLYMPIC PIPELINE | 168,000 | DIESEL FUEL |
| 14 | 03/27/1990 | F-TEXACO REFINERY | 130,000 | DIESEL FUEL |
| 15 | 07/22/1991 | V-TENYO MARU | +100,000 | HEAVY FUEL, OIL & DIESEL |
| 16 | 01/01/1978 | V-COLUMBIA RIVER BARGE*** | 100,000 | DIESEL FUEL |
| 17 | 02/25/1990 | F-MANCHESTER NAVAL SUPPLY DEPOT | 70,000 | DIESEL FUEL |
| 18 | 01/31/1988 | V-MCN#5 BARGE | 70,000 | HEAVY FUEL OIL |
| 19 | 05/08/1986 | P-OLYMPIC PIPELINE | 70,000 | OTHER OIL |
| 20 | 04/20/1996 | T-WIND RIVER TRAIN DERAILMENT**** | 65,000 | DIESEL FUEL |
| 21 | 12/06/1996 | F-GATX HARBOR ISLAND | 49,000 | GASOLINE, UNLEADED |
| 22 | 11/28/1985 | P-OLYMPIC PIPELINE | 34,000 | JET FUEL |
| 23 | 07/14/1990 | F-PNW TERMINALS** | 30,000 | OIL OTHER, TALLOW |
| 24 | 12/31/1994 | V-CROWLEY BARGE 101 | 26,900 | DIESEL FUEL |
| 25 | 06/04/1972 | V-WORLD BOND | 21,000 | CRUDE OIL |
| 26 | 11/03/1992 | P-CHEVRON PIPELINE | 20,000 | JET FUEL |
| 27 | 12/31/1980 | F-WHATCOM CREEK PENTA SPILL | 20,000 | OTHER OIL |
| 28 | 04/27/1980 | V-WILLAPA BAY SPILL*** | 20,000 | OTHER OIL |
| 29 | 04/23/1974 | P-TRANS MOUNTAIN PIPELINE | 16,128 | CRUDE OIL |
| 30 | 06/24/1990 | V-SULAK | 15,000 | DIESEL FUEL |
| 31 | 02/07/1990 | P-OLYMPIC PIPELINE | 12,600 | DIESEL FUEL |
| 32 | 08/12/1988 | F-NAS WHIDBEY ISLAND | 11,000 | JET FUEL |
| 33 | 01/01/1991 | T-MONITOR TANKER***** | 10,000 | GASOLINE |
| 34 | 03/28/1990 | F-U.S. NAVY SUPPLY CENTER | 10,000 | DIESEL FUEL |

V = Vessel spill
P = Transmission pipeline spill
F = Facility spill

**+** The Tenyo Maru contained over 400,000 gallons when it sank, at least 100,000 gallons was released during the initial incident.

The following spills were not included in the report analysis because:

- ***** the spill occurred prior to 1970.
- ** this was a non-petroleum spill.
- ******* there is inadequate spill information.
- ******** this was a land transport spill; considerably less than 65,000 gallons was actually released.
- ********* this was a land transport spill.

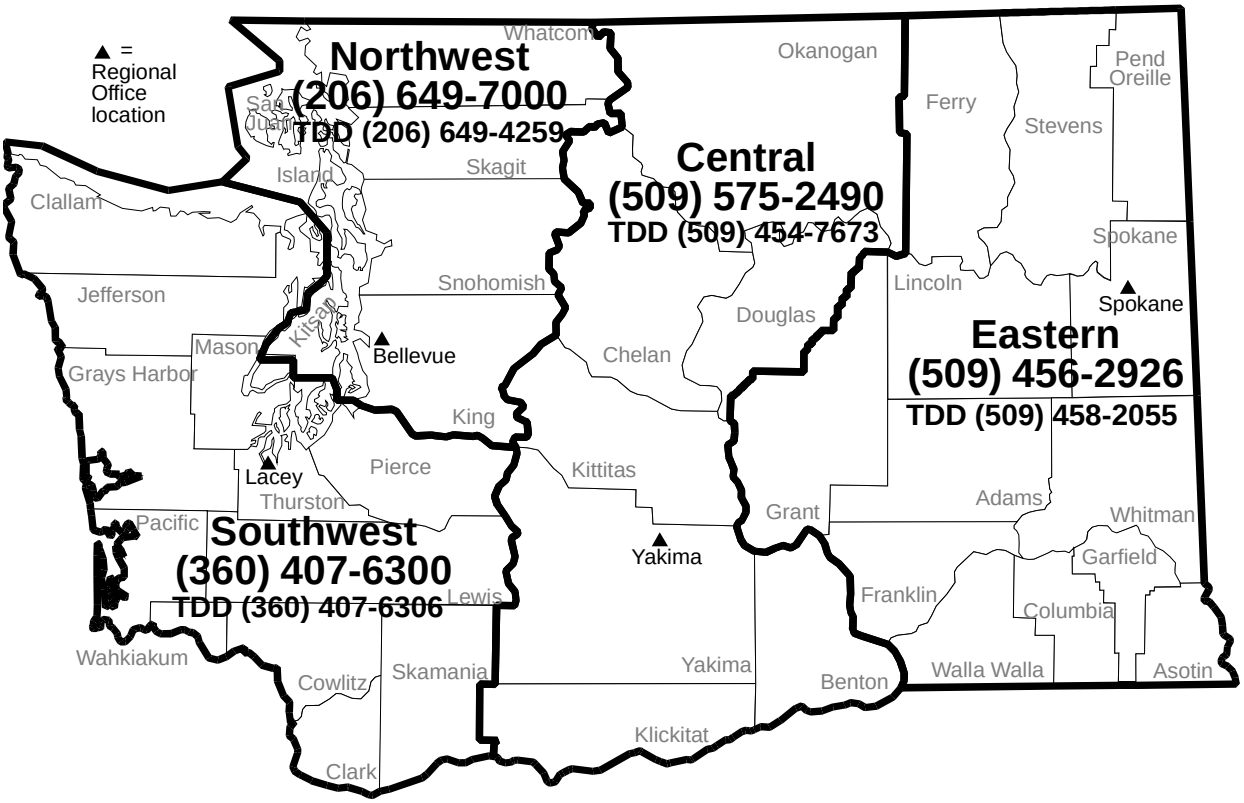
Other major spills will be added to this list as more information becomes available. Additional major spills have occurred at Kalama Chemicals, the City of Tacoma's power plant, US Oil in Tacoma, and on Whidby Island from an unknown source.

## Appendix 5 — Ecology's Regional Offices

# Washington Department of Ecology

### Regional Office 24-Hour Oil and Hazardous Materials Spill Reporting Numbers

WASHINGTON STATE DEPARTMENT OF ECOLOGY




## Need to Know:

- Reporting Party
- Contact Phone(s)
- Responsible Party
- Material Released
- Location
- Dead/Injured Fish or Wildlife
- Quantity
- Concentration
- Cleanup Status

Or call the state Emergency Management Division's 24-hour number at:

**1-800-258-5990** or **1-800-OILS-911**

For EPA and U.S. Coast Guard reporting, call the National Response Center at:

**1-800-424-8802**

**Emergency numbers for other states and federal agencies:**

*Idaho:* Communications Center (208) 327-7422 *Oregon:* Emergency Management (503) 378-6377
*EPA Region X, Seattle:* (206) 553-1263 *British Columbia:* Provincial Emergency Program (800) 663-3456

# Analysis of the Potential Costs of Accidents/Spills Related to Crude by Rail

Prepared

by

Ian Goodman
Brigid Rowan

on behalf of
Oil Change International

Before the
Pipeline and Hazardous Materials Safety Administration
in the Context of
Hazardous Materials: Rail Petitions and Recommendations to Improve the Safety of Railroad Tank Car Transportation
Docket No. PHMSA-2012-0082 (HM-251)

the goodman group, ltd.
http://www.thegoodman.com/

November 8, 2013

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# 1. Introduction

This analysis was prepared by The Goodman Group, Ltd. (TGG), a consulting firm specializing in energy and regulatory economics,[1] on behalf of Oil Change International. Any findings, conclusions or opinions are those of TGG and the authors and do not necessarily reflect those of Oil Change International.

The costs of crude by rail (CBR) accidents/spills can be very large. This analysis demonstrates that a major crude by rail (CBR) unit train accident/spill could cost $1 billion or more for a single event.

The following examples provide key support for our findings:

1. The explosion, fire and spill of Bakken crude from a train derailment in Lac-Mégantic, QC (2013): The Lac-Mégantic rail accident/spill will likely have costs in the order of $500 million to $1 billion. Costs/damages for a similar incident could have been substantially higher had it occurred in a more populated area. Lac-Mégantic is also relevant in that it shows how an accident involving highly flammable light crude (such as the Bakken crude) can have devastating consequences even in a small town in terms of loss of human life and widespread explosion and fire damage to surrounding property.

2. The spill of tar sands dilbit[2] from Enbridge's Line 6B in Marshall, MI (2010): This rupture had costs of about $1 billion for Enbridge. The spill volumes at Marshall were within the range of the amount of spill possible (and, in fact, substantially less than the maximum spill) if a crude by rail unit train released much of its cargo. Costs/damages for similar incident could have also been substantially higher had it occurred in a more populated area. Marshall is also relevant in

[1] www.thegoodman.com This analysis was co-authored by Ian Goodman and Brigid Rowan.
[2] Diluted bitumen. Raw bitumen (a very heavy asphalt-like crude produced from the Alberta tar sands) is diluted for the purposes of rail and pipeline transport. Bitumen is transported in various forms, including a) SCO (raw bitumen upgraded to light synthetic crude oil), b) raw bitumen mixed with a petroleum-based diluent (such as naphtha or condensate) to make it less viscous, or c) raw bitumen (no diluent). SCO and dilbit (diluted bitumen to pipeline specifications, 25–30% diluent) can be transported in standard (non-coiled and non-insulated) tank cars and pipelines. Railbit (bitumen with 15–20% diluent) and raw bitumen can be transported in coiled and insulated tank cars (which are also sometimes used to transport dilbit). Keystone XL Draft Supplemental EIS, p. 1.4-49. Accessed October 30, 2013. http://keystonepipeline-xl.state.gov/documents/organization/205654.pdf

> showing the high potential cost of dilbit spills into water (and rail lines are often highly proximate to water).[3]

The AAR petition for rulemaking states:[4]

> AAR surveyed its members for information on derailments involving packing group I and II materials from '2004-2008. The derailments resulted in one fatality and eleven injuries, the release of approximately 925,000 gallons of these hazardous materials, and cleanup costs totaling approximately $63 million.

The Village of Barrington petition for rulemaking responds:[5]

> Furthermore, while AAR claims that derailment costs totaled approximately $64 million over the past five years, including equipment, lading, response and environmental remediation costs," [footnote 17 in original: March 9, 2011 Petition for Rulemaking letter to Dr. Magdy El-Sibae from Michael Rush of the Association of American Railroads at page 2, footnote 7.] Petitioners question the accuracy of industry's cost-benefit claims. In reviewing the derailment cost chart at Attachment B of AAR's petition, PHMSA should note that there is no apparent accounting for costs associated with civil litigation in the wake of derailments. However, in the Cherry Valley/Rockford derailment, CN paid over $36 million in October of 2011 to settle a lawsuit brought by the family of only one victim. AAR's chart, however, reflects costs of only $8 million for that incident. [footnote 18 in original: At the very least, Petitioners believe it would make sense for the PHMSA to ascertain the costs stemming from civil litigation for the entire list of derailments incidents that the AAR provided to your office on March 9, 2011. Even if it doesn't yet completely balance the cost-benefit equation in favor of public safety, Petitioners would guess that the plaintiffs' bar would look forward to securing ever higher awards for future victims of derailments based on the public record demonstrating that industry chose to do nothing meaningful in terms of investing in a retrofit program of tank cars that are known to be dangerous and that are increasingly serving as a rolling pipeline for the ethanol and crude oil industries.]

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[3] The discussion of the costs of the Lac-Mégantic disaster and the Marshall, MI pipeline rupture is partly based on excerpts from a TGG report filed as written expert testimony at Canada's National Energy Board:
"The Relative Economic Costs and Benefits of the Line 9B Reversal and Line 9 Capacity Expansion," August 8, 2013, pp. 38-41. Accessed October 23, 2013.
https://www.neb-one.gc.ca/ll-eng/livelink.exe?func=ll&objId=985663&objAction=Open

[4] See http://www.regulations.gov/#!documentDetail;D=PHMSA-2012-0082-0005 p. 2. Accessed October 29, 2013.

[5] See http://www.regulations.gov/#!documentDetail;D=PHMSA-2012-0082-0006 p. 8. Accessed October 29, 2013.

In fact, even a single accident relating to a crude by rail unit train can have dramatically higher costs than the costs taken into account in the AAR's cost-benefit claims. As further explained in this briefing, this analysis will demonstrate that a major crude by rail unit train accident/spill, involving either dilbit or a very light crude such as Bakken, could cost $1 billion or more for a single event.

We have limited our cost analysis to environmental and socio-economic impacts that directly affect economic activity and can be somewhat readily (albeit approximately) quantified using market economics. These costs escalate very quickly in more densely populated urban areas. Moreover, as we have witnessed firsthand in Quebec, in summer 2013, unconventional crudes (such as Bakken and dilbit) have hazardous characteristics (notably flammability), such that their unsafe transport can result in the loss of human life. We have not attempted to assign a cost to potential effects on human health and safety or to broader effects on ecosystems (notably residual effects).[6]

As noted above, two relevant examples to support our findings that a single unit-train accident/spill could result in very large costs are the following:

1. the explosion, fire and spill of Bakken crude from a train derailment in Lac-Mégantic, QC (2013).
2. the spill of tar sands dilbit from Enbridge's Line 6B in Marshall, MI (2010).

For each example, TGG will provide:

1. description of the disaster;
2. the cost and sources of the cost data;
3. the relevance of the example to estimating the potential costs of CBR accidents/spills.

[6] Residual effects are those effects remaining after implementation of mitigation measures, such as emergency response and decontamination efforts.

# 2. Estimated Costs of the Crude by Rail Disaster at Lac-Mégantic

## 2.1. Description of Disaster

According to the Transportation Safety Board of Canada (TSB), "[o]n July 6 2013, a unit train carrying petroleum crude oil operated by Montreal, Maine & Atlantic Railway (MMA) derailed numerous cars in Lac-Mégantic, Quebec, and a fire and explosions ensued."[7]

The train with five locomotives was pulling 72 DOT-111 tanker cars full of light crude oil from the Bakken shale play in North Dakota to the Irving Oil refinery in Saint John, New Brunswick. The train was operated by Montreal Maine & Atlantic Railway. The train broke away and derailed, unleashing an explosive ball of burning Bakken crude, which incinerated the downtown core of this small Quebec town.[8]

Quebec's Department of Sustainable Development, Environment and Parks reports that this rail accident released 6.0 million litres[9] of crude oil into the environment (affecting soil, water and air).[10] Among its other findings (as of October 28, 2013):

> A total of 7.7 million litres[11] of crude oil were on the runaway MMA train
>
> from a total of 72 tankers, 63 spilled and 9 avoided spilling during the accident
>
> 43 million litres of oily water have been recovered from Lac-Mégantic's city centre (sewer system, lake, and grounds)
>
> 52,000 litres of oily water removed from the nearby Chaudière River

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[7] See TSB website, Railway investigation R13D0054. Accessed October 29, 2013. http://www.bst-tsb.gc.ca/eng/enquetes-investigations/rail/2013/R13D0054/R13D0054.asp

[8] "Lac-Mégantic: What we know, what we don't," Montreal Gazette, July 22, 2013. Accessed August 2, 2013. http://www.montrealgazette.com/news/M%C3%A9gantic+What+know+what+know/8626661/story.html

[9] Equivalent to 1.6 million gallons.

[10] See Quebec Department of Sustainable Development, Environment and Parks website, Train Accident in Lac-Mégantic (content in French: *Ministère du Développement durable, de l'Environnement, de la Faune et des Parcs (MDDEFP), Accident ferroviaire à Lac-Mégantic*),.Accessed November 8, 2013 http://www.mddep.gouv.qc.ca/lac-megantic/index.htm; and specifically Summary Table on quantities of oil estimated as of October 28, 2013 (*Tableau-Synthèse: Estimation au 28 octobre 2013 des quantités de pétrole brut léger impliquées dans l'accident à Lac-Mégantic*) http://www.mddefp.gouv.qc.ca/lac-megantic/20131028-tableau-synthese-petrole.pdf

[11] Equivalent to 2.0 million gallons.

the oily water recovered has concentrations of oil ranging from 2% to 50%, and it is not possible to determine the exact amount of oil actually recovered.

"The catastrophe killed 47 residents and levelled more than 40 buildings." [12]

According to a September 11, 2013 TSB news release, "TSB test results indicate that the level of hazard posed by the petroleum crude oil transported in the tank cars on the accident train was not accurately documented." The crude was "offered for transport, packaged, and transported as a Class 3, PG III product, which represented it as a lower hazard, less volatile flammable liquid."[13]

## 2.2. Costs and Sources of Cost Data

The TSB investigation into the accident is still ongoing.[14] It is still too early to know the final costs for this disaster (including decontamination, town reconstruction, economic recovery, and compensation for victims' families); but **TGG estimates these costs to be in the hundreds of millions (in the order of $500 million to $1 billion)**.

Preliminary clean-up bills for damage to the town doubled in the weeks following the accident from $4 million to almost $8 million. The MM&A Railway stated at the end of July that it was unable to pay clean-up costs because it was not getting funds from its insurers. At the time, MM&A had outstanding bills for $7.8 million. MM&A also publicly raised the concern that it could go bankrupt.[15] In response, the Quebec government ordered World Fuel Services Corp. to assist with the clean-up. World Fuel "purchased the oil from producers in North Dakota's Bakken region, then leased and loaded rail

[12] McNish, Jacquie and Justin Giovanetti, "Oil Company Disputes Lac-Méganitc Cleanup Order," Globe and Mail. Accessed August 4. http://www.theglobeandmail.com/news/national/oil-company-disputes-lac-megantic-cleanup-order/article13518237/

[13] "TSB calls on Canadian and U.S. regulators to ensure properties of dangerous goods are accurately determined and documented for safe transportation," TSB News release, September 11, 2013. Accessed October 29, 2013. http://www.bst-tsb.gc.ca/eng/medias-media/communiques/rail/2013/r13d0054-20130911.asp
The news release further explains that this misclassification may partly explain why the crude ignited so quickly following the rupture.

[14] See the TSB active investigation page for Lac-Mégantic: http://www.bst-tsb.gc.ca/eng/enquetes-investigations/rail/2013/R13D0054/R13D0054.asp.

[15] Blatchford, Andy, "Railway says it can't pay for Lac-Mégantic disaster cleanup" http://www.theglobeandmail.com/news/national/mma-lays-off-nearly-one-third-of-quebec-workforce-union/article13496970/#dashboard/follows/

cars and arranged for their transport to an Irving Oil refinery in New Brunswick."[16] World Fuel is disputing the cleanup order.

> "In the end, says one expert in civil responsibility, taxpayers could be stuck with a bill in the hundreds of millions of dollars.
>
> Quebec law professor Daniel Gardner says he highly doubts MM&A has enough coverage to absorb the massive, combined financial liabilities of damages like environmental cleanup, emergency-crew salaries and lawsuits.
>
> In fact, he believes the Lac-Megantic derailment could have more financial consequences than any other land disaster in North American history.
>
> "The whole cost of this will be far closer to $1 billion than to $500 million," said the Universite Laval academic, adding he would be surprised if the railway had a total of $500 million in coverage.
>
> "What will probably happen? ...The company will go bankrupt, insurance coverage won't be enough."
>
> Gardner expects governments will wind up covering the difference.[17]

On August 7, 2013, MM&A filed for bankruptcy in both Canada (Quebec) and the US (Maine).[18]

> "It has become apparent that the obligations of both companies now exceed the value of their assets, including prospective insurance recoveries," MM&A chairman Edward Burkhardt said in a statement Wednesday.
>
> Filing for bankruptcy is "the best way to ensure fairness of treatment to all in these tragic circumstances," he said.
>
> The decision means the company will start a judge-supervised process to determine how much money will be paid to its various creditors. The process, which allows the company to tackle its unmanageable debt load and remain viable, can be lengthy and typically places secured creditors ahead of those seeking compensation through a lawsuit.

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[16] See footnote 12.
[17] See footnote 15.
[18] Mackrael, Kim and Tu Thanh Ha, "MM&A files for creditor protection after Lac-Mégantic rail disaster" Globe and Mail. Accessed August 7. http://www.theglobeandmail.com/news/national/rail-company-involved-in-megantic-disaster-files-for-bankruptcy/article13644535/#dashboard/follows/

> MM&A's insurance provider, XL Group, has so far declined to cover the cleanup bills, leaving the province to step in and pay more than $8-million to ensure the work continues.
>
> The court documents indicate that XL has no plans to contribute to continuing environmental recovery costs because it has decided to prioritize claims from victims affected by the disaster. MM&A's insurance policy with XL covers the company for up to $25-million, according to the court documents.
>
> Because of the number of claims and the amounts being claimed, the insurer "cannot provide for payment of covered environmental cleanup costs to the detriment of the third-party claimants, especially where the amounts of the claims exceed the limit of the coverage," the documents state.

Based on the information provided above, the now bankrupt MM&A has liabilities in excess of assets, minimal insurance coverage ($25 million); and the insurer has so far refused to pay environmental cleanup costs.

Ongoing squabbling has recently intensified between Quebec and the Canadian federal government over who should pay for the clean-up, economic recovery and town reconstruction. Quebec is insisting that the federal government pitch in more than the $60M they have committed to. In the October 2013 Throne Speech, the federal government promised to help more with decontamination and reconstruction but have yet to commit to an exact amount.

The Quebec government has still not supplied the federal government with a cost estimate for the cleanup and reconstruction. Federal officials refuse to commit to a fixed amount without a final bill.[19]

While MM&A is bankrupt, some **$25 million** in derailment insurance policy is earmarked by the US bankruptcy trustee for the victim's families. There is a possibility that additional compensation could be obtained for the families from a second insurance policy or from the sale of the company's assets, but these amounts are uncertain.[20]

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[19] The Globe and Mail, "Throne Speech to promise help with Lac-Mégantic cleanup, but not a 'blank cheque,' insiders say," October 15, 2013.
http://www.theglobeandmail.com/news/politics/throne-speech-to-promise-help-with-lac-megantic-cleanup-but-not-a-blank-cheque-insiders-say/article14883079/#dashboard/follows/

[20] Montreal Gazette, "Quebec rail victims could begin to see compensation in mid-2014: U.S. trustee," October 22, 2013.
http://www.montrealgazette.com/business/Quebec+rail+victims+could+begin+compensation+mid2014/9066861/story.html

Certainly, even individual victims of derailment have recently received compensation greater than $25 million,[21] therefore higher compensation, if available, would be justifiable.

On the **decontamination costs alone** there are a series of estimates:

- In late July 2013, a Quebec-based Ecotoxicologist, Emilien Pelletier, estimates that the bill just for decontamination would be **$500 million** and that doesn't include town reconstruction.[22]

- In early August 2013, MM&A was reported to have estimated the decontamination costs at **$200 million** in court documents.[23]

- In an October 2013 article, the Quebec government recently estimated the **soil decontamination costs alone at $150 million**.[24]

**Overall costs estimates** vary from several hundred million dollars to $1 billion:

- As indicated above, Quebec law professor, Daniel Gardner, estimated in August that the costs would far closer to **$1 billion than $500 million**.[25]

- In September 2013, the Toronto Star reported that cleanup costs are pegged as high as **$500 million by some estimates**.[26]

- On October 15, 2013, the Globe and Mail (Canada's National paper), indicated that "[e]xperts and government officials expect that **the bill will easily reach $200-million, and could even end up in the vicinity of $1-billion**."[27]

In light of the above, it would appear that the minimum decontamination costs would be $200 million and the minimum total costs (decontamination, town reconstruction and

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[21] See footnote 5.
[22] See http://www.ledevoir.com/environnement/actualites-sur-l-environnement/383941/blanchet
[23] See http://www.theglobeandmail.com/news/national/quebec-could-still-be-on-hook-for-cleanup-bill/article13680378/#dashboard/follows/ and http://www.thestar.com/news/canada/2013/08/09/lac_megantic_cleanup_to_stretch_into_next_year.html
[24] See http://www.thestar.com/news/canada/2013/10/03/lacmegantic_ottawa_to_pitch_in_more_money_for_cleanup_of_train_derailment.html
[25] See footnote 15.
[26] See http://www.thestar.com/news/canada/2013/09/24/lac_megantic_cleanup_quebec_asks_federal_government_to_share_bill.html#
[27] See footnote 19.

economic recovery, and compensation for victims' families) would be approximately $500 million. The total bill could escalate to $1 billion and beyond. The updated information is consistent with TGG's August 2013 estimate from the NEB expert report:

**"It is far too early to know the final costs for this disaster but they are estimated to be in the hundreds of millions, and possibly exceed $1 billion."** [28]

## 2.3. Relevance of Lac-Mégantic to Estimating the Costs of CBR Accidents/Spills

The Lac-Mégantic tragedy is directly relevant to an estimation of the costs of a major CBR accident/spill for the following reasons:

1. It demonstrates the consequences of a CBR accident in a small town by a lake, thus proximate to people, water and economic activity.
2. The Lac-Mégantic tragedy demonstrates the effect of a rupture of 63 tank cars on a unit train with a total of 72 tankers, all carrying Bakken crude.
3. Bakken crude, which caused the explosion, is very light, and has hazardous characteristics (notably flammability).
4. Rail is now transporting over 600,000 barrels per day (and over 60% of the total) from Bakken production.[29]
5. More generally, the rapid expansion of CBR results from the rapid expansion in production and transport of unconventional crudes (Bakken and other light crudes from shale/tight oil plays and dilbit and other heavy crudes from Canadian tar sands).[30]

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[28] See footnote 3, p. 39.

[29] See North Dakota Pipeline Authority website. Accessed October 30, 2013. http://northdakotapipelines.com/directors-cut/.
Monthly Updates for April 2013-October 2013 (February 2013-August 2013 data), reporting transport by rail ranging from 600,000 to 700,000 barrel per day, comprising 61-75% of total Bakken production.

[30] To date, a sizable proportion of overall recent CBR activity relates to Bakken production. The Keystone XL Draft Supplemental EIS (KXL DSEIS) assumes that CBR could be rapidly expanded to transport expanded Canadian tar sands production of dilbit and other heavy crudes, so as to provide a viable alternative to expanded pipeline capacity. The KXL DSEIS analysis of tar sands CBR is flawed and potentially misleading because it assumes that CBR can be quickly and vastly scaled up, with no significant operating, logistical, economic or regulatory constraints. Nonetheless, some Western Canadian production is already being transported by rail into the US (including dilbit, railbit, and raw bitumen, from both tar sands and non-tar sands), and there is a potential for further expansion of CBR transport of unconventional Canadian crudes.
See footnote 29; Titterton, Paul, Tank Car Update: Presentation to SWARS, February 28, 2013. Accessed October 30, 2013.
http://www.swrailshippers.com/swars_pdfs/2013_gatx_presentation.pdf;
(footnote continued on next page)

6. In addition to the devastation of the Lac-Mégantic town center, there has been significant release of crude oil (6.0 million liters or 1.6 million gallons) into the environment (affecting soil, water and air).[31]
7. There are very serious concerns about who will bear the financial responsibility for the disaster.

Although the Lac-Mégantic accident/spill was devastating and will likely have costs in the order of $500 million to $1 billion, it is nowhere near a worst-case scenario for a CBR accident.

Costs/damages for a similar incident could have been substantially higher had it occurred in a more populated area. Lac-Mégantic demonstrates how an accident involving highly flammable light crude (such as the Bakken crude) can have devastating consequences even in a small town in terms of loss of human life and widespread explosion and fire damage to surrounding property. In an urban area, the effects of such an accident could be catastrophic and costs could easily escalate to the multi-billion dollar range.[32]

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(footnote continued from previous page)
Keystone XL Draft Supplemental EIS, pp. 1.4-33 – 1.4-60. Accessed October 30, 2013. http://keystonepipeline-xl.state.gov/documents/organization/205654.pdf;
Goodman, Ian and Brigid Rowan, Report evaluating the adequacy of the Keystone XL (KXL) Draft Supplemental Environmental Impact Statement (DSEIS) Market Analysis, April 22, 2013, pp. 33-50, Adobe pp. 267-284
http://switchboard.nrdc.org/blogs/aswift/Comments%20of%20Sierra%20Club%2C%20et.%20al.%2C%20on%20the%20Keystone%20XL%20DSEIS.4.22.13.pdf

[31] There have been concerns that the spill affected water quality and drinking water in Lac-Mégantic and nearby towns. Authorities continue to monitor water quality.
"Government Examining Lac-Mégantic Health Risks," The Record, July 31, 2013. Accessed August 2, 2013.
http://www.sherbrookerecord.com/content/gov%E2%80%99t-examining-lac-megantic-health-risks; see also footnote 10.

[32] In the context of the PHMSA rulemaking and elsewhere, some may submit that the Lac-Mégantic accident is an exceptional and possibly worst-case scenario that is unlikely to be repeated. And this particular accident certainly has some attributes that may be atypical or even unique. That said, this accident also occurred in a relatively small town. A similar explosion and fire in a more dense urban area could have had even worse consequences and higher costs. In an urban area, the particular factors in Lac-Mégantic (unattended train rolling down steep grades to crash at high speeds) may be far less likely to occur. On the other hand, in an urban area, there are other risk factors, such as increased danger of collisions with other trains (or other vehicles), as well as proximity to large populations and other infrastructure.

It may also be pointed out that the Lac-Mégantic accident occurred in Canada and that the estimated costs are in Canadian dollars. But in fact, the Lac-Mégantic accident is very relevant for the US. First, US and Canadian dollars now have similar value, so the cost estimates for Lac-Mégantic accident would be similar if presented in US dollars. Second, the accident occurred very close to the US border, on a train that had originated in the US (North Dakota), traveled through numerous US states and cities, and would have again passed through the US (Maine) on its intended routing between Quebec and New Brunswick.

# 3. Estimated Costs of Enbridge's Line 6B Spill in Marshall, MI

## 3.1. Description of Disaster

According to the NTSB, following its investigation of the Enbridge Line 6B Spill (emphasis added):[33]

> On Sunday, July 25, 2010, at about 5:58 p.m., a 30 inch-diameter pipeline (Line 6B) owned and operated by Enbridge Incorporated ruptured and spilled crude oil into an ecologically sensitive area near the Kalamazoo River in Marshall, Mich., for 17 hours until a local utility worker discovered the oil and contacted Enbridge to report the rupture.
>
> The NTSB found that the material failure of the pipeline was the result of multiple small corrosion-fatigue cracks that over time grew in size and linked together, creating a gaping breach in the pipe measuring over 80 inches long.
>
> "This investigation identified a complete breakdown of safety at Enbridge. Their employees performed like Keystone Kops and failed to recognize their pipeline had ruptured and continued to pump crude into the environment," said NTSB Chairman Deborah A.P. Hersman. "Despite multiple alarms and a loss of pressure in the pipeline, for more than 17 hours and through three shifts they failed to follow their own shutdown procedures."
>
> […]
>
> Over 840,000 gallons of crude oil - enough to fill 120 tanker trucks - spilled into hundreds of acres of Michigan wetlands, fouling a creek and a river. A Michigan Department of Community Health study concluded that over 300 individuals suffered adverse health effects related to benzene exposure, a toxic component of crude oil.
>
> Line 6B had been scheduled for a routine shutdown at the time of the rupture to accommodate changing delivery schedules. Following the shutdown, operators in the Enbridge control room in Edmonton, Alberta, received multiple alarms indicating a problem with low pressure in the pipeline, which were dismissed as

[33] NTSB Press Release, "Pipeline Rupture and Oil Spill Accident Caused by Organizational Failures and Weak Regulations," July 10, 2012. Accessed August 3, 2012. http://www.ntsb.gov/news/2012/120710.html

being caused by factors other than a rupture. "Inadequate training of control center personnel" was cited as contributing to the accident.

The investigation found that Enbridge failed to accurately assess the structural integrity of the pipeline, including correctly analyzing cracks that required repair. The NTSB characterized Enbridge's control room operations, leak detection, and environmental response as deficient, and described the event as an "organizational accident."

Following the first alarm, Enbridge controllers restarted Line 6B twice, pumping an additional 683,000 gallons of crude oil, or 81 percent of the total amount spilled, through the ruptured pipeline. The NTSB determined that if Enbridge's own procedures had been followed during the initial phases of the accident, the magnitude of the spill would have been significantly reduced. Further, the NTSB attributed systemic flaws in operational decision-making to a "culture of deviance," which concluded that personnel had a developed an operating culture in which not adhering to approved procedures and protocols was normalized.

The NTSB also cited the Pipeline and Hazardous Materials Safety Administration's weak regulations regarding pipeline assessment and repair criteria as well as a cursory review of Enbridge's oil spill response plan as contributing to the magnitude of the accident.

The investigation revealed that the cracks in Line 6B that ultimately ruptured were detected by Enbridge in 2005 but were not repaired. A further examination of records revealed that Enbridge's crack assessment process was inadequate, increasing the risk of a rupture.

"This accident is a wake-up call to the industry, the regulator, and the public. Enbridge knew for years that this section of the pipeline was vulnerable yet they didn't act on that information," said Chairman Hersman. "Likewise, for the regulator to delegate too much authority to the regulated to assess their own system risks and correct them is tantamount to the fox guarding the hen house. Regulators need regulations and practices with teeth, and the resources to enable them to take corrective action before a spill. Not just after."

As a result of the investigation, the NTSB reiterated one recommendation to PHMSA and issued 19 new safety recommendations to the Department of the Transportation, PHMSA, Enbridge Incorporated, the American Petroleum Institute, the International Association of Fire Chiefs, and the National Emergency Number Association.

## 3.2. Costs and Sources of Cost Data

As of March 31, 2013, Enbridge indicated in its First Quarter Interim Report to Shareholders that the total clean-up for the spill is now estimated to cost approximately $1 billion. Enbridge's civil penalty for the spill was only $3.7 million.[34] Enbridge also points out that there is a possibility that the clean-up bill will continue to increase as the clean-up is still ongoing.

No lives were lost, but as the NTSB citation above indicates: "over 300 individuals suffered adverse health effects related to benzene exposure, a toxic component of crude oil." Furthermore, "[o]ver 840,000 gallons of crude oil - enough to fill 120 tanker trucks - spilled into hundreds of acres of Michigan wetlands, fouling a creek and a river."

## 3.3. Relevance of Marshall, MI to Estimating the Costs of CBR Accidents/Spills

The Marshall, MI pipeline disaster is also highly relevant to an estimation of the costs of a major CBR accident/spill for the following reasons:

1. It demonstrates the costs of a dilbit spill in an environmentally sensitive area (with wetlands and proximity to waterways and human population) in a non-urban area.[35] Marshall, MI is not dissimilar to the many areas through which trains are also routed (along waterways in order to minimize elevation and through population centers throughout the US).

2. The spill volumes at Marshall were within the range of the amount of spill possible (and, in fact, substantially less than the maximum spill) if a crude by rail unit train released much of its cargo. 840,000 gallons (or 3.3 million liters) were spilled at Marshall, the equivalent of the full cargo release of 27 tank cars (carrying 31,000 gallons) or 34 tank cars (carrying 25,000 gallons).[36] With

[34] Enbridge First Quarter Interim Report to Shareholders for the Three Months Ended March 31, 2013, Section 11 Contingencies, Adobe p. 67. Accessed August 3, 2013.
See http://www.enbridge.com/InvestorRelations/FinancialInformation/InvestorDocumentsandFilings.aspx and then click on FIRST QUARTER REPORT under 2013.
[35] The population of Marshall is approximately 7,000.
[36] Maximum capacity per tank car typically varies between 25,000 and 31,800 gallons of crude, based on factors including maximum weight limits, tank car design, and type of crude. Capacity will generally be lower for heavy crudes (such as the dilbit spilled at Marshall), which weigh more per gallon than light crudes (such as the Bakken crude spilled at Lac-Mégantic). Likewise, capacity will be lower for tank cars
(footnote continued on next page)

transport by unit trains on the rise, and unit trains carrying up to 100+ tank cars, it would be possible for a unit train to spill significantly higher volumes than the 840,000 gallons (or 3.3 million liters) released at Marshall. The 6.0 million liters released at Lac-Mégantic (almost twice the amount released at Marshall) provide support for this finding.

3. In light of recent findings regarding the Line 6B spill, the EPA has recently expressed concerns regarding the additional impacts of tar sands crude spills (versus conventional oil), with a particular concern about spills on waterways.[37]

Regarding the need for improved safety regulation for CBR, there are a number of regulatory lessons from the Marshall, MI rupture that should be considered:

1. The NTSB investigation also clearly indicates that in the case of Enbridge, and with respect to the regulation of pipeline operators, "trust us" isn't good enough. Chair Hersman has insightfully pointed out that "for the regulator to delegate too much authority to the regulated to assess their own system risks and correct them is tantamount to the fox guarding the hen house."[38] Chair Hersman's words are even more relevant for the regulation of transport of hazardous materials by rail, which is in many ways both weaker and more fragmented than the regulation of liquid pipelines.[39]

2. The NTSB investigation pointed out that the Marshall rupture was "a wake-up call" to industry, the regulator, and the public." Enbridge knew for years that the

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(footnote continued from previous page)
which have higher tare (unloaded) weights (such as those with heater coils and insulation, which are also sometimes used to transport dilbit).

[37] Comments of EPA on the Department of State's Keystone XL Draft Supplement Environmental Impact Statement (DSEIS). Accessed October 30, 2013. http://epa.gov/compliance/nepa/keystone-xl-project-epa-comment-letter-20130056.pdf

[38] See footnote 33.

[39] As described in various other documents in the current proceeding, there is a long history of problems in regard to transport of hazardous materials (notably flammable liquids) by rail, with only a very slow and partial response to tighten standards to insure public safety. See Village of Barrington, Illinois and The Regional Answer to Canadian National (TRAC) - Petition for Rulemaking (P-1587); National Transportation Safety Board - Accident Report - Derailment of CN Freight Train U70691-18 With Subsequent Hazardous Materials Release and Fire Cherry Valley, Illinois June 19, 2009; and National Transportation Safety Board - Safety Recommendation - R-12-5 through -8, R-07-4 (Reiteration)

In the case of liquid pipelines, the pipeline owner/operator is typically responsible for construction and operation of all facilities within its transport system that are handling hazardous materials (notably flammable liquids), including pipes, valves, and pumping stations. By contrast, in the case of rail, the railroads provide motive power and crews to move hazardous materials (notably flammable liquids) in tank cars which are typically owned, loaded, and unloaded by shippers and other entities besides the railroads.

pipeline was vulnerable; much as the rail industry knows that another CBR spill is only a matter of time.

Although the Line 6B rupture caused widespread devastation to the Kalamazoo and surrounding wetlands and, at $1 billion in clean-up costs, holds the record for the single most expensive onshore spill in US history,[40] it is nowhere near the worst-case scenario for a CBR disaster. Similar to the Lac-Mégantic tragedy involving a CBR release of Bakken, the costs/damages for a CBR dilbit spill could be substantially higher in a more populated area, and costs could easily escalate to the multi-billion dollar range. The clean-up of dilbit, especially in waterways is particularly problematic and expensive. Moreover, the condensate can be highly flammable when spilled and this flammability could have catastrophic consequences in a more densely populated area.

[40] See footnote 33.

# 4. Conclusion

As the examples of the Lac-Mégantic CBR tragedy and the Marshall, MI pipeline rupture have demonstrated, a major CBR unit train accidents/spill could cost $1 billion or more for a single event.

Unit trains now transport unconventional crude, including both dilbit and Bakken, through densely populated urban areas, and this form of transport is rapidly growing. An accident/spill in an urban area could damage and disrupt major infrastructure, result in serious and widespread water and soil contamination, and possibly cause loss of life. The costs of a major unit train derailment in an urban centre could easily escalate into the multi-billion dollar range.

latimes.com/nation/nationnow/la-na-nn-train-crash-alabama-oil-20131109,0,780637.story

# latimes.com

## Train in Alabama oil spill was carrying 2.7 million gallons of crude

By Soumya Karlamangla

6:24 PM PST, November 9, 2013

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A train that derailed and exploded in rural Alabama was hauling 2.7 million gallons of crude oil, according to officials.

The 90-car train was crossing a timber trestle above a wetland near Aliceville late Thursday night when approximately 25 rail cars and two locomotives derailed, spilling crude oil into the surrounding wetlands and igniting a fire that was still burning Saturday.

Each of the 90 cars was carrying 30,000 gallons of oil, said Bill Jasper, president of the rail company Genesee & Wyoming at a press briefing Friday night. It's unclear, though, how much oil was spilled because some of the cars have yet to be removed from the marsh.

"Most of the cars did not spill all of the product that was inside it," Don Hartley, a regional coordinator for the Alabama Emergency Management Agency, told the Los Angeles Times.

Emergency responders have to wait until the fire has burned out, Hartley said.

Hartley said that the marsh where the oil spilled is stagnant, so the oil hasn't spread to other water systems. Scott Hughes, spokesman for the Alabama Department of Environmental Management, told The Times that responders had set up booms to absorb some of the oil.

"Typically wetlands are a sanctuary for a variety of different types of aquatic species, so once we're able to get in and assess environmental impacts, we'll certainly look at any impacts to aquatic organisms and other types of wildlife," Hughes told The Times.

There are extensive wetlands near Aliceville, a town of about 2,400 in western Alabama, according to the state's Forestry Commission website.

Hughes said Friday that a check of the water quality of the nearby drinking wells came up clean. The U.S. Environmental Protection Agency has been at the scene since Friday monitoring air quality in the region.

There are more than 100 people from various local, state and federal agencies surveying the scene, Hartley said.

Hartley said 21 cars were still in the marsh, but that most of the other cars had been moved back onto the track. The most damaged cars in the water will be removed last. The 60-foot-long, 10-foot-high wooden trestle, which also caught on fire, will have to be rebuilt. That will take about a week, Hartley said.

The cause of the crash is under investigation, and will probably take weeks to determine. The train, which was en route from Amory, Miss., to Walnut Hill, Fla., was traveling below the posted track speed of 40 mph, according to Jasper.

“No issues have been found with the performance of the train’s two-man crew,” reads a statement from the train company.

The track was last inspected Monday, and the most recent train to traverse the section of track where the crash occurred passed the site approximately 2.5 hours before the derailment, according to the statement.

The explosion of an oil train in Lac-Megantic, Canada, in July has fueled criticism regarding the use of rail to move oil. Railroads are carrying 25 times more crude oil than they were five years ago. In that incident, a train with 72 tank cars carrying crude oil from North Dakota's Bakken Shale fields ignited an inferno in the city, The Times reported in September.

Hartley said that the Alabama train probably originated from North Dakota.

**ALSO:**

Hawaii House passes same-sex marriage bill

With Hawaii vote, same-sex marriage wave continues to grow

Guns & Ammo editor steps down after gun rights column stirs outrage

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# THE TRUE COST OF COAL

## The Coal Industry's Threat to Fish and Communities in the Pacific Northwest

NATIONAL WILDLIFE FEDERATION 2012

Flickr: Dmitry Klimenko

Report

# THE TRUE COST OF COAL

## The Coal Industry's Threat to Fish and Communities in the Pacific Northwest

# Executive Summary

The era of Big Coal in the United States is on the ropes. Over the last decade we have steadily reduced our reliance on this dirty fuel, both because of its impacts on public health and our global climate, and because coal has been eclipsed by cheaper, cleaner energy options. But despite the gains we have made, the coal industry remains a political powerhouse that isn't going down without a fight: Peabody Energy, Arch Coal, and the other mega-producers have now set their sights on the Asian market, where pollution and climate concerns have taken a backseat to a rabid demand for cheap energy.

In an irony lost on no one, the cheapest and fastest route from the western coal fields of the Powder River Basin goes straight through the Pacific Northwest — a region that is probably the most environmentally conscious in the country. People in the Pacific Northwest know how important a clean environment is to their economy and quality of life, whether that means healthy salmon runs or clean air and water. Sportsmen, Tribes, and citizens everywhere know they face a choice between those values and the opportunity to become a stopover for one of the world's dirtiest industries: To date, Big Coal has proposed at least six export terminals in Washington and Oregon. If all of them are built we could see 150 million tons or more of coal moved by rail, barge, and tanker every year through those states.

