FORT COLLINS MEMORANDUM 2A
TECHNICAL SUPPORT DOCUMENT
CITY OF FORT COLLINS

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1. INTRODUCTION

On February 5, 2013, the citizens of Fort Collins voted to approve a moratorium on hydraulic fracturing and associated waste storage for the next five years.

The goals of this report are to provide an aid to the City of Fort Collins for future decision-making regarding hydraulic fracturing (also called “fracking”) and the implications for the future of hydraulic fracturing in the City of Fort Collins in light of Moratorium 2A, and the August 2014 ruling. More specifically, this report describes:

- The Human Health Risk Assessment process. This process is used by the United States Environmental Protection Agency (EPA) as the core systematic process for evaluating the potential impacts to human health from environmental chemicals. Within this framework, this report describes the potential risk pathways from hydraulic fracturing within the Fort Collin City limits.
- The geology in the vicinity of Fort Collins that makes oil and gas extraction possible.
- A summary of the oil and gas extraction process, with a specific definition of, and an emphasis on hydraulic fracturing.
- The nature of the chemicals used or extracted and a summary of the potential health effects of these chemicals

Oil and gas extraction is a complex process with its own specific terminology, and, hydraulic fracturing is only a particular small part. To limit the extent of this report and to stay focused on the moratorium its focus is primarily hydraulic fracturing, and the storage of its wastes. For purposes of this report, the definition of hydraulic fracturing is provided below, and is taken from the citizen-initiated ordinance proposed in Ballot Measure 2A that was adopted by the City’s voters on November 5, 2013. It reads: (Fort Collins, 2013):

> “The well stimulation process known as hydraulic fracturing is used to extract deposits of oil, gas, and other hydrocarbons through the underground injection of large quantities of water, gels, acids or gases; sands or other proppants, and chemical additives, many of which are known to be toxic.”

Based on this definition, this report focuses on the “direct” impacts associated with this limited phase of well stimulation known as hydraulic fracturing that occurs during a short period of time (a few days to a few weeks) early in the lifecycle of a well, and perhaps again later in the life of the well. These direct impacts may be incurred by a single application of hydraulic fracturing or from the additive impacts of many applications. Direct impacts include, for example, the addition of the chemicals in the fracturing fluid or volatilization of chemicals from flowback water. Because hydraulic fracturing can increase the production in new or existing oil and gas fields it can have “indirect” impacts associated with building, supplying, operating, and managing well operations such as land clearing, new construction, and increased waste management. These indirect impacts are only briefly addressed in this report.

In order to educate and provide a baseline framework to evaluate potential harm, Section 2 of this report provides a brief overview of the human health risk assessment process to show how a source may release chemicals of potential concern (COPCs) that could be transported to a resident, and so have a potential risk of harm to that resident.

Section 3 provides an overview of the oil and gas extraction process, and associated mechanical elements by describing the phases of drilling, extraction, production, and storage; although distribution is not the focus of this report. The term hydraulic fracturing is often inappropriately used to describe the entire process from drilling to storage, but using the definition above, hydraulic fracturing is only the process by which the oil and gas bearing layer of a geologic formation are opened to release more oil and/or gas, which occurs between drilling and the production phase of the well.

Oil and gas production requires the appropriate geologic formations, and a discussion of the geology beneath Fort Collins is provided in Appendix A rather than in the body of this report. The geographic framework of Fort Collins and the surrounding areas (Appendix A), including the geological formations’ depth to groundwater, shale and oil depths, and surface gradients, is important in the context of this report. Major geographic identifiers such as residential locations, oil well locations, and groundwater well locations are outlined in this appendix.

Oil and gas production is undertaken within a multilevel regulatory framework, which is complex and is not reviewed in this technical support document.

Section 4 outlines potential interaction between the public and the oil and gas COPCs used or produced during oil and gas production, and the human health effects resulting from human exposure. Oil and gas production uses a wide range of chemicals to lubricate drills in the exploration and drilling phase and to assist in fracturing the geologic formation that is the source of the oil or gas; the hydrocarbons being extracted are chemicals that have human health and environmental effects. Hydraulic fracturing produces wastewater that may also contain COPCs. This report will outline the possible sources of contamination, the associated COPCs and their potential health effects. The COPCs that are introduced into the environment can potentially impact surface water, groundwater, air, or soil either chemically through ongoing releases or through accidental releases.

Section 5 discusses some future potential scenarios for oil and gas development in relation to the moratorium. While other concerns of hydraulic fracturing, such as increased truck traffic, social cohesion, aesthetic degradation, induced seismicity, and heavy water use during periods of drought conditions are only briefly described in Section 6. The carbon footprint and greenhouse gas releases due to oil and gas production are also of concern to both the citizens and the government of Fort Collins because of their goal of future carbon neutrality. Section 7 briefly discusses greenhouse gases and methane released to the atmosphere in Colorado’s Front Range. Section 8 outlines the current state of research on the quantity of greenhouse gases released from oil and gas production; and where known, the current health studies related to oil and gas development in Colorado, or elsewhere.