Until recently, coal exports weren't even on the list of people's concerns for the Columbia River, Puget Sound, and the other rich but fragile fisheries in Washington and Oregon. Decades of overfishing, pollution and impassible dams took their toll, but progress has been made in recent years as cities and towns prioritize smart development, fish habitat is being restored, Columbia River dams are allowing more juvenile fish to pass and the Northwest's remaining coal plants are being shut down. Fishing remains a multi-billion dollar industry in the region, so when evidence surfaced that the world's dirtiest industry was planning an all-out blitz, residents began to take notice and speak out.

In *The True Cost of Coal Exports*, we examine the likely impacts these projects would have on the communities and ecosystems in their path, with a focus on the danger posed to fisheries and the people who depend upon them for their livelihoods, recreation, and cultures.

Paul K. Anderson

The dangers the Pacific Northwest faces from exporting coal include:

- Diesel emissions and coal dust from mile-and-a-half long rail cars would reduce air quality and deposit toxic elements such as mercury into waterways;
- Port construction and a huge scaling up of barge traffic would harm crucial fish habitat;
- Burning more coal in Asia would drive global warming, ocean acidification, mercury deposition, and other crises that affect species like salmon and steelhead that help power the economies of Washington and Oregon.

We also peel back the curtain on the companies behind the rush to export, and the lessons are clear: Big Coal has razed, dynamited, and excavated immense swaths of once-pristine areas like the Appalachian Mountains and the Powder River Basin, leaving behind a toxic legacy of pollution and shattered communities. Not only is the mining process a fundamentally destructive one, but, as a whole, the coal industry has earned a reputation for unscrupulous—and often illegal—behavior. As if the point needed any emphasis, they have already gotten off on the wrong foot in the Northwest, deceiving regulators about the scope and size of their latest export plans. It is the wrong industry, at the wrong place, at the wrong time.

We have an opportunity to say "NO!" to coal, but it will take a united effort by citizens, states, and the federal government. So far the first two groups have stepped up to the plate, with a growing coalition of diverse Northwestern voices opposing the plans: the health community, conservationists, tribes, fishermen, faith leaders, elected officials and many others. All agree that these proposals contradict deeply held regional values, and come with too high a price. As such, this report is a call to action for Americans to stand up against Big Coal to protect our natural resource legacy and public health.

But the local and regional voices may not be sufficient to push back against the multi-billion dollar expansion plans that Peabody Energy, Arch Coal, and others are determined to push forward.

Given the broad impact that increased coal shipments will have, not only on the local communities and the region's critical natural resources, but also on the global climate, national scrutiny and oversight is essential. And national leadership to pursue an alternate energy path for our country is urgent. We lack crucial data on these issues, and National Wildlife Federation recommends a series of policy steps to ensure that we know the full extent of these proposals' impacts on our environment and public health. A full list of recommendations can be found at the end of this report.

# INTRODUCTION

## STOPPING COAL IN ITS TRACKS

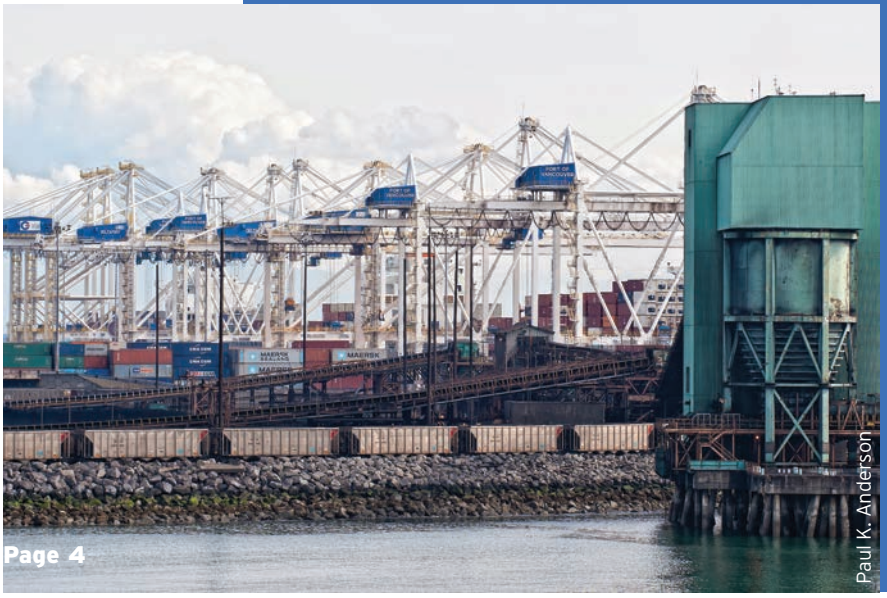
Here's the very good news: In the United States, we have steadily reduced our dependence on coal. In 1988, coal-fired power plants supplied 57 percent of the nation's electricity.[1] At the end of 2011, it had dropped to less than 40 percent.[2]

Coal will assuredly continue to decline as a domestic energy source, for good reason: it is a dirty fuel, with destructive impacts that harm our health, poison our waters and foul our air. A national movement that includes scientists, health care professionals, sportsmen, Tribal leaders, elected officials from both major parties, parents and business leaders are demanding that we replace coal with smarter, more modern, and less caustic energy sources. New coal-fired power plant construction is at a virtual standstill, old ones are slated for retirement, and more renewable energy is coming online every day. As one top industry analyst astutely remarked, "Coal is a dead man walking."

It's not dead yet. The bad news is that the coal industry is responding to this shrinking domestic market by shipping more dirty fuel overseas, especially to growing markets in China and India. Some of the largest coal companies in the U.S. propose building or expanding six coal ports in Oregon and Washington, states that have rejected coal for their own energy needs. (See map, Page 16)

These controversial proposals have opened a new front in the coal wars. In addition to building or enlarging ports in sensitive aquatic habitat, the export plan includes a massive build-up of rail traffic, ferrying tens of millions of tons of coal annually from Wyoming and Montana, through Idaho to ports along the Columbia River and in Puget Sound. Mile-and-a-half long freight trains, known in the railroad world as "black snakes," would leave a trail of coal dust, toxic pollution, health problems and disrupted communities from Wyoming's Powder River Basin to the Pacific Ocean.

The prospect of damaged fisheries, fugitive coal dust and diesel from freight cars, and toxic pollution from burning coal are all good reasons to oppose these port expansion proposals, but there's more: burning coal is one of the world's biggest sources of carbon pollution.[3] Carbon dioxide is a heat-trapping gas when it lodges in our atmosphere. Once there, it warms the planet in much the way wearing a down parka on a warm day will make you overheat. Carbon dioxide build-up is one of the major contributors to higher global temperatures, melting ice caps, and rising seas that researchers have documented all over the globe, and contributes to the strange weather patterns that have escalated in the last century. Our oceans are also absorbing carbon dioxide, which is turning them more acidic and stressing marine life. We can substantially reduce carbon emissions using existing, affordable technologies, but sending American coal to China is simply outsourcing our pollution, and climate change and toxic emissions don't respect international boundaries.



Paul K. Anderson

## COAL AFFECTS US ALL

The fact is these coal expansion proposals affect us all, whether we live near Puget Sound or the Chesapeake Bay. It is an intensely local issue for citizens who live where coal is mined, transported and shipped. It is an issue for any Pacific Northwesterner who values living in one of the country's greenest regions, home to some of the nation's most productive fisheries and progressive energy politics. It is also a national issue for those who care about an energy future that does not include spewing vast quantities of toxics and carbon pollution into our planet's atmosphere.

Fortunately, these port expansion proposals are by no means a done deal. There's a growing backlash to these plans from a wide swath of Pacific Northwest residents and around the nation, despite coal companies' promise of a relatively small number of permanent jobs and additional tax revenues for the states. People who are more accustomed to waiting for salmon runs on riverbanks than "black snakes" at railroad crossings are making their objections known—from Bozeman, Montana to Bellingham, Washington, from Sandpoint, Idaho to Clatskanie, Oregon. Citizens are writing letters, attending meetings, and voicing objections to the proposals. Residents are asking why they should support a commodity whose benefits to the region are overwhelmingly outweighed by its costs.

This report details the main proposals to expand ports and loading facilities in the Pacific Northwest, and walks readers through the plans, companies and concerns associated with this new coal juggernaut. As we said in the beginning, the good news is that a growing number of Americans realize that a successful future will require weaning ourselves off coal while expanding our use of renewable and less carbon-intensive energy sources. This report will help you understand why these coal port expansions are a bad idea, and what you can do to help stop these black snakes from multiplying.

Power Past Coal

# CHAPTER ONE

## Shadows over the Pacific Northwest

### *Opening the floodgates to Big Coal undermines a region's identity – and self-interest*

In March 2011, Washington Governor Christine Gregoire announced plans to close the state's last coal-fired electrical generating plant by 2025. Citing a need to reduce pollution, develop renewable power, and curb the state's greenhouse gas emissions, the Governor joined state legislators, labor unions, and conservation groups to herald the end of the state's coal burning era. Responding to this radical plan, Lou Florence, director of TransAlta, the energy company that runs the coal power plant in Centralia, told the *Centralia Chronicle*: "TransAlta supports the goal of a coal-free Washington."

Oregon had already announced plans to shutter the Boardman Coal Plant by the end of the decade. Boardman is the state's only remaining coal-fired power plant — and its largest single carbon polluter. Instead of burning coal, officials trumpeted that a biofuel refinery would be built in Boardman, and will make ethanol out of poplar trees, wheat straw, and corn stalks. Governor John Kitzhaber said the new plant "will support the long-term development of renewable energy resources and boost economic rural development."

A deeply ingrained environmental ethic runs through the Pacific Northwest, like the Chinook and Coho fingerlings that dart through its waters. The region's natural beauty and bounty bestow both a source of income and a sense of cultural identity to its residents. Its lawmakers, citizens and businesses emphasize smart, green, long-term planning. The politics, economics and industry of the Pacific Northwest have been shifting — away from intense resource extraction like clearcutting timber and overfishing salmon, toward more sustainable and viable long-term stewardship.

Flickr: robert.hamilton

In contrast to these deep-rooted values, Big Coal's proposals to use Oregon and Washington as conduits for millions of tons of dirty fuel on their way to Asian markets are shocking.

Part of what draws people to the Pacific Northwest is a lifestyle linked to clean creeks and streams, healthy conifer forests, outdoor recreation and an appreciation of its abundant natural beauty. Places like Hood River, along the Columbia, have become a global destination for windsurfers, and on a broader scale, consumer spending on outdoor recreation generated $256 billion in 2011, supporting 2.3 million jobs in Western States.[4] Native tribes like the Lummi and the Yakama, the Warm Springs and the Nisqually, whose cultures are inextricably entwined with the salmon and shellfish of the region, see troubling downsides to these proposals.

Another reason that opposition to these proposals is fierce — and getting fiercer — is that despite the region's environmental leadership today,

there's no question that the Pacific Northwest's fisheries have suffered from past development. Salmon runs are slowly being restored after dams, overfishing and toxins depleted them, yet many key species are still endangered or threatened. Ecosystems already struggling to recover do not need the additional stress of dredging, construction, tons of coal dust, and more pollution from coal combustion floating on the jet stream from Asia to coat America's streams and soil.[5]

In a nutshell, here's the irony facing residents of the Pacific Northwest: Just as Washington and Oregon are winding down coal burning because of a long list of environmental and health impacts, coal companies want to use the region's railways, rivers and ports to deliver millions of tons of a pollutant that will haunt the region for decades (see Impacts, Chapter 4). In return, coal companies and their partners are offering a few dozen permanent jobs and some increased tax revenue to offset the coal dust, mercury poisoning, arsenic deposits, congestion and noise that increased rail traffic and port expansions will spawn.

For many in the Pacific Northwest, that's a fool's bargain, and people are organizing to head off this bad idea before it gathers too much steam.

Power Past Coal

Nic Callero

# The Proposals

**LONGVIEW, WA:** The proposed Millennium Bulk Logistics Longview Terminal is located on the Columbia River Estuary and would potentially become a "mega-terminal," the largest West Coast export facility in the nation, exporting up to 60 million tons of coal a year.[6] The estuary is important for shallow-water salmon, smelt, and other marine species.[7] It is also near the confluence of the Cowlitz River and the Columbia; and the lower Columbia River area has been identified as vital habitat for a range of species, from Dungeness crabs to sea lions, starry flounder and shellfish like oysters, clams and mussels.[8] In addition, this stretch of the river is a favorite for sport anglers, especially during spring and fall salmon runs, when hundreds of boats converge upon this famous fishing spot.

The terminal is partly owned by Arch Coal, one of the two biggest coal companies in the U.S., in partnership with the Australian company Ambre Energy. The corporate entity created by Ambre Energy is Millennium Bulk Logistics, which got off on the wrong foot when they lied about the size of the project in their initial proposal, withdrew their permit, and reapplied after paying a fine (see Meet the Players, page 18).

**CHERRY POINT, WA:** The proposed Gateway Pacific Terminal near Bellingham, WA, could ship up to 54 million tons of coal per year. Seattle-based SSA Marine joined Peabody Energy, the country's biggest coal company, to promote this expansion in Whatcom County. (The embattled New York financing company Goldman Sachs owns a portion of SSA's parent company.) SSA Marine already found itself in hot water with Whatcom County, when one of its contractors cleared trees in a wetland without the necessary permits (see page 20).

Located within the Cherry Point Aquatic Reserve,[9] this facility is near one of the region's most important herring spawning grounds. Herring are a key food link for marine species, from Chinook salmon to killer whales, and herring populations are already under stress and declining.[10]

Daniel Dancer

The Lummi Nation, whose lands border the facility, holds treaty rights to the fishing grounds in the area, and is concerned about the impacts on those legal rights.[11] There is vocal opposition from Bellingham residents, who fear the port expansion will degrade their quality of life. A report by Public Financial Management, Inc. of Philadelphia concluded that instead of adding jobs, impacts on the city's image as a clean, healthy city could harm job growth, drive away tourism, and detract from investment.[12]

**PORT OF ST. HELENS, OR:** Near Clatskanie on the Columbia River, Kinder Morgan Energy Partners plans a facility that could ship as much up to 30 million tons of coal annually (received by rail from the Powder River Basin in Wyoming and Montana).

To build this port, Kinder Morgan will partner with a subsidiary of Ambre Energy, the same Australia-based company involved in Longview. As with the Longview project, there are allegations that information about the project's impacts have been kept from the public. Oregon Gov. John Kitzhaber warned that the terminal "should not happen in the dead of night. We must have an open, vigorous public debate before any projects move forward."[13]

**PORT OF MORROW, BOARDMAN, OR:** Upstream from Port St. Helens on the Columbia River, Ambre Energy is planning another expansion — this one a transfer station that would off-load coal from rail cars, load them into barges, and take them downriver to St. Helens. Another Ambre subsidiary, the Coyote Island Terminal LLC of Salt Lake City, is behind this proposal to handle 8.8 million tons of coal per year. The company's own biological assessment showed that port construction and operations would "result in unavoidable impacts to protected species and critical habitat as project activities take place."[14] In April, Governor Kitzhaber sent a letter to federal officials in charge of approving the project, expressing concerns about the "significant" cumulative impacts of all the coal projects and requesting a thorough review.[15]

**GRAYS HARBOR, WA:** The proposed expansion of the Port of Grays Harbor in Hoquiam is near the Grays Harbor National Wildlife Refuge, one of the biggest staging areas for migrating birds in the lower 48.[16] Grays Harbor is an important stopover for Alaska-bound cruise ships, and residents worry that increased coal traffic (reports put the amount at 5 million tons per year) will put a damper on its ability to market its tourist trade. It is also home to important and growing runs of king and coho salmon during fall migration.[17]

**COOS BAY, OR:** The Port of Coos Bay, whose linchpin is wood products, has announced it is in "discussions" with coal developers. This plan, known only as "Project Mainstay," is shrouded in secrecy but could bring 6-10 million tons of coal through Coos Bay annually.

Add it all up and Northwest ports could be shipping over 150 million tons of coal per year, a staggering number that is deeply at odds with the region's ethos, economic aspirations, and future dreams.

Paul K. Anderson

# CHAPTER TWO

## What's Fishy about Coal

Fish, and fishermen, help define the Pacific Northwest, like crabbers in the Chesapeake, shrimpers on the Gulf Coast, and lobstermen in Maine. The salmon and steelhead that make their improbable journey from the Pacific Ocean, up the Sandy and the Skykomish, the Willamette and the Kalama, the Cowlitz and the Columbia, and spawn as far away as Idaho's Salmon River are as much a part of Oregon and Washington's identity as the rain that paints coastal conifer forests into seas of misty green.

Commercial fishermen, professional fishing guides, boaters, weekend anglers, oyster farmers, clam diggers, even the fishmongers at Seattle's famous Pike Place Market, all depend on healthy fish and shellfish stocks to support the local economy. Oceans, estuaries, rivers, sounds, streams, creeks and wetlands are vital parts of the region's employment — and enjoyment — for millions of people in our region. Recreational fishing accounts for $2.7 *billion* a year to the Washington and Oregon economies[18] — in addition to the substantial commercial fishing and aquaculture industries. A 2011 report for the Seattle Marine Business Association calculated that the commercial fishing industry in Washington alone contributed $3.9 billion to the state economy.[19]

In recent decades, the Northwest's aquatic abundance has declined as a result of what fishing guide Bob Reese calls "a thousand cuts."[20] (See "A Guide's Guide to Coal Exports," page 12.) Dams, railroad construction, ports, housing developments, toxins from industrial waste, and even invasive species have all combined to create tough times for fish that live here.[21] Herring, a "keystone species" that salmon rely on, have been in steep decline due to some of these stressors. Not surprisingly, salmon populations have been on a 160-year downward trend and are now a fraction of historic levels. Some salmon runs have slowed to a crawl and others have disappeared altogether.[22]

Flickr: Donald Clark

Expanding coal exports here will make the difficult process of restoration even harder. None of these proposals will make life better for the fish or the people who depend on them — for their livelihoods, for their recreation, for their regional identity, or for their peace of mind.

## Potential Impacts to Pacific Northwest Fish

When it comes to the Pacific Northwest, the coal industry is rushing to build without studying the full consequences of their proposals. There's a big gap in our scientific understanding of how our region's fisheries would be impacted by coal mining, transport, and burning, and common sense tells us to get this information before deciding whether to risk our vital natural resources. Although data for Oregon and Washington are hard to come by, case studies of similar developments around the world paint a troubling picture: From the effects of coal dust on mangroves near Cape Town, South Africa[23] to the adverse effects of coal combustion on juvenile fish populations in South Carolina,[24] from studies of juvenile salmonids and coal dust dispersal in British Columbia[25] to the effects of fly ash dumping on algae off England's coast,[26] these studies provide insight into the impacts we may face in the Pacific Northwest.

Based on the knowledge available, we are concerned about five major potential impacts to our land, water, and fisheries: (1) increased coastal riparian and marine habitat degradation from port expansions and shipping traffic; (2) decreased water quality from coal dust; (3) increased mercury deposition from coal burning and wind-driven transport; (4) increased carbon pollution from coal transport, export, and burning that is driving dangerous climate-related extreme weather nationally and globally; and (5) increased ocean acidity from coal burning.

Flicker: Spappy.jones

**Increased coastal riparian and marine habitat degradation from port and rail expansions** — Human development has squeezed the spawning grounds, estuaries, riverbanks and creekside habitat of all salmon species.[27] Each port expansion would require dredging, filling, new pylons, and shoreline grading.

- In the lone biological assessment prepared for any of these proposals to date, numerous ill effects were catalogued for the Morrow Pacific project in Boardman. For example, "The proposed construction at the Port of Morrow will involve piling installation using vibratory and impact hammers, which produce sound levels above the thresholds for fish disturbance and injury."[28] Construction would also result in increased water turbidity and possible toxic discharges.[29] And an expected doubling of barge traffic would raise the incidence of fuel leaks, wake strandings, noise disturbance, sedimentation, ship strikes, and a host of other threats to Columbia River fish.[30] Closer to the mouth of the river and the Pacific Ocean, marine mammals like orcas would be put in harm's way from possible strikes by barges and tankers.[31]
- Just across the Canadian border from the proposed Cherry Point export facility, dredging and filling for port construction at the Roberts Bank terminal (below) resulted in loss of cobble beach and sandflat habitat, conversion of shallow-water to deepwater habitat, and drying of moisture-dependent eelgrass habitat.[32] Some of these areas are now unusable by fish such as juvenile salmonids, which prefer shallow-water habitat, while further research is needed to examine changes to feeding habits and migration routes as a result of dredging and filling.[33]
- Increasing rail traffic along the Columbia River will require additional construction of rail lines, turnarounds, and passing loops long enough to allow trains operating on a single track to pass each other. There have been at least 30 coal train derailments in the U.S. since 2010 alone, raising the specter of massive coal contamination into river systems.[34] With increased rail traffic, an increase in fuel spills is also likely, which would further damage habitat.
- More exports means more tanker traffic, raising the risk of invasive species. In fact, a few hundred miles down the Pacific coast, San Francisco Bay has some of the highest levels of non-native species in the world: 85 invasives total, two-thirds of which are considered "harmful."[35] In that ecosystem, animals like the Chinese mitten crab were introduced by ballast water discharges, and now pose a risk to native fish (juvenile salmon are a major prey species for the crabs).[36]

**Decreased water quality from coal dust** — Nobody can predict the exact amount of coal dust that will enter Pacific Northwest watersheds as a result of these proposals, but the evidence doesn't look good. According to BNSF Railway, a major railroad company that transports coal from the Powder River Basin, fugitive coal dust is a significant problem for its track maintenance.[37] BNSF has estimated that each coal car loses between 500 and 2000 pounds (1/4 ton to 1 ton) during rail transit.[38] In scientific studies, coal dust has been shown to have a host of biological effects to the marine environment:[39]

- A study of juvenile Chinook in British Columbia found that exposure to the polyaromatic hydrocarbons (PAHs) found in coal dust increased the expression of certain genes that play "crucial roles in cellular metabolism," one of which can convert cancer-causing substances found in PAHs into active carcinogens.[40]
- Coal can physically damage fish habitat: Off the coast of England, a study showed that coal dust and fly ash dumping reduced light penetration and inhibited the growth of algae and bottom-dwelling plants and animals.[41]
- In the marine sediments adjacent to the Westshore Terminals coal facility on Roberts Bank, British Columbia, the concentration of coal residues doubled between 1977 and 1999.[42]

Jerry Bierens

***Right:*** **Wind kicks up a massive cloud of coal dust at the Westshore Terminals export facility in Vancouver, BC.**

Although not yet observed at this site, the concern is that sediments with high levels of coal will become devoid of the oxygen that bottom-dwelling plants and animals need to breathe.[43]

**Increased toxic deposition from coal burning and wind-driven transport** — Burning coal, whether in Centralia or Beijing, releases not just greenhouse gases but also poisonous substances like mercury and arsenic.[44] Toxic chemicals from Asian power plants rise on the winds and carry back across the Pacific Ocean to land on the Pacific Northwest: studies have placed nearly one-fifth of the mercury in the Willamette River, and 14% of the mercury on Mt. Bachelor in central Oregon, as originating from Asia.[45] According to the U.S. Environmental Protection Agency, "coal-burning power plants are the largest human-caused source of mercury emissions to the air in the United States, accounting for over 50 percent of all domestic human-caused mercury emissions."[46] Mercury from coal plants has huge impacts on both land and sea.[47] Mercury accumulates in the food chain, affecting not only fish but also fish-eating mammals and birds. Mercury warnings have become a part of modern life, cautioning citizens (especially pregnant women) to limit their consumption of many marine and freshwater species including swordfish, smallmouth bass, yellow perch and tuna.[48]

**Contributing to global climate change** — Although the politics of climate change are contentious, the science is unequivocal: the human activities of burning coal and other fossil fuels are releasing vast amounts of heat-trapping gases into our atmosphere that have contributed to increasing the average temperature of the planet. The range of climate-related problems is breathtaking:

- Higher temperatures have already contributed to sea level rise, melting glaciers, and increased extreme weather events like droughts, hurricanes, and floods.[49]
- Rising temperatures are warming rivers, contributing to the stress and even causing die-offs of cold-water fish like salmon and trout, particularly in the summer months.[50]
- Climate change is disrupting everything from bird migrations to when farmers can plant their crops, and evidence is mounting that ecosystems and species are changing rapidly — and sometimes disappearing as a result of these rapid changes.[51] For example, in the Pacific Northwest in 2005, a three-month delay to the normal start of upwelling (a crucial marine process that brings nutrients and food sources such as plankton close to shore) was associated with a number of detrimental effects including low survival of Coho and Chinook salmon, complete nesting failure by the seabird Cassin's Auklet, and widespread deaths of other seabirds (common murres, sooty shearwaters).[52]

Flickr: ChrisGoldNY

**Increased ocean acidity from coal burning** — The rising acidity of our oceans may be one of the most devastating — and underpublicized — effects of burning fossil fuels, with serious consequences for salmon, steelhead, and other anadromous species. Use of fossil fuels, like burning coal, releases massive quantities of carbon dioxide ($CO_2$) into our atmosphere. The ocean absorbs much of this carbon dioxide, initiating a chemical reaction that changes the ocean's acidity: oceans are 26% more acidic than they were at the dawn of the Industrial Revolution.[53] One local effect, recently documented by a team of Oregon State University researchers, is that baby oysters in the Pacific Northwest have been dying as a direct result of higher concentrations of $CO_2$.[54] Furthermore, ocean acidification directly affects the ability of mollusks, corals, pteropods, and other organisms to develop their shells and skeletons.[55] In fact, the rate at which reef-building corals produce their skeletons, the ability of marine algae and zooplankton to maintain protective shells, and the survival of larval marine species are reduced.[56] These small creatures are an important food source for salmon and other fish, which are in turn food for orcas, bears, and humans.[57] Coal burning therefore affects not just the tiny creatures that salmon eat, but the entire marine food web we all depend upon.

Although the United States has taken some important steps toward reducing our own carbon pollution, our credibility is at stake: Sending U.S. coal to Asian countries shows that we're not serious about putting the brakes on this dirty fuel, and diminishes U.S. authority during any future climate negotiations.

## A GUIDE'S GUIDE TO COAL EXPORTS

Sixth-generation Oregonian Bob Rees knows pushing more coal through the Northwest is a dangerous idea. One of the most respected fishing guides in the region, Rees doesn't pretend to be a political activist who knows the ins and outs of energy politics. But he is a dedicated angler who believes that if we don't stop burning coal, there will be fewer fish to catch — a nightmare scenario for him. Rees, the executive director of the Northwest Guides and Anglers Association, has cast up and down the Columbia River, its tributaries and estuaries since he was a kid growing up near Tillamook. "It's just in my blood," he says. "Like a salmon, I'm drawn to the river."

Rees knows first-hand that salmon populations are swimming a fine line between salvation and decline. He's watched salmon runs improve after the courts ordered new flow and spill regimes for the dams a few years ago, and lately he's been buoyed by great spring and fall salmon runs.

But Rees also knows that salmon health remains in a precarious state, due to a host of problems — from dams to diminished water quality to overfishing to disappearing food sources. The scientific consensus that emerged from the huge "Salmon 2100" project,[58] Rees says, is this: "If we don't take some serious steps, some of these salmon are as good as extinct."

Plans to increase coal exports strike Rees as a serious step — in the wrong direction. Rees has heard people worry that more coal trains might bring pollution from the coal dust and diesel traffic, as well as construction in critical shoreline fish habitat, but for him there's one overarching problem: the widespread burning of coal is turning the oceans more acidic.

Anybody who has ever taken a high school chemistry class knows that if you add carbonic acid to water, its pH will decline and the water will become more acidic. That's exactly what happens when coal-fired power plants spew carbon dioxide into the seven seas. "It doesn't matter where the coal is burned," Rees says. "It's having monumental effects on the ocean."

It's also bound to harm the salmon and other species that Rees and others depend on for the $2.7 billion dollar recreational fishing industry. Tiny crustaceans, juvenile crab, and shrimp larvae are all having a tough time adapting to the rapid changes in ocean chemistry. Those tiny marine animals are important food sources for the salmon. "It's happening at such a rapid rate," Rees says.

Rees says that many sportsmen already understand the problems that acid rain causes to lakes and streams, but they need to realize that burning coal is one of the biggest reasons that oceans are becoming more acidic. Encouraging more coal trains to pass along the Columbia River where he's been fishing his whole life just doesn't make any sense to him. "We have to take care of our side of the street, or we're going to be largely responsible for the destruction of the species we love the most," says Rees. "It's time to pay attention."

# The Salmon People's Concerns

Darla Leslie

Northwest tribes' concerns over the coal port proposals echo many of the others listed in this report, but there are additional issues that directly affect Native ways. If you're wondering if these proposals will have any effect on Native life and culture in the Northwest, consider the words of Nisqually elder Billy Frank, Jr.: "Pretend you're a salmon."

Pretend you're a salmon that has been struggling with dams, pesticides, herbicides, nuclear facilities, mercury contamination, barge traffic, diesel pollution, overfishing, clear cutting, piers and pylons, rock and metal rip-rap from road and rail construction, bridges, weirs, diversions, dredging, dikes, warming water, acidification and other indignities over the past century and a half.

Pretend you're a salmon that has noticed some recent improvements. A dam gets taken down. A Native hatchery helps your fry survive. A dike is modified, a forest replanted, a wetland restored, a spawning stream becomes accessible again. The humans that you share these rivers with appear to be paying more attention to what you need. Things seem to be looking up.

Now, pretend you're a salmon about to face another onslaught: more dredging, more coal dust containing mercury and arsenic coating your rivers, warmer water, more diesel, more spills, more acid, more barge traffic. More trouble ahead.

The tribes of the Pacific Northwest — the "Salmon People" — don't need to be told what a long and difficult path they've trod to get to the point where treaty language from the 1850s actually began to mean something:

> *"The exclusive right of taking fish in all the streams, where running through or bordering said reservation, is hereby secured to said confederated tribes and bands of Indians; as also the right of taking fish at all usual and accustomed places, in common with citizens of the Territory, and of erecting temporary buildings for curing them; together with the privilege of hunting, gathering roots and berries, and pasturing their horses and cattle upon open and unclaimed land."*
>
> *—Yakama Treaty of 1855*[59]

These hard-fought treaty rights mean much more than simply claiming the right to fish.[60] They mean that Northwest tribes have the right to *have* healthy populations of fish. They mean the right to *have* fish that don't contain contaminants, and that are suitable for subsistence, for livelihoods, and for cultural practices.

These treaty rights are again in the cross-hairs, this time from industry's high-impact set of proposals that will use the railroads and ports along the region's waterways to transport one of the dirtiest commodities imaginable.

The coal proposals will mean ongoing habitat destruction, which the tribes have long opposed and continue to fight. In a July 2011 report from the Treaty Indian Tribes in Western Washington entitled "Treaty Rights at

Flickr: Greg Shields

**Steelhead at Lucia Falls**

Flickr: Michael @ NW Lens

Risk: Ongoing Habitat Loss, the Decline of the Salmon Resource, and Recommendations for Change," the first and most important point was simple and direct: "Stopping habitat degradation is the cornerstone of salmon recovery." As Mike Grayum, executive director of the Northwest Indian Fisheries Commission said, "The problem here is that we're losing it faster than we can restore it."

There is more than just salmon recovery at stake for Native peoples in the coal debates. What is at stake is nothing less than the tribes' efforts to find balance — between humans and other creatures that cohabit this planet; between old ways and modern times; between operating in the United States' political sphere and maintaining tribal sovereignty.

It is hard to list all the impacts these proposals will have on Indian ways. The impacts on treaty rights, mentioned above, are paramount. But tribes are also concerned about impacts to cultural resources and traditional cultural properties, access to tribal fishing grounds, increased barge and rail traffic that will impact subsistence fishermen disproportionately, and increased mercury contamination in salmon, which constitute a much higher percentage of Native diets than among non-Natives. While salmon are critical, shellfish and the subsistence gathering of wild foods are also threatened by the cumulative effects of more coal mining, transport and burning.[61]

Increased rail traffic will make it more difficult for Native fishermen to access the river and will almost certainly kill or maim more people in rail accidents.[62] Shellfish, filters of the estuaries and coasts, will have to contend with even more toxics and particulates that may suffocate or poison them. Even as tribes celebrated the demolition of the Elwha and Condit dams that might signal a salmon renaissance, the herring stocks they depend on face another threat: the dredging, in-filling and expansion at Cherry Point, in the Lummi Nation's backyard. The barge traffic on the Columbia and on Puget Sound, already impacting Native fishermen, will increase many times.

Tribes are at a legal and biological crossroads in their efforts to recover the salmon and sustain Native cultures, and these coal expansion plans spell nothing but bad news for those efforts. Already, the Yakama Nation has written extensive letters to the Oregon Department of State Lands and the U.S. Army Corps of Engineers, outlining the tribe's deep concern over the wide-ranging impacts of "'development' undertaken in the name of immediate economic gain and without regard for the long-term consequences." The Lummi Nation is undertaking a comprehensive review of the likely impacts of more coal coming to the region, and Merle Jefferson, Sr. of the tribal council wrote in the *Bellingham Herald* that the proposed development "would substantially impact the ability of Lummi fishermen to exercise their treaty rights."[63] The Columbia River Inter-Tribal Fish Commission, in a letter to the Army Corps of Engineers (the federal agency tasked with oversight), voiced concern about the multiple impacts from these projects, saying that "the pressures on the Basin fish will be substantial."

It's clear that these coal export proposals stand in direct conflict with the time-honored Native worldview of maintaining reverence for nature while seeking a balance between humans and non-humans. They threaten to unravel many modern Native achievements and aspirations.

As Billy Frank said, "pretend you're a salmon." But this time, make sure it's a salmon that can talk, write letters, attend meetings, and press tribal councils and other leaders to act.

Flickr: bretvogel

## "WE NEED TO START MAKING NOISE"

**Bruce Jim is a veteran's veteran of the Northwest's salmon wars. As a kid, he'd fish the Celilo Falls with his grandfather, Chief Henry Thompson, in the days before the Dalles Dam silenced the legendary fishing grounds. As an adult, he's fought for Native treaty rights, served as the past chairman of the Columbia River Inter-Tribal Fish Commission, and still puts out his gill nets along the river he's fished his entire life. He says that to be honest, he had gotten used to the coal train traffic that passes within 50 feet of his home and near his fishing sites, until one day a coal train passed and was silhouetted by the sinking sun. In that backlight, Jim saw what looked like a gigantic cloud of black, sparkly mist, and wondered, "What the hell is that?" Soon he realized what it was: "Man, that's a lot — *a lot* — of coal dust!"**

**To Jim, a Warm Springs tribal elder who serves as a member of the tribe's fish and wildlife committee, adding even more coal dust to the mix is what a bad idea looks like. It's both a tribal issue and a personal one. Jim has fishing rights at three sites that are directly impacted by the proposed expansion of the port near Boardman, where he lives. In late August every year, Jim heads down to the beach and sets up his 300-foot nets, anchoring one to the shore and one to a buoy in the river. . Three hundred feet downstream, he repeats the set-up, and then does it again. "Those sites will be wiped out completely," he says, which is exactly what happened to one of his sites after a previous expansion at the Coyote Island Terminal.**

**Jim can't see an upside in allowing more coal to pass along the Columbia. The tribes have made great strides in restoring habitat, not just for the salmon but also for other "First Foods," like deer and chokeberries, mountain sheep and wild roots. The coal dust, he's convinced, can't be good for those food sources, which are still vital to him and other tribal members. "That's what worries me," he says.**

**What also worries him is the persistent cough he's developed, which he can't swear is from the coal dust but sure makes him wonder. "People are breathing this and don't realize it," he says. "I never realized it until I saw it in that light."**

**For Jim, the issue about whether government agencies should approve these coal proposals boils down to the same thing he's been fighting most of his life: treaty rights. "All these government agencies, they have a trust responsibility," Jim says. "Part of that responsibility means asking the question, 'how is this going to affect the tribes?' I remind them of that at every meeting."**

**He says that growing up, it was impossible to believe that places like Celilo Falls or Indian Head Rapids could disappear. "Then, in a blink of an eye, it's all gone." The lesson that Jim takes from those sad chapters in history is that it's important to stand up before the damage is done, and get loud. "When a baby makes noise, the mother is going to pay attention," says Jim. "If nobody cries, nobody will pay any attention." Pausing to think about a message he wants to share with other tribal members, he answers with conviction: "We need to start making noise."**

## PLANNED PORTS OR P

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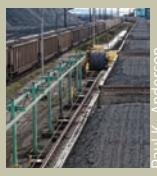
**CHERRY POINT:**
Amount: 54 million tons annually. Developer: Peabody and Pacific International Terminals, a subsidiary of SSA Marine.


Paul K. Anderson

**PORT OF GRAYS HARBOR:**
Amount: 5 million tons annually. Developer: RailAmerica Inc.

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**LONGVIEW:**
Amount: Up to 60 million tons annually. Developer: Millennium Bulk Terminals Longview LLC, owned by Ambre Energy and Arch Coal Inc.

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**PORT OF ST. HELENS:**
Amount: 15-30 million tons annually. Developer: Kinder Morgan.

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**COOS BAY (OR):**
Amount: 10 million tons annually. Developer: unknown

### PLANNED PORTS OR PLANNED EXPANSIONS KEY

5 ↓ 80 million tons per annum

Proposed Coal Train Routes

Powder River Coal Basin

Towns within 10 Miles of Proposed Coal Train Route

## LANNED EXPANSIONS

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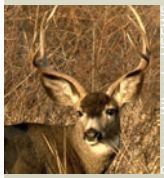
**PORT OF MORROW (OR):**
Amount: up to 8.8 million tons annually. Developer: Ambre Energy.

Flickr NWFisheries

**The salmon and steelhead runs on the Columbia River are legendary, with Spring, Summer and Fall Chinook, Summer Steelhead, Coho and Sockeye all offering strong prospects for sport fishermen, commercial fishermen and tribes. Despite the relative health of these runs there currently exists thirteen separate Columbia River salmon and steelhead runs listed as Threatened or Endangered by the NOAA Fisheries.**


Barbara Wheeler/USFWS

**The Powder River Basin is one of the best habitats for mule deer. Biologists believe that mule deer and their habitats can be harmed because of oil, gas and mineral exploration and extraction. An increase in mortality, ingestion of toxins, loss of habitat, barriers to migratory mule deer that move from winter to summer ranges, and disturbance that fragments and degrades habitats have the potential to affect mule deer populations.**

# CHAPTER THREE

## Meet the Players:

### *Brought to you by the same people who…*

One of the gifts of the Information Age is that bad corporate citizens can no longer hide as easily from their records. Tricks that were successful in the past, like creating shell companies to duck responsibility, can now be tracked back to their sources with a couple of mouse clicks. Court decisions, federal and state sanctions, and ongoing lawsuits can be more easily uncovered and shared. Ordinary citizens can scrutinize companies to see whether their promises square with their past actions.

In the case of the companies involved in the coal export expansions, their track records leave considerable doubt about their willingness to obey environmental laws and be good neighbors. The coal companies, their subsidiaries, port owners, investors and transportation outfits at the heart of the Northwest's coal export proposals have a record of polluting

Power Past Coal

the communities where they operate, exerting ruthless political clout to reduce environmental and workplace safeguards, settling lawsuits for undisclosed millions of dollars without admitting "wrongdoing," and even facing convictions for criminal behavior. From their notorious practice of mountaintop removal mining to their support of groups that seek to discredit climate scientists, and even their disingenuous "clean coal" campaign, Big Coal has a disturbing legacy of environmental degradation and scorched earth political tactics.

Jeff Goodall's intrepid book *Big Coal: The Dirty Secret Behind America's Energy Future* details Peabody and other coal companies' influence peddling — and influence. In 2009, the coal mining lobby donated more than $10 million to members of Congress, according to the Center for Responsive Politics.[64] Two of the top contributors were Peabody Energy and Arch Coal. In 2010, they also spent $6.5 million in reported lobbying activity, mostly to counter efforts to tighten pollution standards for power plants.[65]

Like tobacco companies (see sidebar *Big Tobacco, Big Coal*, page 21), the coal industry has spent millions of dollars on disinformation campaigns, including trying to convince the public that "clean coal" technologies were on the horizon.[66] The truth is that carbon sequestration techniques have never been

Power Past Coal

implemented at the scale necessary for industrial coal-fired power plants — and none are likely to come online anytime in the near future. Author Goodall calls clean coal "one of the great oxymorons of our time."[67]

## PEABODY ENERGY

Singer/songwriter John Prine immortalized this company in his song, "Paradise," when he wrote about how the company ravaged the Appalachian countryside: "Mr. Peabody's coal train has hauled it away." The company — the world's largest private sector coal firm — has a long history of strong-arm tactics with its workers, countless safety violations, and an unabashed abuse of political donations and lobbying to beat back environmental, health and workplace safety laws.

Peabody and the coal industry have a long history of funding concerted efforts to discredit mainstream climate change science. The company has been a supporter of the American Legislative Exchange Council (ALEC), a powerful, behind-the-scenes group that has worked to entrench climate change denial in public school curriculums.[68] Peabody has also been linked, through leaked emails and memos, to organized efforts to "sow discord" in regions that are trying to limit greenhouse gas emissions from coal-fired power plants.[69]

Peabody has repeatedly tried to delay or eliminate rules that would reduce the amount of toxic pollution the industry emits. One infamous memo to the former Peabody CEO tries to discredit efforts to reduce mercury, a potent neurotoxin. "Our strategy in dealing with mercury has been two-fold:" the memo explained. "Prevent states from taking precipitous or unwarranted action to regulate mercury and engage in the federal rulemaking to protect the interests of coal-based electricity."[70]

The federal Mine Safety and Health Review Commission has repeatedly found Peabody to be a leader in violations, and in 2011 the MSHA began fining Peabody for not providing Peabody's records for a federal audit.[71] According to the company's own annual report, it received 3,233 notices of violations — about 9 per day — from the federal mine inspection agency, which proposed nearly $6 million in fines for Peabody.[72] In March 2011, Peabody settled a longstanding and bitter $600 million lawsuit with the Navajo Nation over allegations that Peabody cheated the tribe for years.[73] The terms of the settlement were not revealed.

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## ARCH COAL

Arch Coal, the nation's second-largest coal company, purchased a 38 percent stake in the proposed Longview Port in early 2011. Arch has settled many cases involving alleged violations of the Clean Water Act in Virginia, West Virginia and Kentucky, where they practice "mountaintop removal" mining, and has been involved in repeated lawsuits regarding its failure to clean up toxic runoff from its mine sites.[74] Some recent lowlights:

- In March 2011, the EPA and the U.S. Justice Department announced that Arch Coal would pay $4 million to settle a Clean Water Act case.[75]
- In April 2011, the U.S. Department of Justice filed suit against Arch Coal Inc. to try to recover money the federal Superfund program spent cleaning up the company's Cape Girardeau site in Missouri.[76]
- In January 2012, Arch agreed to pay a $750,000 fine to the federal government and contribute $6.75 million to the West Virginia Land Trust, to settle a suit over selenium pollution.[77]

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## AMBRE ENERGY

The Australian-based company purchased a majority stake in the Longview Port, and owns parts of other proposed Pacific Northwest coal export expansion plans. Ambre and its subsidiaries are already under fire for their calculated attempt to deceive local officials about the scope of their plan at Longview: The company originally asked Cowlitz County for a permit to export 5.7 million tons of coal, and received the permit in 2010. When a coalition of environmental groups challenged the permit, company documents revealed their real plans were to export 10 times that amount — up to 60 million tons per year. Internal company emails between Ambre executives indicated that deception was part of the plan: "Any expansion plans...should not be made available to any outside party," read one leaked email.[78] Another read: "We are at too sensitive a juncture to raise the plans to build a second berth. The community is small and the risk to the current permit path is too large."[79]

The press also reported recently that Ambre Energy is on shaky financial footing, after losing a major project in Australia that was rejected by the local government after meeting strong resistance from farming communities. According to *The Australian* newspaper, Ambre posted a $24 million loss last calendar year (2011).[80]

## SSA MARINE

Seattle-based SSA Marine boasts that the company and its affiliates "operate more cargo terminals than any other company in the world."[81] Apparently, though, bigger isn't always smarter: SSA also got off on the wrong foot with its preliminary work on the Cherry Point facility. After a Whatcom County Councilmember noticed some illegal clearing of a wetland while he was walking his dog, he traced it to an SSA Marine contractor. At first, SSA denied doing anything wrong, but when it became apparent they didn't have the required permits, they admitted they had made a mistake. The county fined them what local advocates said was a laughable amount: $4,200 — a $2,000 fine and $2,400 to cover county staff costs.

For many people in the area, this breach of trust warned of further troubles ahead. "Their actions have already spoken louder than their words," said Bob Ferris, Executive Director of RE Sources for Sustainable Communities, a local advocacy group.

## KINDER MORGAN

Energy conglomerate Kinder Morgan is behind the proposal to expand the Port of St. Helens along the Columbia River and ship up to 30 million tons of coal to Asian markets. According to a report by the Sightline Institute, Kinder Morgan's track record in the Northwest and beyond "is one of pollution, law-breaking, and cover-ups."[82] The report details how Kinder Morgan's coal export facilities in Louisiana, Virginia, and South Carolina have contaminated local communities with coal dust pollution, and shows how Kinder Morgan officials have been implicated in bribery scandals, theft, lying to regulators, and managing pipelines that have exploded and leaked. And maybe Oregon should expect much of the same: a company spokesman told the Portland Business Journal, "What we're proposing is not something we don't already do."[83]

Paul K. Anderson

## BIG COAL AND BIG TOBACCO

Whatever your opinion is about smoking, it's obvious that the tobacco industry has plenty of skeletons in the closet. Tobacco companies once advertised the health benefits of cigarettes and spent millions suppressing information about tobacco's deadly effects. But after the link between cigarettes and diseases became indisputable, including the dangers of second-hand smoke, Americans responded. It took an all-out fight to force companies to admit the medical facts about their product, but the Surgeon General succeeded in putting a warning label on every pack of cigarettes: "Smoking Causes Lung Cancer, Heart Disease, Emphysema, and May Complicate Pregnancy."

The similarities of coal's story to the tobacco industry are eerie. The coal industry bills itself as a cheap, abundant, domestic energy source, but as the health and environmental impacts of mining and burning coal became clear (including causing some of the same diseases as cigarettes), Americans began opposing new coal-fired plants and closing old ones.

Like Big Tobacco, Big Coal isn't going down without a fight. In April 2012, the coal lobby launched a $120 million, three-year, national television campaign touting cheap electricity from coal, complete with waving American flags and an ominous voice that warns, "The clock is ticking, America."[84]

Like Big Tobacco, coal wields enormous political influence. In 2011, according to the Center for Responsive Politics, the coal lobby spent $18.1 million in donations to Congress, while the tobacco industry spent $17 million.[85] Even more telling is how much these industries intensified their lobbying to counter changing societal values: In 1998, when Big Tobacco was fighting a landmark settlement case of more than $200 billion, it spent a whopping $65 million in lobbying.[86] In the meantime, Big Coal ramped up their lobbying efforts, from $2.1 million in 1998 to $18 million in 2011. It's one sure sign that coal is feeling the heat.

Much like cigarettes harm our lungs, particulate from coal-burning power plants infiltrates the air, causing hundreds of thousands of cases of asthma and other respiratory diseases.[87] One significant difference between tobacco and coal, however, is that coal's "second-hand smoke" affects the entire planet. The equivalent of the Surgeon General for the environment warns that coal is hazardous to our planet's health — in March 2012, the U.S. Environmental Protection Agency (EPA) set new rules to discourage coal-fired electricity generation, and a recent letter from the EPA to the Army Corps of Engineers (which is reviewing the Pacific Northwest coal export proposals) noted that transporting coal through the Pacific Northwest "has the potential to significantly impact human health and the environment."[88]

Sound familiar? The stark truth is that coal should come with a warning label, similar to those required on cigarettes: Coal is Hazardous to Our Health.

WARNING: Mining, transporting and burning coal can be harmful to your health. Ingredients in coal can cause black lung disease, emphysema, birth defects, asthma, heart attacks, and cancers. Pregnant women, children and the elderly are particularly vulnerable to emissions from burning coal. Mammals, fish and other animals are harmed by mercury and arsenic, two components released by coal burning. Transporting coal by rail releases coal dust, produces diesel pollution, increases congestion in rural communities, and delays emergency medical response times.

# CHAPTER FOUR

## Spotlight on the Powder River Basin:

### *Massive coal mines take their toll on wildlife, water, and wild places*

Driving near the town of Sheridan, Wyoming, visitors can see and feel the impact of Big Coal at its biggest. Giant dust plumes from blasting rise from the plains, and a few gigantic coal-pit crevasses are visible from the road, tens of miles long and hundreds of feet deep. A steady stream of coal trains rumbles along tracks that parallel the highway, sending 40 percent of the nation's coal to far-flung domestic power plants.

This is the heart of the Powder River Basin, a vast coal stronghold straddling northeastern Wyoming and southeast Montana. Bordered by the Big Horn Mountains and the Black Hills, interlaced by iconic western rivers like the Yellowstone and the Tongue, the Little Missouri and the Platte, the nation's top coal-producing region has also created a monstrously large problem for future generations of people — and wildlife.

According to the Western Organization of Resource Councils, the problem with coal mining in the region boils down to this: "Coal extraction in the Powder River Basin is detrimental to land, water, air and public health for the communities and people that live in and around coal production areas, and leaves behind a legacy of reduced productivity and waste."[89]

The region's high plains and rolling hills, sagebrush flats and pine covered ridges provide food and shelter for mule deer and elk, sage grouse, wild turkey and antelope. Sportsmen know the Powder River Basin is one of the most special and valuable places for hunting in the nation, drawing thousands of hunters every year. In the river bottoms and valleys, ranching communities struggle to maintain traditions under increasing threat from mineral extraction, as water quality and quantity suffer with

Flickr: Clint Koehler

Stephen Ting, USFWS

every ton of coal that is extracted. Coal bed methane, often linked with coal production, has contaminated groundwater to the point where ranchers have infamously lit the water from their faucets on fire.

Much of the region has already been transformed into an industrial extraction zone scarred by enormous strip mines and by oil and gas development. Increasing coal exports to Asia will only compound the problems and hurt our chances for protecting the vast open landscape of prairies, rolling hills, wide, flat streambeds and broad floodplains that evokes the iconic West — and embodies the values of freedom and opportunity that Americans have come to associate with such places.

The National Wildlife Federation and other groups are fighting to put the brakes on this runaway destruction, including efforts to protect landscapes from the proposed Otter Creek mine in Montana, which, if it goes forward as planned, would become one of the biggest coal mines in the country. What's happening in the Pacific Northwest has a direct impact on wildlife in Montana and Wyoming, because every port proposal that's stopped makes it that much harder for Big Coal to increase mine production.

# Impacts

When humans began burning huge amounts of coal to fuel the Industrial Revolution in the 1800s, there were few energy alternatives that could power mass manufacturing, and little was known about the effects of mining and burning coal. Fast forward into the 21st century. Humans now know that every step of the coal industry's life cycle comes with destructive side effects to human health and to the planet that sustains us. Today, many alternatives exist to produce electricity without burning coal: wind, solar, sustainable biofuels, and natural gas are just some of them.

Some of the main impacts from exporting coal through the Pacific Northwest:

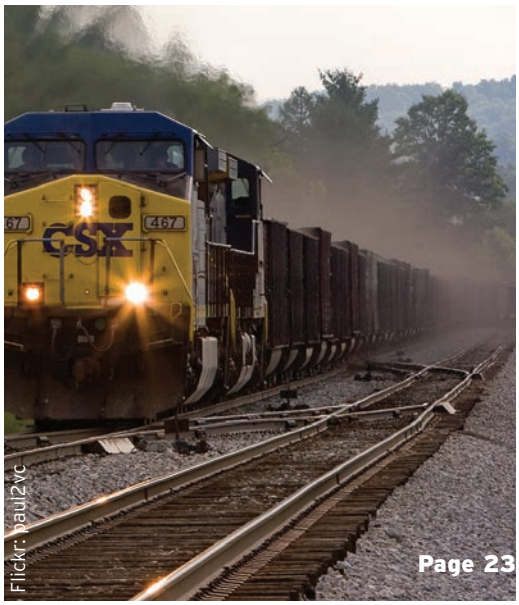
## MINING

Powder River Basin coal is a relatively cheap, bulk commodity that sells for an average of about $12-15 *per ton*, according to the U.S. Energy Information Administration.[90] Vast amounts need to be mined to be profitable, and mining is an incredibly destructive process, a massive industrial operation that permanently alters the terrain. Coal mining contaminates groundwater, eats up forests and prairie habitat, and creates sacrifice zones where animals can no longer survive, and where humans are forced to relocate or live with a profoundly altered landscape. Furthermore, coal mining can cause respiratory diseases, including black lung — not just in underground mines but also at surface mines like those in the Powder River Basin.[91]

## RAIL TRANSPORT

If all of the industry's proposals go forward, exports to Asia would increase by around 150 million tons annually — compared to just 3.8 million tons in 2009.[92] Getting this colossal amount from the Powder River Basin to the coast means railroads — and lots of them. These mile-and-a-half long coal trains will shed toxic coal dust, belch diesel emissions that damage ecosystems and wildlife, and disrupt communities along the way. Adding insult to injury, rail lines would need to be improved, and past experience has indicated that taxpayers, not private companies, may be left with the infrastructure bill.[93]

- Each coal train carries about 15,000 tons, usually in open cars that shed coal dust en route to their destinations. According to a report by the Western Organization of Resource Councils, about 10 coal trains currently pass through the region every day, but increasing exports to the scale proposed by industry would require at least a six-fold increase in train traffic — or 60 trains a day.[94] (Keep in mind each train has to travel to *and* from the mines on each trip.) Because conditions vary substantially, it is difficult to assess the exact amount of coal dust that floats away during transport, but BNSF says it is concerned about coal dust escaping from loaded coal cars in transport from the Powder River Basin to the new terminals.[95]



Flickr: paul2yc

- Health professionals in the Pacific Northwest and elsewhere have catalogued a litany of negative health impacts from diesel particulate matter, including impaired pulmonary development in children, increased incidence of asthma, higher cancer rates, more heart attacks, and other diseases.[96]
- The World Health Organization recently declared that diesel exhaust (like the engine emissions from coal trains) is carcinogenic to human; of particular concern is its link to lung cancer.[97]
- A less obvious impact from rail transport is the increased noise exposure for citizens living near railroad tracks. Medical literature shows that exposure to the kinds of noise levels associated with increased train traffic comes with a price: high blood pressure, cardiovascular disease and sleep disturbance.[98]
- A train wreck in the Columbia River Gorge in July 2012 resulted in the derailment of 30 coal cars in Mesa, Washington, spilling coal and blocking a busy rail corridor. An increase in rail traffic would almost certainly lead to an increase in these accidents.
- Many communities along the rail lines already experience temporary road closures when trains pass through. A substantial increase in rail traffic through these towns will likely result in longer delays for emergency medical treatment and lost productivity for local businesses.[99]
- Trains routinely kill and maim people in accidents. According to the National Transportation Safety Board, in 2010 there were 813 rail fatalities in the U.S.[100]

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## WATER TRANSPORT

Several of the coal terminal proposals would increase barge traffic on the Columbia River, and all of them would result in more tanker traffic near coastal zones. The Morrow Pacific project in Boardman, for example, would entail more than 5,000 additional barge trips per year (once upriver, once downriver), a 94% increase over 2010 levels.[101] A biological assessment prepared for Ambre Energy and submitted to the Army Corps of Engineers admitted that "the proposed project will result in unavoidable impacts to protected species and critical habitat," potentially harming steelhead, salmon, bull trout, green sturgeon, and dozens of other fish and aquatic mammals.[102]

## BURNING

The level of atmospheric carbon dioxide has risen substantially over the past 150 years, much of that from burning fossil fuels like coal.[103] Today, coal-fired power plants account for about one-third of energy-related $CO_2$ emissions in the US.[104]

Burning coal, even overseas, has three main impacts that should concern Pacific Northwesterners: It changes the ocean's chemistry and makes it more acidic (see What's Fishy about Coal, page 9); it releases mercury and other toxic chemicals that infiltrate the food chain, and it contributes to a warmer planet that creates more extreme weather events and changes ecosystems so fast that many species cannot adapt.

Flickr: Captain Kimo

## A DOC'S VIEW

For Dr. Frank James, a Bellingham, WA family physician and San Juan County Health Officer, an increase in coal exports will cause two certain side effects: an increase in disease, and an increase in deaths.

James has pored over the medical literature along with his colleagues in the "Whatcom Docs," a group of about 200 local physicians who are concerned about the health and safety impacts of the Cherry Point proposal. They don't like what they've found: Evidence points to greater health problems for communities near coal export facilities or near rail corridors, and James is calling for a comprehensive (and independent) Health Impact Assessment to drill down on just how much port and rail communities would be affected by the coal industry's projects.

For James, the issue is both personal and professional. An asthmatic since he was a child (a condition he ascribes partly to the fact that his father was a heavy smoker) James has seen the effects of bad air on children's lungs in his family practice. Living with his family near the railroad tracks only increases his concerns.

What troubles James most is the increase of diesel particulate matter that will be a certain by-product of four-engine rail convoys coming through town, up to 20 times a day. Between that and the increase of "Cape class ships" — the world's largest oceangoing vessels — the amount of diesel pollution around Bellingham will increase. "It will bring a dramatic drop in the quality of the air," says James, "as well as the quality of our lives."

That in turn will affect the health of Bellingham's residents, especially the young, the elderly, and those closest to the tracks. The Whatcom Docs have catalogued potential health impacts to the community in four categories: diesel particulates, which especially trouble James; coal dust; noise exposure; and delays in emergency medical responses when train traffic shuts down road crossings.[105] Simply put, he says, "It's not about 'Jobs vs. the Environment.' Real people's health will be impacted — our patients and your families. Heart attacks, strokes, asthma and many other conditions will become more common, and current patients will be made worse."

James and his colleagues have combed the peer-reviewed medical literature and made inquiries to colleagues around the country. In Spokane, WA, James found studies that indicated increased cancer deaths near the tracks. He phoned officials in Newport News, VA, and found out that everything from asthma rates to property values have been affected by the coal export facilities there.

The Whatcom Docs include cardiologists, infectious disease specialists, radiologists, and general practitioners, and they all agree: These projects would result in significant increases of airborne pollutants from diesel engines and coal dust, would raise levels of noise pollution, and would elevate the risk of vehicle and pedestrian injuries along the tracks. It's a heavy cost to pay, and one that would be borne by communities, not the coal industry.

# Recommendations

Given the broad impact that increased coal shipments will have, not only on the local communities and the region's critical natural resources, but also on the global climate, national scrutiny and oversight is essential. And national leadership to pursue an alternate energy path for our country is urgent.

**THE NATIONAL WILDLIFE FEDERATION CALLS ON ELECTED OFFICIALS TO:**

1. **Require a thorough examination of the climate impacts** of an expanded coal export market (both in the Pacific Northwest and elsewhere), and include these considerations as part of any environmental analysis evaluating federal decisions involved in exporting coal, extracting coal or leasing federal lands for coal development, given the evidence at hand that we are nearing the tipping point for disastrous climate effects;

2. **Require the U.S. Army Corps of Engineers** to complete a comprehensive, area-wide analysis to fully assess the potential impacts — including climate and other factors — from these port and rail expansions; and ensure that Endangered Species Act consultation takes place with federal wildlife agencies to ensure that populations of salmon, marine mammals and other protected species are kept from harm;

3. **Direct the National Academy of Sciences** to conduct a study on the impact of major coal port expansions (and associated infrastructure such as rail expansions) on terrestrial and marine habitat, in particular that of endangered and threatened salmon species in the Pacific Northwest;

4. **Require federal and state permitting agencies** to fully engage Tribes in the process of analyzing these proposals; and make sure that Tribal treaty rights are upheld without exception.

Flickr: Andrew E. Larsen

# CHAPTER FIVE

## Get Involved

*Top 5 reasons not to invest in coal export terminals*

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1. **Coal kills** — The mining, transport and burning of coal impacts human health, plants and animals, changes global ocean chemistry, and contributes to the world's increasingly extreme weather events and changing climate.
2. **Coal has no place in the Pacific Northwest** — Oregon and Washington plan to shut down their remaining coal-fired plants; the region is a leader in sustainable development and should not be used as a conduit for dirty coal.
3. **Coal companies and their partners have been bad neighbors** — The main players in the Northwest export expansions have a demonstrated legacy of pollution, broken environmental laws, and ruthless business practices. For Peabody, Arch Coal and the rest, their bottom line — not good citizenship — is the most important thing.
4. **Coal is dirty** — Humans were burning coal when horse and carriage transport was commonplace and whale oil was still in widespread use. Many cleaner energy options have been developed and continue to come online in the U.S. and around the world. The future of the world energy economy lies in renewables, not dirty fossil fuels.
5. **Coal will harm economic development** — Negative impacts on salmon and other species will hurt our fishing economy, and as the Public Financial Management report showed in Bellingham, coal exports would box out other industries like tourism.

Local, state and federal agencies will be examining all of the port proposals in the months and years to come. There will be ample opportunity — at public meetings, "scoping hearings," public comment periods, and through other forms of citizen involvement, to influence their decisions.

It won't be easy to fend of the coal industry. The companies involved know how to play the political game at the highest levels — through political contributions, lobbying efforts, high-priced public relations firms, and other tried and true methods of influence.

But citizens around the country have been successful in demonstrating to their elected officials that coal is not a welcome neighbor. New coal-fired power plants have been stopped in their tracks in dozens of communities around the country, and groups around the Pacific Northwest have formed to bring persuasive local voices to the table.

NWF is an active member of the *Power Past Coal* coalition (www.powerpastcoal.org), a regional coalition of organizations working to prevent the export of coal from the Northwest. Major partners include Climate Solutions, Columbia Riverkeeper, Earth Justice, Sierra Club, Washington Environmental Council, and the Western Organization for Resource Councils. In partnership with the Power Past Coal Coalition, NWF is focused on three areas that are essential for blocking the plans of the coal industry:

1. Prevent the permitting of new port projects along the Columbia River and Puget Sound that would be needed to support increased coal exports;
2. Prevent expanded coal rail infrastructure between Eastern Montana and the Pacific coast, that would cross pristine river valleys, farms and ranches, and prime hunting grounds; and
3. Prevent new coal mine leases in the Powder River Basin.

To find out about current ways to have your voice heard on this issue, go to: **www.nwf.org/coalexports** where you'll see a list of tools to help you participate.

Perhaps the most important thing you can do is let decision-makers know that you're paying attention. Write your members of Congress, and tell them that the country needs an energy policy that moves away from coal and other fossil fuels towards more renewable, sustainable energy and energy conservation strategies.

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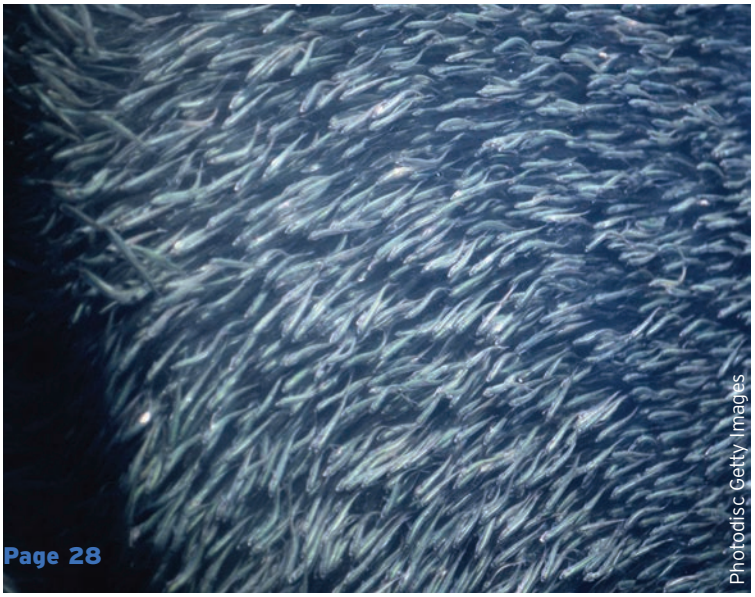

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Nic Callero

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# New Dawn fuel barge ran aground in the Columbia River, response was confusion, report says

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By **Scott Learn, The Oregonian**

Thomas Boyd, The Oregonian

The New Dawn fuel barge ran aground in the Columbia River in July 2009. Workers had to off load half the fuel before it was able to continue. The official report of the response said that "confusion" about who was in charge reigned in the early hours after the spill.

When a fuel barge transporting a million gallons of gasoline ran aground in the Columbia River last summer there was a "great deal of confusion" initially over who was in charge, with agencies responsible for containing a fuel spill left out of the loop for hours after the accident, investigation documents released by the **U.S. Coast Guard** indicate.

The New Dawn, a fuel barge owned and piloted by **Tidewater Barge Lines** of Vancouver, ran aground on an uncharted mud shoal just off Hood River shortly after 3 a.m. on July 9. No fuel spilled during or after the accident, and the Coast Guard and the company, citing the soft river bottom and the barge's double hull, judged spill risk as very low and treated the grounding as a relatively simple "salvage operation."

But spill response officials from Washington, Oregon and the U.S. **Environmental Protection Agency** objected to that approach, saying in a debriefing weeks after the incident that they should have been notified earlier and the response should have been more aggressive.

"We have a protocol with the Coast Guard that vessel incidents that present a potential for spill should be treated the same as an actual spill, and that didn't happen in this case," Ron Holcomb, a spill responder with the Washington Department of Ecology, said in a recent interview. "We don't see a barge soft aground; we see a million gallons of gasoline in a place where it's not supposed to be."

The 1,500-foot safety zone established around the 282-foot barge would have been too small if a leak occurred, the spill response agencies said in the debriefing. The agencies were late to establish a unified

command center, so Tidewater assumed "the primary leadership role" and set up the command center in Vancouver rather than near the accident site. And there was "limited coordination between agencies on response and management issues."

The Coast Guard released the documents at The Oregonian's request, but only after it completed its accident investigation. The documents underscore the complexity of spill response on the Columbia, which relies on multiple federal and state agencies as well as local officials.

Officials from Tidewater and the Coast Guard have since agreed to quickly notify the spill response agencies even if there's only potential for a spill, Tidewater officials and regulators said.

"Going forward if there's a fuel barge grounding the expectation is that immediately, in addition to a salvage component, there has to be a spill prevention component," said John Pigott, assistant to Tidewater's president. "We're good with that."

Tidewater is the primary carrier of petroleum products -- almost entirely gasoline and diesel fuel -- on the Columbia east of Portland. The company says its safety record includes no tank barge fuel leaks in nearly 16 years, despite about 400 fuel tanker round trips a year.

The New Dawn grounded at 3:15 a.m. while being pushed upriver to a fuel terminal at Pasco, Wash., by a Tidewater tug operator who was preparing to move under the Hood River Bridge. It remained stuck for about 36 hours, before Tidewater freed it by transferring about half its fuel load to another barge, a process known as "lightering."

Tidewater notified the Coast Guard 15 minutes after the incident, the investigation report indicates, scouted the barge within half an hour and surveyed surrounding waters, finding no leaks or sheen on the water.

But it took more than two hours to notify the states spill response agencies and more than three hours to notify the EPA, the federal agency in charge of spill response on the Columbia above **Bonneville Dam**.

Confusion about whether the Coast Guard or the EPA should take the lead complicated the response, all the parties said. Frequent turnover among Coast Guard personnel also complicates coordinated spill response; two of the Coast Guard's key responders on the New Dawn incident have already transferred to other posts.

A Coast Guard marine inspector and response personnel arrived on the scene at 8 a.m., about five hours after the grounding, according to an incident timetable. The timetable says a structural analysis of the barge was completed shortly after noon. "That's quite a bit of time that you're not 100 percent certain of what the status of the vessel is," Holcomb said.

Mike Zamperini, a commander in the Coast Guard's Portland office, the inspection happened "fairly quickly"

given requirements to check oxygen levels before entering the interior of the barge.

At the time of the accident, the Coast Guard, Tidewater and the U.S. Army Corps of Engineers, which is responsible for maintaining the Columbia's navigation channel, disagreed over whether the barge was in the channel when it grounded. A marker buoy indicated the area was inside the river's shipping lane, but a Corps spokeswoman said recently that the Corps still believes the barge was outside the official federal channel.

The charted depth at the site of the grounding was 29 feet, the Coast Guard documents say. The actual depth was 7 feet.

Pigott and Zamperini said the Coast Guard has since moved the buoy to steer ships away from the shoal. The **National Oceanic and Atmospheric Administration** is working on updated river mapping, Zamperini said.

Richard Franklin, EPA's Portland-based spill response coordinator, said the agency regularly drills with barge companies, the Coast Guard and spill responders. The Coast Guard has already notified EPA more quickly in subsequent incidents in the Columbia and off the coast, he said.

"We're doing better at calling each other," Franklin said. "It's not perfect, but I think we're doing pretty well."

-- **Scott Learn**

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Filed Under: Business, Economy, Gulf Coast, Local, National, News, Regional, State

# River traffic resumes after barge accident but threats remain

**4th June 2011 · 0 Comments**

**By Susan Buchanan**
*The Louisiana Weekly*

Traffic on the lower Mississippi River restarted last Tuesday after a four-day closure caused by a Baton Rouge barge collision. So if you scrambled up the levee last week to investigate the water's height, you probably saw tows pushing lots of barges again. Barges, however, remain a challenge for pilots to control in today's fast current.

Three grain barges sank in Baton Rouge on May 20, and they could remain under water for up to two months until the river recedes, according to the U.S. Coast Guard. When the Baton Rouge stretch was closed recently, shippers sending cargo upriver from New Orleans had to adjust by using rail or trucks, or they just waited until the situation improved.

To understand what an errant barge is like, think of a frisky dog or toddler that suddenly tears away from your family outing in the park.

Captain Mike Lorino, president of the Associated Branch Pilots in New Orleans, said "as far as ships are concerned, we haven't had any groundings or collisions on the Lower Mississippi this year. But tows are another matter because they don't have the power of ships, and if they get out of position they can't recover in the strong current."

On May 20, the Crimson Gem, a 195-foot vessel pushing 20 barges of corn, collided with a sulfuric-acid barge at the Rhodia Dock in Baton Rouge, according to Brian Dochtermann, spokesman for the U.S. Coast Guard's Marine Safety Office. The barges avoided hitting the neighboring Highway 190 bridge, he said. Three corn barges sank, however. American River Transportation Co. or ARTCO, a subsidiary of Archer Daniels Midland Co. in Illinois, owns the Crimson Tide.

"Luckily, there was no release of sulfuric acid," Dochtermann, based in Baton Rouge, said. "No injuries, water, or air pollution occurred, and the Coast Guard is investigating the incident."

But, he said "because of the accident and extreme high water, vessel traffic southbound was closed for nine miles from May 20 to 24–from mile markers 228 to 237 near the Highway 190 bridge." The Coast Guard reopened the waterway to southbound traffic last Tuesday afternoon, with some restrictions. And after the four-day closure, downriver traffic was backed up by at least 50 towing vessels, pushing a large number of barges. Late last week, river traffic remained log-jammed north of the sunken barges.

Dochtermann said last week "we have limited south and northbound, daylight operations now, and no vessel traffic is allowed at night. Tow boats are allowed to push no more than twenty barges, and must operate with a

minimum of 300 horsepower per barge for southbound transit."

At Wilkinson Point north of Baton Rouge, at miles 232 to 237 on the river, special rules are in effect for southbound pilots. They must use an assisting, towing vessel, with a minimum of 5,000 horsepower at the Point, employ radar and radio communications, and coordinate their transit in that area with the Coast Guard's traffic service in New Orleans. Even under normal conditions, tow pilots are careful to avoid contact with loading operations at river mile 234 at Wilkinson Point.

"We also have high water restrictions in force for barge fleeting areas, where barges are picked up and dropped off in the river," Dochtermann said. Restrictions depend on a facility's location in the river, and on whether the cargo is grains, chemicals or something else. "There are special restrictions on barge configurations in fleeting areas now," he said. "We can't check that every barge is moored properly, but the marine industry does a good job of policing itself in fleeting areas."

Dochtermann said "when breakaways occur, we send someone to investigate whether there was neglect or misconduct, and if there was, the Coast Guard takes action. Companies don't want to go through that."

ARTCO, the Crimson Tide's owners, hired salvage firms McKinney Salvage & Heavy Lift in Baton Rouge and Budwine & Associates in New Orleans to remove the three sunken barges—which are 70 feet, 90 feet, and 100 feet under water, respectively. "The barges are being monitored by the salvage companies daily with side-scan sonar," Dochtermann said. "They haven't moved, and at this point are stationary."

He continued, saying "their locations are not physically marked because of the strength of the current, but they're under enough water so that they don't pose any threat to vessel traffic, and most mariners are probably aware of them."

Dochtermann said "the river's current remains very fast at six knots, and the salvage operation probably won't take place until the current is moving at fewer than 3 knots," something that may not happen for a couple of months. "Our main concern now is the safety of the general public, the mariners and those who will be involved in salvaging."

River pilots are trained for water at all stages, said Captain Mike Lorino, president of the Associated Branch Pilots in New Orleans. "We have a different river every year," he said. "The last high-water event was in 2008, and every year prior to that we had high-water conditions."

Lorino said "during high water, ships moving downriver must have enough power to travel faster than the speed of the current." If the current is six knots, they must travel faster than six knots. "And in high water, pilots have to make plans sooner to turn on the river," he said. In his view, navigation by lower Mississippi River pilots has been exceptional in the past month and in every other, high-water phase in recent years.

Chris Bonura, spokesman for the Port of New Orleans, discussed the swollen river's effect on the Crescent City and said "under high-water restrictions, barges have to stay at least 180 feet away from levees between New Orleans and Baton Rouge. He pointed to restrictions on the number of barges in a tow, and said tow boats must have enough horsepower to fight the current. However, "it's a misconception that this month's barge accident in Baton Rouge had a big impact on the Port of New Orleans," Bonura said. He noted that between Venice and Baton Rouge, five port authorities oversee 250 miles of river engaged in domestic and foreign trade. "Cargo in our region can be moved by barges, railways and trucks," he said. "When the river was closed for four days in

Baton Rouge this month, we could, for example, still receive foreign steel, but for several days it couldn't get above New Orleans by barge." However, steel could be moved by rail, he said.

"It's normal to have a large shipment of imported steel headed to, say Indiana, taken off a ship here and then moved by both barge and rail," Bonura explained. "What's needed right away in Indiana is sent by rail, and what they can wait for, they move by barge, which is slower but also cheaper."

Lorino discussed current and future river conditions, and said "pilots know where the sunken barges are in Baton Rouge, and while it's not an ideal situation, they can go around them." He said there are only a few daytime, navigation restrictions in the Lower Mississippi now, but warned "things could change in ten to twelve days as the river drops back below 17 feet, because sediment in the water will start building up and will reduce the draft in Southwest Pass." The Southwest Pass near Venice is the main entrance for deep-draft navigation into the Mississippi River.

Lorino said the tight, federal budget has hampered dredging activities in the lower river. However, he said "the Army Corps at the present time is using five dredges in the Southwest Pass area" as the river shoals or accumulates silt.

He also said "the Corps just received an additional $10 million to increase the number of dredges in Southwest Pass, but there were no industry bidders on the contract, and therefore we have money but not enough equipment." He added, "even with that $10 million, we are still $60 million short this fiscal year to keep the channel to its project dimensions." The Army Corps dredges most parts of the lower river to 45 feet.

For fiscal 2011, the Army Corps allotted $63 million to dredge the river from Baton Rouge south, and at the start of the year said that was all that would be provided. In prior years, the Corps redirected money from other projects to keep the channel dredged. Maintaining the lower river at 45 feet can cost $85 million to $100 million annually in dredging.

Exporters, including grain companies, worry that silt buildups at the mouth of the Mississippi will force them to load ships with lighter cargoes, and that in turn will slow downriver barge traffic and raise their operating costs.

Meanwhile, even with the high water, the Port of New Orleans has stayed on schedule with its expansion plans this month. "In early May, we received two gantry, containerized-cargo cranes built in Korea, and unloaded them onto the dock at the Napoleon Avenue container wharf," Bonura said. The new cranes are able to reach 19 rows across the width of a ship and can pick up containers stacked that far from the dock.

"They're much bigger than the other four cranes at Napoleon Avenue, and because they operate on a rail system, moving up and down the dock, the port is building another set of rails now," Bonura said. "We expect the rails to be ready for cargo in November." Bonura said "in addition, five acres of marshaling yards, big open spaces to hold incoming cargo, are under construction at Napoleon Avenue. They have thick pads of concrete and can support stacks of five containers." The port is spending $36.6 million on the new cranes and marshaling yards as part of a planned $250 million to upgrade and expand the port.

"As ships get bigger and wider, new infrastructure is needed to handle them," Bonura said. Work is partly in preparation for the widening and deepening of the Panama Canal, expected to be complete in late 2014 or early 2015.

Docthermann said at any given time, weather, especially hurricanes, along with high or low river water, operator error, nighttime conditions and other factors can threaten barges on the Mississippi.

A mid-2008 oil spill on the river in downtown New Orleans was the result of human error, and occurred when a barge split open in a collision with the Liberian-flagged tanker Tintoretto, closing 85 miles of river to traffic for almost a week. No major injuries occurred, but nearly 200 ships and barge tows were delayed as they waited to transit the area.

Meanwhile, the local hurricane season starts in June, and barges will have to be secured or moved when storms approach to prevent damage to riverbank properties.

*This story originally published in the May 30, 2011 print edition of The Louisiana Weekly newspaper.*

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Members of the U.S. Coast Guard examine a huge gash in the side of a tanker...

The Coast Guard on Friday partially reopened a five-mile stretch of the Mississippi River upriver from New Orleans after oil spilled from a barge following an early morning collision.

Capt. Pete Gautier, the Coast Guard's captain of the port, said southbound traffic on the river can move through the affected area until 6 p.m. Then, from 6 p.m. to 6 a.m. Saturday, northbound traffic will be allowed to transit the area.

"One of our priorities is to facilitate the safe continuation of commercial traffic," Gautier said in a news release. "Safety is paramount, and the unified command is working to minimize the impact this spill has on people, the environment and commerce."

Officials said a tanker barge pushed downriver by the towboat Clarence Settoon rammed a crane barge being pushed upriver by the tugboat Alydar about 2 a.m. on Friday about 50 miles upriver from New Orleans. The collision tore a 10-foot by 5-foot gash above the waterline of the double-hulled tanker barge and oil spewed less than 10,000 gallons of Louisiana sweet crude oil into the water, Gautier said. The tank contained about 148,000 gallons of oil, but the spill was substantially less than the tank's contents, the Coast Guard said.

Chief Petty Officer John Edwards said no injuries were reported and neither barge nor tugboat sank. He said the leak has been contained.

The Coast Guard said the Clarence Settoon deployed 100 feet of containment boom soon after the collision, and another 30,000 feet was available if needed. A cleanup company has been hired to take further steps to deal with the spill.

St. Charles Parish authorities downriver from the crash closed intakes that draw water for drinking from the river, but said an adequate supply is on hand until water quality can be checked. They described the move as precautionary and said there appeared to be no public danger from the spill. The intakes were reopened later Friday.

The section of river where the crash occurred is part of a busy shipping and industrial corridor that stretches from New Orleans north to Baton Rouge. It is lined by refineries, chemical plants and the massive Port of South Louisiana, which handles much of the grain exported from farms in the U.S. heartland.

Their operations did not appear to be seriously hampered by the river's closing.

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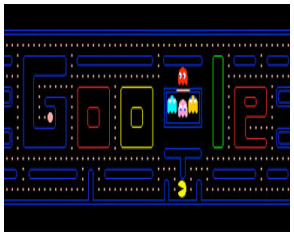

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# HIGH PRODUCTION VOLUME (HPV) CHEMICAL CHALLENGE PROGRAM

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## CRUDE OIL CATEGORY
## CATEGORY ASSESSMENT DOCUMENT

**Submitted to the US EPA**

**by**

**The American Petroleum Institute**
**Petroleum HPV Testing Group**

**Consortium Registration #**

**January 14, 2011**

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Gasoline Blending Steams Mammalian Toxicity Summary (separate document)

Crude Oil Robust Summaries (separate document)

## EXECUTIVE SUMMARY

Only one substance, Petroleum (CAS # 8002-05-9) is in the HPV Crude Oil Category. Petroleum is defined as *"A complex combination of hydrocarbons. It consists predominantly of aliphatic, alicyclic and aromatic hydrocarbons. It may also contain small amounts of nitrogen, oxygen and sulfur compounds. This category encompasses light, medium, and heavy petroleums, as well as the oils extracted from tar sands. Hydrocarbonaceous materials requiring major chemical changes for their recovery or conversion to petroleum refinery feedstocks such as crude shale oils, upgraded shale oils and liquid coal fuels are not included in this definition*". Throughout this document the common name "crude oil" is used for Petroleum.

Crude oil is a naturally occurring substance derived from the decomposition over thousands of years of plant and animal organic matter under elevated temperature and pressure. In appearance, crude oils range from mobile, volatile, light colored liquids to dark, viscous tar-like materials with low vapor pressure. Although, crude oils are assigned a single CAS #, they are generally classified by their density, predominant type of hydrocarbon (paraffinic or naphthenic) present, and whether their sulfur content is high (sour) or low (sweet).

Crude oil is a complex combination of hydrocarbons consisting predominantly of paraffinic (straight and branched-chain alkanes), naphthenic (cycloalkanes or cycloparaffins), and aromatic hydrocarbons. The hydrocarbons in crude oil have carbon numbers that range from four ($C_4$ or butanes), to large molecules containing more than sixty carbons. Sulfur, oxygen and nitrogen compounds, organometallic complexes notably of nickel and vanadium, and dissolved gases, such as hydrogen sulfide, are also found in crude oil. An "average" crude oil contains 84% carbon, 14% hydrogen, 1-3% sulfur, and approximately 1.0% nitrogen, 1.0% oxygen and 0.1% minerals and salts. Analytical studies indicate that similar hydrocarbons, heterocyclics, metals and other constituents, e.g. hydrogen sulfide, are present in all crude oils but their proportions vary depending on the crude source. The composition of crude oils from different producing regions, and even from within a particular geological formation, can vary widely.

### Environmental

Due to their complex compositions, crude oils vary widely in their physical/chemical properties. Despite these differing physical and chemical characteristics, some generalizations can be made regarding the environmental behavior of crude oil. When a release to the environment occurs, components of crude oil will partition into various environmental compartments. The lower molecular weight components may dissolve in water or volatilize to the atmosphere, intermediate fractions may float and spread out on water where the fractions may form emulsions and/or adsorb to soil and sediment, and the viscous, heavy or high molecular weight components may agglomerate and float or sink in water or adhere to soil and sediment. The rate at which partitioning occurs depends not only on the nature of the crude but also on the severity of the weathering processes encountered.

Chemical and physical transformations occur as components of crude oil disperse. Constituents that partition to the air interact with hydroxyl radicals in the atmosphere and have half-lives ranging from 0.4 days to 6.5 days; examples of compounds at either end of the half-life range include n-dodecane and benzene, respectively. Crude oils are subject to biodegradation, but biodegradation rates vary considerably, and crude oils are not considered “readily biodegradable” in standard tests. Low molecular weight components may readily biodegrade, but as molecular weight increases, hydrocarbons become increasingly insoluble in water, so that their bioavailability is limited. In general, hydrocarbons are regarded as being inherently biodegradable, although the degradation rates of the more complex, high molecular weight fractions may be very low.

As a result of crude oil spills and continuous long-term releases of crude oil components, a plethora of real-world data is available on the acute and chronic environmental effects of crude oil. Crude oil is, in general, harmful to aquatic organisms. In both marine and freshwater environments a spill event may cause extensive mortality to non-motile susceptible species such as phytoplankton, crustaceans and larvae or eggs of fish and invertebrates. In contrast, spills of crude oil may not acutely affect highly mobile species such as adult fish. Also, mollusks and polychaete worms have an apparent tolerance to oil contamination.

Because crude oil is extracted from world-wide sources and composed of many different types and molecular weights of hydrocarbons, it may be impractical to assign specific acute aquatic toxicity values that cover the full domain of crude types. In general, aquatic toxicity of crude oil is not likely to be any greater than that represented by the most toxic fraction. For concentrations presented as loading rates, acute toxicity could potentially fall within the range of 1 – 10 mg/L. Acute toxicity is attributed to those water-soluble hydrocarbon components that are either saturates (aliphatic and alicyclic) or mono- and di-aromatics. Polycyclic aromatic hydrocarbons (PAHs) in crude oil are not expected to contribute significantly to acute aquatic toxicity due to their limited bioavailability. However, their partition coefficients, i.e. log $K_{ow}$ 3 to >6, indicate a potential to bioaccumulate, thus the chronic toxicity of PAHs may be a concern.

Other risks to other aquatic species including semi-aquatic birds, and sea mammals include physical fouling of plumage, fur, gills etc, by floating oil product. This results in loss of buoyancy, insulation and smothering of intertidal animals. Ingestion of oil resulting from attempts by animals to clean contaminated body parts may result in toxicity, including severe enteritis.

Spills in freshwater environments have been shown to adversely affect the aquatic macroinvertebrate community, with the observed effects associated with oil sorption and substrate coating. Recovery of such communities in some habitats may be rapid, e.g., riffle areas of streams/rivers, while impacts to backwater areas may persist for months. Ultimately, the type of crude oil and the local conditions and habitats will dictate the extent to which crude oil persists and the potential effects in the environment.

***Human Health Effects***

Crude oils have demonstrated little local irritation or acute dermal toxicity ($LD_{50}$ >2.0 g/kg dermal). However, exploration, production, and transport of crude oil can result in significant levels of hydrogen sulfide and/or volatile organic compounds (VOCs) in some situations (i.e., enclosed spaces). The acute inhalation hazard is primarily from hydrogen sulfide. When the acute toxicity of hydrogen sulfide was assessed in rats, the calculated $LC_{50}$ for a 4-hour inhalation exposure was 444 ppm. VOCs from crude oil are similar to the hydrocarbons found in gasoline and gasoline blending streams. The results of acute toxicity testing indicate that these materials are not acutely toxic by the inhalation exposure route, e.g., Rat $LC_{50}$ >5g/m$^3$.

Repeat dose and developmental studies on inhaled hydrogen sulfide have determined NOAECs of 10 ppm and 80 ppm, respectively. The inhalation NOAECs for repeat dose and developmental effects of VOCs from crude oil are read-across data from studies on gasoline and gasoline blending streams. These values are: Repeat Dose NOAEC: 1507mg/m$^3$ to 10,153mg/m$^3$ (427 – 2880ppm$^3$); Developmental NOAEC: 5970mg/m$^3$ to 27750mg/m$^3$ (1694 – 7873ppm$^3$ ); *[ Total hydrocarbon determined as parts-per-million (ppm) hexane equivalents.]*

In the repeat dose inhalation studies with hydrogen sulfide and gasoline blending streams, there were no specific adverse effect on reproductive organs. In addition, two multi-generation reproduction studies on gasoline vapor in rats have determined NOAECs of over 20,000 mg/m$^3$. This data supports the conclusion that hydrogen sulfide and VOCs from crude oil have limited potential to be reproductive toxicants.

In situations involving repeated dermal exposure, the constituents with the greatest potential for toxicity are the polycyclic aromatic compounds (PACs). Analysis of 46 crude oils showed significant variation in the PAC profile between samples. Solvent extracts of crude oils which concentrate the PAC constituents have induced gene mutations in bacteria. In contrast, the injection of mice with whole crude oil did not produce activity in micronucleus assays but did induce an increase in sister chromatid exchanges. Several samples of crude oil have produced skin-tumors in mice following long-term skin application.

Studies of repeated exposure by the dermal route have demonstrated toxicity that was manifested by aberrant hematology, liver enlargement and thymic atrophy. Measured and modeled toxicity endpoints show a wide range of responses from different samples of crude oil. The benchmark dose ($BMD_{10}$) for measured data on two crude oils and the predicted dose response ($PDR_{10}$) for modeled data on 46 crude oil samples were between 55 and 544 mg/kg/day.

In developmental toxicity studies in rats, crude oils, primarily at maternally toxic doses, caused fetal death, decreased fetal weight, delayed skeletal ossification and parturition. Measured and modeled developmental toxicity endpoints show a wide range of responses from different samples of crude oil. The benchmark dose ($BMD_{10}$) for measured data on two crude oils and the predicted dose response ($PDR_{10}$) for modeled

data on 46 crude oil samples were between 53 and 2000 mg/kg/day. Crude oil is not expected to be a reproductive toxicant since repeated dermal exposures to crude oil for 13-weeks have not produced adverse effects in the reproductive organs of either male or female rats.

The Testing Group believes that the potential for mutagenicity and the systemic toxicity, developmental toxicity and/or carcinogenic effects from repeated dermal exposure is related to the PAC profile of the specific crude oil.