This report will not go into detail on the probability of oil and natural gas production, the possible advancements in technology that may lead to future drilling, or the governmental regulations that are in place. Instead, this report will examine where possible contamination may add risks for Fort Collins residents, which may require investigation. A summary of findings and conclusions is presented in Section 9, with cost ranges for monitoring or research programs that could be undertaken. These are not recommendations for future work, but are provided for comparative purposes.

2. RISK ASSESSMENT: A BASIS FOR DECISION MAKING

The section of the report provides a general overview of the risk assessment process, a description of why it was selected as the framework for the discussion and a brief description of each component in the process. Risk assessment is a tool used in risk management because it is a systematic way of laying out how an individual might be exposure to chemicals in the environment, and the potential health problems they might cause.

Risk assessment is the process that scientists and government officials use to estimate the increased risk of health problems in people who are exposed to different amounts of toxic substances. Figure 2-1 was excerpted from the EPA’s 1991 web site on air toxics (EPA, 1991) and it shows the four steps of the risk assessment process. The process systematically breaks down each step to identify the sources of chemicals, the media they impact, transport mechanisms that allow chemicals to migrate to an individual, called a receptor, and allows for the ranking or the calculation of potential risks and hazards. For each site or facility being assessed, this information is pictured in a Conceptual Site Model (CSM). A simple example of a CSM is shown in Figure 2-2.

Two types of “health risks” are typically calculated, 1) cancer risk, which is defined as the increased potential of developing cancer over a lifetime of exposure, and 2) non-cancer hazard, which is the probability of other health effects.

The hazard is the increased potential of developing non-cancer health effects (such as asthma, liver or kidney problems) over the exposure period. In this example, exposure is compared to an acceptable level of exposure and a ratio is calculated to give a measurement that is called a Hazard Index (often abbreviated to HI).