# 1. DESCRIPTION OF CRUDE OIL

## 1.1 Types and Composition:

Crude oils range from light colored oils to thick, black oil similar to melted tar. All crude oils contain carbon, hydrogen, sulfur, nitrogen, oxygen, minerals and salts in varying proportions depending on their source. Table 1 provides examples of the broad chemical composition of various crude oils.

**Light/Heavy Crude Oils**

The designation of "light" or "heavy" for crude oils is based on their density. API gravity is the common measure of crude oil density and is calculated as °API = 141.5/Sp. Gr. – 131.5; the higher the API gravity, the lower the specific gravity. Crude oils with lower densities and viscosities, and thus higher API gravities, usually contain higher levels of naphtha (gasoline-range hydrocarbons) with predominately volatile paraffinic hydrocarbons, which can be processed readily to produce gasoline and are considered "light" crude. Heavy crude oils are more viscous, have higher boiling ranges and higher densities, and thus have lower API gravities. Heavy crude oils are usually rich in aromatics and tend to contain more residual material, e.g. asphaltenes, and heterocyclics, e.g. sulfur, nitrogen, oxygen-containing hydrocarbon analogs.
For example, a Saudi Light Crude that is 63% paraffins, 37% naphthenes and aromatics and a Saudi Heavy crude that is 60% paraffins, 40% naphthenes and aromatics appear to differ only slightly in general hydrocarbon class content, but the compounds making up those classes vary significantly in molecular structure and size distribution, e.g. level of saturated hydrocarbons *vs*. unsaturated and naphtha *vs.* asphaltene content, respectively, so that their API gravities are sufficiently different to classify, within the same oil field, one crude as "light" with 34°API and the other as "heavy" with 28°API. The currently accepted API gravity values that differentiate between light and heavy crude oils are ≥33°API for "light" and ≤28°API for "heavy" (Platt's, 2003).

**Paraffinic/Naphthenic Crude Oils**

Crude oils are composed of paraffinic, naphthenic (cycloparaffinic) and aromatic hydrocarbons, and may be described as either paraffinic or naphthenic depending on the predominant proportion of hydrocarbon type present (The Petroleum Handbook, 1983). Paraffinic crude oils are rich in straight chain and branched saturated hydrocarbons while naphthenic or asphaltic crude oils contain mainly cycloparaffinic, saturated-ring hydrocarbons and aromatic, unsaturated ring hydrocarbons with at least one benzene ring (IARC, 1989). The aromatic fraction of crude oil contains higher molecular weight aromatic molecules including polycyclic aromatic hydrocarbons (PAH) which consist of only carbon and hydrogen and polycyclic aromatic compounds (PAC) in which some carbon atoms are substituted with heteroatoms, such as sulfur, oxygen and/or nitrogen. Most PAC and PAH in crude oil have one or more alkyl side-chains on the ring structure.

**Sweet/Sour Crude Oils**

A crude oil may also be described as sweet or sour depending on its sulfur content. As a general rule, crude oils with less than 1% sulfur are "sweet" and crude oils with over 1% are "sour". Strategic Petroleum Reserve (SPR) "sour" crude oils contain a maximum of 1.99 weight % total sulfur and "sweet" crude oils contain a maximum of 0.5 weight % total sulfur.

**Table 1. Properties of Whole Crude Oils**

| Crude Source | Paraffins % vol | Naphthenes % vol | Aromatics % vol | Sulfur % wt. | API gravity (°API) |
|---|---|---|---|---|---|
| Light Crudes | | | | | |
| Saudi Light | 63 | 18 | 19 | 2.0 | 34 |
| South Louisiana | 79 | 45 | 19 | 0.0 | 35 |
| Beryl | 47 | 34 | 19 | 0.4 | 37 |
| North Sea Brent | 50 | 34 | 16 | 0.4 | 37 |
| Lost Hills Light | 50% Aliphatics | - | 50 | 0.9 | >38 |
| Mid range Crudes | | | | | |
| Venezuela Light | 52 | 34 | 14 | 1.5 | 30 |
| Kuwait | 63 | 20 | 24 | 2.4 | 31 |
| USA West Texas sour | 46 | 32 | 22 | 1.9 | 32 |
| Heavy Crudes | | | | | |
| Prudhoe Bay | 27 | 36 | 28 | 0.9 | 28 |
| Saudi Heavy | 60 | 20 | 15 | 2.1 | 28 |
| Venezuela Heavy | 35 | 53 | 12 | 2.3 | 24 |
| Belridge Heavy | Aliphatics 37% | | 63 | 1.1 | 14 |

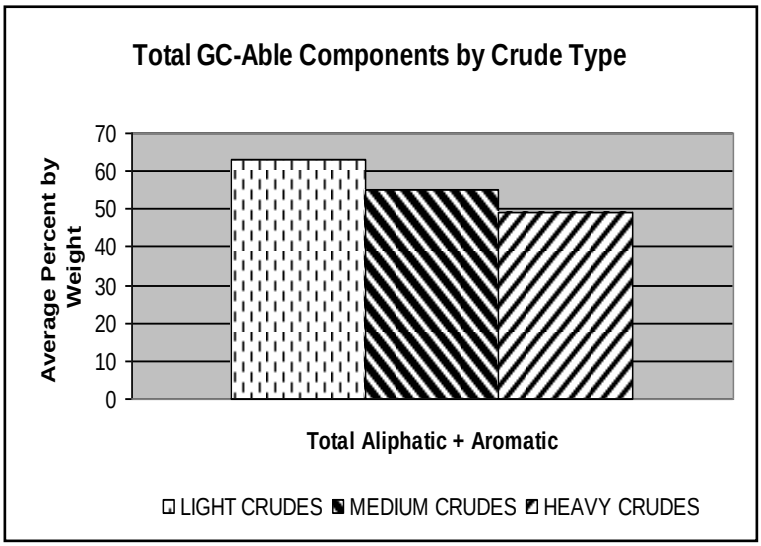
IARC, 1989; Mobil, 1997; OSHA, 1993 & International Crude Oil Market Handbook, 2004

### 1.2 Analytical Characterization

A comprehensive evaluation of gas chromatographic (GC)-analyzable fractions of 77 crude oils from worldwide oil fields (Figure 1) provides a profile of compositional similarities and differences among crude oils (US DOE/PERF, 2001). Total petroleum hydrocarbon (TPH) content was sorted as aliphatics up to C16, combining the saturated aliphatic paraffins and naphthenes (cycloparaffins), and as aromatic hydrocarbons, unsaturated rings from C6 to greater than C21. Content of benzene/toluene/ethylbenzene/xylene (BTEX), content of the 16 EPA standard marker polycyclic aromatic hydrocarbons, and distribution of 4-6 ring polycyclic aromatic hydrocarbons (PAH) were determined. The amount of material available for GC analysis is influenced by molecular structure and size. The heavier crude oils which have higher boiling ranges and higher densities contain a greater proportion of complex, high molecular weight hydrocarbons, e.g. asphaltenes and resins, in the non-distillable

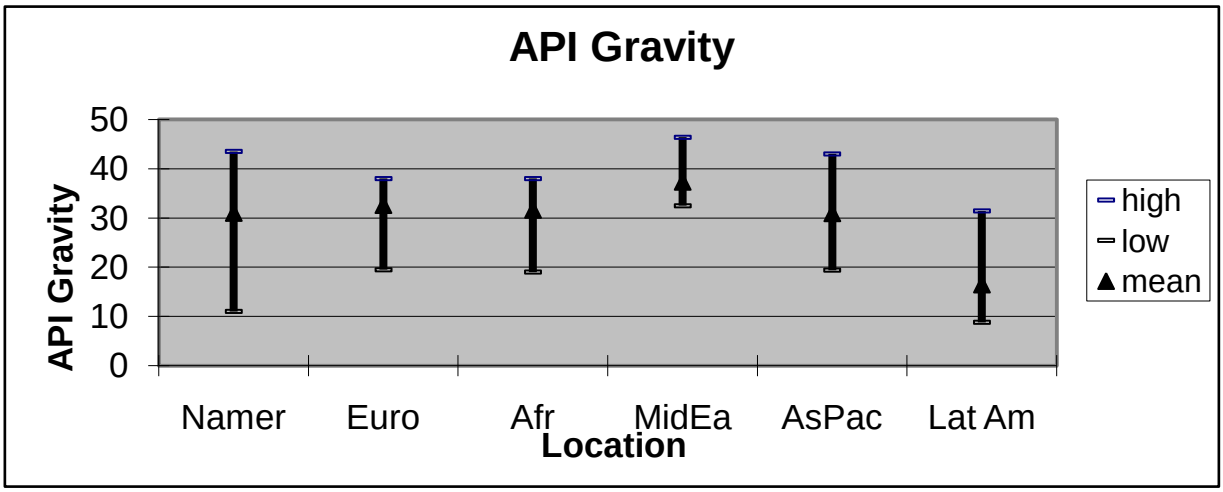
range, thus reducing the size of the fraction available for GC analysis as shown in Figure 1.

Figure 1




Results from testing 64 crude oils with identified API gravities are summarized in Figure 2 which demonstrates the range of API gravities of crude oils from various regions. In this study, North American (Namer) crudes show a wide range from very heavy, e.g. 11°API, to highly desirable light crudes, e.g. 43.5°API, with an average of 31°API. The European, Asian Pacific and African crude oils sampled averaged in the mid-range, i.e. >30° to <33° API. The Middle Eastern crude oils sampled tended to be lighter, e.g. 37°API, and more easily used for gasoline production. The Latin America crude oils sampled were heavier, i.e. average 16°API, and are therefore more useful as sources for lubricant base oils and heavier fuels, e.g. fuel oil #6.

Figure 2: API Gravity for Crude Oils



Light crude oils with lower boiling ranges and lower densities are richer in aliphatic hydrocarbons (Figure 3a) while heavy crudes contain a greater proportion of aromatic compounds with increasingly broad carbon ranges (Figure 3b).

Figure 3a

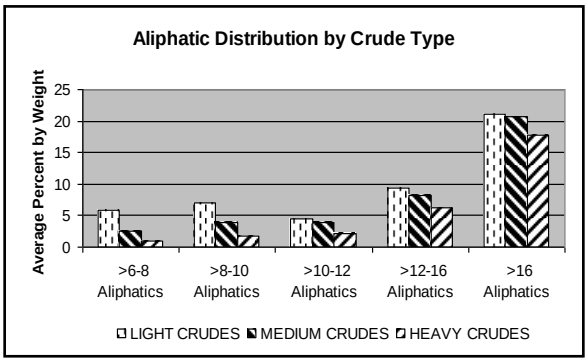
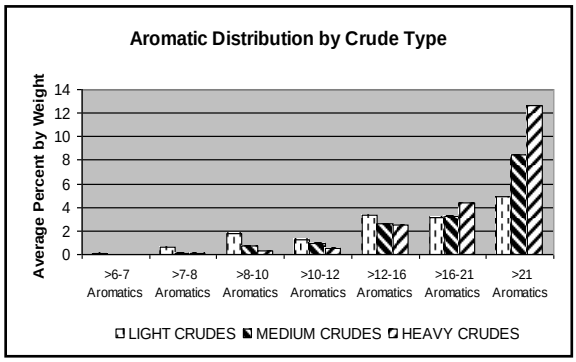


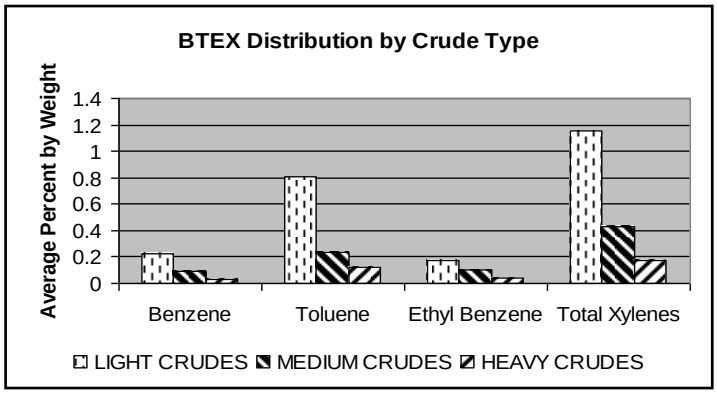

Figure 3b




Of the total petroleum hydrocarbons analyzed, the average weight % of fractions containing less than six carbons was greater in the light crudes, i.e. 6.6%, than in the medium crudes, i.e. 4.7%, and lowest in the heaviest crude oils, i.e. 1.2%. Conversely heavy crude oils contain larger percentages of molecules with carbon distributions greater than C44, i.e. 36%, compared to medium crudes, i.e. 16%, and light crudes, i.e. 8%.

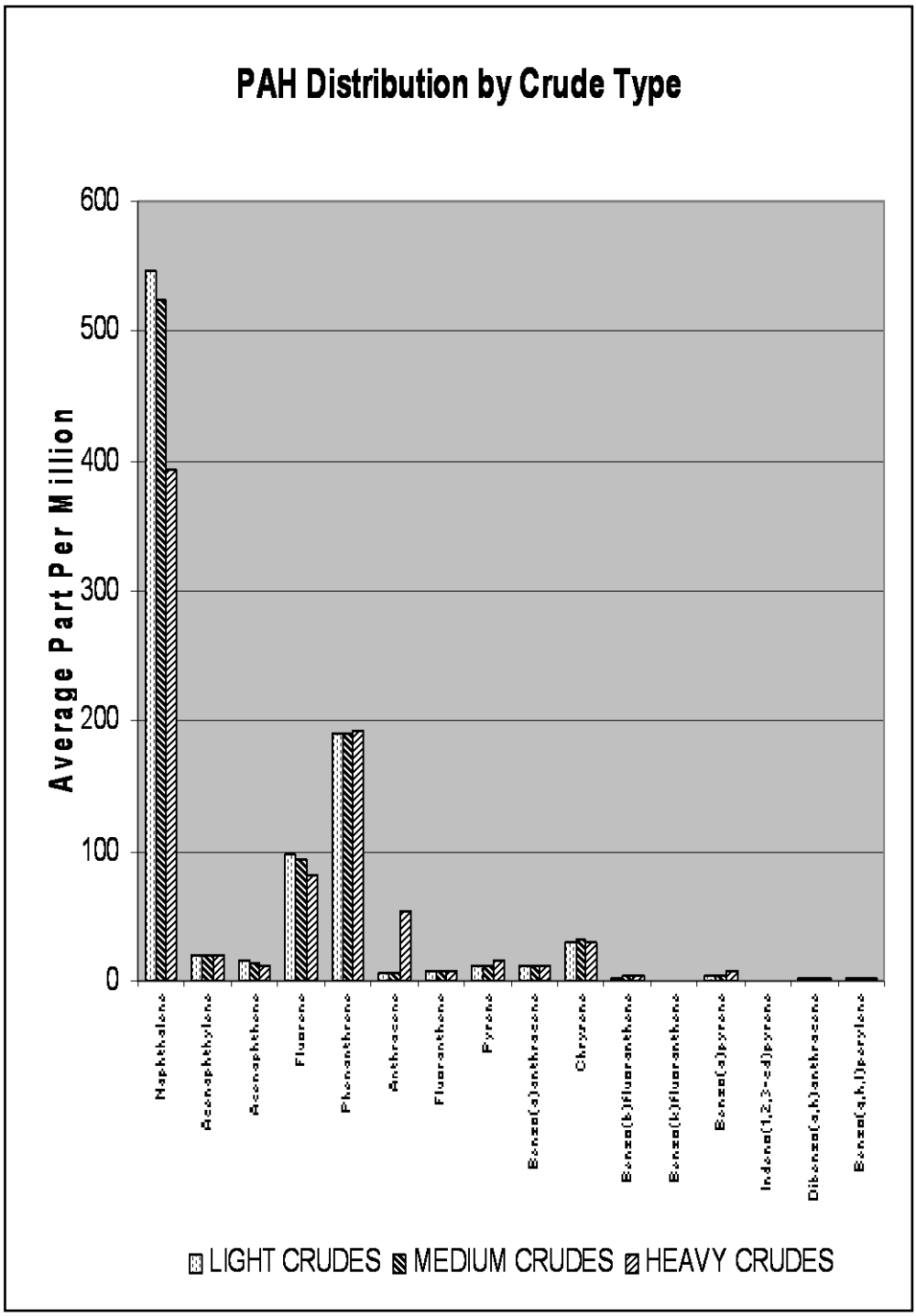
The distribution of BTEX is greater in the lower density light crudes as seen in Figure 4, although the weight % never exceeds 1.2%.

Figure 4




Analysis for the 16 EPA standard marker PAH compounds found that naphthalene was present at the highest concentration of >500 ppm in the light crude and at 400 ppm in the heavy crude while the known PAH carcinogens, benzo(a)pyrene and benzo(a)anthracene were present at very low levels in all the crude oil samples (Figure 5).

Figure 5.


PAH Distribution by Crude Type
Average Part Per Million
600
500
400
300
200
100
0
Naphthalene
Acenaphthylene
Acenaphthene
Fluorene
Phenanthrene
Anthracene
Fluoranthene
Pyrene
Benzo(a)anthracene
Chrysene
Benzo(b)fluoranthene
Benzo(k)fluoranthene
Benzo(a)pyrene
Indeno(1,2,3-cd)pyrene
Dibenzo(a,h)anthracene
Benzo(g,h,i)perylene
LIGHT CRUDES
MEDIUM CRUDES
HEAVY CRUDES

Crude oils contain polycyclic aromatic compounds (PACs). Although similar to polycyclic aromatic hydrocarbons (PAHs) that contain two or more fused-aromatic rings consisting only of carbon and hydrogen, PACs are a broader group of compounds that also includes heterocyclic compounds in which one or more of the carbon atoms in the PAH ring system is replaced by nitrogen, oxygen, or sulfur atoms. The PACs in Crude oil are formed when organic matter is converted into petroleum under elevated pressure and moderate temperatures (130 – 150°C). The nature of the processes which convert organic matter into petroleum involves semi-random chemical processes. The formation of crude oil produces hundreds to thousands of individual PACs. The types of PACs formed in petroleum include a complex variety of parent, i.e. un-substituted, and alkylated structures. The alkyl-substitutions are usually one to four carbons long and can include non-carbon compounds, such as sulfur. Multiple alkyl and cycloparaffinic substitutions of the parent structure are also common, especially in higher boiling fractions of petroleum. The relative abundance of the alkylated polycyclic aromatics ($C_{1-4}$) in petroleum far exceeds the abundance of the non-alkylated species ($C_0$) (Speight, 2007). The fact that the concentration of alkylated polycyclic aromatics is much greater than the non-alkylated polycyclic aromatics is the main feature of the petrogenic PACs found in petroleum.

The profile of PAC in some petroleum streams has been shown to be important for predicting the possible effects that can occur with repeated dermal exposures (TERA, 2008). For that reason, recently developed data on the percent of each Aromatic Ring Class (ARC) in 46 individual pentane de-asphalted crude oil samples are shown in Table 2. The Table is sorted by API Gravity, lowest to highest (heavy crude oil to lighter crude oil).

**Table 2. PAC Profile of 46 Crude Oils [1,2]**

| Sample Number | Total DMSO extractable wt% | ARC 1 Wt% | ARC 2 Wt% | ARC 3 Wt% | ARC 4 Wt% | ARC 5 Wt% | ARC 6 Wt% | ARC 7 Wt% | API Gravity |
|---|---|---|---|---|---|---|---|---|---|
| 70920 | 5.8 | 0.0 | 0.6 | 1.7 | 1.2 | 1.2 | 0.6 | 0.3 | 13.9 |
| 50905 | 3.3 | 0.0 | 1.0 | 1.6 | 0.3 | 0.2 | 0.1 | 0.0 | 19.4 |
| 10953 | 3.7 | 0.0 | 1.8 | 1.1 | 0.4 | 0.2 | 0.0 | 0.0 | 19.6 |
| 70918 | 3.9 | 0.1 | 1.6 | 1.6 | 0.4 | 0.4 | 0.1 | 0.0 | 20.8 |
| 30903 | 4.4 | 0.0 | 1.3 | 1.3 | 0.4 | 0.4 | 0.4 | 0.0 | 21.2 |
| 30913 | 3.7 | 0.0 | 1.9 | 1.5 | 0.2 | 0.1 | 0.1 | 0.0 | 21.4 |
| 70912 | 4.0 | 0.0 | 0.8 | 1.6 | 0.8 | 0.4 | 0.4 | 0.1 | 21.9 |
| 70917 | 5.3 | 0.1 | 1.6 | 1.6 | 1.1 | 0.5 | 0.5 | 0.1 | 23.3 |
| 30905 | 3.3 | 0.0 | 1.7 | 1.0 | 0.2 | 0.1 | 0.1 | 0.0 | 23.4 |
| 70916 | 4.2 | 0.1 | 1.2 | 1.2 | 0.8 | 0.4 | 0.3 | 0.1 | 23.4 |
| 70910 | 3.9 | 0.0 | 1.2 | 1.6 | 0.4 | 0.3 | 0.2 | 0.0 | 25.4 |
| 50910 | 4.3 | 0.0 | 0.9 | 2.1 | 0.9 | 0.3 | 0.2 | 0.0 | 26.6 |
| 10956 | 1.9 | 0.0 | 0.4 | 0.2 | 0.1 | 0.0 | 0.0 | 0.0 | 28.6 |
| 50907 | 2.5 | 0.0 | 0.5 | 1.0 | 0.5 | 0.3 | 0.2 | 0.1 | 28.9 |

| Sample Number | Total DMSO extractable wt% | ARC 1 Wt% | ARC 2 Wt% | ARC 3 Wt% | ARC 4 Wt% | ARC 5 Wt% | ARC 6 Wt% | ARC 7 Wt% | API Gravity |
|---|---|---|---|---|---|---|---|---|---|
| 70911 | 3.8 | 0.1 | 1.5 | 1.2 | 0.4 | 0.4 | 0.3 | 0.0 | 28.9 |
| 50908 | 2.7 | 0.1 | 1.3 | 0.8 | 0.2 | 0.1 | 0.1 | 0.0 | 29.3 |
| 10959 | 2.6 | 0.1 | 1.5 | 0.8 | 0.2 | 0.1 | 0.0 | 0.0 | 29.6 |
| 30965 | 3.9 | 0.1 | 2.3 | 1.2 | 0.2 | 0.2 | 0.1 | 0.0 | 29.6 |
| 10952 | 3.2 | 0.0 | 2.2 | 1.0 | 0.2 | 0.0 | 0.0 | 0.0 | 29.8 |
| 10954 | 3.3 | 0.0 | 1.6 | 1.0 | 0.3 | 0.1 | 0.0 | 0.0 | 30.4 |
| 50906 | 3.3 | 0.0 | 1.6 | 1.3 | 0.2 | 0.1 | 0.1 | 0.0 | 30.5 |
| 70913 | 4.7 | 0.1 | 1.9 | 1.4 | 0.5 | 0.3 | 0.2 | 0.0 | 30.5 |
| 50909 | 3.2 | 0.0 | 1.0 | 1.6 | 0.3 | 0.2 | 0.1 | 0.0 | 30.6 |
| 30902 | 4.5 | 0.2 | 2.2 | 1.3 | 0.4 | 0.3 | 0.2 | 0.0 | 30.7 |
| 70919 | 4.0 | 0.0 | 1.2 | 1.2 | 0.8 | 0.4 | 0.3 | 0.0 | 31.1 |
| 30906 | 5.0 | 0.2 | 2.5 | 1.5 | 0.4 | 0.3 | 0.1 | 0.0 | 31.5 |
| 30907 | 4.1 | 0.2 | 2.5 | 1.2 | 0.2 | 0.1 | 0.1 | 0.0 | 31.5 |
| 30909 | 5.0 | 0.1 | 3.5 | 1.0 | 0.1 | 0.0 | 0.0 | 0.0 | 32.4 |
| 30910 | 4.4 | 0.1 | 2.2 | 1.3 | 0.4 | 0.2 | 0.1 | 0.0 | 32.4 |
| 50904 | 3.6 | 0.0 | 1.4 | 1.4 | 0.3 | 0.2 | 0.1 | 0.0 | 32.4 |
| 10960 | 2.7 | 0.0 | 1.9 | 0.5 | 0.2 | 0.0 | 0.0 | 0.0 | 32.7 |
| 30904 | 4.6 | 0.1 | 2.8 | 1.4 | 0.1 | 0.0 | 0.0 | 0.0 | 33.1 |
| 10957 | 3.1 | 0.1 | 1.6 | 0.9 | 0.3 | 0.1 | 0.0 | 0.0 | 33.3 |
| 30964 | 4.9 | 0.1 | 2.0 | 2.0 | 0.4 | 0.2 | 0.2 | 0.0 | 33.3 |
| 30908 | 3.5 | 0.1 | 2.1 | 0.7 | 0.1 | 0.1 | 0.1 | 0.0 | 33.3 |
| 10951 | 3.8 | 0.0 | 2.3 | 1.1 | 0.4 | 0.1 | 0.0 | 0.0 | 33.4 |
| 50902 | 3.0 | 0.0 | 1.2 | 1.5 | 0.3 | 0.1 | 0.1 | 0.0 | 33.6 |
| 70914 | 2.5 | 0.0 | 1.2 | 0.7 | 0.2 | 0.1 | 0.1 | 0.0 | 36.5 |
| 10958 | 2.6 | 0.1 | 1.5 | 0.8 | 0.2 | 0.0 | 0.0 | 0.0 | 36.9 |
| 50901 | 3.7 | 0.1 | 1.9 | 1.5 | 0.2 | 0.1 | 0.1 | 0.0 | 38 |
| 30911 | 4.5 | 0.3 | 2.7 | 1.3 | 0.1 | 0.0 | 0.0 | 0.0 | 38.3 |
| 10955 | 3.0 | 0.1 | 1.8 | 0.9 | 0.2 | 0.0 | 0.0 | 0.0 | 39.1 |
| 30914 | 3.3 | 0.1 | 2.6 | 0.7 | 0.0 | 0.0 | 0.0 | 0.0 | 39.1 |
| 50903 | 4.2 | 0.0 | 2.1 | 1.7 | 0.2 | 0.1 | 0.0 | 0.0 | 39.4 |
| 30912 | 3.0 | 0.1 | 2.1 | 0.6 | 0.1 | 0.1 | 0.1 | 0.0 | 41.8 |
| 70915 | 3.2 | 0.2 | 1.9 | 0.6 | 0.2 | 0.1 | 0.1 | 0.0 | 46.2 |

1) As determined by PAC-2 Method as described by Roy *et al,* 1985 &1988.
2) ARC is “aromatic ring class”. “ARC 1 %” is the weight percent of PACs that have 1 aromatic ring within the total sample. “ARC 2 %” is the percent of PACs with 2 aromatic rings, and so forth to 7 aromatic rings.

Crude oils also contain varying amounts of non-hydrocarbon sulfur, nitrogen, oxygen and trace metals. Sulfur is present as hydrogen sulfide ($H_2S$), thiols, mercaptans,

sulfides, benzothiophenes, polysufides, and/or as elemental sulfur. As a rule, the proportion, stability and complexity of sulfur compounds are greater in heavier crude oil fractions. $H_2S$ is a primary contributor to corrosion in refinery process units and combustion of sulfur-containing petroleum products can produce undesirable byproducts such as sulfuric acid and sulfur dioxide. The total sulfur content of crude oils spans a range of <0.1% to ~5.0% by elemental analysis. In general, as API gravity decreases, sulfur content increases. For example, a light US crude from Rodessa, Louisiana, has an API gravity of 42.8 and a sulfur content of 0.28%, while an extremely heavy crude from Venezuela has an API gravity of 9.5 and contains 5.25% sulfur (Dickey, 1981; IARC, 1989).

Table 2 illustrates the range of sulfur content in the blended light/medium crude oils that comprise the US Strategic Petroleum Reserve [SPR] stored at 4 cavern sites – Bryan Mound, West Hackberry, Bayou Choctaw, and Big Hill (US DOE, 2002). In the SPR, sour crude oils contain a maximum of 1.99 weight % total sulfur and sweet crude oils contain a maximum of 0.5 weight % total sulfur. Sulfur is removed during refining by catalytic hydrogenation, by caustic wash or other sweetening processes.

**Table 3. Properties of Crude Oil in the Strategic Petroleum Reserve**

| Crude Source | Paraffins % vol | Naphthenes % vol | Aromatics % vol | Sulfur % wt. | API gravity ($^0$API) |
|---|---|---|---|---|---|
| Bryan Mound Sweet | 68 | 24 | 8 | 0.33 | 36 |
| Bryan Mound Sour | 71 | 18 | 11 | 1.39 | 35 |
| West Hackberry Sweet | 57 | 30 | 13 | 0.32 | 37 |
| West Hackberry Sour | 75 | 19 | 6 | 1.41 | 34 |
| Bayou Choctaw Sweet | 63 | 26 | 11 | 0.36 | 36 |
| Bayou Choctaw Sour | 68 | 21 | 11 | 1.38 | 32 |
| Big Hill Sweet | 61 | 30 | 9 | 0.48 | 36 |
| Big Hill Sour | 68 | 19 | 13 | 1.41 | 31 |

US DOE SRC, 2002

Heterocyclic PACs containing nitrogen include anilines, pyridines, quinolines, pyrols, carbazoles, benzonitriles and amides. Nitrogen is found in lighter fractions as basic compounds and in heavier fractions as non-basic compounds. Total nitrogen varies from <0.01% to 1.0% by elemental analysis. Oxygen-containing PACs in crude oils are generally in the phenol, ketone and carboxylic acid families.

The polar compounds in crude oils contain the heteroatoms of oxygen (O), nitrogen (N), and/or sulfur (S) and are known by a variety of names, including heterocyclics, resins, NSOs, polars, and asphaltenes (Prince, 2002, Tissot and White,1984). In crude oils, sulfur-containing heterocyclics exist in the greatest proportion with nitrogen heterocyclics occurring at much lower concentrations (Potter and Simmons, 1998). The majority of the sulfur and nitrogen-containing compounds of petroleum have high molecular masses and high boiling points, thus these materials become concentrated in the heavy fuel oil and tar fractions (Tissot and White, 1984). Although NSO-heteroatom

PACs are discussed here separately, these heteroatoms can occur together in the same highly complex, high molecular weight fractions. Heterocylic compounds also may contain metals in the form of salts of carboxylic acids or more typically as porphyrin chelates or organo-metal complexes (Tissot and White, 1984; Potter and Simmons, 1998; Prince, 2002).

Many of the non-hydrocarbon constituents in crude oil are entrained in non-distillable residues with high boiling ranges that can exceed 720°C (1328°F) and consist almost exclusively of heterocompounds. These residues, e.g. resins, maltenes, and asphaltenes, typically account for 30-50% total sulfur, 70-80% total nitrogen and 80-90% total vanadium and nickel in crude oil. Saturates and aromatics make up only a few weight percent of the non-distillable residue while 40-70% is pentane-insoluble asphaltenes. Resins and asphaltenes with molecular weights of 500-10,000 may constitute from 10% in light paraffinic crude oils to 20-60% in heavy crude oils. The viscosity of a crude oil is greatly affected by the presence of non-distillable residual fractions. The broad molecular range of heterocompounds in this fraction, low volatility and limited solubility severely impair analytical characterization (Algelt and Bodieszynski, 1994). These large, minimally soluble, highly polar molecular structures have very limited bioavailability and absorption, so that heterocompounds and small concentrations of metals entrained in these molecules cannot contribute significantly to possible biological activity induced by exposure to crude oil.

Small quantities of metals naturally occur in crude oils due to their presence in rock formations or salt water deposits from which the oils are drawn or introduced during processing (IARC, 1989). The metals are primarily in the form of stable molecular complexes that can be distilled at temperatures above 500 °C (IARC, 1989). Table 4 summarizes the concentration of metals in 26 representative crude oils from a PERF project where the mean concentrations detected were less than 1.5 ppm for all metals, i.e. total of 18 detectable metals, except nickel at 20 ppm, vanadium at 63 ppm and zinc at 3 ppm (API, 2001). Most metals are present in similar concentrations in all crude types with the exceptions of nickel and vanadium, which appear to increase in concentration as crude oils become heavier (API, 2001). Similar results (Table 5) were found in an API analysis of 46 crude oils that had been processed in the US where nickel and vanadium were found in the highest concentrations in the heaviest crude oils.

Metals are present in crude oils in such low levels that the potential for human health risks and ecological impact is unlikely to be a major risk management consideration at crude oil spill sites (Magaw *et al*., 2000). Inorganic salts such as magnesium chloride or calcium chloride are suspended as minute crystals in crude oil or dissolved in entrained water (brine). These salts are removed or neutralized prior to processing to prevent catalyst poisoning, equipment corrosion and fouling.

## Table 4. PERF Survey of Metal Concentrations (ppm) in Crude Oils

| Metal | LOD ppm | Light Crude Oils (≥33°API) | | | Medium Crude Oils (>28°- <33°API) | | | Heavy Crude Oils (≤28°API) | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | **Mean (range)** | **N** | **Dec Freq %** | **Mean (range)** | **N** | **Dec Freq %** | **Mean (range)** | **N** | **Dec Freq %** |
| Ag [silver] | 0.01 | 0.15 (0.07-0.3) | 11 | 100 | *0.16 (0.14 - 0.23)* | 7 | 100 | 0.13 (0.05 – 0.28 | 10 | 100 |
| As [arsenic] | 0.08 | 0.02 | 1 | 9 | *0.13 (0.09 – 0.57)* | 3 | 43 | 0.06 (0.17 – 0.19) | 3 | 30 |
| Ba [barium] | 0.001 | 0.04 (0.01 - 0.37) | 5 | 45 | 0.02 (0.003 - 0.04) | 5 | 71 | *0.08 (0.002 – 0.2)* | 9 | 90 |
| Be [beryllium] | 0.005 | - | ND | 0 | - | ND | 0 | - | ND | 0 |
| Cd [cadmium] | 0.002 | 0.01 (0.003 – 0.03) | 11 | 100 | 0.01 (0.003 – 0.11) | 7 | 100 | 0.01 (0.005 - 0.02) | 10 | 100 |
| Co [cobalt] | 0.01 | 0.07 (0.003 – 0.44) | 4 | 36 | 0.10 (0.02 – 0.38) | 3 | 43 | *0.65 (0.11 – 1.33)* | 10 | 100 |
| Cr [chromium] | 0.005 | 0.08 (0.02 – 0.37) | 10 | 91 | 0.35 (0.07 – 0.87) | 7 | 100 | *0.46 (0.07 – 1.43)* | 10 | 100 |
| Cu [copper] | 0.01 | 0.06 (0.01 – 0.13) | 11 | 100 | *0.09 (0.02 – 0.24)* | 7 | 100 | 0.01 (0.03 – 0.23) | 10 | 100 |
| Hg [mercury] | 0.01 | *0.14* | 1 | 9 | - | ND | 0 | - | ND | 0 |
| Mo [molybdenum] | 0.02 | 0.51 (0.31 – 0.87) | 11 | 100 | 0.43 (0.31 – 0.53) | 7 | 100 | *1.23 (0.53 – 4.01)* | 10 | 100 |
| Ni [nickel] | 0.02 | 2.48 (0.05 – 7.28) | 11 | 100 | 8.45 (4.32-14.1) | 7 | 100 | *48.0 (6.87 – 93.0)* | 10 | 100 |
| Pb [lead] | 0.001 | *0.49 (0.005 – 0.10)* | 11 | 100 | 0.03 (0.009 – 0.07) | 7 | 100 | 0.04 (0.005 – 0.15) | 10 | 100 |
| Sb [antimony] | 0.001 | 0.004 (0.001 – 0.02) | 6 | 54 | 0.006 (0.003 – 0.01) | 7 | 100 | *0.02 (0.001 – 0.06)* | 10 | 100 |
| Se [selenium] | 0.02 | 0.06 (0.02-0.27) | 9 | 82 | 0.08 (0.03 – 0.13) | 7 | 100 | *0.33 (0.04 – 0.52)* | 10 | 100 |
| Sn [tin] | 0.01 | *1.91 (0.11 - 9.66)* | 11 | 100 | 0.92 (0.04 – 2.3) | 7 | 100 | 0.92 (0.04 – 3.26) | 10 | 100 |
| Tl [thallium] | 0.002 | *0.001* | 2 | 18 | 0.0003 | 1 | 14 | - | ND | 0 |
| V [vanadium] | 0.02 | 3.42 (0.13 - 20.0) | 11 | 100 | 16.72 (0.15 – 40.0) | 7 | 100 | *154.2 (1.4 – 370)* | 10 | 100 |
| Zn [zinc] | 0.08 | 3.56 (2.04 – 8.42) | 10 | 91 | *4.09 (1.28 – 10.9)* | 7 | 100 | 1.42 (0.58 – 3.70) | 8 | 80 |

N = Number of samples
ND = None detected

Means and ranges for 26 crude oils from various sources throughout the world. *ITALICS* indicates highest mean metal concentration between grades of crude oil (Magaw, 1999 & API 2001)

**Table 5. API Analysis of Certain Metal Concentrations in 46 Crude Oils**

| **Metal** | **LOD ppm** | **Light Crude Oils (N=15)** (≥33°API) | | **Medium Crude Oils (N=19)** (>28°- <33°API) | | **Heavy Crude Oils (N=12)** (≤28°API) | |
|---|---|---|---|---|---|---|---|
| | | **Mean (range) ppm** | **Dec. Freq. %** | **Mean (range) ppm** | **Dec. Freq. %** | **Mean (range) ppm** | **Dec. Freq. %** |
| Fe [iron] | 0.1 | 2.18 (0.2-15.9) | 73 | 1.22 (0.2-6.1) | 74 | *8.1 (0.3-48.2)* | 100 |
| Ni [nickel] | 0.1 | 2.10 (0.5-3.8) | 100 | 8.8 (0.1-33.2) | 95 | *37.2 (4.3-71.5)* | 100 |
| V [vanadium] | 0.1 | 4.04 (0.2-11.6) | 93 | 14.03 (0.4-33.0) | 95 | *80.7 (7.6-175)* | 100 |

Note: Means and ranges for metal concentrations (ppm) analyzed according to ASTM D5708 for 46 randomly chosen crude oils processed in the US in 2004 (Wilhelm et al, 2007).

Dec. Freq. = Detection frequency above the limit of detection
LOD = Limit of detection

## 2.0 CATEGORY DEFINITION and RATIONALE

Only one Chemical Abstract Service (CAS) number (Petroleum, 8002-05-9) represents all crude oils and constitutes the HPV Crude Oil Category. Crude oil is a Chemical Substance of Unknown, of Variable Composition, or of Biological Origin (UVCB) in the Toxic Substances Control Act (TSCA) Chemical Inventory and is defined as follows:

> *"A complex combination of hydrocarbons. It consists predominantly of aliphatic, alicyclic and aromatic hydrocarbons. It may also contain small amounts of nitrogen, oxygen and sulfur compounds. This category encompasses light, medium, and heavy petroleums, as well as the oils extracted from tar sands. Hydrocarbonaceous materials requiring major chemical changes for their recovery or conversion to petroleum refinery feedstocks such as crude shale oils, upgraded shale oils and liquid coal fuels are not included in this definition".*

Although the terms "crude oil" and "petroleum" refer to the same UVCB substance, to avoid confusion only the more commonly used term "crude oil" is used throughout this document.

Although crude oils are composed of a wide variety of constituents, analytical studies indicate that hydrocarbons, heterocyclics, metals and other constituents, e.g. hydrogen sulfide, are present in all crude oils with the diversity of crude oils originating from the proportional variability in these components depending on the source of the oil. Therefore, grouping all crude oils together into one category is appropriate to evaluate and predict potential screening level hazards.

The physical/chemical properties of crude oil are directly related to their carbon range and to a much lesser extent to their paraffinic, naphthenic and the aromatic character. The carbon range influences the volatility, water solubility, and viscosity of crude oils which in turn determines the environmental fate, ecotoxicity, and potential bioavailability of components. Hydrogen sulfide, volatile organic compounds (VOCs), and polycyclic aromatic compounds (PAC) found in crude oils are the most common constituents which present human health hazards.

## 3.0 TEST MATERIALS

Forty-six samples of uniquely identified crude oils were randomly chosen from a collection of 170 crude oil streams processed in the US in 2004 (Wilhelm et al, 2007). These samples were analyzed by the API for Metals by ICP-AES (ASTM D5708), Boiling Point Distribution of Samples with Residues by High Temperature GC (ASTM D7169), Density and Relative Density of Crude Oils (ASTM D5002). PAC-2 (Roy et al, 1985 &1988) analysis was done after the samples were pentane de-asphalted (modified ASTM D6560).

## 4.0 PHYSICAL-CHEMICAL PROPERTIES

In appearance, crude oils range from mobile, volatile, light colored liquids consisting to black, viscous tar-like materials. The chemical compositions of crude oils from different producing regions, and even from within a particular formation, can vary widely.

Although some physical-chemical property data exist for some crude oils, not all of the endpoints indicated below are defined and a consensus database for physical-chemical values for all crude oils does not exist. Further, because crude oils are complex substances with variable compositions, the measurement or calculation of a single numerical value for some of the physicochemical properties is not possible. For example, a substance that contains multiple constituents does not have a melting point, but rather a melting point range that reflects the constituents' properties. Where appropriate, values for physical-chemical properties are represented as a range of values according to crude oil's general composition of hydrocarbon compounds. Measured data have been provided when available. When measured values were not available, estimates of the values for physical-chemical endpoints were made for representative constituents covering a potential range of molecular weights and hydrocarbon isomeric structures using the EPI-Suite™ structure-activity estimation models (EPA, 2000).

### 4.1 Physical-Chemical Endpoints

The physicochemical endpoints for the EPA HPV chemical program include the following:

melting point,
boiling point,
vapor pressure,
octanol/water partition coefficient ($K_{ow}$), and
water solubility.

### 4.2 Melting Point

For complex substances like crude oil, melting point may be characterized by a range of temperatures reflecting the melting points of the individual components. To better describe phase or flow characteristics of petroleum products, including crude oil, the pour point is routinely used. The range of Figures quoted in the robust summary, -30°C to 30°C, is a typical range for the pour point as measured by a standard oil industry procedure, i.e. ASTM 1991b (ECB, 2000). Some low-wax crudes have pour points below -30°C.

**Conclusion:** The pour points of the majority of crude oils fall within an approximate range of -30°C to 30°C.

### 4.3 Boiling Point

Distillation temperatures for crude oil range from approximately -1°C to over 720°C (30 – 1328 °F) at 1013 Pa. This approximate range for crude oil is based on the boiling point of n-butane for the lower end and an upper estimate based on ASTM D7169 – 05, "Standard Test Method for Boiling Point Distribution of Samples with Residues Such as Crude Oils and Atmospheric and Vacuum Residues by High Temperature Gas Chromatography" (ASTM, 2005). The boiling points of 46 crude oils are presented in Table 6. The "percent recovered" in Table 6 indicates that some portion of the crude oil sample often boils above the limits of this analytical method (approximately 720°C or 1328°F). In practice, atmospheric distillation of crude oil at a refinery is not conducted above 275-300°C, to avoid thermal decomposition.

**Table 6. Boiling Point Distribution of 46 Crude Oils[1]**

| Sample No. | API Gravity | Boiling Range ($^0$F) | | | |
|---|---|---|---|---|---|
| | | Initial BP | T50[2] | Final BP | % Recovered |
| 70920 | 13.9 | 171 | 853 | 1312 | 86 |
| 50905 | 19.4 | 86 | 852 | 1321 | 78 |
| 10953 | 19.6 | 90 | 827 | 1319 | 87 |
| 70918 | 20.8 | 92 | 866 | 1316 | 76 |
| 30903 | 21.2 | 91 | 916 | 1302 | 72 |
| 30913 | 21.4 | 86 | 831 | 1303 | 79 |
| 70912 | 21.9 | 111 | 928 | 1298 | 72 |
| 70917 | 23.3 | 124 | 744 | 1281 | 87 |
| 30905 | 23.4 | 93 | 817 | 1310 | 80 |
| 70916 | 23.4 | 54 | 791 | 1286 | 82 |
| 70910 | 25.4 | 158 | 737 | 1303 | 93 |
| 50910 | 26.6 | 82 | 754 | 1285 | 85 |
| 10956 | 28.6 | 169 | 700 | 1289 | 90 |
| 50907 | 28.9 | 124 | 687 | 1300 | 91 |
| 70911 | 28.9 | 79 | 598 | 1269 | 100 |
| 50908 | 29.3 | 84 | 737 | 1293 | 84 |
| 10959 | 29.6 | 80 | 738 | 1316 | 86 |
| 30965 | 29.6 | 84 | 732 | 1299 | 87 |
| 10952 | 29.8 | 77 | 691 | 1318 | 94 |
| 10954 | 30.4 | 112 | 626 | 1079 | 100 |
| 50906 | 30.5 | 95 | 732 | 1324 | 84 |
| 70913 | 30.5 | 48 | 581 | 1168 | 93 |
| 50909 | 30.6 | 86 | 739 | 1305 | 82 |
| 30902 | 30.7 | 75 | 720 | 1294 | 85 |
| 70919 | 31.1 | 112 | 698 | 1280 | 86 |
| 30906 | 31.5 | 78 | 605 | 1338 | 100 |
| 30907 | 31.5 | 82 | 713 | 1317 | 88 |
| 30909 | 32.4 | 79 | 598 | 1269 | 100 |
| 30910 | 32.4 | 77 | 671 | 1297 | 88 |

| | | | | | |
|---|---|---|---|---|---|
| 50904 | 32.4 | 82 | 662 | 1275 | 89 |
| 10960 | 32.7 | 87 | 571 | 1269 | 95 |
| 30904 | 33.1 | 97 | 577 | 1274 | 95 |
| 10957 | 33.3 | 86 | 674 | 1314 | 95 |
| 30908 | 33.3 | 44 | 928 | 1298 | 72 |
| 30964 | 33.3 | 75 | 649 | 1310 | 89 |
| 10951 | 33.4 | 81 | 642 | 1305 | 97 |
| 50902 | 33.6 | 86 | 583 | 1202 | 100 |
| 70914 | 36.5 | 46 | 610 | 1254 | 97 |
| 10958 | 36.9 | 79 | 618 | 1226 | 86 |
| 50901 | 38 | 74 | 540 | 1242 | 100 |
| 30911 | 38.3 | 80 | 583 | 1317 | 92 |
| 10955 | 39.1 | 78 | 557 | 1312 | 96 |
| 30914 | 39.1 | 96 | 502 | 1284 | 96 |
| 50903 | 39.4 | 66 | 499 | 1269 | 100 |
| 30912 | 41.8 | 92 | 618 | 1272 | 79 |
| 70915 | 46.2 | 103 | 478 | 1088 | 93 |

[1] ASTM D 7169
[2] Temperature at which 50% of the sample boils

**Conclusion:** The distillation range of crude oil is approximately -1°C to over 720°C (30°F to over 1328°F). In practice, the upper range of atmospheric distillation at a refinery is typically limited to 275-300°C to avoid thermal decomposition.

### 4.4 Vapor pressure

A range of vapor pressures of 6 to 45 kPa have been reported for different crude oils (Jokuty *et al*., 2002). Crude oil vapor pressure is a function of oil temperature and composition. The cited values represent vapor pressures of different crude oil types as reported in the Environment Canada database (Jokuty *et al*., 2002).

**Conclusion:** Vapor pressures of crude oils have been measured from 6 kPa to 45 kPa.

### 4.5 Partition Coefficient

The range of partition coefficients for constituent hydrocarbons in crude oil is 2 to > 6, based on the calculated log $P_{ow}$ at 25°C (ECB, 2000). The calculation was done by the CLOGP Version 3.5 program (Calculation of LOG Partition coefficient octanol/water). The Figures represent the spread of calculated and/or measured values for typical hydrocarbon components of crude oil. Calculated values for higher molecular weight hydrocarbons are above 6, but such values are notional, since no correlation has been established between calculated and experimental values.

**Conclusion:** The range of partition coefficients of individual constituent hydrocarbons in crude oil covers an approximate range of 2 to >6.

### 4.6 Water Solubility

The aqueous solubilities of the main classes of hydrocarbons present in crude oil increase in the order of n-alkanes<isoalkanes<cycloalkanes< aromatics (McAuliffe, 1966; Tissot and Welte, 1984). The water solubilities of individual constituents also decrease with increasing molecular weight and size of alkyl substituents (McAuliffe, 1966: Tissot and Welte, 1984). Solubilities of crude oil components may extend up to one or two percent individually, however, total solubility of all components will be dictated by component composition and loading rates of oil to water (Shiu *et al*., 1990). Concentrations of dissolved hydrocarbons in the water-soluble fractions of twelve crude oils are reported in the robust summaries. Measurements were made in distilled and saltwater under different temperatures by purge-and-trap gas chromatography. Concentrations of hydrocarbons ranged from 10.42 mg/L to 58 mg/L in distilled water and from 7.75 mg/L to 25.5 mg/L in saltwater (Shiu *et al*., 1990).

**Conclusion:** Aqueous concentrations of petroleum hydrocarbons for 12 crude oils ranged from 10.42 to 58 mg/L in distilled water and from 7.75 to 25.5 mg/L in saltwater. At any particular loading rate, i.e. total nominal amount of substance per unit volume, the aqueous concentrations of each constituent represent a balance between the relative volumes of aqueous and petroleum phases, partition coefficient between phases, amount of component present and the maximum water solubility of each constituent.

### 4.7 Assessment Summary for Physical-Chemical Properties

Crude oil is comprised of many materials existing in varying proportions depending on the source of the crude oil. For this reason, specific physical-chemical properties also vary and may only be presented as wide ranges that reflect the underlying properties of the constituent compounds. The values reported above for pour point, boiling point, vapor pressure, partition coefficient, and water solubility as reported in reliable literature sources and databases, are provided for a range of different crude oils

## 5.0 ENVIRONMENTAL FATE

When a complex substance such as crude oil is released into the environment, the individual constituents separate and partition to the different environmental compartments in accordance with their own physical-chemical properties. The ultimate fates of the individual components in crude oil are influenced by both abiotic and biotic processes, and the relative importance of these processes will depend upon the environmental compartment to which the individual components partition. By understanding the environmental fate characteristics of these individual components, an overall assessment of the whole crude oil is possible. Therefore, the environmental fate attributes of various hydrocarbon constituents in crude oil are described in the following sections.

## 5.1 Environmental Fate Endpoints

The U.S. EPA has selected the following environmental fate endpoints by which these substances may be characterized:

photodegradation,
stability in water (hydrolysis),
environmental distribution (fugacity), and
biodegradation.

In determining these fate characteristics for constituents in crude oil, the U.S. EPA's collection of physical-chemical and environmental fate models in EPI Suite™ (USEPA, 2000a) was used to estimate the properties of photodegradation, stability in water, and environmental distribution. Measured data, when available, were also included in the assessment. Biodegradation was examined for these substances in light of their physical-chemical properties and their capacities to undergo microbial oxidation/reduction reactions.

## 5.2 Photodegradation

### 5.2.1 Direct Photodegradation

A prerequisite for direct photodegradation is the ability of one or more bonds within a chemical to absorb ultraviolet (UV)/visible light in the 290 nm to 750 nm wavelength range. Light wavelengths longer than 750 nm do not contain sufficient energy to break chemical bonds, while wavelengths below 290 nm are shielded from the earth by the stratospheric ozone layer (Harris, 1982a). However, to a limited extent, some degradation of polycyclic aromatic hydrocarbon (PAH) molecules in crude oil may occur as the result of photo-oxidative processes, although PAHs bound to sediments are reported to be less susceptible to photo-oxidation. The persistence of PAHs in sediments may in part be due to lack of light for photo-oxidation. Therefore, this fate process will not contribute to a measurable degradative removal of chemical components in this category from the environment.

### 5.2.2 Indirect Photodegradation

Fractions of crude oil that volatilize to air may undergo a gas-phase oxidation reaction with photochemically produced hydroxyl radicals ($OH^{-}$). Atmospheric oxidation as a result of hydroxyl radical attack is not direct photochemical degradation, but rather indirect degradation (Schwarzenbach, 2003). The atmospheric oxidation potential (AOP) of the major constituents in crude oil was estimated using AOPWin (atmospheric oxidation program for Microsoft Windows), a subroutine in the EPI Suite™ (U.S. EPA, 2000) models and used by the US EPA OPPTS (Office of Pollution Prevention and Toxic Substances). This program calculates a reaction rate constant ($cm^3$/molec-sec) and a chemical half-life, i.e. hour or days, of a compound based upon average atmospheric concentrations of hydroxyl radicals ($1.5 \times 10^6$ $OH^{-}/cm^3$) and a 12-h day at 25°C.

Atkinson (1990) gives data which enables half-lives to be calculated for the degradation of hydrocarbons in contact with hydroxyl radicals under sunlight conditions in the troposphere. Half-life values for typical hydrocarbon constituents in crude oils that volatilize to air are as follows:

| Constituent | Half-life, days |
|---|---|
| benzene | 6.5 |
| n-butane | 3.2 |
| n-hexane | 1.4 |
| toluene | 1.3 |
| cyclohexane | 1.1 |
| n-decane | 0.69 |
| n-tetradecane | 0.42 |
| naphthalene | 0.37 |

Hydrocarbons of carbon number greater than C20 will have little or no tendency to partition to air.

**Conclusion:** Direct photodegradation is not expected to play an important role in the environmental fate of crude oils. Indirect photodegradation via reaction with hydroxyl radicals may be important in the gas-phase degradation of hydrocarbons that volatilize to the troposphere. Atmospheric half-lives of 0.37 to 6.5 days have been calculated for representative components of crude oil.

### 5.3 Stability in Water (Hydrolysis)

Hydrolysis of an organic chemical is the transformation process by which a water molecule or hydroxide ion reacts to form a new carbon-oxygen bond. Chemicals that have a potential to hydrolyze include alkyl halides, amides, carbamates, carboxylic acid esters and lactones, epoxides, phosphate esters, and sulfonic acid esters (Harris, 1982b). The majority of chemical components in crude oils are hydrocarbons, which are not included in these chemical groups, and are not subject to hydrolysis reactions with water.

**Conclusion:** The substances in crude oil do not contain chemical moieties that undergo hydrolysis and, therefore, this process would not be expected to be an important fate pathway.

### 5.4 Transport Between Environmental Compartments

Equilibrium models can provide information on the way in which a chemical is likely to partition in the environment. These data are useful in identifying environmental compartments that could potentially receive a released chemical. A widely used fugacity model is the EQC (Equilibrium Criterion) model (Mackay *et al*., 1996, 1997). In its guidance document for HPV data development, the USEPA states that Level I fugacity

data is acceptable as an estimate of chemical distribution values. The EQC model is a Level I model that describes the equilibrium distribution of a fixed quantity of conserved, i.e., non-reacting, chemical at steady state within a closed environment with assumed volumes of air, water, soil and sediment. The model assumes the chemical becomes instantaneously distributed to an equilibrium condition using physical-chemical properties to quantify the chemical's behavior. The model does not include degrading reactions, advective processes or inter-media transport between compartments.

Results of Level I models are basic partitioning data that allow for comparisons between chemicals and indicate the compartment(s) to which a chemical is likely to partition in the environment. Fugacity modeling for constituents in crude oil indicates that, at steady-state, the lower molecular weight components will mainly partition to air, with a maximum of about 1% of mono-aromatic hydrocarbons partitioning to water. As the molecular weights increase, less tendency exists for the hydrocarbons to partition to air with increasingly greater percentages distributing to soil. Collectively, the wide molecular weight range of the hydrocarbons in crude oil will mean that at equilibrium, distribution will be mainly to air and soil, with much less than 1.0% being present in water. These data are adequate to define environmental distribution of crude oil components.

**Conclusion:** When crude oil enters the environment, the constituent hydrocarbons will partition in accordance with their own physical-chemical characteristics. Because crude oil consists of a wide range of molecular weight and hydrocarbon types, fractions will partition mainly to air and soil.

### 5.5 Biodegradation

Most of the understanding on the biodegradability of petroleum hydrocarbons comes from biodegradation studies on crude oil, various streams from the fractional distillation of crude oil, and investigations of spill events, much of which have been reviewed by Bartha and Atlas (1977) and Connell and Miller (1980). Together with more recent reviews by Prince (2002), Prince *et al*. (2003) and Garrett, *et al*. (2003), a general consensus has developed regarding the biodegradability of petroleum hydrocarbons. First, virtually all kinds of crude oils are susceptible to microbial oxidation. The rate of oxidation is influenced by the microbial species and environmental factors such as available nutrients, oxygen, temperature and degree of dispersion. Second, molecular weight influences the rate at which microbial communities can utilize hydrocarbons. Low molecular weight components degrade relatively easy, while higher molecular weight components take longer to be consumed. Third, molecular structures of the hydrocarbons in the petroleum substance affect aerobic microbial biodegradation. Generally speaking, the structure-related pattern shows hydrocarbons in order of increasing difficulty of degradation: (1) n-alkanes, (2) isoalkanes, (3) alkenes, (4) one-ring alkylbenzenes (e.g., BTEX), (5) polycyclic hydrocarbons, and (6) high molecular weight cycloalkanes (Bartha and Atlas, 1977; Potter and Simmons, 1998). This order has been reported for spills in both temperate climates and arctic summer conditions (Garrett *et al*., 2003). The relative ease of biodegradability of these structures is a

generalization, and the body of scientific data points to various factors that might influence this pattern.

Other constituents of crude oil, such as those grouped in the general category of heterocyclic compounds because of their heteroatom content, i.e. oxygen, nitrogen, and sulfur may be more or less degraded according to their molecular weight distribution. However, many of these constituents exist as large molecular weight compounds that end up in the heaviest products resulting from crude oil refining. Current knowledge suggests these are not very biodegradable and will persist in the environment (Prince, 2002).

Empirical data indicate that crude oil can be -degraded equally well in sea water or fresh water, with the nutrient availability being a key factor in determining the rate of degradability. Adapted microorganisms are often found in ocean areas where crude oil spills are common. Zobell (1969) has calculated that when an adapted microbial population is available in well-aerated seawater at 20 to 30°C, the rate of crude oil oxidation ranges from 0.02 to 0.2 g of oil oxidized/m² ocean surface area/day. The same author found experimentally that complete oxidation of 1.0 mg of hydrocarbon requires between 3 and 4 mg of oxygen, i.e. has a biological oxygen demand (BOD) of 3 to 4 mg oxygen/mg. Since the oxygen content of sea-water is between 6 and 11 mg/L, depending on salinity and temperature, this means that the oxygen from about 320,000 liters of sea water is required to oxidize one liter of crude oil.

Five day respirometric tests run both in fresh water and in salt water at 30°C using a Kuwait crude oil resulted in 15% and 3% biodegradation, respectively (Bridie and Bos, 1971). Biodegradation rates for crude oils will vary considerably, but in standard 28-day studies, none would be expected to be readily biodegradable. However, the evidence from spillages and from natural seepages is that most of the non-volatile constituents of crude oil are inherently biodegradable, but that some of the highest molecular weight components are persistent in water (CONCAWE, 2001).

**Conclusion:** Whole crude oil would not be classified as readily biodegradable. However, the constituent hydrocarbons in crude oils are considered inherently biodegradable.

### 5.6 Assessment Summary for Environmental Fate

When crude oil enters the environment, the individual constituents partition to different environmental compartments and degrade in accordance with their own physical-chemical properties. In soils, crude oil will absorb into the soil matrix and volatile components will gradually partition to the atmosphere. Over time hydrocarbons available for microbial attack may be slowly degraded. In aquatic environments, crude oil will spread as a film on the surface of the water facilitating the loss of volatile components. Components that enter the troposphere will not likely persist as interactions with hydroxyl radicals leads to indirect photodegradation. Most components in crude oil are insoluble in water, but dissolved fractions become available for

biodegradation. Rates of mineralization are limited by available nutrients. As crude oil weathers, the fraction that does not biodegrade or volatilize can be physically isolated through incorporation into sediments and soils. Crude oil is not considered readily biodegradable, but the individual hydrocarbon constituents in general are regarded as inherently biodegradable.

## 6.0 ENVIRONMENTAL EFFECTS

The environmental effects endpoints in the HPV Challenge program include:

- Acute Toxicity to Fish,
- Acute toxicity to Aquatic Invertebrates, and
- Toxicity to Algae (Growth Inhibition).

For the assessment of ecotoxicity of poorly water-soluble mixtures such as crude oil, "loading rate" is now generally accepted as the way in which study results should be expressed (OECD, 2000). The "loading rate" is defined as the amount of the substance equilibrated with the aqueous test medium, and the aqueous phase at equilibrium is termed the water-accommodated fraction (WAF) for the loading rate (OECD, 2000). Toxicological endpoints such as the lethal loading rate ($LL_{50}$) or effective loading rate ($EL_{50}$) are used to express the amount of substance per unit volume that is lethal or produces a specific effect to 50% of the test organisms. Studies in which the results are expressed in terms of dilutions of a water-soluble fraction (WSF) do not allow the ecotoxicity of a substance to be expressed in terms of the amount of that product required to produce a particular effect. Therefore, such results are not comparable to results obtained by other exposure methods (Girling and Whale, 1994). Some studies have used oil/water dispersions (OWD) in which organisms are exposed to mixtures of oil and water resulting from high energy mixing of whole oil product in the dilution water. This method results in an expression of concentration of the applied substance (i.e., mg test substance/L), but the method does not prevent adverse effects due to physical entrapment or other adverse mechanical effects due to the insoluble oil. Besides endorsing the WAF method for preparation of exposure solutions, OECD (2000) also recommends the use of sealed test vessels with minimal or no headspace to minimize loss of volatile components in the exposure solutions. This procedure should be used in preparation of the WAF as well as test vessels during testing, as studies have clearly documented the loss of volatile hydrocarbons with open-air vessels or use of aeration during testing (Anderson et al., 1974; Lockhart et al., 1987; Tsvetnenko and Evans, 2002).

Although the WAF technique of preparing exposure solutions of sparingly soluble substances is currently preferred (OECD, 2000), to disregard other research using alternative exposure techniques would be to ignore a large and important body of work. For example, the Chemical Response to Oil Spills: Ecological Effects Research Forum (CROSERF) was formed to create and evaluate an alternative exposure regime for assessing the ecotoxicity of spilled oils (Aurand and Coelho, 2005). The CROSERF test protocols were established on the basis that realistic environmental exposure to spilled oils is not constant, but begins with an exposure “spike” that subsides as the spilled oil

weathers (Aurand and Coelho, 2005). Testing in this manner is not consistent with regulatory ecotoxicological hazard assessment methods which attempt to maintain consistent exposure concentrations for the duration of the exposure period (OECD Guidelines for Testing of Chemicals). The CROSERF program included many test species and in some cases comparisons of spiked exposures to continuous exposures, and thus is valuable to the overall understanding of the toxicity of crude oil to aquatic organisms.

In this overview of the ecotoxicity hazard of crude oil, studies were selected such that toxicity comparisons could be made on the basis of similar exposure techniques. Whenever possible, the data review included studies of whole oil exposures as well as WAF and WSF exposures. For citing WAF and WSF studies, preference was given to those that included analytical measurements of the dissolved hydrocarbons in the exposure solutions. WAF and WSF preparation techniques have a large influence on the concentration and characterization of the dissolved components, and the analytical verification of the dissolved hydrocarbon concentrations provides some common means of comparing exposures. The following sections present selected acute aquatic toxicity studies of fish, aquatic invertebrates, and algae. Data are tabulated such that comparisons can be made on the basis of similar exposure techniques.

## 6.1 Acute Aquatic Toxicity

Crude oils would be expected to produce a similar range of acute toxicity for the three types of organisms (e.g., vertebrate, invertebrate, and plant) based on results of studies using comparable standardized test methods and exposure solution preparation procedures. This is expected because the majority of constituents in crude oil are neutral organic hydrocarbons that act in a common mode of action termed “non-polar narcosis”, which is brought about by disruption of biological membrane function (van Wezel and Opperhuizen 1995; Di Toro, et al., 2000). Any differences between toxicity endpoints (i.e., LC/LL50, EC/EL50) can be explained by the differences between the target tissue-partitioning behaviors of the individual chemicals (Verbruggen et al., 2000). For example, the existing fish toxicity database for hydrophobic neutral chemicals supports a critical body residue (CBR, the internal concentration that causes mortality) of approximately 2-8 mmol/kg fish (wet weight) (McCarty and Mackay, 1993; McCarty et al., 1991). When normalized to lipid content the CBR is approximately 50 µmol/g of lipid for most organisms (Di Toro et al., 2000). Similarities in the range of toxic response elicited by exposure to complex petroleum substances may also be predicted based on physical-chemical properties and acute toxicities of the individual hydrocarbons (Peterson, 1994, CONCAWE, 1996a).

Whenever possible, aquatic toxicity test data with fish, invertebrates, and algae included studies that employed exposure solutions made by independent WAFs, dilutions of WAFs or WSFs, WAFs using spiked exposures, and whole oil:water dispersion techniques. When the data were available, endpoint results were based on measurements of dissolved hydrocarbons. Some of the studies included endpoints based on WAF loading rates as well as measured hydrocarbons. Techniques used to measure the dissolved fraction varied, but tended to include gas chromatography with

flame ionization detection (GC-FID) or GC coupled with a mass spectrometer (GC-MS). GC-FID was by far the more common technique, but differences in sample handling procedures such as purge-and-trap, solvent extraction, or a combination of both methods likely introduced some bias in the range of molecular weight hydrocarbons that defined the measurement. Thus, the endpoint basis column in the tables of toxicity data includes a clarification if a specific fraction of the total dissolved hydrocarbons was reported. The dissolved fraction may include C10 – C36 hydrocarbons or in some studies, a separate fraction of C6 – C9 may have been measured then added to the C10 – C36 fraction, which was expressed as the total hydrocarbon concentration (mg THC/L). The contribution of one or another hydrocarbon fraction to the total dissolved hydrocarbons is a variable that could have a bearing on the calculated toxicity value, and not all reports provided a detailed description of the analytical method.

### 6.1.1 Acute Toxicity to Aquatic Vertebrates

Table 7 presents aquatic toxicity data for aquatic vertebrates (fish) using independent WAFs, dilutions of a WAF or WSF, spiked exposures, and whole oil:water dispersions. Fuller and Bonner (2001) ran duplicate tests of Arabian Medium crude oil with inland silversides (*Menidia beryllina*) and sheepshead minnows (*Cyprinodon variegatus*). Using independent WAFs and measured dissolved hydrocarbons, the authors measured LC50 values of 4.9 mg/L and 5.5 mg/L, and 3.9 mg/L and 4.2 mg/L, respectively, for the two oils. The close proximity of the LC50 values for duplicate tests likely resulted from their preparation and testing methods. The use of sealed test vessels with no headspace combined with daily renewals of the test solutions helped maintain exposure concentrations.

## Table 7. Acute Toxicity of Crude Oil to Fish

| Crude Oil Type | Fish Species | Test/ Exposure Type | Endpoint Basis | Endpoint Value, mg/L | Reference |
|---|---|---|---|---|---|
| **Independent WAF** | | | | | |
| Arabian Medium crude oil | *Menidia beryllina* (inland silversides) | Independent WAFs; sealed vessels/zero headspace; daily static-renewal | GC-MS measured mg TPH/L (C10-C36) | 96-h LC50 = 4.9 (test 1) 5.5 (test 2) | Fuller and Bonner (2001) |
| Arabian Medium crude oil | *Cyprinodon variegatus* (sheepshead minnow) | Independent WAFs; sealed vessels/zero headspace; daily static-renewal | GC-MS measured mg TPH/L (C10-C36) | 96-h LC50 = 3.9 (test 1) 4.2 (test 2) | Fuller and Bonner (2001) |
| Alaska North Slope crude oil | *Menidia beryllina* (inland silversides) | Independent WAFs; covered vessels; daily static-renewal; aerated | GC-FID measured VOA (C6-9) + TPH (C10-36) = mg THC/L | 96-h LC50 = 15.59 96-h LL50 = 1,641 | Rhoton et al. (2001) |
| Prudhoe Bay crude oil | *Menidia beryllina* (inland silversides) | Independent WAFs; covered vessels; daily static-renewal; aerated | GC-FID measured VOA (C6-9) + TPH (C10-36) = mg THC/L | 96-h LC50 = 14.81 96-h LL50 = 4,965 | Rhoton et al. (2001) |
| **WAF or WSF with Dilutions** | | | | | |
| Norman Wells crude oil | *Oncorhychus mykiss* (rainbow trout) | WSF, 1:12.5 oil:water (v/v); dilutions; static; 3 tests (sealed, open, open aerated) | Headspace GC-FID (C1-C7) + solvent extraction (C8-C12) GC-FID measured mg TPH/L | 48-h LC50 = 10.4 (sealed) 11.6 (open) N.D. (open/aerate) | Lockhart, et al. (1987) |
| Bass Strait crude oil | *Melanotaenia fluviatilis* (crimson-spotted rainbow fish) | WAF, 1:9 oil:water (v/v); dilutions; daily static-renewal | GC-FID mg TPH/L | 96-h LC50 = 1.28 | Pollino and Holdway (2002) |
| **Spiked Exposure** | | | | | |
| Louisiana Sweet crude oil | *Menidia beryllina* (inland silversides) | 1:40 oil:water (v/v) WAF then diluted; static; open/aerated | GC-FID measured mg TPH/L | 96-h LC50 = >2.9 | Hemmer, et al. (2010) |

| | | | | | |
|---|---|---|---|---|---|
| Arabian Medium crude oil | *Menidia beryllina* (inland silversides) | Independent WAFs; CROSERF flow-through spiked exposure | GC-MS measured mg TPH/L (C10-C36) | 96-h LC50 = >14.5 (test 1) >32.3 (test 2) | Fuller and Bonner (2001) |
| Arabian Medium crude oil | *Cyprinodon variegatus* (sheepshead minnow) | Independent WAFs; CROSERF flow-through spiked exposure | GC-MS measured mg TPH/L (C10-C36) | 96-h LC50 = >6.1 (test 1) >5.7 (test 2) | Fuller and Bonner (2001) |
| Alaska North Slope crude oil | *Menidia beryllina* (inland silversides) | Independent WAF; CROSERF flow-through spiked exposure | GC-FID measured VOA (C6-9) + TPH (C10-36) = mg THC/L | 96-h LC50 = 26.36 96-h LL50 = 3520 | Rhoton, et al. (2001) |
| Prudhoe Bay crude oil | *Menidia beryllina* (inland silversides) | Independent WAF; CROSERF flow-through spiked exposure | GC-FID measured VOA (C6-9) + TPH (C10-36) = mg THC/L | 96-h LC50 = >19.86 96-h LL50 = >8152 | Rhoton, et al. (2001) |
| **Whole OWD** | | | | | |
| Kuwait crude oil | *Cyprinodon variegatus* (sheepshead minnow) | OWD; open/mixed | Nominal whole oil loading, mg/L | 96-h LC50 = >80,000 | Anderson, et al. (1974) |
| | *Fundulus similis* (longnose killifish ) | OWD; open/mixed | Nominal whole oil loading, mg/L | 96-h LC50 = 14,800 | Anderson, et al. (1974) |
| | *Menidia beryllina* (inland silverside) | OWD; open/mixed | Nominal whole oil loading, mg/L | 96-h LC50 = 9,400 | Anderson, et al. (1974) |
| South Louisiana crude oil | *Cyprinodon variegatus* (sheepshead minnow) | OWD; open/mixed | Nominal whole oil loading, mg/L | 96-h LC50 = 29,000 | Anderson, et al. (1974) |
| | *Fundulus similis* (longnose killifish ) | OWD; open/mixed | Nominal whole oil loading, mg/L | 96-h LC50 = 6,000 | Anderson, et al. (1974) |
| | *Menidia beryllina* (inland silverside) | OWD; open/mixed | Nominal whole oil loading, mg/L | 96-h LC50 = 3,700 | Anderson, et al. (1974) |

Rhoton, et al. (2001) conducted acute toxicity tests of Alaska North Slope and Prudhoe Bay crude oils to inland silversides. Those tests revealed acute LC50 values of 15.59 mg/L and 14.81 mg/L, respectively, for the two crude oils. While the difference in toxicity may be due to the nature of the crude oils (for example, corresponding LL50 values were 1,641 and 4,965 mg/L), the authors acknowledged that despite daily renewals of the test solutions, aeration of the test solutions caused a drop in the concentration of dissolved hydrocarbons to near the detection limit after 12 hours (Rhoton et al., 2001).

Lockhart, et al. (1987) compared the toxicity of Norman Wells crude oil when tested using sealed, open, and open/aerated test vessels. Using dilutions of a 1:12.5 oil/water WSF and measuring the dissolved hydrocarbons by GC-FID, the authors measured the 48-hour LC50 to rainbow trout (*O. mykiss*) to be 10.4 mg/L using sealed vessels, 11.6 mg/L using open vessels, and no toxicity occurred in the vessels that were left open and were aerated. While the effect of aeration of the test solutions on toxicity was dramatic, the solutions left open to the air but not aerated appeared to retain hydrocarbons for a sufficient duration for toxicity to occur. Of all the fish studies cited here, the lowest LC50 was reported by Pollino and Holdway (2002). The authors calculated an LC50 of 1.28 mg/L based on measured dissolved hydrocarbons. Details of the experimental methods were not provided, and this precluded a full understanding what the analytical measurements represented with respect to range of carbon numbers.

As described in Section 6.0, the CROSERF protocols were designed to simulate what was believed to be an environmentally realistic exposure following an oil spill (Aurand and Coelho, 2005). Therefore, this design created an initial high concentration that gradually declined as the spilled crude oil weathered and the lighter fractions volatilized (Aurand and Coelho, 2005). The studies grouped as “Spiked Exposure” in Table 7 present acute toxicity values using this exposure scenario. For some tests, concentrations of dissolved hydrocarbons did not persist long enough in the exposure solutions to elicit toxicity (e.g., LC50 > initial measured concentration). Additionally, the LC50 values were generally greater than what was shown in static-renewal tests. This latter point can be seen by comparing the tests by Rhoton, et al. (2001) and Fuller and Bonner (2001) using static-renewal tests with independent WAFs versus the spiked exposure tests. In each comparison, the LC50 values for the spiked exposure tests were greater than the LC50 values for the static-renewal tests. These comparisons demonstrate that the exposure design can influence the toxicity endpoints for these tests.

For studies conducted using oil:water dispersions, the data produced by Anderson, et al. (1974) demonstrate that the source of the crude oil as well as differences in species sensitivity affect the test endpoints. Because the studies cited in Table 7 for OWDs were conducted in a similar manner at the same laboratory, inter-laboratory variability was controlled and the differences in toxicity were most likely due to the controlled variables of crude type and test species. Because dissolved hydrocarbons were not measured, the endpoints were defined by the total oil loading per unit volume of water. These tests were done in open/mixed vessels, and loss of volatile components of the oil would be expected. However, these nominal concentrations reveal that total oil loadings

necessary to elicit toxicity are quite high in comparison to what might be expected in the dissolved fraction. The range of LC50 values reported by Anderson, et al. (1974) was 3,700 mg/L to >80,000 mg/L. The static-renewal tests conducted by Rhoton, et al. (2001) reported LC50s and LL50s. The LL50 values for *Menidia* exposed to Alaska North Slope and Prudhoe Bay crude oils were 1,641 and 4,965 mg/L, respectively. These values were somewhat lower than those of Anderson, et al. (1974) and may have been due to daily renewal of the test solutions.

### 6.1.2 Acute Toxicity to Aquatic Invertebrates

Table 8 presents aquatic toxicity data for aquatic invertebrates using independent WAFs, dilutions of a WAF or WSF, spiked exposures, and whole oil:water dispersions. For studies conducted with independent WAFs and renewal of the test solutions, the EC50 values ranged from a low of 0.56 mg/L to 2.61 mg/L (Fuller and Bonner, 2001; Rhoton et al., 2001) when based on mean measured dissolved petroleum hydrocarbons (GC-FID or GC-MS). Rhoton et al. (2001) aerated the vessels and although test solutions were renewed, some loss of dissolved hydrocarbons was likely to have occurred. This may explain the higher LC50 values measured in their studies as compared to those of Fuller and Bonner, who employed sealed test vessels without aeration.

## Table 8. Acute Toxicity of Crude Oil to Aquatic Invertebrates

| Crude Oil Type | Invertebrate Species | Test/ Exposure Type | Endpoint Basis | Endpoint Value, mg/L | Reference |
|---|---|---|---|---|---|
| **INDEPENDENT WAF** | | | | | |
| Arabian Medium crude oil | *Americamysis bahia* (saltwater mysid) (formerly Mysidposis bahia) | Independent WAFs; sealed vessels; static-renewal | GC-MS measured mg TPH/L (C10-C36) | 96-h LC50 = 0.56 (test 1) 0.67 (test 2) | Fuller and Bonner (2001) |
| Alaska North Slope crude oil | *Chionocetes bairdi* (Tanner crab) | Independent WAFs; static-renewal | GC-FID measured VOA (C6-9) + TPH (C10-36) = mg THC/L | 96-h LC50 = 2.54 96-h LL50 = 12.48 | Rhoton (1999) |
| Alaska North Slope crude oil | *Americamysis bahia* (saltwater mysid) | Independent WAFs; static-renewal | GC-FID measured VOA (C6-9) + TPH (C10-36) = mg THC/L | 96-h LC50 = 2.61 96-h LL50 = 160 | Rhoton (1999) |
| **WAF or WSF with dilutions** | | | | | |
| 10 different crude oils | *Daphnia magna* | 1:40 oil:water (v/v) WSF then diluted; sealed vessels/zero headspace; static | Purge and trap; GC-FID | 48-h EC50 = 4.6 to 13.3 (2 oils not toxic) | Environment Canada (1994) |
| 13 different crude oils | *Daphnia magna* | 1:40 oil:water (v/v) WSF then diluted; sealed vessels/zero headspace; static | Headspace; GC-MSD | 48-h EC50 = 4.8 to 28.7 (7 oils not toxic) | Environment Canada (1994) |
| **WAF spiked exposure** | | | | | |
| Arabian Medium crude oil | *Americamysis bahia* (saltwater mysid) (formerly Mysidposis bahia) | Independent WAFs; CROSERF flow-through | GC-MS measured mg TPH/L (C10-C36) | 96-h LC50 = >14.3 (test 1) >11.6 (test 2) | Fuller and Bonner (2001) |

| | | | | | |
|---|---|---|---|---|---|
| Louisiana Sweet crude oil | *Americamysis bahia* (saltwater mysid) | 1:40 oil:water (v/v) WAF then diluted; static; open/aerated | GC-FID measured mg TPH/L | 48-h LC50 = 2.7 | Hemmer, et al. (2010) |
| Alaska North Slope crude oil | *Chionocetes bairdi* (Tanner crab) | Independent WAFs; CROSERF flow-through | GC-FID measured VOA (C6-9) + TPH (C10-36) = mg THC/L | 96-h LC50 = 13.85<br>96-h LL50 = 285 | Perkins, et al. (2003) |
| Alaska North Slope crude oil | *Americamysis bahia* (saltwater mysid) | Independent WAFs; CROSERF flow-through | GC-FID measured VOA (C6-9) + TPH (C10-36) = mg THC/L | 96-h LC50 = 9.625<br>96-h LL50 = 654 | Perkins, et al. (2003) |
| **Whole OWD** | | | | | |
| Kuwait crude oil | *Mysidopsis almyra* | OWD; open/mixed | Nominal whole oil loading, mg/L | 48-h LC50 = 63 | Anderson, et al. (1974) |
| Kuwait crude oil | *Paleomonetes pugio* | OWD; open/mixed | Nominal whole oil loading, mg/L | 48-h LC50 = 6,000 | Anderson, et al. (1974) |
| South Louisiana crude oil | *Mysidopsis almyra* | OWD; open/mixed | Nominal whole oil loading, mg/L | 48-h LC50 = 37.5 | Anderson, et al. (1974) |
| South Louisiana crude oil | *Paleomonetes pugio* | OWD; open/mixed | Nominal whole oil loading, mg/L | 48-h LC50 = 200 | Anderson, et al. (1974) |
| South Louisiana crude oil | *Penaeus aztecus* | OWD; open/mixed | Nominal whole oil loading, mg/L | 48-h LC50 = >1000 | Anderson, et al. (1974) |
| 11 crude oils from North Sea origin | *Cragon cragon* | OWD, open | Nominal whole oil loading, mg/L | 96-h LC50 = 27 to 110 | Franklin and Lloyd (1982) |
| 8 crude oils from Middle East origin | *Cragon cragon* | OWD, open | Nominal whole oil loading, mg/L | 96-h LC50= 41 to 119 | Franklin and Lloyd (1982) |

Environment Canada (1994) tested 23 different crude oils from various parts of the world against *Daphnia magna* using dilutions of a WSF (1:40 oil/water ratio). Nine of the 23 crude oils produced insufficient toxicity to derive EC50 values, and for those crude oils that elicited toxicity, the EC50 values ranged from 4.6 mg/L to 28.7 mg/L.

Tests run with crude oil prepared as spiked concentrations with aquatic invertebrates showed results similar to the fish studies. EC50 values were higher than those obtained via independent WAF tests (with exposure solutions renewals) or those using dilutions of WSFs when attempts were made to maintain exposure concentrations (e.g., use of static/sealed test vessels). Toxicity values ranged from low of 2.7 mg/L (Hemmer, et al. 2010) to 13.85 mg/L (Perkins et al., 2003). Fuller and Bonner (2001) reported an LC50 greater than the highest concentration (>11.6 mg/L). Toxicity data for the spiked studies were based on measured concentrations at the beginning of the test and did not reflect exposures over the course of the testing period. The values cited by Hemmer, et al. (2010) appeared lower than what might be expected for a spiked exposure, but may be due to the use of open and aerated test vessels. Their report did not provide details of their analyses; therefore, the range of molecular weight hydrocarbons measured by their method was unknown.

The dispersion studies run by Anderson et al. (1974) and Franklin and Lloyd (1982) have value in that they permit comparisons to be made between test species and between different crude oils while maintaining standard testing procedures. Anderson et al. (1974) measured LC50 values ranging from 37.5 mg/L to 6000 mg/L. One crude oil was not toxic at the highest loading rate (LC50 > 1000 mg/L). These LC50s are considerably lower than LC50 values reported by the same authors for fish (Table 7) in tests of the same crude oils. Franklin and Lloyd (1982) used a dispersion technique similar to Anderson et al. (1974). For 11 crude oils from the North Sea region, LC50 values ranged from 27 to 110 mg/L, while those for eight Middle East crude oils ranged from 41 to 119 mg/L.

### 6.1.3 Toxicity to Algae

Although the effects of crude oil on algae have drawn less attention than those on fish and aquatic invertebrates, the data reviewed here suggest responses similar to those reported for aquatic invertebrates. Table 9 presents study results for tests of crude oil to algae. Gaur and Singh (1989) tested Assam crude oil in two ways, first using dilutions of a WSF, then in another test using direct addition of the crude oil to the algae medium via oil-soaked absorbent pads. The direct addition method resulted in lower EC50 values for both growth rate and cell yield than using dilutions of the WSF, but only by a factor of approximately 1.5. The authors used a 15-day exposure duration, and no data was reported for the standard 3-4 day time period commonly used in regulatory testing. Tsvetnenko and Evans (2002) conducted their tests in a manner more in line of standard regulatory guidelines (e.g., OECD, ASTM). They tested three crude oils having °API gravities of 21, 34, and 48. The crude oil having the greatest specific gravity (°API 21) resulted in the lowest EC50 values when based on cell biomass or growth rate (0.94 and 6.16 mg/L, respectively). Toxicity was somewhat less with the crude oils having higher °API gravities, but the endpoint values for the 34 and 48 °API crudes were not substantially different from each other.

**Table 9. Acute Toxicity of Crude Oil to Algae**

| Crude Oil Type | Algal Species | Test/Exposure Type | Endpoint Basis | Endpoint Value, mg/L | Reference |
|---|---|---|---|---|---|
| Assam crude | *Anabaena doliolum* | Dilutions of 1:20 oil/water WSF<br><br>Direct Addition | Dissolved hydrocarbons by spectrofluorometry | 15-d EC50 =<br><br>9.06 (rate)<br>10.45 (cell yield)<br><br>5.73 (rate)<br>7.47 (cell yield) | Gaur and Singh, 1989 |
| Western Australia crude °API=21 | *Isochrysis sp.* | Dilutions of 1:10 oil/water WSF | GC-MS purge/trap (C6-C9) + solvent extraction and GC-FID (C10-C36) | 96-h EC50 =<br><br>0.94 (biomass)<br>6.16 (rate) | Tsvetnenko and Evans, 2002 |
| °API =34 | | | | 5.51 (biomass)<br>8.38 (rate) | |
| °API=48 | | | | 3.6 (biomass)<br>7.38 (rate) | |

None of the cited studies were run using sealed test vessels to prevent the loss of volatile components, and Tsvetnenko and Evans (2002) measured a 50 – 70% drop in the dissolved hydrocarbons between the beginning and end of their tests. Gaur and Singh (1989) did not indicate the frequency of their hydrocarbon measurements, but the 15-d duration of their test suggests that loss of volatile fractions may have occurred.

### 6.1.3 Summary of Acute Aquatic Toxicity

The studies cited above and described more fully in the robust summaries show a wide range of organisms' responses to oil exposures. Some of this variability is due to using different methodologies, such as independent WAFs, dilutions of a WAF or WSF, spiked exposures, oil:water dispersions, and the use of open versus sealed test vessels. The choice of the analytical method also is important when the toxicity endpoints are based on measured concentrations of dissolved hydrocarbons. Analytical instruments used in the reviewed studies include GC-MS, GC-FID, and spectrofluorometry. These instruments together with the different sample preparation methods (e.g., solvent extraction, purge and trap, headspace analysis) may capture a wide range of molecular weight hydrocarbons or focus on a narrow range of carbon chain lengths. All these techniques were used in some of the cited reports, and this too presents a source of variability in the calculated endpoints.

Because crude oils are of such compositional complexity, to fully characterize all components that potentially might contribute to aquatic toxicity is not possible. However, crude oils and their refined products cause acute toxicity via nonpolar narcosis mode of action (van Wezel and Opperhuizen, 1995). Therefore, an understanding of the acute aquatic toxicity of crude oil relative to fractions of crude oil can be obtained from the ranges in ecotoxicity endpoint values for different distillation fractions. Presenting the acute toxicity of the different distillation fractions of crude oil provides an aquatic hazard of each fraction and collectively forms a set of ecotoxicity values within which crude oil falls. This is illustrated in Table 10, which shows the ranges of effect values (e.g. LL/EL50) for selected data cited in the crude oil robust summaries and the robust summaries of other petroleum HPV categories. Reports were selected based on similar testing methodology.

**Table 10. Ranges for Ecotoxicity Endpoints for Crude Oil and Different Distillation Fractions of Crude Oil Based on WAF Studies**

| Petroleum HPV Category | Typical Carbon Range | Range of Effect Levels, LL/EL$_{50}$ (mg/L) | | | Source |
|---|---|---|---|---|---|
| | | Fish | Invertebrate | Algae | |
| **Crude Oil** | C4 –C60+ | 1641 – 4965 | 12.48 - 160 | No WAF Data | Rhoton (1999)<br>Rhoton et al. (2001) |
| **Gasoline** | 4 – 12 | 8.2 – 46 | 4.5 - 32 | 1.1 - 64 | CONCAWE (1996b)<br>Stonybrook Laboratories (1995a-d) |
| **Kerosene** | 9 – 16 | 10 – 100 | 1.4 - 89 | 5 - 30 | EBSI (1995a,b)<br>Shell (1995a-c) |
| **Gas Oil** | 9 – 30 | 3.2 – 65 | 2 - 300 | 1.9 - 78 | Clark, *et al*. (2003)<br>EBSI (1998a,b)<br>EBSI (2001)<br>Shell (1995d) |
| **Heavy Fuel Oil** | 7 – 50 | 100 - 10,000 | 220 - 10,000 | 3 - 5,000 | Mobil (1987a-c)<br>Shell (1997a-c) |
| **Lube Oils** | 15 - 50 | >100 - >1,000 | >1000 - >10,000 | >50%[1] | BP International (1990a,b)<br>EBSI (1995c) |

| | | | | | |
|---|---|---|---|---|---|
| | | | | | Shell (1988) |
| **Aromatic Extracts** | 15 – 50 | >1,000 | >1,000 | >1,000 | BP Oil Europe (1994a-c) |
| Note: For the purpose of comparison, the above data are from summarized referenced sources that employed water-accommodated fractions (WAFs) as exposure solutions. Other ecotoxicity data in the public domain may be from oil-water dispersions (CONCAWE 2001) or water-soluble fractions as with some studies cited in the discussion herein and hence may not be directly comparable to studies using WAF solutions.<br>[1] The endpoint value for algae represents a 50% dilution of a 1000 mg/L WAF, and was the highest level used in the test. | | | | | |

The world's supplies of crude oils are represented by hydrocarbons covering a wide range of molecular weights. The point illustrated in Table 10 is that streams that are derived from crude oil that contain primarily relatively low molecular weight hydrocarbons such as gasoline (C4-C12), kerosene (C9-C16), and gas oil (C9-C30), typically show greater toxicity than those streams having predominantly higher molecular weight hydrocarbons (heavy fuels, lube oils, and aromatic extracts). Such a trend may be explained by the greater bioavailability of the low molecular weight and higher levels of more water soluble constituents. As petroleum streams become composed of higher molecular weight hydrocarbons, their limited water solubilities limit bioavailability, and hence toxicity. Regardless of the source of the crude oil, aquatic toxicity is not likely to be any greater than that represented by the most toxic distillation fraction. Thus, while the lowest acute toxicity endpoint for a crude oil was 12.48 mg/L, acute toxicity could potentially fall within the range of 1 – 10 mg/L, depending on the proportion of low molecular weight hydrocarbons in the crude's composition. This may be expected when testing is conducted using WAF loading rates using standard methods for difficult substances (OECD, 2000).

## 6.2 Aquatic Chronic Toxicity

Chronic toxicity to aquatic organisms would be expected based on the wide range of partition coefficients, i.e. log $K_{ow}$ 2 to >6, of constituents in crude oils. Because thousands of hydrocarbon components in crude oils could potentially affect chronic toxicity, no reliable correlation exists between crude oil composition and chronic aquatic toxicity as determined by current, standardized test methods. However, chronic toxicity of crude oil fractions to the early life stages of fish is an area of ongoing research (Rhodes, *et al*., 2005). A review of data published in the scientific literature and summarized in the robust summaries indicates that chronic adverse effects to aquatic organisms are caused by exposure to crude oil, and the effects cover a range of chronic toxicity endpoints such as growth, embryo and larval survival, fecundity, gametophyte viability, developmental processes, cardiac arrhythmia, and osmoregulation (Pollino and Holdway, 2002; Perkins *et al*., 2003; Holdway, 2002; Din and Abu, 1992; Moffitt *et al*., 1992; Rhodes *et al*., 2005; Lockhart *et al*., 1996; Incardona *et al*., 2009). Chronic toxicity values vary with species and type of exposure, e.g., WAF, WSF, etc., but adverse effects have been reported at WAF loading rates of <1 mg/L.

## 6.3 Assessment Summary for Environmental Effects

Because crude oil is extracted from world-wide sources and composed of many different types and molecular weights of hydrocarbons, it may be impractical to assign specific acute aquatic toxicity values that cover the full domain of crude types. However, a generalization of the acute aquatic toxicity based on the data cited above indicates that when based on total crude oil loadings in water, either as WAFs or OWD, aquatic invertebrates are more sensitive than fish to crude oil exposure, and the lowest EL50 values may approach 10 mg/L. The lowest acute EL50 among the cited studies was 12.48 mg/L (Rhoton, 1999). When toxicity endpoints are based on measured concentrations of hydrocarbons in the dissolved phase of the exposure solutions, aquatic invertebrates still appeared to be more sensitive than fish or algae. The lowest EC50 value was 0.56 mg/L (Fuller and Bonner, 2001). All acute endpoints for fish were >1 mg/L when based on measured dissolved hydrocarbons. For algae, one test endpoint yielded an EC50 of 0.94 mg/L, but other data all fell within the range of 6 to 11 mg/L. In general, aquatic toxicity of crude oil is not likely to be any greater than that represented by the most toxic fraction. For concentrations presented as loading rates, acute toxicity could potentially fall within the range of 1 – 10 mg/L.

# 7.0 HUMAN HEALTH EFFECTS

Human health hazards associated with the exploration, production, and transportation of crude oil are most often from hydrogen sulfide, volatile organic compounds (VOCs) similar to gasoline, and polycyclic aromatic compounds (PAC). The inhalation exposure hazards of hydrogen sulfide and VOCs are described in the Petroleum HPV Category Assessment Documents for Refinery Gases and Gasoline Blending Streams respectively (Petroleum HPV, 2008 and 2009). The dermal exposure hazard of PAC is described in recent reports (API, 2008 and TERA, 2008) and also summarized in Appendix 3.

The analytical data in Table 2 is related to a series of statistical models that were developed to predict the potential repeated-dose and developmental toxicity of high-boiling petroleum substances by the dermal route of exposure in rats. The development of these models began with the observation that the more significant effects of several types of petroleum refinery streams in both developmental and repeated-dose studies appeared to be related to the total amount of 3-7 ring PACs (Feuston et al, 1994). The relationship was only qualitative and not predictive for individual samples. More recently statistical models were developed by API that quantitatively predict the doses at which potential effects occur on most sensitive endpoints in rats based on the profile of PACs in each sample. The models are empirically based on a number of toxicity studies on refinery streams for which analyses of PAC profile using a “PAC-2” method also existed. The PAC-2 analyses provided the percent of each aromatic ring class (ARC) that served as a basis for the models, i.e. ARC %, in Table 2. The endpoints used in the models were selected by an extensive analysis to determine the most sensitive endpoints among studies of developmental toxicity, repeated-dose toxicity, and optimized Ames tests.

These models have been applied to predict the potential toxicity of untested crude samples described later in this section.

Three types of quantitative values are used in this document.
1) Data from appropriate studies, such as No Observed Adverse Effect Level (NOAEL) on tested samples,
2) $BMD_{10}$ (Bench Mark Dose) which is the dose that produces a 10% response relative to the control group that is calculated from data on tested samples (Crump, 1984),
3) $PDR_{10}$ (Predicted Dose Response) which is the dose that produces a 10% change in the response relative to the control group predicted by statistical modeling using the PAC profile of untested samples (Appendix 3).

Appendix 5 contains summaries of several published studies that used unrealistic routes of administration and extremely high doses. Because of those deficiencies, the Petroleum HPV Testing Group recommends that they not be used for hazard or risk evaluation of crude oil. They are included in this document only for completeness.

### 7.1 Acute Toxicity

Crude oils have been tested for acute toxicity and were associated with low toxicity in all species *via* a variety of routes and endpoints. Data on the acute dermal toxicity and eye and skin irritation potential of five crude oils, i.e. four light crudes and one heavy crude, are summarized in Table 11. The results indicate that acute exposures to crude oils did not produce significant systemic toxicity by the dermal route and induced only minimal skin irritation. Only Lost Hills Light crude oil induced some conjunctival irritation at 24 hours.

**Table 11. Acute Toxicity of Crude Oils[1]**

| **Sample** | **Dermal $LD_{50}$ (Rabbit) g/kg** | **Skin Irritation (Rabbit)[2]** | | **Eye Irritation (Rabbit 24hr) Conjunctival** |
|---|---|---|---|---|
| | | **Erythema** | **Edema** | |
| Beryl [36.5°API] | >2.0 | ND[c] | ND | 1.7 |
| Arab Lt [34.5 °API] | >2.0 | 0.9 | 0.1 | 1.3 |
| Mid-Continent [40°API] | >2.0 | ND | ND | 0.3 |
| Lost Hills Light [>38°API] | >2.0 | 1.6 | 1.3 | 3.7 |
| Belridge Heavy [14°API] | >2.0 | 0.6 | 0.8 | 0.8 |

[1]Mobil, 1984a,b; 1985a,b; 1990a,b
[2] Mean scores on a scale of 0-4 of reactions at 24, 48, and 72 hrs. (Mobil 1985b)
ND = Not Determined

Lost Hills Light and Belridge Heavy crudes did not cause dermal sensitization in the guinea pig when tested using the Buehler method (Mobil, 1991a,b).

Exploration, production, and transport of crude oil can result in significant levels of hydrogen sulfide and/or VOCs in some situations (i.e., enclosed spaces). The acute inhalation hazard is primarily from hydrogen sulfide. When the inhalation acute toxicity of hydrogen sulfide was assessed in male and female Sprague-Dawley rats, the calculated $LC_{50}$ was 444 ppm, with a confidence interval of 416 – 473 ppm (Tansy *et al*., 1981). VOCs from crude oil are expected to have low acute toxicity by the inhalation exposure route; e.g., Rat $LC_{50}$ >5g/$m^3$ for 6-hour exposures, based on testing of various naphtha blending streams and gasoline (Petroleum HPV, 2008).

**Conclusion:** Crude oils have demonstrated little local irritation or systemic toxicity by dermal exposure. Neither of the two tested crude oils was a skin sensitizer. The acute inhalation hazard of crude oil is likely from the presence of hydrogen sulfide gas in some crude oils under specific conditions, i.e., enclosed spaces.

### 7.2 Repeat -Dose Toxicity

Inhalation Exposure:

Hydrogen sulfide toxicity, including nasal and pulmonary effects, was characterized in adult male and female Fischer-344 and Sprague–Dawley rats and $B_6C_3F_1$ mice (Dorman, 2004). Animals underwent whole-body exposure to 0, 10, 30, or 80 ppm $H_2S$ for 6 h/day for at least 90 days. Exposure to 80 ppm $H_2S$ was associated with reduced feed consumption during either the first exposure week (rats) or throughout the 90-day exposure (mice). Male Fischer-344 rats, female Sprague–Dawley rats, and female $B_6C_3F_1$ mice exposed to 80 ppm $H_2S$ had depressed terminal body weights when compared with air-exposed controls. Subchronic $H_2S$ inhalation did not result in toxicologically relevant alterations in hematological indices, serum chemistries, or gross pathology. Histologic evaluation of the nose showed an exposure-related increased incidence of olfactory neuronal loss (ONL) and rhinitis. ONL occurred following exposure to ≥30 ppm $H_2S$ in both sexes of all experimental groups, with one exception, male Sprague–Dawley rats demonstrated ONL following exposure to 80 ppm $H_2S$ only. A 100% incidence of rhinitis was found in the male and female B6C3F1 mice exposed to 80 ppm $H_2S$. In the lung, exposure to $H_2S$ was associated with bronchiolar epithelial hypertrophy and hyperplasia in male and female Sprague–Dawley rats following exposure to ≥30 ppm $H_2S$ and in male Fischer-344 rats exposed to 80 ppm $H_2S$. 10 ppm represented the NOAEC for hydrogen sulfide following subchronic inhalation.

The VOCs from crude oil are similar to those from gasoline and gasoline blending streams. Gasoline and gasoline blending streams have been evaluated for repeat dose hazard potential by inhalation (Petroleum HPV, 2008). Study details and references are found in Appendix 6. Subchronic studies demonstrate that the inhalation NOAECs and LOAECs were similar between the different hydrocarbon classes in the streams and the formulated product, gasoline, in rats. Since there were no appreciable differences between paraffinic, olefinic, naphthenic, and aromatic streams, a range of values derived from all of those repeated dose inhalation studies can be used to estimate the hazard of VOCs from crude oil. These values are:

LOAEC: 6572 mg/m$^3$ – 27,800 mg/m$^3$ (1864 – 7885ppm[a])
NOAEC: 1507mg/m$^3$ – 10,153 mg/m$^3$ (427 – 2880ppm[a])

*[[a] - Total hydrocarbon determined as parts-per-million (ppm) hexane equivalents.]*

Dermal Exposure:
Lost Hills Light (>38°API, 0.86 wt% S) and Belridge Heavy (14°API, 1.05 wt% S) crude oils were applied dermally, without occlusion, to the clipped backs of male and female Sprague Dawley rats at dose levels of 0, 30, 125, and 500 mg/kg/day, 5 days/week for 13 weeks with accumulated material wiped off once weekly, one day after the last daily dose (Table 12). Following treatment, minimal skin irritation, i.e. flaking, was produced on the treated rats while hyperplasia and hyperkeratosis were evident in all the rats exposed to Lost Hills Light and almost all the rats treated with Belridge Heavy.

The effects of dermal exposure at 500 mg/kg of Belridge Heavy included reduced mean body weight gain and decreased platelet counts in male rats only and decreased hemoglobin, hematocrit and red blood cell counts in both sexes. Absolute liver weights and liver to body weight ratios, i.e. relative liver weights, were increased and absolute and relative thymus weights were decreased in both sexes at 500 mg/kg. Microscopically, the incidence of thymic atrophy was substantially increased in both sexes for most of the rats treated with 500 mg/kg of Belridge Heavy. Also, the incidence of hypertrophy and hyperplasia of the thyroid follicular epithelium was very apparent in males at the 500 mg/kg dose level of Belridge Heavy while a lower but still elevated incidence was observed at the two lower doses with no related thyroid effects observed in the female rats.

Dermal exposure to Lost Hills Light at 500 mg/kg did not affect body weight or body weight gain but did decrease hemoglobin, hematocrit and red blood cell counts in male rats only. Increased absolute and relative liver weights were found in both sexes at 500 mg/kg of Lost Hills Light but no significant thymus weight changes were seen at any dose. Microscopically, hyperplasia of treated skin was observed at all doses for Lost Hills Light and Belridge Heavy but was slightly more severe with Lost Hills Light than Belridge Heavy as would be expected with lower viscosity petroleum-related materials because of their greater potential to cause drying of the skin. With 500 mg/kg of Lost Hills Light treatment, thymic atrophy was observed in only ~16% of the rats while 500 mg/kg of Belridge Heavy produced this same effect in 65%. Hypertrophy and hyperplasia of the thyroid was observed in almost all of the Lost Hills Light treated males and a few of the females in the 30 mg/kg group were also affected while higher doses did not increase the incidence of the thyroid effects over control levels. No adverse effects were reported in other organ systems in either sex at any dose.

This study's Lowest Observable Adverse Effect Level (LOAEL) for all effects, without a NOAEL being established, for both crude oils was determined to be the lowest dose used, i.e. 30 mg/kg, which was based on the occurrence of skin irritation and marginal thyroid effects. Also, Belridge Heavy was richer in 3-5 ring polycyclic aromatic compounds (PAC) than Lost Hills Light demonstrated more severe toxicity as indicated by decreases in body weight gain, aberrant hematology, thymus atrophy and bone marrow histopathology (Feuston *et al*.,1997b). The refinery streams tested by Feuston *et al,* 1994 produced

similar toxicity with these endpoints, e.g. reduced body weight gain, aberrant hematology and thymus atrophy as well as also being associated with elevated PAC content.

**Table 12. Dermal Repeat-Dose Toxicity Endpoints**

| Crude oil type | Study type | Doses | Results | Refer. |
|---|---|---|---|---|
| Lost Hills Light | Animal Rat<br>Sex Male<br>Route Skin<br>Freq. Daily<br>Duration 90 d. | 30, 125 & 500 mg/kg | Body wt gain Reduced (500[2] mg/kg)<br>Hematology Changes (500[1]- 125[2] mg/kg)<br>Liver Enlargement (500[1]- 125[2]mg/kg)<br>Thymus Wt Reduction (500[2] mg/kg)<br><br>Histopathology Incidence:<br>Skin - Inflammation (≤30[1] mg/kg)<br>Thyroid – Hypertrophy/Hyperplasia of Follicular Epithelium (≤30[1] mg/kg)<br>Thymus – Atrophy (500[1] – 125[2] mg/kg) | Feuston, 1997b & Mobil 1992a |
| Belridge Heavy | Animal Rat<br>Sex Male<br>Route Skin<br>Freq. Daily<br>Duration 90 d. | 30, 125 & 500 mg/kg | Body wt gain Reduced (500[1]-125[2] mg/kg)<br>Hematology Changes (500[1]- 125[2] mg/kg)<br>Liver Enlargement (125[1]- 30[2] mg/kg)<br>Thymus wt. Reduction (500[1]- 125[2] mg/kg)<br><br>Histopathology Incidence:<br>Skin - Inflammation (≤30[1] mg/kg)<br>Thyroid – Hypertrophy/Hyperplasia of Follicular Epithelium (500[1] – 125[2] mg/kg)<br>Thymus – Atrophy (500[1] – 125[2] mg/kg)<br>Bone Marow – Increased Cellularity & Focal Necrosis (500[1] – 125[2] mg/kg) | Feuston, 1997b & Mobil 1992b |

[1]LOAEL that is ≤ the lowest adverse effects dose when a NOAEL is not established.
[2]NOAEL

$BMD_{10}$ values, as described by Crump (1984) and derived from the actual Feuston, *et al* 1997b studies are given in Table 13 for reductions in the following endpoints: absolute thymus weight, liver/body weight ratio, hemoglobin concentration and platelet count following dermal Lost Hills Light or Belridge Heavy treatment of rats. These calculated $BMD_{10}$ values indicated that Belridge Heavy crude caused effects at lower doses for thymus weight, liver/body weight ratio and platelet counts. Exposure to Lost Hills Light had the most pronounced effect on hemoglobin concentrations.

**Table 13. $BMD_{10}$ Values for Sensitive Endpoints in Repeat Dose Studies**

| Repeat-dose endpoint | $BMD_{10}$ (mg/kg/d) | |
|---|---|---|
| | LOST HILLS LIGHT | BELRIDGE HEAVY |
| Absolute Thymus weight | | |
| Male | 146 | 65 |
| Female | 491 | 287 |
| Liver/body weight ratio | | |
| Male | 236 | 62 |
| Female | 449 | 82 |

| | | |
|---|---|---|
| Hemoglobin concentration | | |
| Male | 195 | 467 |
| Female | 307 | 631 |
| Platelet count | | |
| Male | 855 | 619 |
| Female | >2000 | 614 |

Using the statistical models described in Appendix 3, the $PDR_{10}$ values, for 46 crude oil samples were calculated for the most sensitive endpoints that were previously selected for this type of study (Table 14). The lowest sample $PDR_{10}$s ranged from 55 to 544 mg/kg and the effects associated with the lowest endpoint $PDR_{10}$s were either a depression in platelet count or a reduced absolute thymus weight.

**Table 14. $PDR_{10}$ Values[1] for Sensitive Endpoints in Repeat Dose Studies**

| Sample Number | API Gravity | Thymus Weight[2] | | Platelet Count[2] | | Hemoglobin Concentration[2] | | Liver/body weight ratio[2] | | Lowest $PDR_{10}$ |
|---|---|---|---|---|---|---|---|---|---|---|
| | | Male | Female | Male | Female | Male | Female | Male | Female | |
| | Degree | $PDR_{10}$ | $PDR_{10}$ | $PDR_{10}$ | $PDR_{10}$ | $PDR_{10}$ | $PDR_{10}$ | $PDR_{10}$ | $PDR_{10}$ | |
| 70920 | 13.9 | 63 | 55 | 194 | 197 | 669 | 669 | 255 | 254 | 55 |
| 50905 | 19.4 | 599 | 529 | 2000 | 2000 | 2000 | 2000 | 840 | 834 | 529 |
| 10953 | 19.6 | 268 | 236 | 233 | 236 | >1000 | >1000 | >1000 | >1000 | 233 |
| 70918 | 20.8 | 408 | 360 | 534 | 542 | >1000 | >1000 | >1000 | >1000 | 360 |
| 30903 | 21.2 | 246 | 217 | 353 | 358 | 983 | 983 | 367 | 365 | 217 |
| 30913 | 21.4 | 388 | 342 | 394 | 399 | 2000 | 2000 | 636 | 632 | 342 |
| 70912 | 21.9 | 143 | 126 | 266 | 270 | 551 | 551 | 229 | 228 | 126 |
| 70917 | 23.3 | 106 | 93 | 123 | 125 | 485 | 485 | 228 | 227 | 93 |
| 30905 | 23.4 | 876 | 772 | 202 | 205 | 2000 | 2000 | 1638 | 1638 | 202 |
| 70916 | 23.4 | 147 | 130 | 177 | 179 | 739 | 739 | 352 | 350 | 130 |
| 70910 | 25.4 | 346 | 305 | 733 | 744 | 2000 | 2000 | 633 | 630 | 305 |
| 50910 | 26.6 | 250 | 221 | 453 | 460 | 1108 | 1107 | 416 | 410 | 221 |
| 10956 | 28.6 | 617 | 544 | 545 | 553 | >1000 | >1000 | >1000 | >1000 | 544 |
| 50907 | 28.9 | 196 | 173 | 441 | 447 | 1003 | 1002 | 422 | 420 | 173 |
| 70911 | 28.9 | 327 | 289 | 305 | 309 | 1630 | 1629 | 637 | 633 | 289 |
| 50908 | 29.3 | 864 | 762 | 337 | 342 | 2000 | 2000 | 1350 | 1342 | 337 |
| 10959 | 29.6 | 907 | 800 | 341 | 347 | >1000 | >1000 | >1000 | >1000 | 341 |
| 30965 | 29.6 | 407 | 359 | 204 | 207 | >1000 | >1000 | >1000 | >1000 | 204 |
| 10952 | 29.8 | 367 | 324 | 213 | 216 | 2000 | 2000 | 2000 | 2000 | 213 |
| 10954 | 30.4 | 363 | 320 | 275 | 280 | >1000 | >1000 | >1000 | >1000 | 275 |
| 50906 | 30.5 | 443 | 391 | 391 | 397 | 2000 | 2000 | 925 | 920 | 391 |
| 70913 | 30.5 | 288 | 254 | 224 | 227 | 2000 | 2000 | 943 | 937 | 224 |
| 50909 | 30.6 | 599 | 529 | 2000 | 2000 | 2000 | 2000 | 840 | 834 | 529 |
| 30902 | 30.7 | 410 | 364 | 203 | 205 | 2000 | 2000 | 1125 | 1118 | 203 |
| 70919 | 31.1 | 176 | 156 | 201 | 204 | 1267 | 1267 | 603 | 599 | 156 |
| 30906 | 31.5 | 333 | 294 | 205 | 208 | 2000 | 2000 | 2000 | 2000 | 205 |
| 30907 | 31.5 | 552 | 487 | 218 | 221 | 2000 | 2000 | 2000 | 2000 | 218 |
| 30909 | 32.4 | >1000 | >1000 | 221 | 225 | 2000 | 2000 | 2000 | 2000 | 221 |

| | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| 30910 | 32.4 | 525 | 463 | 205 | 209 | 2000 | 2000 | 2000 | 2000 | 205 |
| 50904 | 32.4 | 408 | 360 | 558 | 567 | 2000 | 2000 | 1273 | 1266 | 360 |
| 10960 | 32.7 | 358 | 316 | 193 | 196 | 2000 | 2000 | >1000 | >1000 | 193 |
| 30904 | 33.1 | 393 | 347 | 299 | 303 | 2000 | 2000 | 1266 | 1258 | 299 |
| 10957 | 33.3 | 649 | 572 | 282 | 286 | >1000 | >1000 | >1000 | >1000 | 282 |
| 30908 | 33.3 | 439 | 387 | 131 | 133 | 2000 | 2000 | >1000 | >1000 | 131 |
| 30964 | 33.3 | 476 | 420 | 212 | 215 | 2000 | 2000 | 1605 | 1595 | 212 |
| 10951 | 33.4 | 255 | 225 | 177 | 179 | >1000 | >1000 | >1000 | >1000 | 177 |
| 50902 | 33.6 | 565 | 498 | 816 | 828 | 1985 | 1984 | 642 | 638 | 498 |
| 70914 | 36.5 | 813 | 717 | 418 | 424 | 2000 | 2000 | 2000 | 2000 | 418 |
| 10958 | 36.9 | 1034 | 912 | 287 | 292 | 2000 | 2000 | 2000 | 2000 | 287 |
| 50901 | 38 | 842 | 743 | 396 | 401 | 2000 | 2000 | 847 | 842 | 396 |
| 30911 | 38.3 | 378 | 334 | 429 | 435 | 2000 | 2000 | 1638 | 1638 | 334 |
| 10955 | 39.1 | 877 | 774 | 265 | 269 | 2000 | 2000 | 2000 | 2000 | 265 |
| 30914 | 39.1 | 429 | 379 | 239 | 243 | 2000 | 2000 | 2000 | 2000 | 239 |
| 50903 | 39.4 | 377 | 332 | 343 | 348 | 2000 | 2000 | 2000 | 2000 | 332 |
| 30912 | 41.8 | 601 | 530 | 187 | 190 | >1000 | >1000 | >1000 | >1000 | 187 |
| 70915 | 46.2 | 1137 | 1003 | 207 | 210 | 2000 | 2000 | 2000 | 2000 | 207 |

[1]mg/kg/day dose
[2]reduction

**Conclusions**: Repeat dose inhalation studies have not been done with crude oil but numerous studies on gasoline and gasoline blending streams (similar to the VOCs from crude oil) in rats have determined a range of NOAECs that can be use for read-across to crude oil; NOAEC: 1507mg/m$^3$ to 10,153mg/m$^3$ (427 – 2880ppm[a]) *[[a] - Total hydrocarbon determined as parts-per-million (ppm) hexane equivalents.]* Repeat dose studies with hydrogen sulfide have established a NOAEC of 10 ppm in rats and mice based on injury to the nasal olfactory epithelium.

Studies of repeated exposure by the dermal route have demonstrated toxicity that was indicated by changes in hematology values, liver enlargement and thymic atrophy. Measured and modeled toxicity endpoints show a wide range of responses from different samples of crude oil. The benchmark dose ($BMD_{10}$) for measured data on two crude oils and the predicted dose response ($PDR_{10}$) for modeled data on 46 samples of crude oil were between 55 and 544 mg/kg/day.

### 7.3 Genetic Toxicity: *In Vitro*

Standard gene mutation assays performed with *S. typhimurium,* with and without metabolic activation from rodent liver homogenate, did not produce mutagenic activity with the crude oils, Arab Light, 34.5°API, light crude (Petrilli *et al*., 1980) or Wilmington, 18°API, heavy crude (Lockard *et al*., 1982). This lack of response in the *in vitro* systems is thought to be due to limited solubility of the oils in aqueous medium and possible competition of non-biologically active components for available metabolic sites (Hermann *et al*., 1980; Cragg *et al*., 1985; Vandermeulen *et al*., 1985).

Testing of Kuwait, 31°API a medium crude, and Saran Gachs crude oil and their water-soluble fractions (WSF) with 5 strains of *S. typhimurium* also gave no significant indication of mutagenicity in spot tests or plate tests, i.e. top agar + test material with or without metabolic activation mixture poured on agar plate (Vandermeulen *et al*., 1985). Four chromatographic fractions of Kuwait crude and its water soluble fraction were obtained by elution with 2 bed volumes each of hexane, followed by 10% benzene/hexane, 50% benzene-hexane and acetone. Significant mutagenic activity was obtained in the F4 fraction which contained unresolved peaks of presumably polar DMSO-soluble high molecular weight components of Kuwait crude oil. Mutagenic activity was not enhanced by metabolic activation. Less mutagenic activity was also seen in F2 which contained 3-4 ring material. Testing of fractionated Kuwait-WSF produced variable results not clearly indicative of mutagenesis. The higher mutagenic response seen by F4 compared to F2 indicated that considerable mutagenic activity resides in the DMSO-soluble large molecular weight components of 4 rings or higher identified by HPLC/UV analysis.

The optimized Ames test, which employs DMSO extraction, hamster liver S-9 and increased metabolic activation mixture (see Appendix 2 for details) identifies mutagenic potential and predicts potential dermal carcinogenicity of petroleum-based complex mixtures and is correlated with the level of 3-7 ring PAC (ASTM, 2002; Mackerer *et al*., 2003). In 1995, the optimized Ames test was standardized as an ASTM method [ASTM E1687-95]. When several crude oils were tested in the optimized Ames test, Arab Light (Mobil, 1984), Beryl (Mobil, 1984), Mid-Continent (Mobil 1984) and Belridge Heavy (Mobil, 1990c) all showed significant mutagenic activity. However, Lost Hills Light crude oil did not produce a mutagenic response when tested with the optimized Ames test (Mobil, 1984; 1990c).

Studies by Roy *et al*. (1985; 1988) have demonstrated a strong correlation between PAC content and mutagenicity index in the optimized Ames test for petroleum-derived substances which produce dermal tumors when tested in mice. The utility of this relationship for read-across to untested substances has been expanded by statistical modeling (see Appendix 2 for details). The outcome of optimized *Salmonella* tests can be predicted from PAC compositional information with an accuracy that seems comparable to that associated with variability inherent with either the experimental methods or the methods used to calculate mutagenicity index from the experimental data. The mutagenicity index (MI) results for 46 samples of crude oil were predicted using the statistical model. The MI is the slope of the initial portion of the dose response curve expressed in units of revertants per microliter. The mutagenicity index was highly correlated with dermal carcinogenic potential, suggesting that oils with MI values < 1 were unlikely to be dermally carcinogenic, oils with MI values $\geq$ 1 but < 2 were indeterminate, and oils with MI values $\geq$ 2 would likely produce skin tumors if tested in mice.

When predictive modeling was done on 46 samples of crude oil for MI, only 2 of the 46 samples gave predicted MIs of less than 1(samples 10960 and 10956 in Table 2). These results demonstrate that most crude oils are expected to be in vitro mutagens and potential dermal carcinogens.

When tested in *In vitro* studies crude oils did not induce cytotoxicity or chromosome damage in Chinese Hamster ovary cells (Mobil, 1991c,d). Wilmington crude did not induce sister chromatid exchange in human lymphocytes *in vitro* (Lockard *et al*., 1982).

**Conclusions:** *In vitro* gene mutation has been demonstrated in bacterial assays for extracts of a variety of crude oils. Predictive modeling based on analytical determination of their PAC profile also demonstrates that crude oil is typically expected to be an in vitro mutagen and potential dermal carcinogen. Generally, standard *in vitro* tests performed without extraction or optimization of test conditions with crude oils in bacterial or mammalian cells did not demonstrate genetic toxicity.

### 7.4 Genetic Toxicology: *In Vivo*

Results of micronucleus assays in Sprague Dawley rats treated dermally for 13-weeks with Lost Hills Light or Belridge Heavy crude oils at doses of 0, 30, 125 or 500 mg/kg for 13 weeks demonstrated that these crude oils did not induce cytogenetic damage in the bone marrow of the treated rats after repeated exposures (Mobil, 1990c; 1991e). Also, a single intraperitoneal (ip) injection of Wilmington heavy crude oil at a dose of 6.1 g/kg to ICR mice did not induce an increase in micronuclei (Lockard *et al*., 1982). However, intraperitoneal injection of 7.2 g/kg did induce a slight statistically significant increase in sister chromatid exchanges (Lockard *et al*., 1982). Sister chromatid exchange is indicative of DNA perturbation expressed as a direct transfer of similar labeled genetic material between chromatids with no loss or gain of chromatin. The biological significance is unknown.

**Conclusions:** The "in vivo" micronucleus assay does not demonstrate cytogenetic activity from crude oil exposure either by the dermal route, the most relevant to man, or by the more extreme intraperitoneal route. The results of micronucleus tests on a range of petroleum HPV category substances in addition to crude oil support the conclusion that clastogenic effects are unlikely to be induced by crude oils. (McKee *et al*, 2010).

### 7.5 Developmental Toxicity

<u>Inhalation Exposure:</u>

Hydrogen sulfide has been studied to determine if it had an adverse impact on pregnancy outcomes, offspring prenatal and postnatal development, or offspring behavior (Dorman et. al., 2000). Virgin male and female Sprague–Dawley rats (12 rats/sex/concentration) were exposed (0, 10, 30, or 80 ppm $H_2S$; 6 h/day, 7 days/week) for 2 weeks prior to breeding. Exposures continued during a 2-week mating period (evidence of copulation = gestation day 0 = GD 0) and then from GD 0 through GD 19. Exposure of dams and their pups (eight rats/litter after culling) resumed between postnatal day (PND) 5 and 18. Adult male rats were exposed for 70 consecutive days. Offspring were evaluated using motor activity (PND 13, 17, 21, and 60 ± 2), passive avoidance (PND 22 ± 1 and 62 ± 3), functional observation battery (PND 60 ± 2), acoustic startle response (PND 21 and 62 ± 3), and neuropathology (PND 23 ± 2 and 61 ± 2). There were no deaths and no adverse physical signs observed in $F_0$ male or female rats during the study. A statistically significant decrease in feed consumption was observed in $F_0$ male rats from the 80-ppm hydrogen

sulfide exposure group during the first week of exposure. There were no statistically significant effects on the reproductive performance of the $F_0$ rats as assessed by the number of females with live pups, litter size, average length of gestation, and the average number of implants per pregnant female. Exposure to hydrogen sulfide did not affect pup growth, development, or performance on any of the behavioral tests.

The VOCs from crude oil are similar to those from gasoline and gasoline blending streams. Numerous developmental toxicity studies have been done on gasoline and gasoline blending streams (Petroleum HPV, 2008). Study details and references can be found in Appendix 6. Developmental toxicity has not observed in inhalation in rats for samples in any gasoline blending stream with the exception of one 40% olefinic sample [chamber vapor content 41% olefins] developmental study in which increased resorptions were reported at the highest dose [2128ppm; (7660mg/m$^3$)]. Of note is that the authors were not sure of the biological significance of this occurrence. Another sample of the same substance with higher olefin content [chamber vapor content 61% olefins] run at higher exposure concentrations did not show any developmental toxicity. In addition, no developmental effects were seen with wholly vaporized gasoline [NOAEC = 1600ppm (5970mg/m$^3$], a 10% distillate sample of unleaded gasoline [NOAEC = 8993ppm (23881mg/m$^3$)], or a gasoline vapor condensate [NOAEC = 20,638 mg/m$^3$]. No increases in resorptions were reported in any of these studies. NOAEC values for developmental effects reflect the maximum doses tested. Parental systemic LOAEC and NOAEC values over all studies reflect primarily decreases in body weights at maximum doses. The read-across ranges that can be used for VOCs from crude oil are:

Developmental NOAEL = 5970mg/m$^3$ to 27750mg/m$^3$,

Parental systemic toxicity LOAEL = 13650 mg/m$^3$ to 27750 mg/m$^3$:
NOAEL = 2275 mg/m$^3$ to 25000 mg/m$^3$

<u>Dermal Exposure:</u>
Lost Hills Light and Belridge Heavy crude oils were evaluated for pre- and post-natal developmental toxicity by the dermal route (Feuston *et al*., 1997a; Mobil, 1991f,g). “Prenatal rats” were sacrificed on GD20; “postnatal rats” delivered naturally and remained, untreated, with their litters until sacrifice at 3-4 weeks postpartum. Lost Hills Light was applied to clipped backs of pregnant rats at doses of 0, 125, 500 and 1000 for the postnatal group and 2000 for the prenatal group mg/kg/day on GD 0-19. Belridge Heavy was applied with the same regimen at doses of 0, 30, 125, and 500 mg/kg/day. Application sites were not occluded but rats were fitted with Elizabethan collars to inhibit possible oral ingestion of test material. The studies are summarized in Table 15.

Both crude oils produced maternal and developmental toxicity. Maternal effects included slight (Lost Hills Light) to moderate (Belridge Heavy) skin irritation. For prenatal treatment with Lost Hills Light or Belridge Heavy the NOAEL for maternal toxicity was 125 mg/kg while the LOAEL was 500 mg/kg for decreases in body weight gains and increases in relative liver weights. Also, maternal treatment with 2000 mg/kg of Lost Hills Light produced decreases in absolute and relative thymus weights. For postnatal treatment the NOAEL for maternal toxicity was 500 mg/kg for Lost Hills Light and 125 mg/kg for Belridge

Heavy. The LOAEL for Lost Hills Light was 1000 mg/kg and for Belridge Heavy was 500 mg/kg for decreases in body weight gains during gestation.

In the prenatal rats treated with Lost Hills Light, the NOAEL was not established but the LOAEL for developmental toxicity was ≤125 mg/kg for delayed ossifications. Delayed ossifications occurred with all doses of Lost Hills Light while decreases in fetal body weights and live fetuses and increases in resorptions with concomitant decrease in litter size occurred at 2000 mg/kg. Further, a visceral malformation described as a "right-sided esophagus" was found at a low (4.1%) incidence with a 2000 mg/kg Lost Hills Light dose. For Belridge Heavy, the NOAEL for developmental toxicity was 125 mg/kg and the LOAEL was 500 mg/kg for decreases in fetal body weights and live fetuses, increases in resorptions and delayed ossifications.

In the postnatal rats treated with Lost Hills Light, the NOAEL for developmental toxicity was 500 mg/kg and the LOAEL was 1000 mg/kg for decreases in pup weights on Days 21 and 28. The NOAEL for developmental toxicity with Belridge Heavy was not established but the LOAEL was ≤30 mg/kg for the reduction in the "day four pup viability index". The pup viability index was reduced with all doses of Belridge Heavy while parturition delays occurred at 500 mg/kg. (Feuston *et al*., 1997a; Mobil, 1991f,g). In addition, although Lost Hills Light treatment induced delayed ossification at 125 mg/kg and the higher doses, Belridge Heavy produced much more serious toxicity at doses lower than those where Lost Hills Light produced the same adverse effects, e.g. increased resorptions and decreased fetal weights or produced adverse effects that did not occur even with the highest Lost Hills Light dose, e.g. decreased pup viability index and delayed parturition. Generally, the greater severity of effects was seen in animals from groups exposed to Belridge Heavy.

The developmental toxicity results with crude oil are consistent with results of studies performed with petroleum refinery streams and products that have significant concentrations of PACs. Feuston *et al*,. 1994 demonstrated following the dermal application of a series of refinery steams, a correlation between the incidence of resorptions as well as a decrease in fetal weights and increasing 3-5 ring PAHs content with a LOAEL range for an increased incidence of resorptions of 8 to 1000 mg/kg( See Appendix 3).

**Table 15. Developmental Toxicity Studies with Crude Oil**

| **CRUDE OIL** | **STUDY**<br>ANIMAL/<br>ROUTE/EXPOSURE<br>DAY (s) | **DOSE RANGE** | **RESULTS**<br>{Exposure Day(s)} | **REFER.** |
|---|---|---|---|---|
| LOST HILLS LIGHT | Rat/Dermal / GD 0-19/<br>(GD 20 Necropsy) | 125, 500 or 2000 mg/kg/ day<br>(Prenatal) | Maternal<br><br>NOAEL= 125 mg/kg<br>LOAEL= 500 mg/kg Body Wt. Gain Decreases & Increases Relative Liver Wts.<br><br>Offspring<br>LOAEL ≤125 mg/kg for Delayed Ossifications | Feuston, 1997a & Mobil 1991f |

| | | | | |
|---|---|---|---|---|
| LOST HILLS LIGHT | Rat/Dermal / GD 0-19/ (Parturition Day: 21 for Maternal & 28 for Pup Necropsy) | 125,500 or 1000mg/kg/ day (Postnatal-Not dosed) | Maternal<br><br>NOAEL= 500 mg/Kg<br>LOAEL= 1000 mg/kg for Body Wt. Gain Decreases on GD 20<br><br>PUPS<br>NOAEL= 500 mg/kg<br>LOAEL= 1000 mg/kg for Decreases in Body Wts. on Parturition Day 21 & 28. | Feuston, 1997a & Mobil 1991f |
| BELRIDGE HEAVY | Rat/Dermal / GD 0-19/ (GD 20 Necropsy) | 30,125 or 500 mg/kg/ day (Prenatal) | Maternal<br><br>NOAEL= 125 mg/kg<br>LOAEL= 500 mg/Kg for Body Wt. Gain Decreases & Increase Relative Liver Wts.<br><br>Offspring<br><br>NOAEL= 125 mg/kg<br>LOAEL = 500 mg/kg for Increased Resorptions, and Decreased Fetal Wts., Live Fetuses & Delayed Ossifications | Feuston, 1997a & Mobil 1991g |
| BELRIDGE HEAVY | Rat/Dermal / GD 0-19/ (Parturition Day: 21 for Maternal & 28 for Pup Necropsy) | 30,125 or 500 mg/kg/ day (Postnatal-Not dosed) | Maternal<br><br>NOAEL= 125 mg/kg<br>LOAEL= 500 mg/Kg for Body Wt. Gain Decreases<br><br>Offspring<br><br>LOAEL <30 mg/kg for Decreased Viability Indices | Feuston, 1997a & Mobil 1991g |

GD = Gestation Day(s)

$BMD_{10}$ values, as described by Crump (1984) and derived from the actual Feuston, *et al* 1997a studies are given in Table 16 for reductions in the following endpoints: fetal body weight, live fetuses per litter, and percent resorptions following dermal treatment of rats with Lost Hills Light or Belridge Heavy crude oil. For $BMD_{10}$ values the Percent Resorptions were the most sensitive indicator of developmental toxicity.

**Table 16. $BMD_{10}$ Values for Sensitive Endpoints in Pre-Natal Developmental Toxicity Studies**

| **Developmental endpoint** | **$BMD_{10}$ (mg/kg/d)** | |
|---|---|---|
| | **LOST HILLS LIGHT** | **BELRIDGE HEAVY** |
| | | |
| Fetal Body Weight | 1870 | 370 |
| | | |
| Live Fetuses per Litter | 424 | 122 |

| | | |
|---|---|---|
| | | |
| Percent Resorptions | 91 | 106 |
| | | |

Using the statistical models described in Appendix 3, the predicted dose response ($PDR_{10}$) values for 46 crude oil samples with PAC analytical data were calculated (Table 17). The statistical models generate estimates for sensitive pre-natal developmental toxicity endpoints. The lowest sample $PDR_{10}$s ranged from 53 to 2000 mg/kg and the consistent indicator of the lowest endpoint $PDR_{10}$s was the number of live fetuses per liter.

**Table 17. $PDR_{10}$ Values[1] for Pre-Natal Developmental Toxicity Endpoints[2]**

| Sample No. | API Gravity | Fetal Body weight[3] | Live Fetuses/Litter[3] | % Resorption[4] | Lowest $PDR_{10}$ |
|---|---|---|---|---|---|
| | Degree | $PDR_{10}$ | $PDR_{10}$ | $PDR_{10}$ | |
| 70920 | 13.9 | 202 | 61 | 100 | 61 |
| 50905 | 19.4 | 2000 | 666 | 1494 | 666 |
| 10953 | 19.6 | | | | |
| 70918 | 20.8 | >1000 | | | >1000 |
| 30903 | 21.2 | 431 | 89 | 157 | 89 |
| 30913 | 21.4 | 1036 | 221 | 399 | 221 |
| 70912 | 21.9 | 282 | 68 | 119 | 68 |
| 70917 | 23.3 | 214 | 53 | 90 | 53 |
| 30905 | 23.4 | 1504 | 431 | 672 | 431 |
| 70916 | 23.4 | 346 | 96 | 160 | 96 |
| 70910 | 25.4 | 1037 | 233 | 426 | 233 |
| 50910 | 26.6 | 679 | 169 | 304 | 169 |
| 10956 | 28.6 | | | | |
| 50907 | 28.9 | 515 | 151 | 258 | 151 |
| 70911 | 28.9 | 653 | 138 | 237 | 138 |
| 50908 | 29.3 | 1507 | 381 | 634 | 381 |
| 10959 | 29.6 | | | | |
| 30965 | 29.6 | 2000 | >1000 | 2000 | >1000 |
| 10952 | 29.8 | 2000 | | | 2000 |
| 10954 | 30.4 | 2000 | | | 2000 |
| 50906 | 30.5 | 1528 | 517 | 942 | 517 |
| 70913 | 30.5 | 819 | 227 | 371 | 227 |
| 50909 | 30.6 | 2000 | 666 | 1494 | 666 |
| 30902 | 30.7 | 926 | 224 | 364 | 224 |
| 70919 | 31.1 | 478 | 129 | 213 | 129 |
| 30906 | 31.5 | 1581 | 1151 | 1391 | 1391 |
| 30907 | 31.5 | 1571 | 662 | 938 | 662 |
| 30909 | 32.4 | | | | |
| 30910 | 32.4 | 1525 | 698 | 947 | 698 |
| 50904 | 32.4 | 2000 | 1115 | 2000 | 1115 |
| 10960 | 32.7 | 2000 | | | 2000 |
| 30904 | 33.1 | 1403 | 588 | 967 | 588 |

| | | | | | |
|---|---|---|---|---|---|
| 10957 | 33.3 | 2000 | | | 2000 |
| 30908 | 33.3 | | | | |
| 30964 | 33.3 | 1722 | 840 | 1289 | 840 |
| 10951 | 33.4 | 2000 | | | 2000 |
| 50902 | 33.6 | 1467 | 349 | 679 | 349 |
| 70914 | 36.5 | 2000 | 913 | 1336 | 913 |
| 10958 | 36.9 | 2000 | >1000 | >1000 | >1000 |
| 50901 | 38 | 1703 | 390 | 716 | 390 |
| 30911 | 38.3 | 2000 | 2000 | 2000 | 2000 |
| 10955 | 39.1 | 2000 | >1000 | | >1000 |
| 30914 | 39.1 | 2000 | 2000 | 2000 | 2000 |
| 50903 | 39.4 | >1000 | | | >1000 |
| 30912 | 41.8 | 2000 | | | |
| 70915 | 46.2 | 1409 | 387 | 579 | 387 |

[1] mg/kg/day dose
[2] blank cells indicate the model results were considered unreliable
[3] reduction
[4] increase

**Conclusions:** Inhalation exposure to the volatile constituents of crude oil, e.g., hydrogen sulfide or gasoline-like VOCs, are not expected to be a significant developmental toxicity hazard. A developmental neurotoxicity study on inhaled hydrogen sulfide determined a NOAEC of 80 ppm. VOCs from crude oil can be evaluated by using read-across data from studies on gasoline and gasoline blending streams. The developmental NOAEC values from various gasoline and gasoline blending streams studies are 5970mg/m$^3$ to 27750mg/m$^3$ (1694 – 7873ppm[a]). *[[a] - Total hydrocarbon determined as parts-per-million (ppm) hexane equivalents.]*

Studies of a “light” and a “heavy” crude oil by the dermal route have demonstrated developmental toxicity that was indicated by changes including , (1) decreases in fetal body weights, (2) decreases in the Pup Viability Indices, (3) increases in resorption incidences. Measured and modeled developmental toxicity endpoints show a wide range of responses from different samples of crude oil via dermal exposure. The benchmark dose ($BMD_{10}$) for measured data on two crude oils and the predicted dose response ($PDR_{10}$) for modeled data on 46 crude oil samples were between 53 and 2000 mg/kg/day.

Adverse developmental effects have been observed in animals treated dermally with individual PAC or petroleum-related materials with substantial concentrations of PAC. The results with crude oil are consistent with data from similar studies conducted with petroleum refinery streams that revealed a relationship between endpoints of developmental toxicity and increasing levels of 3-7 ring PAC (Feuston *et al*., 1994).

### 7.6 Reproductive Toxicity

Inhalation Exposure:

Hydrogen sulfide has been studied to determine if it had an adverse impact on pregnancy outcomes, offspring prenatal and postnatal development, or offspring behavior (Dorman et. al., 2000). Virgin male and female Sprague–Dawley rats (12 rats/sex/concentration) were

exposed (0, 10, 30, or 80 ppm $H_2S$; 6 h/day, 7 days/week) for 2 weeks prior to breeding. Exposures continued during a 2-week mating period (evidence of copulation = gestation day 0 = GD 0) and then from GD 0 through GD 19. Adult male rats were exposed for 70 consecutive days. There were no deaths and no adverse physical signs observed in $F_0$ male or female rats during the study. A statistically significant decrease in feed consumption was observed in $F_0$ male rats from the 80-ppm hydrogen sulfide exposure group during the first week of exposure. There were no statistically significant effects on the reproductive performance of the $F_0$ rats as assessed by the number of females with live pups, litter size, average length of gestation, and the average number of implants per pregnant female. In this study, as well as the repeat dose inhalation studies with hydrogen sulfide (Dorman et al., 2004), there were no specific adverse effects on male or female reproductive organs.

The VOCs from crude oil are similar to those from gasoline and gasoline blending streams. Several developmental/ reproduction screening studies have been done in rats with gasoline blending streams and two multi-generation reproductions studies have been done in rats with gasoline vapor (Petroleum HPV, 2008). Study details and references can be found in Appendix 6. The range of NOAEC for reproductive effects from all the available studies was 13650 mg/m$^3$ to 27750 mg/m$^3$. These results can be used to read-across to the reproductive toxicity of crude oils. In addition, in the repeat dose inhalation studies with gasoline and gasoline blending streams, there were no specific adverse effect on reproductive organs.

<u>Dermal Exposure:</u>
Guideline compliant reproductive toxicity studies were not found for crude oils. However, no changes in weight or histopathological effects were found in the reproductive organs of male and female rats exposed dermally for thirteen-weeks to two crude oils, i.e. Lost Hills Light and Belridge Heavy, at doses up to 500 mg/kg (Feuston *et al*., 1997b; Mobil, 1992a,b).The same studies reported no effects on epididymal spermatozoa morphology and count or testicular spermatid counts but a significant decrease in sperm motility was observed at 500 mg/kg/day with one crude oil, but not the other. Data from the repeat dose and developmental studies on Lost Hills Light and Belridge Heavy crudes oils are sufficient for evaluating reproductive toxicity under the EPA guidance for the HPV Challenge Program.

Reproductive toxicity screening studies in male and female rats of clarified slurry oil (CSO), a product of refinery processing of crude oil, utilizing dermal administration has been reported (Hoberman et al., 1995a). CSO typically contains very high levels of PAC constituents and is considered to be the most mutagenic and carcinogenic substances produced by petroleum refining with a high degree of developmental toxicity, i.e. dermal developmental toxicity LOAEL of 1 mg/kg (Hoberman, et al., 1995b). Reproductive endpoints, e.g., sperm production and male and female fertility, were unaffected at 250 mg/kg/day of CSO, a dose at which fetal survival was severely compromised in a developmental toxicity study that extended to postnatal day (PND) 4. Assuming that the reproductive toxicity of clarified slurry oil is representative of other PAC-containing petroleum substances, a reasonably assumption could be made that reproductive effects,

such as fertility and sperm production, would not be sensitive effects of PAC-containing materials compared to developmental toxicity effects.

In addition, the potential for a variety of PAC-containing petroleum substances, including crude oils, to affect reproductive organs was assessed via a series of 13-week repeat-dose studies in which the testes, accessory sex organs, and epididymides were weighed in males, and the potential for pathological changes was evaluated with microscopic examinations. Little evidence of reproductive organ effects was found in the repeated-dose studies of crude oil or the other petroleum streams evaluated. Accordingly, a conclusion could be reached that effects on reproductive organs are not a likely consequence of exposure to PAC-containing petroleum substances.

Across a number of developmental toxicity studies that examined embryonic and fetal development, the effects most commonly observed, and statistically significant at the LOAELs, were related to fetal/pup survival and body weight (Feuston et al, 1994; API, 2008). Little evidence of teratogenicity, i.e. malformations, was found in any of the conventional developmental toxicity studies. As expected, increased incidences of skeletal variations, i.e., delayed ossification, were often observed at dose levels producing decreased fetal/pup body weight. Based on the results of a large number of repeat-dose studies and developmental toxicity studies, as well as the two reproductive toxicity screening studies of CSO, the most sensitive endpoints related to reproductive and developmental toxicity appear to be those associated with the survival and growth of fetuses and offspring; effects on fertility, sperm production and reproductive organ effects do not appear to be sensitive endpoints for assessment of the potential hazards of PAC-containing petroleum substances.

**Conclusions:**
Inhalation exposure to volatile constituents of crude oils are not expected to produce reproductive toxicity since they did not produced adverse effects in the reproductive organs of male and female rats exposed for 13 weeks. In those studies with hydrogen sulfide or gasoline blending streams, no changes in weight or histopathological effects were found in the reproductive organs. Developmental studies on hydrogen sulfide or gasoline blending streams show they are also unlikely to produce reproductive toxicity at relevant exposure concentrations. In addition, two multi-generation reproductions studies have been done in rats with gasoline vapor (see Appendix 6). The NOAECs for reproductive effects in both those studies were greater than 20,000 mg/m$^3$.

Dermal exposure to crude oils are not expected to produce reproductive toxicity since they did not produce adverse effects in the reproductive organs of male and female rats exposed for 13 weeks to light and heavy crude oils. In those studies, no changes in weight or histopathological effects were found in the reproductive organs and epididymal spermatozoa morphology and count and testicular spermatid counts were unaffected. (Feuston *et al*., 1997b; Mobil, 1992a,b). Although a definite number cannot be provided for a NOAEL for reproductive effects, available data from three sources provide sufficient information to conclude that the NOAEL for reproductive effects would be greater than the NOAEL for developmental toxicity. First, little evidence of changes in weight or histological

appearance of reproductive organs of male and female rats via the dermal routes of exposure in the 13-week subchronic studies of crude oils. Second, developmental toxicity endpoints in studies of crude oils, including both *in utero* and postnatal development, were more sensitive than effects on the reproductive organs and semen in 90-day repeat-dose toxicity studies. Third, the published NOAEL in a pair of screening-level fertility studies with a refinery stream containing high amounts of PACs, was >250 mg/kg (Hoberman et al., 1995a). Given the hypothesis that reproductive toxicity would also be correlated with PAC profile, it can be concluded that the NOAEL for reproductive toxicity is expected to be greater than the NOAEL for developmental toxicity.

### 7.7 Other Health Effects

A number of crude oil samples, representing a range of compositions, have been investigated for their potential to cause skin cancer in mouse skin-painting studies of 104-110 week duration. All four crude oils including some distillation fractions of API Crude C and D (See below), produced skin tumors in 33-100% of mice with latency periods of 40-76 weeks, and were considered dermal carcinogens. Tumor incidence and latency depended on crude oil source and dose (Table 18). Numerous studies have shown that the mutagenic and carcinogenic potential of complex petroleum-related substances, all of which are derived from crude oil, correlates with the presence of 3-7 ring PAC (Roy *et al*, 1988; Blackburn *et al*., 1984; Cruzan *et al*., 1986; Blackburn *et al*., 1986). Further studies have shown these PAC can be absorbed through the skin and enter the general circulation (Roy *et al*., 1996; Roy *et al*., 1998)

**Table 18. Summary of Mouse Skin Carcinogenesis Studies with Crude Oil**

| Crude Oil | Dosing Regimen | % of Animals with Tumors | Mean Latency | Reference |
|---|---|---|---|---|
| Naphthenic (Gulf Coast). API Crude C | 50mg, 2x/week for 110 weeks | 33% | 76 weeks | Lewis et al, 1984 |
| Paraffinic (high Sulfur) API Crude D | 50mg, 2x/week for 110 weeks | 56% | 64 weeks | Lewis et al, 1984 |
| San Joaquin Valley, $21^0$ API gravity | 17mg, 3x/week for 105 weeks | 84% | 62 weeks | Clark et al, 1988 |
| Wilmington, $18^0$ API gravity | 0.17mg, 3x/week for 104 weeks<br>1.7mg, 3x/week for 104 weeks<br>16.8mg, 3x/week for 104 weeks | 0<br>46%<br>100% | -<br>40 weeks<br>67 weeks | Renne et al, 1981 |

**Conclusions**: Crude oil applied to mice has caused statistically significant increases in skin tumors.

### 7.8 Assessment Summary for Health Effects

Crude oils have demonstrated little local irritation or acute systemic toxicity ($LD_{50}$ >2.0 g/kg dermal). However, transport and storage of crude oil can result in significant levels of hydrogen sulfide and/or volatile organic compounds (VOCs) in some situation (i.e., enclosed spaces). The acute inhalation hazard is primarily from hydrogen sulfide. When the acute toxicity of hydrogen sulfide was assessed in rats, the calculated $LC_{50}$ for a 4-hour inhalation exposure was 444 ppm. VOCs from crude oil are similar to the hydrocarbons found in gasoline and gasoline blending streams. The results of acute toxicity testing indicate that these materials are not acutely toxic by the inhalation exposure route, e.g., Rat $LC_{50}$ >5g/m$^3$.

Repeat dose and developmental studies on inhaled hydrogen sulfide have determined NOAECs of 10 ppm and 80 ppm, respectively. The inhalation NOAECs for repeat dose and developmental effects of VOCs from crude oil are read-across data from studies on gasoline and gasoline blending streams. These values are:

Repeat Dose NOAEC:1507mg/m$^3$ to 10,153mg/m$^3$ (427 – 2880ppm$^a$)
Developmental NOAEC: 5970mg/m$^3$ to 27750mg/m$^3$ (1694 – 7873ppm$^a$ )
*[$^a$ - Total hydrocarbon determined as parts-per-million (ppm) hexane equivalents.]*

In the repeat dose inhalation studies with hydrogen sulfide and gasoline blending streams, there were no specific adverse effect on reproductive organs. In addition, two multi-

generation reproduction studies on gasoline vapor in rats have determined NOAECs of over 20,000 mg/m$^3$. This data supports the conclusion that hydrogen sulfide and VOCs from crude oil have limited potential to be reproductive toxicants.

In situations involving repeated dermal exposure, the constituents with the greatest potential for toxicity are the polycyclic aromatic compounds (PACs). Solvent extracts of crude oils which concentrate the PAC constituents have induced gene mutations in bacteria. In contrast, the injection of mice with crude oil did not produce activity in micronucleus assays but did induce an increase in sister chromatid exchanges. Several samples of crude oil have produced skin-tumors in mice following long-term skin application.

Studies of repeated exposure by the dermal route have demonstrated toxicity that was indicated by changes in hematology values, liver enlargement and thymic atrophy. Measured and modeled toxicity endpoints show a wide range of responses from different samples of crude oil. The benchmark dose ($BMD_{10}$) for measured data on two crude oils and the predicted dose response ($PDR_{10}$) for modeled data on 46 crude oil samples were between 55 and 544 mg/kg/day.

In developmental toxicity studies in rats, crude oils, primarily at maternally toxic doses, caused fetal death, decreased fetal weight, delayed skeletal ossification and parturition. Measured and modeled developmental toxicity endpoints show a wide range of responses from different samples of crude oil. The benchmark dose ($BMD_{10}$) for measured data on two crude oils and the predicted dose response ($PDR_{10}$) for modeled data on 46 crude oil samples were between 53 and 2000 mg/kg/day. Crude oil is not expected to be a reproductive toxicant since repeated dermal exposures to crude oil for 13- weeks have not produced adverse effects in the reproductive organs of either male or female rats.

The Testing Group believes that the potential for mutagenicity and systemic toxicity, developmental toxicity and/or carcinogenic effects from repeated dermal exposure is related to the PAC profile of the specific crude oil.

## 8.0 HUMAN EXPOSURE SUMMARY

Crude oil is not a consumer product and general population exposure including children is not expected. However, inhalation and dermal exposure of workers to crude oil may take place during the drilling and completion of a well (exploration and production), and the transport, storage, and refining of crude oil.

### 8.1 Occupational Exposure

The individual constituents of crude oil volatilize accordance with their own individual physical-chemical properties. The two primary inhalation hazards are from hydrogen sulfide and from the VOCs similar to gasoline which can readily volatilize from crude oil. There are enforceable (OSHA Permissible Exposure Limits) and recommended (ACGIH Threshold Limit Values) occupational exposure standards for numerous volatile constituents typically found in crude oil. Examples of these standards are shown in Table 19. These standards are one means by which human exposures to individual crude oil constituents are controlled.

**Table 19. OSHA and ACGIH Occupational Exposure Standards for Some Volatile Constituents of Crude Oil (8-hour Time Weighted Averages)**

| Category | Crude Oil | | | | | | |
|---|---|---|---|---|---|---|---|
| | | | | | | | |
| Carbon Number | C4 | C5 | C6 | C7 | C8 | C9 | Others |
| **Component**<br><br>OSHA and/or ACGIH Occupational Exposure Standard | **Butane**<br><br>**ACGIH**<br>1000 ppm (C1-C4 alkanes) | **Pentane**<br><br>**OSHA**<br>500 ppm (n-pentane)<br><br>**ACGIH**<br>600 ppm (all isomers) | **Benzene**<br><br>**OSHA**<br>1 ppm<br><br>**ACGIH**<br>1 ppm | **Toluene**<br><br>**OSHA**<br>200 ppm<br><br>**ACGIH**<br>20 ppm | **Ethyl Benzene**<br><br>**OSHA**<br>100 ppm<br><br>**ACGIH**<br>100 ppm | **Cumene**<br><br>**OSHA**<br>50 ppm<br><br>**ACGIH**<br>50 ppm | **Hydrogen sulfide**<br><br>**OSHA**<br>2 $mg/m^3$<br><br>**ACGIH**<br>1 ppm |
| | **Propane, 2-methyl**<br><br>**ACGIH**<br>1000 ppm (C1-C4 alkanes) | | **Hexane**<br><br>**OSHA**<br>500 ppm<br><br>**ACGIH**<br>50 ppm | | **Xylenes**<br><br>**OSHA**<br>100 ppm<br><br>**ACGIH**<br>100 ppm | **Trimethyl Benzene**<br><br>**ACGIH**<br>25 ppm (all isomers) | **Methyl mercaptan**<br><br>**ACGIH**<br>0.5 ppm |
| | | | **Cyclohexane**<br><br>**OSHA**<br>300 ppm<br><br>**ACGIH**<br>100 ppm | | | | **Gasoline**<br><br>**ACGIH**<br>300 ppm |

Specific laws and regulations are in place to limit occupational exposure during exploration and production activities and transportation of crude oil. These include;

1. Occupational Safety and Health Act
   a. 29 CFR 1910.106 Flammable and combustible liquids
   b. 29 CFR 1910.110 Storage and handling of liquefied petroleum gases
   c. 29 CFR 1910.119 Process safety management of highly hazardous chemicals
   d. 29 CFR 1910.132-1910.138 Personal protective equipment
   e. 29 CFR 1910.146 Permit-required confined spaces
   f. 29 CFR 1910.147 The control of hazardous energy (lockout/tagout)
   g. 29 CFR 1910.307 Hazardous (classified) locations
   h. 29 CFR 1910.1000 Air contaminants
   i. 29 CFR 1910.1003 Access to employee exposure and medical records.
   j. 29 CFR 1910.1028 Benzene
   k. 29 CFR 1910.1051 1,3-Butadiene.
   l. 29 CFR 1910.1200 Hazard communication
   m. 29 CFR 1910.1201 Retention of DOT markings, placards and labels.
   n. 29 CFR 1910.1450 Occupational exposure to hazardous chemicals in laboratories
2. Marine Occupational Safety and Health Standards
   a. 46 CFR 197.501 Applicability
   b. 46 CFR 197.505 Definitions
   c. 46 CFR 197.510 Incorporation by reference
   d. 46 CFR 197.515 Permissible exposure limits
   e. 46 CFR 197.520 Performance standard
   f. 46 CFR 197.525 Responsibility of the person in charge
   g. 46 CFR 197.530 Persons other than employees
   h. 46 CFR 197.535 Regulated areas
   i. 46 CFR 197.540 Determination of personal exposure
   j. 46 CFR 197.545 Program to reduce personal exposure
   k. 46 CFR 197.550 Respiratory protection
   l. 46 CFR 197.555 Personal protective clothing and equipment
   m. 46 CFR 197.560 Medical surveillance
   n. 46 CFR 197.565 Notifying personnel of benzene hazards
   o. 46 CFR 197.570 Recordkeeping
   p. 46 CFR 197.575 Observation of monitoring
   q. 46 CFR 197.580 Appendices
3. International Convention for the Safety of Life at Sea
   a. 74 Fed. Reg. 30,612 (June 26, 2009)
4. Hazardous Materials Transportation Act
   a. 49 CFR 105 Hazardous Materials Program Definitions and General Procedures
   b. 49 CFR 106 Rulemaking Procedures
   c. 49 CFR 107 Hazardous Materials Program Procedures
   d. 49 CFR 110 Hazardous Materials Public Sector Training and Planning Grants
   e. 49 CFR 130 Oil Spill Prevention and Response Plans
   f. 49 CFR 171 General Information, Regulations, and Definitions
   g. 49 CFR 172 Hazardous Materials Table, Special Provisions, Hazardous Materials Communications, Emergency Response Information, Training Requirements, and Security Plans
   h. 49 CFR 173 Shippers General Requirements for Shipments and Packaging
   i. 49 CFR 176 Carriage by Vessel
   j. 49 CFR 178 Specifications for Packaging
   k. 49 CFR 180 Continuing Qualifications and Maintenance of Packaging

## 8.2 Environmental Releases

Exploration and production activities and transportation of crude oil are controlled under a number of laws and regulations to limit release of crude oil into the environment. These include:

1. Clean Water Act
   a. National Pollutant Discharge Elimination System: Onshore Wells, Stripper Wells, Stormwater Discharges*
      i. Exemption. The 1987 Water Quality Act (WQA) amended the CWA to specify that EPA and states shall not require NPDES permits for uncontaminated storm water discharges from oil and gas exploration, production, processing or treatment operations, or transmission facilities.
      ii. 40 CFR Part 122, Subpart A Definitions and General Program Requirements
      iii. 40 CFR 122.21 Application for A Permit
      iv. 40 CFR 122.22 Signatories to Permit Application
      v. 40 CFR 122.26 Storm Water Discharges
      vi. 40 CFR 122.28 General Permits
      vii. 40 CFR 122.29 New Sources and New Dischargers
      viii. 40 CFR Part 122, Subpart C Permit Conditions
      ix. 40 CFR Part 122, Subpart D Transfer, Modification, Revocation and Reissuance, and Termination of Permits
      x. 40 CFR Part 125, Subpart A Criteria and Standards for Imposing Technology-Based Treatment Requirements under Sections 301(b) and 402 of the [CWA]
      xi. 40 CFR Part 125, Subpart D Criteria and Standards for Determining Fundamentally Different Factors under Sections 301(b)(1)(A), 301(b)(2)(A) and (E) of the [CWA]
      xii. 40 CFR Part 125, Subpart G Criteria for Modifying the Secondary Treatment Requirements under Sections 301(h) of the [CWA]
      xiii. 40 CFR Part 125, Subpart H Criteria for Determining Alternative Effluent Limitations under Section 316(a) of the [CWA]
      xiv. 40 CFR Part 125, Subpart I Requirements Applicable to Cooling Water Intake Structures for New Facilities under Sections 316(b) of the [CWA]
      xv. 40 CFR Part 403 General Pretreatment Regulations for Existing and New Sources of Pollution
      xvi. 40 CFR Part 435 Oil and Gas Extraction Point Source Category
   b. Oil Spill Prevention, Notification and Cleanup
      i. 30 CFR 250.203, 250.204, 254 Oil Spill Contingency Plan
      ii. 33 CFR 133 Oil Spill Liability Trust Fund; State Access
      iii. 33 CFR 135 Offshore Oil Pollution Compensation Fund
      iv. 33 CFR 136 Oil Spill Liability Trust Fund; Claims Procedures; Designation of Source; and Advertisement
      v. 33 CFR 137 Oil Spill Liability: Standards for Conducting All Appropriate Inquiries under the Innocent Land-Owner Defense
      vi. 33 CFR Part 153 Control of Pollution by Oil and Hazardous Substances, Discharge Removal
      vii. 33 CFR Part 154 Facilities Transferring Oil or Hazardous Material in Bulk
      viii. 33 CFR Part 156 Oil and Hazardous Material Transfer Operations
      ix. 40 CFR 110 Discharge of Oil
      x. 40 CFR 112 Oil Pollution Prevention
      xi. 40 CFR 116 Designation of Hazardous Substances
      xii. 40 CFR 117 Determination of Reportable Quantities for Hazardous Substances
   c. Wetlands
      i. 33 CFR Part 320-330 Procedures and Criteria for the Issuance of Permits

ii. 40 CFR Part 230 Guidelines for Specification of Disposal Sites
iii. 40 CFR Part 231 Discharge of Dredged or Fill Material
iv. 40 CFR Part 232 Program Definitions and Exemptions

**2.** Safe Drinking Water Act*

a. Exemption. The SDWA, under 42 U.S.C. § 300h, currently requires states to regulate, and imposes minimum regulatory requirements on, "subsurface emplacement of fluids by well injection" in order to protect drinking water supplies. The Act currently exempts from such requirements the underground injection of fluids or propping agents (other than diesel fuels) pursuant to hydraulic fracturing operations related to oil, gas, or geothermal production activities.
b. 40 CFR 144-148 Underground Injection Control (UIC) program

**3.** Outer Continental Shelf Lands Act

a. 30 CFR 250 Oil and Gas and Sulphur Operations in the Outer Continental Shelf
b. 30 CFR 251 Geological and Geophysical (G&G) Explorations of the Outer Continental Shelf
c. 30 CFR 252 Outer Continental Shelf (OCS) Oil and Gas Information Program
d. 30 CFR 253 Oil Spill Financial Responsibility for Offshore Facilities
e. 30 CFR 254 Oil Spill Response Requirements for Facilities Located Seaward of the Coastline
f. 30 CFR 256 Leasing of Sulphur or Oil and Gas in the Outer Continental Shelf
g. 30 CFR 259 Mineral Leasing Definitions
h. 30 CFR 260 Outer Continental Shelf Oil and Gas Leasing
i. 30 CFR 270 Nondiscrimination in the Outer Continental Shelf

**4.** Clean Air Act

a. National Emission Standards for Hazardous Air Pollutants
i. 40 CFR Part 63, Subpart Y National Emission Standards for Marine Tank Vessel Loading Operations

## 9.0 CATEGORY ANALYSIS CONCLUSIONS

Only one substance, Petroleum (CAS # 8002-05-9), is in the Crude Oil Category. Crude oils are a naturally-occurring substance that formed over millions of years, Crude oil is a complex combination of hydrocarbons consisting predominantly of paraffinic (straight and branched-chain alkanes), naphthenic (cycloalkanes) and aromatic hydrocarbons covering the carbon number range from $C_4$ to $C_{60}$+. Also included are low concentrations of heterocyclics, e.g. sulfur, nitrogen, oxygen-containing hydrocarbon analogs and metals, e.g. nickel and vanadium. An "average" crude contains 84% carbon, 14% hydrogen, 1-3% sulfur, and approximately 1.0% nitrogen, 1.0% oxygen and 0.1% minerals and salts.

Analytical studies indicate that similar hydrocarbons, heterocyclics, metals and other constituents, e.g. hydrogen sulfide, are present in all crude oils with the diversity of crude oils originating from the proportional variability in these components that depends on the source of the oil. This means certain generalities in the physicochemical and environmental fate attributes can be inferred given the predominant types of structures making up the crude oil. First, regardless of the structure type, low molecular weight constituents tend to have higher vapor pressures, lower partition coefficients and higher water solubilities than higher molecular weight components and second, given similar molecular weights, saturated hydrocarbons tend to have greater vapor pressures, higher partition coefficients, and lower water solubilities than aromatic constituents.

From an environmental fate perspective, constituent hydrocarbons in crude oil follow specific pathways. Overall, members of this category with relatively lower molecular weights and higher volatilities will partition to the air more than higher molecular weight components. Once in air, these more volatile constituents will not persist, but will be removed by reaction with hydroxyl radicals or direct photolytic reactions. Less volatile constituents will partition to soils and/or sediments. Hydrocarbons dissolved in water are resistant to hydrolytic reactions, but the dissolved fraction may partition to suspended matter, volatilize, or biodegrade.

Because crude oil is extracted from world-wide sources and composed of many different types and molecular weights of hydrocarbons, it may be impractical to assign specific acute aquatic toxicity values that cover the full domain of crude types. However, a generalization of the acute aquatic toxicity based on the data cited above indicates that when based on total crude oil loadings in water, either as WAFs or OWD, aquatic invertebrates are more sensitive than fish to crude oil exposure, and the lowest EL50 values may approach 10 mg/L. When toxicity endpoints are based on measured concentrations of hydrocarbons in the dissolved phase of the exposure solutions, aquatic invertebrates still appeared to be more sensitive than fish or algae. All acute endpoints for fish were >1 mg/L when based on measured dissolved hydrocarbons. For algae, one test endpoint yielded an EC50 of 0.94 mg/L, but other data all fell within the range of 6 to 11 mg/L. In general, aquatic toxicity of crude oil is not likely to be any greater than that represented by the most toxic fraction. For concentrations presented as loading rates, acute toxicity could potentially fall within the range of 1 – 10 mg/L.

There are numerous existing regulations on the exploration, production, and transportation of crude oil to limit release into the environment. These include the Clean Water Act, the Outer Continental Shelf Lands Act, and the Clean Air Act.

The human health effects of crude oil can be from both inhalation and/or dermal exposure. Because crude oils vary in their composition, the worst case hazard is assumed until sufficient data is available on a specific crude oil or situation (like enclosed spaces) to make an informed judgment about the presence or severity of the hazard.

The dermal hazard of crude oil from a single exposure is low ($LC_{50}$ >2g/kg). The acute inhalation hazard of crude oil is most likely from hydrogen sulfide. When the acute toxicity of hydrogen sulfide was assessed in rats, the calculated $LC_{50}$ for a 4-hour inhalation exposure was 444 ppm. VOCs from crude oil are similar to the hydrocarbons found in gasoline and gasoline blending streams. The results of acute toxicity testing indicate that these materials are not acutely toxic by the inhalation exposure route with the rat $LC_{50}$ >5g/m$^3$. Repeat dose and developmental studies on inhaled hydrogen sulfide have determined NOAECs of 10 ppm and 80 ppm, respectively. The inhalation NOAECs for repeat dose and developmental effects of VOCs from crude oil are read-across data from studies on gasoline and gasoline blending streams. These values are: Repeat Dose NOAEC:1507mg/m$^3$ to 10,153mg/m$^3$ (427 – 2880ppm$^a$) and Developmental NOAEC: 5970mg/m$^3$ to 27750mg/m$^3$ (1694 – 7873ppm$^a$ ) *[$^a$ - Total hydrocarbon determined as parts-per-million (ppm) hexane equivalents.]*

In the repeat dose inhalation studies with hydrogen sulfide and gasoline blending streams, there were no specific adverse effect on reproductive organs. In addition, two multi-generation reproduction studies on gasoline vapor in rats have determined NOAECs of over 20,000 mg/m$^3$. This data supports the conclusion that hydrogen sulfide and VOCs from crude oil have limited potential to be reproductive toxicants.

There are occupational exposure standards established for many volatile crude oil constituents that limit worker exposure to acceptable concentrations. These standards include the Marine Occupational Safety & Health Standards, the ACGIH® TLVs, and the International Convention for the Safety of Life at Sea.

In situations involving dermal exposure, the constituents with the greatest potential for toxicity are the polycyclic aromatic compounds (PACs). Data on 46 crude oils show that the PAC profile (the 1 to 7 aromatic ring classes) is highly variable from sample to sample. Solvent extracts of crude oils which concentrate the PAC constituents have induced gene mutations in bacteria. The injection of mice with whole crude oil did not produce activity in micronucleus assays but did induce an increase in sister chromatid exchanges. Several samples of crude oil have produced skin-tumors in mice following long-term skin application.

Studies of repeated exposure by the dermal route have demonstrated toxicity that was indicated by changes in hematology values, liver enlargement and thymic atrophy. Measured and modeled toxicity endpoints show a wide range of responses from different samples of crude oil. The benchmark dose ($BMD_{10}$) for measured data on two crude oils and the predicted dose response ($PDR_{10}$) for modeled data on 46 crude oil samples were between 55 and 544 mg/kg/day.

In developmental toxicity studies in rats, crude oils, primarily at maternally toxic doses, caused fetal death, decreased fetal weight, delayed skeletal ossification and parturition. Measured and modeled toxicity endpoints show a wide range of responses from different samples of crude oil. The benchmark dose ($BMD_{10}$) for measured data on two crude oils and the predicted dose response ($PDR_{10}$) for modeled data on 46 crude oil samples were between 53 and 2000 mg/kg/day. Crude oil is not expected to be a reproductive toxicant since repeated dermal exposures to crude oil for 13-weeks have not produced adverse effects in the reproductive organs of either male or female rats.
The Testing Group believes that the potential for mutagenicity, systemic toxicity, developmental toxicity and/or carcinogenic effects from repeated dermal exposure is related to the PAC profile of the specific crude oil. The data described above for crude oil are sufficient to fully characterize the HPV Program screening level endpoints for Physical/Chemical Properties, Environmental Fate, Environmental Effects, and Human Health Effects.

## 10.0 Data Matrix for Crude Oil

| Endpoint | Hydrogen Sulfide | VOCs (Gasoline and Gasoline Blending Streams) | Measured Data on Crude Oil | Predicted Results for Crude Oil | Read-Across to Untested Crude Oils |
|---|---|---|---|---|---|
| Pour Point | | | -30°C to 30°C | | -30°C to 30°C |
| Boiling Range | | | -1°C to over 720°C | | -1°C to over 720°C |
| Vapor Pressure | | | 6 kPa to 45 kPa. | | 6 kPa to 45 kPa. |
| Partition Coefficient | | | | 2 to > 6 | 2 to >6 |
| Water Solubility | | | 10.42 to 58 mg/L in distilled water and from 7.75 to 25.5 mg/L in saltwater | | 7.75 to 58 mg/L |
| Photodegradation | | | | Atmospheric half-lives of 0.37 to 6.5 days have been calculated for representative components of crude oil. | 0.37 to 6.5 days |
| Stability in Water | | | | Stable. No hydrolysis expected | Stable |
| Environ. Transport | | | | Because crude oil consists of a wide range of molecular weight and hydrocarbon types, fractions will partition mainly to air and soil. | Mainly to air and soil |
| Biodegradation | | | | Whole crude oil would not be classified as readily biodegradable. However, the constituent hydrocarbons in crude oils are considered inherently biodegradable. | Not readily biodegradable |
| Acute Fish | | | | The acute toxicity could potentially fall within the range of 1 – 10 mg/L WAF, depending on the proportion of low molecular weight hydrocarbons in the crude's | 1 – 10 mg/L WAF |

| | | | | | |
|---|---|---|---|---|---|
| | | | | composition. | |
| Acute Daphnia | | | | The acute toxicity could potentially fall within the range of 1 – 10 mg/L WAF, depending on the proportion of low molecular weight hydrocarbons in the crude's composition. | 1 – 10 mg/L WAF |
| Algae | | | | The acute toxicity could potentially fall within the range of 1 – 10 mg/L WAF, depending on the proportion of low molecular weight hydrocarbons in the crude's composition. | 1 – 10 mg/L WAF |
| $LD_{50}$ Dermal | | | >2 g/kg | | >2 g/kg |
| $LC_{50}$ | 444 ppm (4-hr) | >5 mg/m$^3$ (6-hr) | | | In the absence of H2S, >5 mg/m$^3$ |
| Repeat Dose (inhalation) | NOAEC = 10 ppm | NOAECs = 1507 mg/m$^3$ to 10,153 mg/m$^3$ (427 – 2880 ppm) | | | In the absence of H2S, NOAEC >1507 mg/m3 (427 ppm) |
| Repeat Dose (dermal) | | | Benchmark Dose ($BMD_{10}$) = 62 to 146 mg/kg/d | Predictive Dose Response ($PDR_{10}$) = 55 to 544 mg/kg/day | 55 to 544 mg/kg/day |
| In vitro Mutagenicity | | | Optimized Ames test positive for several crude oils | Mutagenicity Index (MI) predicted to be >1 for most crude oils | Positive |
| In vivo Mutagencity | | | Negative in micronuclei assay | | Negative |
| Developmental Toxicity (inhalation) | NOAEC = 80 ppm | NOAEC = 5970 mg/m$^3$ to 27750 mg/m$^3$ | | | In the absence of H2S, NOAEC >5970 mg/m$^3$ |
| Developmental Toxicity (dermal) | | | Benchmark Dose ($BMD_{10}$) = 91 to 106 mg/kg/d | Predictive Dose Response ($PDR_{10}$) = 53 to 2000 mg/kg/day | 53 to 2000 mg/kg/day |
| Reproductive Toxicity (inhalation) | NOAEC = 80 ppm | The range of NOAECs for reproductive effects from | | | In the absence of H2S, NOAEC >13650 mg/m3 |

| | | | | | |
|---|---|---|---|---|---|
| | | all available studies was 13650 mg/m$^3$ to 27750 mg/m$^3$ | | | |
| Reproductive Toxicity (dermal) | | | >91 mg/kg/d (Developmental $BMD_{10}$) | > 53 to mg/kg/day (Developmental $PDR_{10}$ ) | Greater than the metrics for Developmental Toxicity |

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## 12. LIST OF APPREVIATIONS AND ACRONYMS

API – American Petroleum Institute
°API – API gravity
ARC – Aromatic Ring Class
ASTM – American Society for Testing and Materials.
ATSDR– Agency for Toxic Substances and Disease Registry.
AUGC – Area Under the Growth Curve
BMD10 – Benchmark Dose for estimated dose that produces a 10% response relative to the control group.
$BMD_{PAC10}$ – Benchmark Dose for the estimated PAC dose that produces a 10% response relative to the control group.
BOD – Biological Oxygen Demand

CAD – Category Assessment Document
CAS RN/CAS #/CAS No. - Chemical Abstract Service Registry Number
$^{o}C$ – Degrees Celsius
CIR – Cosmetics Ingredients Review Panel
CONCAWE – CONservation of Clean Air and Water in Europe.
d – Day(s)
DMSO – Dimethyl Sulfoxide
EINECS – European Inventory of Existing Commercial Chemical Substances
$EL_{50}$ – Effective loading rate lethal to 50% of the test population
$E_bL_{50}$ – Effective loading rate that causes 50% reduction in algal cell biomass
$E_rL_{50}$ – Effective loading rate that causes 50% reduction in algal growth rate
EMBSI – ExxonMobil Biomedical Sciences Inc.
EPA/US EPA – United States Environmental Protection Agency
FWPCA – Federal Water Pollution Control Act.
$g/cm^3$ – Grams per cubic centimeter
h - Hour
HLS – Huntingdon Life Sciences
hPa – Hectopascal or $10^2$ pascals; standard metric system unit for pressure
HPV – High Production Volume Challenge Program (EPA)
HSDB – Hazardous Substances Data Bank
IARC – International Agency for Research on Cancer (WHO)
ip – intraperitoneal route of administration
IP – Institute of Petroleum.
IPCS – International Programme on Chemical Safety (WHO)
IRDC – International Research and Development Corporation
°K – Degrees Kelvin
$K_{ow}$ – Octanol-Water Partition Coefficient
kPa – Kilopascal or $10^3$ pascals; standard metric system unit for pressure
$LC_{50}$ – Lethal concentration for 50% of the test population
$LC_{50}$ – Lethal dose level for 50% of the test population
$LL_{50}$ – Lethal loading rate for 50% of the test population
LOAEL – Lowest observable adverse effect level
MCHC – Mean Corpuscular Hemoglobin Concentration
mg/kg – Milligrams per kilogram
mg/L – Milligrams per liter
$mg/m^3$ – Milligrams per cubic meter
mL – Milliliter
mm – Millimeter
ND – Not Determined or None Detected
nm – Nanometer
NOAEL – No Observable Adverse Effect Level
NOEC – No Observable Effect Concentration
NOEL – No Observable Effect Level
NOELR – No Observable Effect Loading Rate
NTP – National Toxicology Program
OECD – Organization for Economic Cooperation and Development

OPPTS – US EPA Office of Prevention, Pesticides and Toxic Substances
OSHA – Occupational Safety and Health Administration.
PAC – Polycyclic Aromatic Compound
PAH – Polycyclic Aromatic Hydrocarbon
$PDR_{10}$ – Predicted Dose Response estimate developed from the regression model for the dose of
PCA that produces a 10% change in the response relative to the control group.
PERF – Petroleum Environmental Research Forum.
PNA – Polynuclear Aromatic
$P_{ow}$ – n-Octanol/water Partition coefficient
ppm – Part per million
S – Sulfur
SETAC – Society of Environmental Toxicology and Chemistry.
SIDS – Screening Information Data Set
TSCA – Toxic Substances Control Act.
UNEP – United Nations Environment Program
U.S. DOE – U.S. Dept. of Energy.
US EPA – United States Environmental Protection Agency
UV - Ultraviolet
UVCB – Chemical Substance of Unknown or Variable Composition
WAF – Water Accommodated Fraction
wt% - Weight percent
μg - Microgram
μg/L – Microgram/Liter
> Greater than

## 13.0 GLOSSARY

**NOTE:** The following terms are used in this document. To the extent possible definitions were taken from relevant authoritative sources such as EPA, OECD, ASTM and IUPAC.

**Alicyclic:** A class of organic compounds containing only carbon and hydrogen atoms joined to form one or more rings but is not aromatic.

**Aliphatic:** A group of organic chemical compounds in which the carbon atoms are linked in open chains**.**

**°API:** API gravity is a measure of density, not an indicator of paraffinic or aromatic content of crude oil and is calculated as °API = 141.5/Sp. Gr. – 131.5. The currently accepted API gravity values to differentiate between light and heavy crude oils are ≥33°API equals “light” and ≤28°API equals “heavy” (Platt’s, 2003).

**Asphalt**: A very complex combination of high molecular weight organic compounds containing a relatively high proportion of hydrocarbons having carbon numbers

predominantly greater than C25 with high carbon-to-hydrogen ratios. It also contains small amounts of various metals such as nickel, iron, or vanadium. It is obtained as the non-volatile residue from distillation of crude oil or by separation as the raffinate from a residual oil in a deasphalting or decarbonization process. (**US EPA**; http://iaspub.epa.gov/sor_internet/registry/substreg/home/overview/home.do)

**Asphaltenes:** A group of complex aromatic hydrocarbons that are found in the heavier fractions of crude oil, e.g. asphalt (bitumen) and are soluble in carbon disulfide and insoluble in petroleum naphthas.

**Atmospheric oxidation potential (AOP) program ( AOPWIN™):** Estimates the gas-phase reaction rate for the reaction between the most prevalent atmospheric oxidant, hydroxyl radicals, and a chemical. (http://www.epa.gov/oppt/exposure/pubs/episuite.htm)

**Atrophy:** A wasting of tissues, organs or the entire body.

**Bioavailability**: The state of being capable of being absorbed and available to interact with the metabolic processes of an organism. Typically a function of chemical properties, physical state of the material to which an organism is exposed, and the ability of the individual organism to physiologically take up the chemical. Also, the term used for the fraction of the total chemical in the environment which is available for uptake by organisms.

**Bitumen:** Asphalt

**Category Member:** The individual chemical or substance entities that constitute a chemical category.

**Category:** A chemical category, for the purposes of the HPV Challenge Program, is a group of chemicals whose physicochemical and toxicological properties are likely to be similar or follow a regular pattern as a result of structural similarity. These structural similarities may create a predictable pattern in any or all of the following parameters: physicochemical properties, environmental fate and environmental effects, and/or human health effects.

**Corpora lutea:** A temporary endocrine structure in mammals formed in the ovary at the site of a ruptured ovarian follicle.

**Cracking:** The breaking up of heavy molecular weight hydrocarbons into lighter hydrocarbon molecules by the application of heat and pressure, with or without the use of catalysts. **(US OSHA**
**Technical Manual SECTION IV: CHAPTER 2 PETROLEUM REFINING PROCESSES**
**http://www.osha.gov/dts/osta/otm/otm_iv/otm_iv_2.html)**

**Crude Oil (Petroleum)**: A complex combination of hydrocarbons. It consists predominantly of aliphatic, alicyclic and aromatic hydrocarbons. It may also contain small

amounts of nitrogen, oxygen and sulfur compounds. (**US EPA;** http://iaspub.epa.gov/sor_internet/registry/substreg/home/overview/home.do)

**Dose:** The amount of a substance available for interactions with metabolic processes or biologically significant receptors after crossing the outer boundary of an organism. The **potential dose** is the amount ingested, inhaled, or applied to the skin. The **applied dose** is the amount presented to an absorption barrier and available for absorption (although not necessarily having yet crossed the outer boundary of the organism). The **absorbed dose** is the amount crossing a specific absorption barrier (e.g., the exchange boundaries of the skin, lung, and digestive tract) through uptake processes. **Internal dose** is a more general term denoting the amount absorbed without respect to specific absorption barriers or exchange boundaries. The amount of the chemical available for interaction by an particular organ or cell is termed the delivered or **biologically effective dose** for that organ or cell **(US EPA, 2002)*.***

**Dose-Response Relationship:** The relationship between a quantified exposure (dose) and the proportion of subjects demonstrating specific biological changes in incidence or in degree of change (response) **(US EPA, 2002).**

**Dystocia:** Difficult childbirth.

**Ecological Effects** – All endpoints (OECD definitions)

**Fish, Acute Toxicity Test:** In a four-day exposure, acute toxicity is defined by the $LC_{50}$, the concentration of test substance in water which kills 50% of the test population of fish. Test methodology is described in OECD Guideline 203, in OECD Guidelines for the Testing of Chemicals.

***Daphnia* sp., Acute Immobilization Test:** In a one or two-day exposure, acute toxicity is defined by the $EC_{50}$, the concentration of test substance in water which causes immobilization to 50% of the test population of invertebrates. Test methodology is described in OECD Guideline 202, Part 1, in OECD Guidelines for the Testing of Chemicals.

**Alga, Growth Inhibition Test:** In a three-day exposure, growth inhibition is defined by the $EC_{50}$, the concentration of test substance in growth medium which results in a 50% reduction in either alga cell growth or growth rate relative to a control group. Test methodology is described in OECD Guideline 201, in OECD Guidelines for the Testing of Chemicals.

**Endpoint:** In the context of the EPA High Production Volume Challenge Program, an endpoint is a physical-chemical, environmental fate, ecotoxicity, and human health attribute measurable by following an approved test methodology (e.g., OECD Guidelines for Testing of Chemicals). Melting point, biodegradation, fish acute toxicity, and genetic toxicity are examples of endpoints that are measured by an approved test method.

**Environmental Fate Effects** – All endpoints (OECD definitions)

**Photodegradation:** The photochemical transformation of a molecule into lower molecular weight fragments, usually in an oxidation process. This process may be

measured by Draft OECD Guideline, "*Phototransformation of Chemicals in Water – Direct and Indirect Photolysis*". This process also may be estimated using a variety of computer models.

**Stability in Water:** This environmental fate endpoint is achieved by measuring the hydrolysis of the test substance. Hydrolysis is defined as a reaction of a chemical RX with water, with the net exchange of the group X with OH at the reaction center. Test methodology for hydrolysis is described in OECD Guideline 111, in OECD Guidelines for the Testing of Chemicals.

**Transport Between Environmental Compartments:** This endpoint describes the distribution of a chemical between environmental compartments using fugacity-based computer models. The results of the model algorithms provide an estimate of the amount of the chemical within a specific compartment. The environmental compartments included in many models are air, water, soil, sediment, suspended sediment, and aquatic biota.

**Biodegradation:** Breakdown of a substance catalyzed by enzymes *in vitro* or *in vivo*. As an endpoint in EPA's HPV program, biodegradation is measured by one of six methodologies described in OECD Guidelines 301A-F, in OECD Guidelines for the Testing of Chemicals.

**Exposure:** Contact made between a chemical, physical, or biological agent and the outer boundary of an organism. Exposure is quantified as the amount of an agent available at the exchange boundaries of the organism (e.g., skin, lungs, gut). **(US EPA, 2002).**

**Feedstock:** A refinery product that is used as the raw material for another process; the term is also generally applied to raw materials used in other industrial processes. **(Speight, 2007).**

**Female Mating Index:** Number of females with confirmed mating (sperm and/or vaginal plug)/number of females placed with males. (**OECD**)

**Fugacity:** Estimate of the "escaping" tendency of a chemical species from a particular environmental compartment.

**Gas Oil:** Middle-distillate petroleum fraction with a boiling range of about 350°-750° F, usually includes diesel fuel, kerosene, heating oil, and light fuel oil. **(US OSHA Technical Manual SECTION IV: CHAPTER 2 PETROLEUM REFINING PROCESSES http://www.osha.gov/dts/osta/otm/otm_iv/otm_iv_2.html)**

**Hazard Assessment:** The process of determining whether exposure to an agent can cause an increase in the incidence of a particular adverse health effect (e.g., cancer, birth defect) and whether the adverse health effect is likely to occur in humans **(US EPA, 2002)**.

**Hazard Characterization:** A description of the potential adverse health effects attributable to a specific environmental agent, the mechanisms by which agents exert their toxic effects, and the associated dose, route, duration, and timing of exposure **(US EPA, 2002).**

**Hazard:** A potential source of harm **(US EPA, 2002**).

**Health Effects** – All endpoints (OECD definitions, unless otherwise specified)

**Acute Toxicity:** The adverse effects occurring within a short time-frame of administration of a single dose of a substance, multiple doses given within 24 hours, or uninterrupted exposure over a period of 24 hours or less. Exposure may be via oral, dermal or inhalation routes as described in OECD Guidelines 401, 402, 403, and 420 in OECD Guidelines for the Testing of Chemicals.

**Developmental Toxicity:** Adverse effects on the developing organism that may result from exposure prior to conception (either parent), during prenatal development, or postnatally until the time of sexual maturation. The major manifestations of developmental toxicity include death of the developing organism, structural abnormality, altered growth, and functional deficiency.

**Genetic Toxicity *in vivo* (Chromosomal Aberrations):** The assessment of the potential of a chemical to exert adverse effects through interaction with the genetic material of cells in the whole animal. Genotoxicity may be studies in the whole animal using methods described in OECD Guideline 475, in OECD Guidelines for the Testing of Chemicals.

**Genetic Toxicity *in vitro* (Gene Mutations):** The assessment of the potential of a chemical to exert adverse effects through interaction with the genetic material of cells in cultured mammalian cells. Genotoxicity may be studies in cultured cells using methods described in OECD Guideline 476, in OECD Guidelines for the Testing of Chemicals.

**Repeated Dose Toxicity:** The adverse effects occurring due to repeated doses that may not produce immediate toxic effects, but due to accumulation of the chemical in tissues or other mechanisms, produces delayed effects. Repeated dose toxicity may be studied following methods described in OECD Guidelines 407, 410, or 412 in OECD Guidelines for the Testing of Chemicals.

**Reproductive Toxicity:** The occurrence of biologically adverse effects on the reproductive systems of females or males that may result from exposure to environmental agents. The toxicity may be expressed as alterations to the female or male reproductive organs, the related endocrine system, or pregnancy outcomes. The manifestation of such toxicity may include, but not be limited to, adverse effects on onset of puberty, gamete production and transport, reproductive cycle normality, sexual behavior, fertility, gestation, parturition, lactation, developmental toxicity, premature reproductive senescence, or modifications in other functions that are dependent on the integrity of the reproductive systems.

**Hematocrit:** The proportion of the blood that consists of packed red blood cells and is expressed as a percentage by volume.

**Hyperkeratosis:** Hypertrophy of the horny layer of the epidermis.

**Hyperplasia:** A condition in which an increase in the number of normal cells exists in a tissue or organ.

**Hypertrophy:** Enlargement or overgrowth of an organ or tissue due to the increased size of its constituent cells

**Loading Rate**: The amount of the test material that is equilibrated with the aqueous test medium or the total amount of test substance added to dilution water to prepare water accommodated fractions (WAFs) for ecotoxicity testing (OECD, 2000).

**Lowest-Observed-Adverse-Effect Level (LOAEL):** The lowest exposure level at which a statistically or biologically significant increase exists in the frequency or severity of adverse effects between the exposed population and its appropriate control group **(US EPA 2002).** Note: In studies with an absence of a NOAEL the LOAEL is considered ≤ the lowest adverse effects dose

**Maltenes**: The fraction of asphalt which is soluble in n-alkane solvent; such as, pentane or heptane.

**Mean corpuscular hemoglobin concentration (MCHC):** The average concentration of hemoglobin in a given volume of packed red blood cells.

**Naphtha:** A general term used for low boiling hydrocarbon fractions that are a major component of gasoline. Aliphatic naphtha refers to those naphthas containing less than 0.1% benzene and with carbon numbers from C3 through C16. Aromatic naphthas have carbon numbers from C6 through C16 and contain significant quantities of aromatic hydrocarbons such as benzene (>0.1%), toluene, and xylene. (US OSHA Technical Manual SECTION IV: CHAPTER 2 PETROLEUM REFINING PROCESSES http://www.osha.gov/dts/osta/otm/otm_iv/otm_iv_2.html)

**No-Observed-Adverse-Effect Level (NOAEL):** The highest exposure level at which no biologically significant increase exists in the frequency or severity of adverse effects between the exposed population and its appropriate control group; some effects may be produced at this level, but these effects are not considered adverse or precursors to adverse effects **(US EPA 2002)**.

**Pathosis:** A state of disease.

**Portal-of- Entry Effect:** A local effect produced at the tissue or organ of first contact between the biological system and the toxicant

**Pour point:** The lowest temperature in °F at which an oil will flow (ASTM D97)

**Resin (petroleum):** A complex combination of organic compounds, predominantly hydrocarbons, obtained as a fraction of the extract from solvent extraction of residuum. It consists predominantly of high molecular weight compounds with high carbon-to-hydrogen ratios.

**Read Across:** Read-across can be regarded as using data available for some members of a category to estimate values (qualitatively or quantitatively) for category members for which no such data exist.

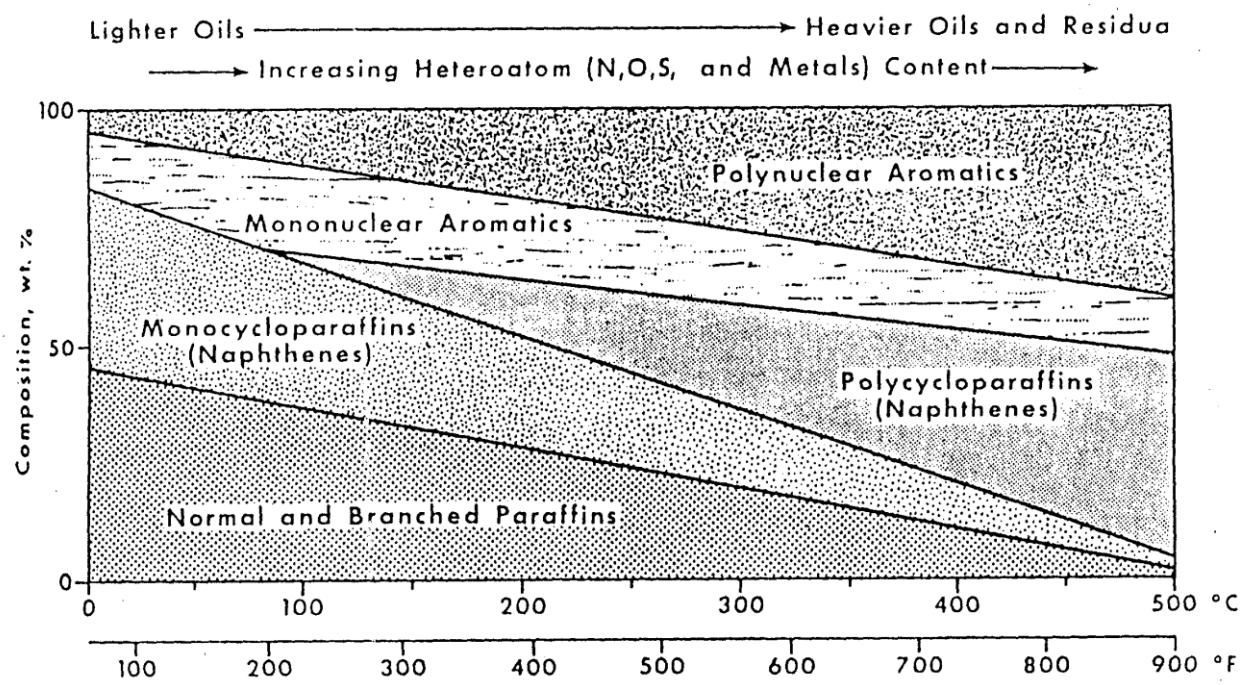
**Systemic Effects or Systemic Toxicity:** Toxic effects as a result of absorption and distribution of a toxicant to a site distant from its entry point **(US EPA 2002)**.

**Target Organ:** The biological organ(s) most adversely affected by exposure to a chemical or physical agent **(US EPA 2002).**

**Tar**: Viscous, dark-brown to black substances obtained by the destructive distillation of coal.

## APPENDIX 1; Crude Oil Chemistry and Composition

The hydrocarbons in crude oil – paraffins, naphthenes (cycloparaffins) and aromatics – share some structural features but differ in the ratio of hydrogen to carbon atoms and how those atoms are arranged. Olefins are not present in crude oils and are formed from rearrangement of atoms during the cracking process to produce gasoline-blending streams. Paraffins occur in higher concentrations in lower boiling fractions of crude oil while the concentration of naphthenes (cycloparaffins) and aromatics increase in the higher boiling range fractions (Figure A1-1)




Feedstock composition represented by the distribution of chemical types.

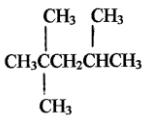
Mobil, 1997

Hydrocarbon molecules in crude oil may include from 1 to more than 50 carbon atoms at room temperature. When isolated, hydrocarbons with 1-4 carbon atoms are gases, those with 5-19 carbon atoms are usually liquid, and those with 40 or more carbon atoms are solids.

Paraffins: $C_nH_{2n+2}$ where n= number of carbon atoms.

Carbons are joined by single bonds (e.g. butane, $CH_3CH_2CH_2CH_3$). Paraffins with 4 or more C atoms may have 2 or more structural arrangements or structural isomers, for example:

normal octane, $CH_3CH_2CH_2CH_2CH_2CH_2CH_2CH_3$ or isooctane

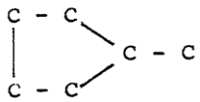


Normal paraffins occur in most crude oils but vary in total concentration (King, 1983). As a rule, crude oils of older geological age contain higher quantities of n-paraffins. Occurrences of paraffins relative to other hydrocarbon classes decreases as the boiling point range of fractions distilled from crude oil increases

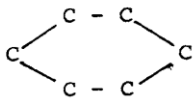
Branched or isoparaffins are found throughout the crude oil boiling range but do diminish with increasing boiling point. Certain lower molecular weight branched paraffins are capable of producing kidney damage, i.e. light hydrocarbon nephropathy through a mechanism that is specific to male rats and not relevant to humans (EPA, 1991).

Naphthenes: Cycloparaffins in gasoline have 5 or 6 carbon atoms arranged in a ring and belong to either a cyclopentane or cyclohexane series, for example:

$C_6H_{12}$ Methylcyclopentane



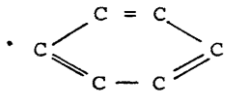
$C_6H_{12}$ Cyclohexane



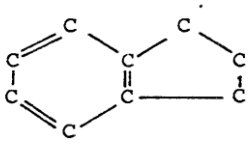
Cycloparaffins constitute a substantial proportion of petroleum with 5- to 6-membered ring structure being the predominant type. Most individual cycloparaffins that have been isolated are in the boiling range of gasoline and jet fuel. The cycloparaffin portion of the lubricant oil fractions of crude oil are a complex mixture of non-condensed and condensed 5- and 6-member rings. Polycycloparaffins may act as inhibitors in skin carcinogenesis (King, 1988)

Aromatics: Some carbon atoms are arranged in a ring joined by aromatic bonds, e.g.

benzene, $C_6H_6$ .



In polycyclic aromatic hydrocarbons (PAHs), some carbons are shared by 2 or more rings, e.g. indane, $C_9H_{10}$



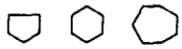
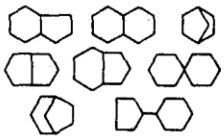
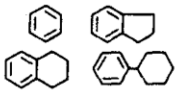
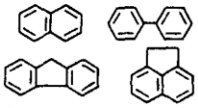
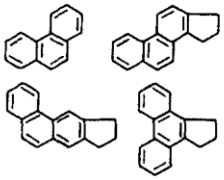
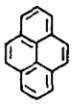
Aromatic hydrocarbon types are typically present in the same relative proportion in different crude oils. Where several possibilities for alkyl substitution exist, the predominant isomers are generally those containing substituents with the lowest number of carbon

atoms. In heavier, lubricant-type fractions, mixed aromatic-cycloparaffin hydrocarbons predominate, as mono-, di-, or tricyclic aromatic-cycloparaffin hydrocarbons. Certain polycyclic aromatics (PACs) are associated with mutagenicity, systemic toxicity and skin cancer. Heterocycles are closely related compounds in which an atom of nitrogen, oxygen or sulfur replaces one of the carbon atoms in the ring and are commonly found with PAHs (API, 2002).

Resins and asphaltenes are high molecular wt fractions (500-10,000) containing N, S, and oxygen found in the residuum/bottoms of crude oils. These classes of hydrocarbons have high polarity, low solubility and limited bioavailability and toxicity and typically constitute 10% of light paraffinic oils and up to 60% of heavy crude oils.

Much of the compositional information described above was derived from the extensive analysis of a Ponca Oklahoma crude, performed under the sponsorship of the American Petroleum Institute and is summarized in Table 1.1 (King, 1983).

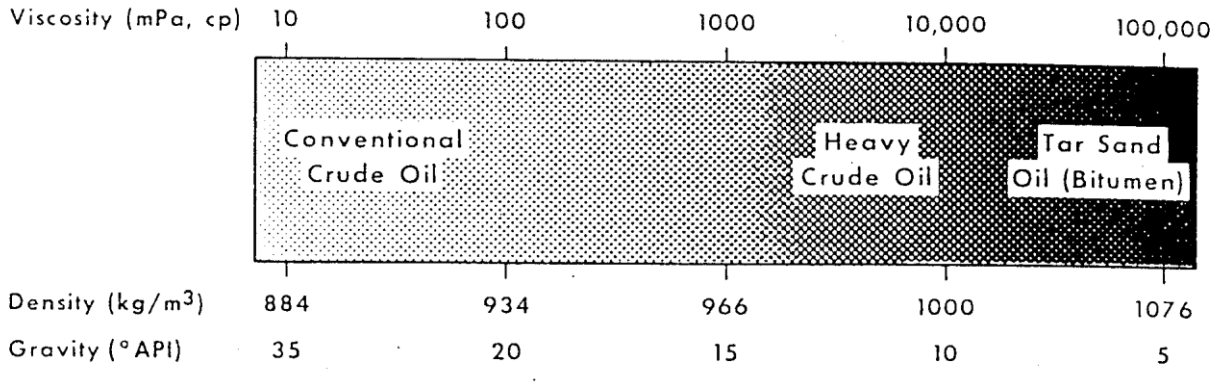
TABLE 1.1: Types of Hydrocarbons Isolated from Ponca Crude

| HYDROCARBON TYPE | BASIC STRUCTURES | NUMBER ISOLATED | FRACTIONS WHERE FOUND |
|---|---|---|---|
| **Paraffins** | | | |
| n-Paraffins | C-C-C-C-C-C- | 33 | All Distillates |
| Branched Paraffins | C C<br>C-C-C-C-C-C- | 41 | Gasoline, Light Gas Oil |
| **Cycloparaffins** | | | |
| Monocycloparaffins |  | 39 | Gasoline, Kerosine |
| Bicycloparaffins |  | 29 | Gasoline, Kerosine |
| Tricycloparaffins | | 3 | Gasoline, Kerosine |
| **Aromatics** | | | |
| Mononuclear Aromatics |  | 48 | Gasoline, Kerosine, Light Gas Oil |
| Dinuclear Aromatics |  | 60 | Kerosine, Light Gas Oil |
| Trinuclear Aromatics |  | 10 | Heavy Gas Oil-Light Lubricant |
| Tetranuclear Aromatics |  | 3 | Heavy Gas Oil-Light Lubricant |

## APPENDIX 2: Crude Product Potential

Crude oils are classified by viscosity, density and API gravity. API gravity was developed as a means to identify the gasoline production potential of a crude oil; the higher the API gravity, the more valuable the crude. Figure A2-1 illustrated classification of crude oil by this density-gravity method.

Figure A2-1: Classification of crude oil by density-gravity method.

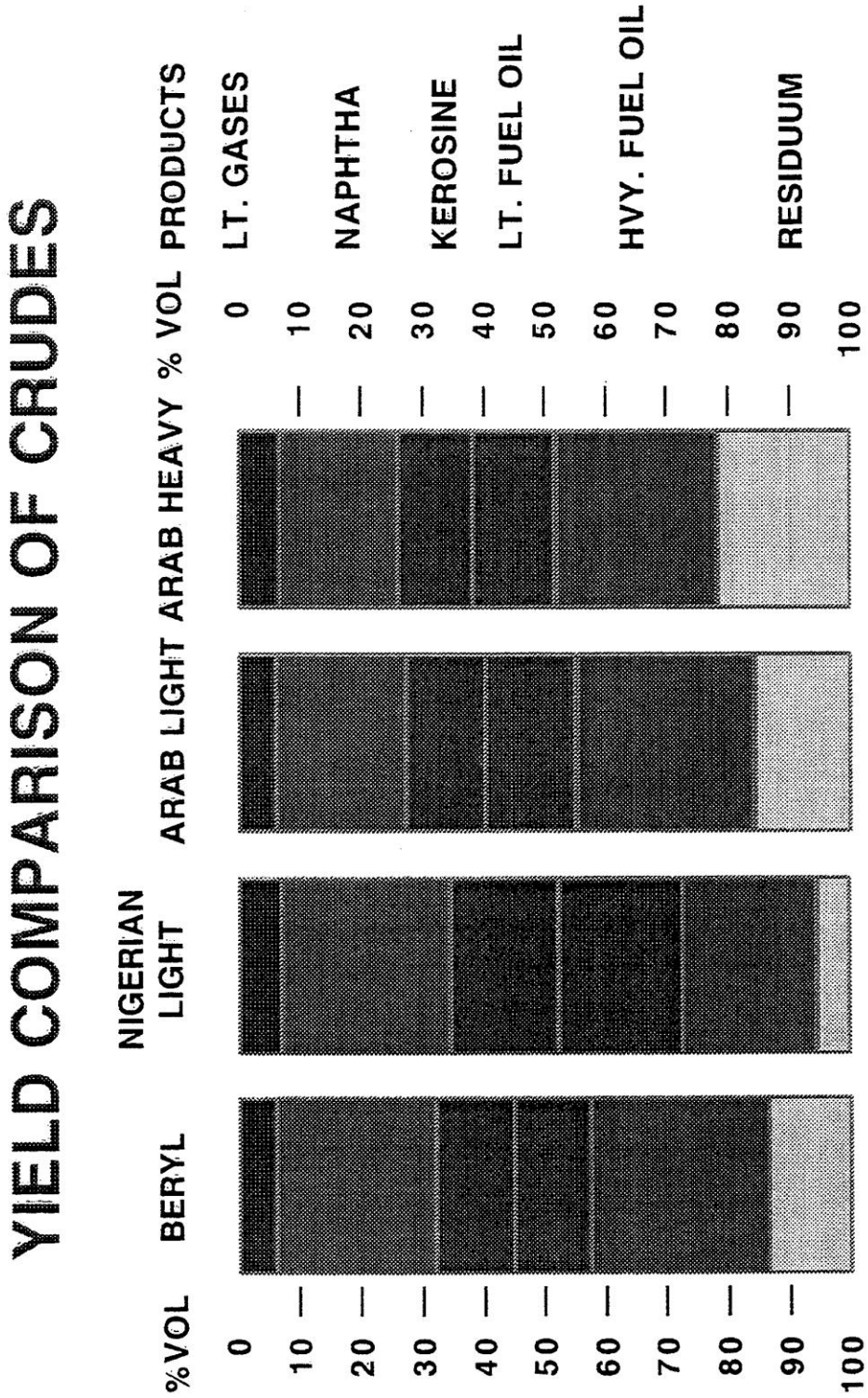



| Type of Crude | Characteristics |
|---|---|
| 1. Conventional or "light" crude | Density-gravity range less that 934kg/m$^3$ (>33$^0$API) |
| 2. "Heavy" crude oil | Density-gravity range from 1000kg/m$^3$ to more than 934kg/m$^3$ (10$^0$API to <28$^0$API)<br>Maximum viscosity of 10,000mPa.s(cp) |
| 3. "Extra-heavy" crude oil; may also include atmospheric residua. (b.p.>340$^0$C; >650$^0$F) | Density-gravity greater than 1000kg/m$^3$ (<10$^0$API)<br>Maximum viscosity of 10,000mPa.s(cp) |
| 4. Tar sand bitumen [before upgrade] or natural asphalt; may also include vacuum residua. (b.p.>510$^0$C; >950$^0$F) | Density-gravity greater than 1000kg/m$^3$ (<10$^0$API)<br>Viscosity greater than 10,000mPa.s(cp) |

Mackerer and Biggs, AIHCE, 1996; Platts, 2003

Heavier crude oils have higher density-gravity values and higher viscosity, with lower API gravity, making them less suitable for gasoline stocks but better candidates for lubricant and heavy fuel production. Figure A2-2 shows yield comparisons for 4 typical crude oils.

Figure A2-2: Yield comparison of crude oils



## Table 2.1 BRIEF SUMMARY OF THE HISTORY OF REFINING PROCESSING

| YEAR | PROCESS NAME | PROCESS PURPOSE | BYPRODUCTS, ETC. |
|---|---|---|---|
| 1862 | Atmospheric Distillation | Produce Kerosine | Naphtha, Tar, etc. |
| 1870 | Vacuum Distillation | Lubricants (original)<br>Cracking feedstocks (1930's) | Asphalt, Residual<br>Coker Feedstocks |
| 1913 | Thermal Cracking | Increase Gasoline | Residual, Bunker Fuel |
| 1916 | Sweetening | Reduce Sulfur | |
| 1930 | Thermal Reformation | Improve Octane Number | Residual |
| 1932 | Hydrogenation | Remove Sulfur | Sulfur |
| 1932 | Coking | Produce Light Products | Coke |
| 1933 | Solvent Extraction | Improve Lubricant Viscosity Index | Aromatics |
| 1935 | Solvent Dewaxing | Improve Pour Point | Waxes |
| 1935 | Cat. Polymerization | Improve Gasoline Yield & Octane No. | Petrochem Feedstocks |
| 1937 | Catalytic Cracking | Higher Octane Gasoline | Petrochem Feedstocks |
| 1939 | Visbreaking | Reduce Viscosity | Increased Distillate, Tar |
| 1940 | Alkylation | Increase Gasoline Octane & Yield | High Octane Aviation Gasoline |
| 1940 | Isomerization | Produce Alkylation Feedstock | Naphtha |
| 1950 | Deasphalting | Increase Cracking Feedstock | Asphalt |
| 1952 | Catalytic Reforming | Convert Low Quality Naphtha | Aromatics |
| 1954 | Hydrodesulfurization | Remove Sulfur | Sulfur |
| 1956 | Inhibitor Sweetening | Remove Mercaptans | |
| 1957 | Cat. Isomerization | Convert to Molecules w/High Oct. No. | Alkylation Feedstocks |
| 1960 | Hydrocracking | Improve Quality & Reduce Sulfur | Alkylation Feedstocks |
| 1961 | Fluid Cat. Cracking | Increase Gasoline Yield | Petrochem Feedstocks |
| 1974 | Catalytic Dewaxing | Improve Pour Point | |
| 1975 | Resid. Hydrocracking | Increase Gasoline Yield from Residual | |

Table A2-1 summarizes the history of petroleum refining. Since the first refinery was established in 1862, processes have been developed and continually improved to maximize the yield and efficiency of production of high quality fuels, lubricants and petrochemicals from petroleum crude, and concomitantly to minimize or eliminate undesirable components.

## APPENDIX 3: Correlation between PAC Profile and Selected Endpoints of Mammalian Toxicity

As indicated in the Crude Oil Test Plan submitted to the EPA in 2003, the mammalian toxicity of crude oils is expected to be related to their PAC profiles; particularly the toxicity measured in repeat-dose, developmental, and *in vitro* mutagenicity studies. The PAC[1] profile is the weight percent of DMSO-extractable, aromatic compounds contained in the 1 to 7 aromatic ring classes.

The initial indication that PAC content could be used to predict the toxicity of untested petroleum-related materials including crude oils was based on the publication by Feuston et al. (1994). Their research, based on thirteen petroleum-derived refinery streams, examined the correlations between the weight percentage of several chemical classes of compounds and the magnitude of various effects produced in rats treated dermally with these substances in repeat-dose and developmental toxicity studies. In general, Feuston et al. found that the toxicity of the streams was correlated with the concentrations of the 3 to 7 ring PACs. The analyses were based on the ranks of several measures of toxicity and the individual PAC concentrations.

In 2004, the API Testing Group recognized the need to further evaluate the observations made by Feuston et al. (1994) and commissioned a Task Group (PAC Analysis Task Group, or TG) comprised of experts in the fields of petroleum chemistry, toxicology, and biostatistics. The TG issued a report describing the relationships between PAC profile and the repeat-dose and developmental toxicities of high-boiling petroleum-related substances, i.e. those with initial boiling points greater than approximately 300 °F (API, 2008). Predictive models for seven selected repeat-dose and developmental dermal toxicity endpoints in the rat were reported (API, 2008). The report was reviewed in a peer consultation process and/are publicly available (TERA, 2008). Reports are in preparation on the relationship between PACs and reproductive and genetic toxicities of high-boiling petroleum substances.

Four potential sources of information were reviewed for the project: the publication by Feuston et al (1994); other published literature on the toxicity of individual PAH and PAC containing materials; studies sponsored by the American Petroleum Institute (API); and unpublished company laboratory reports. The unpublished laboratory reports consisted of: (1) reports of repeat-dose toxicity studies, (2) reports of developmental toxicity studies, (3) two reproductive toxicity screening studies, one each with treated males and females, on a single substance containing a high concentration of PAC, (4) an exploratory dose range-finding study in non-pregnant female rats, (5) reports of mutagenesis tests, primarily results of optimized Ames tests, and (6) reports of compositional data on the tested substances. All unpublished company laboratory reports (repeat-dose, developmental

[1] Note that "polycyclic aromatic hydrocarbons" (PAH) refers to compounds of two or more fused-aromatic rings consisting of carbon and hydrogen only. Polycyclic aromatic compounds (PAC) is a more inclusive term than PAH since, in addition to the PAHs, PAC also includes compounds in which one or more atoms of nitrogen, oxygen or sulfur (a heteroatom) replaces one or more of the carbon atoms in a fused ring system and perhaps more importantly includes alkylated (methyl, ethyl, etc.) rings **(API, 2008)**.

toxicity, and analytical) were judged to be either “reliable without restrictions” or “reliable with restrictions, i.e. reliability scores of 1 or 2 (Klimsch, et al. 1997).

The relationship between acute toxicity and PAC was not investigated statistically since the reported oral $LD_{50}$ values for high-boiling petroleum substances are generally greater than the maximum doses tested, typically 5 g/kg and 2 g/kg for oral and dermal exposures, respectively (API 2001, 2002, 2003a, b, c & d, 2004). These data demonstrate that the respective petroleum-derived streams are not toxic, at least within the operational definitions of the regulatory testing guidelines.

To model the outcomes of repeat-dose and developmental studies, sets of matched data of PAC composition and biological effects were selected. Each biological endpoint had an average of about 80 data points. The seven biological endpoints that were selected for final statistical characterization were four repeat-dose measures, i.e. thymus weight, liver to body weight ratio, platelet count and, hemoglobin concentration, and three developmental measures, i.e. fetal weight, live fetal count, and percent resorptions. The endpoints selected for modeling are consistent with effects reported for both individual PACs and PAC containing substances (SCF, 2002, ATSDR, 1995; IPCS, 1998; IRIS 2007; RAIS, 2007). The endpoints selected are also supported by other studies on PAC-containing petroleum-related substances submitted by the Petroleum HPV Testing Group as robust study summaries to satisfy the USEPA HPV Challenge Program requirements for the Aromatic Extracts, Crude Oil, Gas Oils, Heavy Fuel Oils, Lubricating Oil Basestocks, and Waxes and Related Materials.

The PAC compositional data was developed using an analytical technique referred to as the “PAC-2 Method,” or ‘Mobil Oil PAC Method” or, simply “Method II” (Feuston et al., 1994; Roy et al., 1985; Roy et al., 1988), a variation of the Institute of Petroleum IP 346 method (IP, 1980). In the PAC-2 Method, the percent of sample mass is determined for each PAC ring class (1 through 7) contained in PAC-concentrated dimethyl sulfoxide (DMSO) extracts of the test material. The analysis was performed by gas chromatography with flame ionization detection (GC/FID) or mass spectrometry (GC/MS).

The dose-response relationships between the “PAC profile” and specific biologic effects were successfully predicted using linear regression models. The correlations between observed and model-predicted data were very high ($r > 0.90$). The predictive ability of the models was rigorously tested and the models were found to be accurate predictors when used with interpolated data. A test material that has its PAC profile and dose within the range of the PAC profiles and doses used to develop the model gives rise to an interpolated model prediction. Predictions from samples that do not meet this requirement are considered extrapolated predictions. Extrapolated predictions might not be accurate and are considered unreliable by the Testing Group.

Interpolated model results can be used to estimate the dose that would cause a 10% change in the response relative to the control group ($PDR_{10}$). The concept is similar to the Benchmark Dose (BMD) for continuous endpoints (Crump, 1984). Comparison of the $PDR_{10}$ and $BMD_{10}$ from a series of samples has shown a close agreement indicating the

usefulness of the $PDR_{10}$ when no biological endpoint testing data exists and only the PAC profile is available to assess toxicity.

While similar to the BMD, the $PDR_{10}$ has several advantages:

- The $PDR_{10}$ is based on one validated model, whereas the BMD can be developed from several competing models, making the BMD strongly dependent on the selected model (Gephart et al, 2001).
- The $PDR_{10}$ can be applied to untested materials for which there are compositional data (ie, PAC profiles) but no response data, whereas the BMD cannot be used for untested materials.
- The $PDR_{10}$ is based on the large amount of data accumulated over multiple studies, whereas the BMD is based on a single study, usually with only 3 to 5 data points.

A copy of the full report detailing the development and testing of the predictive models developed by the Testing Group can be obtained through either API or TERA (API, 2008; TERA, 2008).

The genetic toxicity endpoints, *in vitro* gene mutation and in vivo chromosomal aberrations, assessed principally in micronucleus tests, are addressed in Appendix 4.

## APPENDIX 4: Optimized AmesTest and Statistical Modeling

The optimized Ames test was developed to improve the performance of the reverse mutation *Salmonella* assay for detecting mutagenic and potentially carcinogenic lubricant base stocks and related refinery streams (ASTM, 2002). The method involves concentration of polycyclic aromatic compounds (PAC) by extraction, employing the most consistently PAC- sensitive strain of *Salmonella* [TA98] and increasing the metabolic activation system to maximize metabolism of the streams being evaluated. These modifications allowed detection of positive bacterial gene mutation response identified as an increase of mutant colonies in treated groups at least 2-fold that of negative controls as in the Standard Ames Assay and allowed prediction of potential dermal carcinogenesis by calculation of a mutagenicity index (MI).

The mutagenicity index (MI) is the slope of the initial portion of the dose response curve expressed in units of revertants per microliter. The mutagenicity index was highly correlated with dermal carcinogenic potential, suggesting that oils with MI values < 1 were unlikely to be dermally carcinogenic, oils with MI values $\geq$ 1 but < 2 were indeterminate, and oils with MI values $\geq$ 2 would likely produce skin tumors if tested in mice. The test method was refined to provide the greatest predictive value of gene mutagenicity and potential carcinogenicity for the widest range of high boiling [>300$^0$C] PAC-containing streams and thus provides a more sensitive general *Salmonella* protocol for this class of petroleum substances. In 1995, the optimized Ames test was standardized as an ASTM method [ASTM E1687-95].

Correlation of Mutagenic Activity with PAC Profile

The relationship of the MI with the PAC profile of refinery streams with known dermal carcinogenic potential has been established. The method of quantifying PAC constituents in which the condensed ring aromatics are removed by DMSO extraction and analyzed for 3-7 ring PAC by gas chromatography (GC) was developed by Roy *et al*. (1985; 1988). Having demonstrated a strong correlation between analytical distribution of PAC and mutagenicity in the optimized Ames test for petroleum-derived substances which produce dermal tumors when tested in mice, the utility of this relationship for read-across to untested substances has been expanded by statistical modeling.

Statistical Modeling of Analytical Data with the Optimized Salmonella Assay (Ames Test)

A statistical model has been developed to predict MI scores for untested substances encompassing precision in the critical 0-2 range (McKee, et al., 2010). This model employs the 1-7 ring PAC profile for each sample to predict MI scores. This model separated the data from 193 samples of a range of PAC-rich petroleum streams into those with mutagenicity index values equal to or greater than 1.0 and those with MI values less than 1.0. This model was not designed to quantify mutagenic potency but to identify whether or not a substance had an MI value less than 1 or not; this result can be used as an indication of whether the material has the potential to induce gene mutations in the optimized *Salmonella* assay and thus, to potentially be active in dermal carcinogenesis assays as well.

The statistical model is based on a series of three steps each predicting if the test substance was above or below an MI cut-point using a binary logistic general additive model. Step 1 predictes the probability that the substance has an MI of 5 or larger. The second step used only the substances predicted to have an MI below 5 and tested for a split at an MI of 2 or larger (the samples from the first step that are predicted to be above 5 were set at 5 and were no longer in the model process). The third step uses only the substances predicted to have an MI below 2 and tested for a split at an MI of 1 or larger (again with the substances from the second step that were predicted to be greater than 2 were set to 2 and were no longer in the modeling process). At each step the probability for a decision is based on a value of 0.50. For example, in the first step, if the probability of the substance having an MI less then 5 was greater than 0.50 the substance was assigned a predicted MI of 'less than 5.' The final result was the combination of the results from the 3 steps with each substance predicted as being either < 1 or ≥ 1.

The model predictions agreed with the experimentally determined results 98% of the time, with the majority of the incorrect predictions being at MI values that were close to 1.0. When the model was tested with 49 hold out samples, 94% of the predictions were in agreement with the experimentally determined values.

From this information it is apparent that the outcome of optimized Ames tests can be predicted from compositional information with an accuracy that seems comparable to that associated with variability inherent with either the experimental methods or the methods used to calculate mutagenicity index from the experimental data.

## APPENDIX 5. Other Routes of Exposure

This Appendix contains summaries of several published studies that used unrealistic routes of administration and extremely high doses. Because of those deficiencies, the Petroleum HPV Testing Group recommends that they not be used for hazard or risk evaluation of crude oil. They are included in this document only for completeness.

Acute Toxicity

Data on the acute oral toxicity of five crude oils, i.e. four light crudes and one heavy crude oil, are summarized in the Table below.

| Sample[1] | Oral $LD_{50}$ (Rat) g/kg |
|---|---|
| Beryl [36.5°API] | >5.0 |
| Arab Lt [34.5 °API] | >5.0 |
| Mid-Continent [40°API] | >5.0 |
| Lost Hills Light [>38°API] | >5.0 |
| Belridge Heavy [14°API] | >5.0 |

[1]Mobil, 1984a,b; 1985a,b; 1990a,b

In a study of three crude oil samples, Smith (1981) reported acute oral $LD_{50}$ values in the mouse ranging from >10.0g/kg for mixed crude oils to >16.0g/kg for Wilmington heavy crude (18°API) and Recluse crude.

Repeat Dose

Three crude oils (Arab Light, 34.5°API, light; Prudhoe Bay, 28°API, heavy; and South Louisiana, 35°API, light) were administered orally to male CD-1 mice once daily for five days. Prudhoe Bay crude oil was administered at doses of 0, 2, 4, 8, 10, 12, or 16 ml/kg/day; Arab Light and South Louisiana crude oils were given at 10 ml/kg/day only. All three crude oils induced small hematologic changes, i.e. decreases in packed cell volume and mean corpuscular hemoglobin concentration (MCHC) that was consistent with hemolysis. At all doses tested these oils also produced liver enlargement and thymic and splenic atrophy without concurrent pathological effects on tissue structure. However, liver enlargement was considered likely an adaptive, physiological response and thymic atrophy, a non-specific, stress-related secondary effect (Leighton, 1990).

Developmental

Prudhoe Bay heavy crude oil (PBO) (28°API) was administered orally to pregnant Sprague Dawley rats either as a single dose of 5 ml/kg on selected days of gestation, i.e. 3, 6, 11, 15 or 17 , as a single dose at levels up to 10 ml/kg on Day 6 of gestation or as repeated daily doses of 1 or 2 ml/kg/day on gestation days (GD) 6-17 (Khan *et al*., 1987). With all three treatment regimes, at maternally toxic doses, increased rates of resorptions, increased fetal deaths and decreased fetal weights were observed. Administration of 5 ml/kg PBO, on Day 6 of gestation vs. the other gestation days, produced the maximum

effect on the increase in resorption rates and decrease in fetal weights as well as the decrease in maternal weight gains. When a series of doses of PBO were administered on Day 6 of gestation, even the lowest dose of 2 ml/kg was able to produce a significant increase in resorption rates and a decrease in maternal body weight gains. A NOAEL was not established, but a Lowest Observable Adverse Effect Level (LOAEL) for maternal and developmental toxicity was determined to be ≤1 ml/kg when PBO was administered daily on days 6-17 of gestation.

Reproduction

Sperm morphology in mice was also examined after five days of daily intraperitoneal injections of 18°API Wilmington heavy crude at levels up to 2.1 g/kg/day. Evaluation of tissue samples did not indicate any significant increase in the incidence of abnormal sperm (Lockard *et al*., 1982).

A Nigerian Bonny Light crude oil (NBL) dissolved in a nonionic surfactant (Tween 80) and water mixture and administered orally by gavage to male rats at doses of 200, 400, and 800 mg/kg daily for 7 days provided suggestive evidence of dose-dependent testicular and epididymal toxicity (Orisakwe *et al*., 2004). Histopathological changes occurred at all doses in the testes and included thickening of the connective tissue lining, distortion of the basement membrane at 200 mg/kg of NBL and degeneration of seminiferous tubules, coagulation of spermatocytes and cellular necrosis at the higher doses. However, testes weights both absolute and relative to body weight were significantly lower only in the 800 mg/kg group, i.e. 36% and 26% relative to the control animals, respectively. In contrast, relative testes weight was significantly increased compared to controls at 200 mg/kg.

Also, at all doses, final body weights were significantly lower relative to the control group but a dose-response relationship was not apparent. Epididymal sperm number was reduced in the 400 and 800 mg/kg groups, i.e. by 64% and 81%, relative to the control group, respectively. A NOAEL was not established in this study, but a LOAEL of ≤200 mg/kg existed for a decrease in body weight gain and the histopathological changes in the testes (Orisakwe *et al*., 2004).

The Orisakwe *et al* (2004) study had a number of significant limitations. First, the group size was small, consisting of only 5 rats per group. Second, the results were poorly reported. For example, entirely different dose levels of the test material were reported in Tables 1 and 2 of this publication. Third, the rats weighed 80%, 92%, and 85% of the control value at the low, middle, and high dose level, respectively, after only one week of exposure. Weight changes of this magnitude suggest that dose levels were selected without regard for the maximum tolerated dose. In fact, in another publication, the same authors reported that Nigerian Bonny light crude oil produced hematologic effects at the low dose and liver toxicity and “severe pathologic changes” at all doses (Orisakwe *et al*., 2005). The possibility that testicular changes may be secondary effects of severe systemic toxicity was not discussed. And fourth, in this study, the presence of the surfactant changed the physical characteristics of the crude oil through emulsification and may have altered the absorption of the PACs or other crude oil components in the gastrointestinal tract in the test animals and may thereby have affected the toxicity and the potency of this

crude oil relative to treatment with this same crude oil without surfactant or other tested oils (Orisakwe et al., 2004).

In another study, Obidike et al. (2007) reported changes in testicular morphology and cauda epididymal sperm reserves of male rats exposed to Nigerian Qua Iboe Brent (NQIB) light crude oil (36°API). In this study, male rats were administered 0.1, 0.2 or 0.4 ml/rat of NQIB crude oil orally by gavage every other day for 4 weeks. Treatment with NQIB produced a dose-dependent reduction in the cauda epididymal sperm reserves and histopathological changes including interstitial exudates, degeneration, and necrosis of spermatogenic and interstitial (Leydig) cells. These adverse changes led to a marked reduction in the number of spermatocytes, spermatids and spermatozoa but with a relative increase in the number of spermatogonia suggesting that crude oil exposure disrupts the maturation process of spermatogonia (Obidike *et al*., 2007).

This study had a number of serious deficiencies. First, there was no appropriate control group. The authors reported that the control animals “received no crude oil;” apparently, the controls received no gavage treatment of any sort. Second, the doses of NQIB were given as absolute amounts and not relative to body weights that could result in a change in the dosage with each dose. Third, the authors reported a statistically significant increase in relative testes weight at the low and high dose levels. However, the data are inconsistent with a statistically significant increase at any dose. For example, the control and high dose values were 1.25±0.06 and 1.26±0.02, respectively. Fourth, since final body weights were not reported, a determination of whether the maximum tolerated dose was exceeded could not be made. Food or water consumption, clinical symptoms, or histological changes in any organ other than the testes were not reported. The selected dose levels in this study may have been chosen without regard for the maximum tolerated dose. Whether the induced testicular changes may be secondary effects of severe systemic toxicity was not discussed.

In a follow-up study by the same authors, male rats were allowed to recover for 8 weeks after exposure to 165, 330, or 660 mg/kg of NQIB crude oil given orally by gavage every other day for 4 weeks (Igwebuike *et al*., 2010). All the treated rats had similar testicular pathology and a dose-related reduced spermatogenic activity in the seminiferous tubules, oligospermia in the cauda epididymides as well as hyperemia and edema in the interstices. The authors reported that there was “evidence of recovery and the restoration of active spermatogenesis.” Unfortunately, this study suffered from many of the same limitations as the initial study (Obidike *et al*., 2007). Further, there were significant discrepancies between the results of the two studies. Since final body weights were not reported for the two studies of NQIB mentioned above a determination of whether the maximum tolerated dose was exceeded could not be made. Food or water consumption, clinical symptoms, or histological changes in any organ other than the testes were not reported. The selected dose levels in these studies may have been chosen without regard for the maximum tolerated dose. Whether the induced testicular changes may be secondary effects of severe systemic toxicity was not discussed. Consequently, the studies are of limited value and need to be replicated