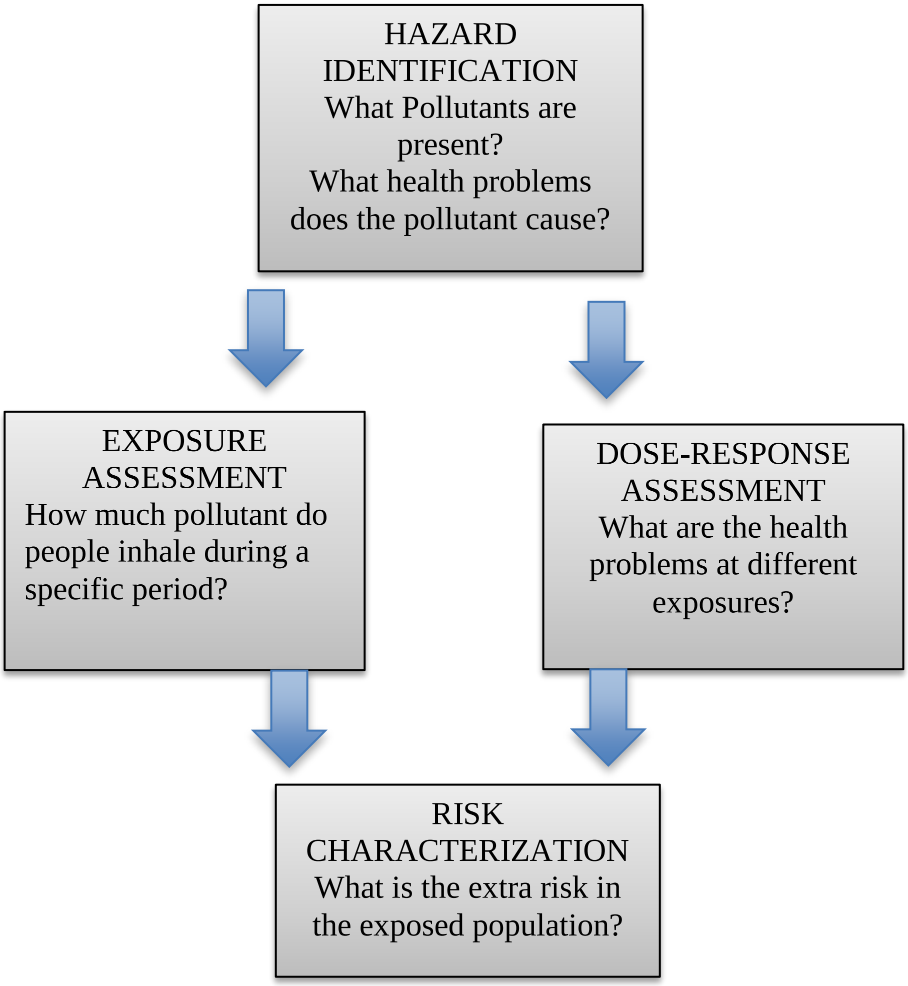


FIGURE 2-1
THE FOUR-STEP RISK ASSESSMENT PROCESS

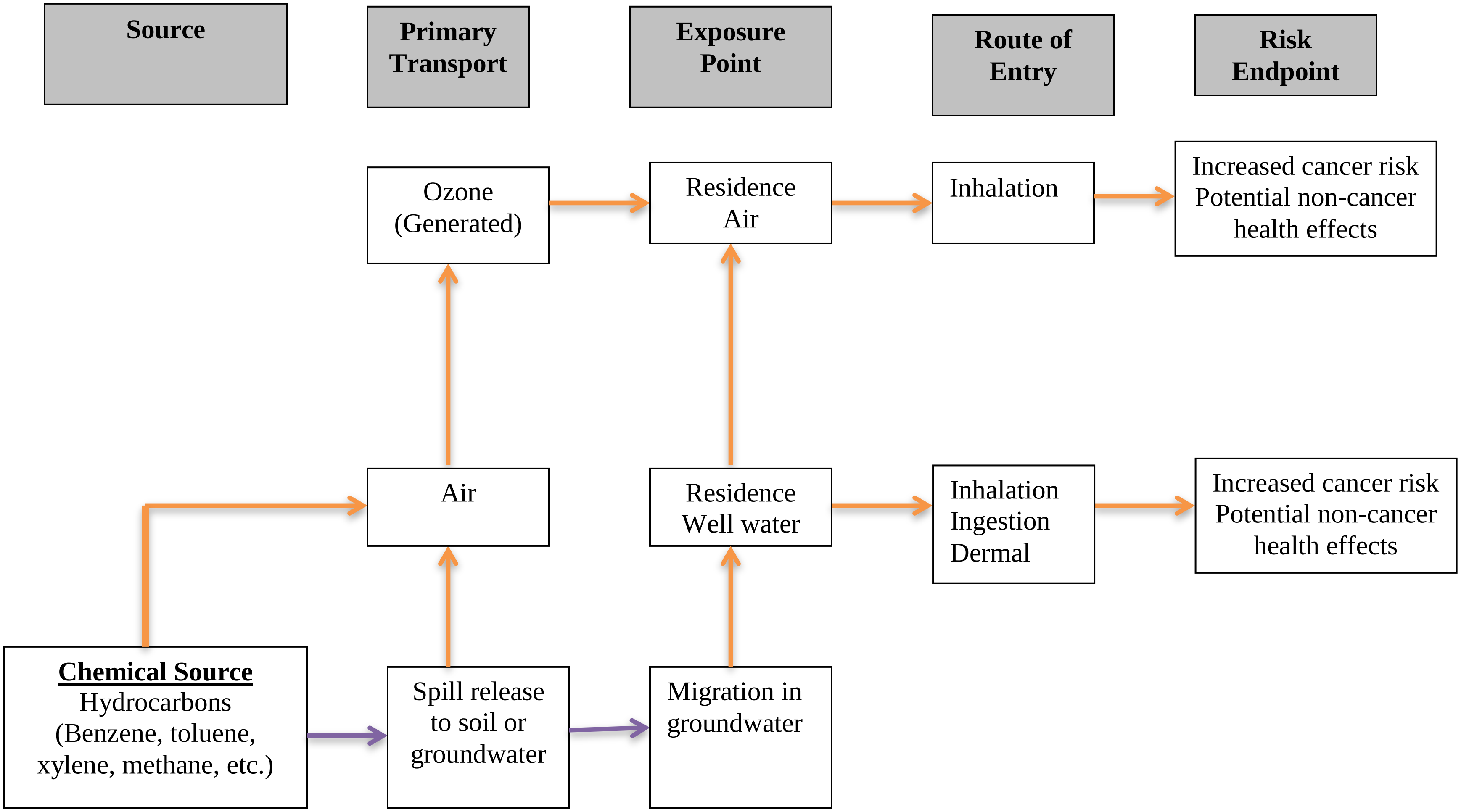


FIGURE 2-2 SIMPLE CONCEPTUAL SITE MODEL

2.1 HAZARD IDENTIFICATION

Identifying risks and hazards starts with understanding the process by which chemicals are used, generated, or released into the environment. For the hydraulic fracturing process, fracturing fluids, water and proppants are used to liberate oil, volatile petroleum compounds, and gas, which are then extracted. Fracturing fluids are a mixture of multiple individual chemical compounds with different physical properties, and human health effects. A list of chemicals used in fracturing fluids is shown in Appendix B. Some fracturing fluids and their uses are shown in Appendix B-1. The chemicals used in hydraulic fracturing identified by the US House of Representatives Committee on Energy (US House, 2011) are shown in Appendix B-2.

Initially in the risk assessment process, all of the chemicals in the mixture are considered; petroleum is a mixture of aromatic and aliphatic hydrocarbons. Some of the chemicals in the mixture have more severe adverse health effects, than others, and are of greater interest. The chemical with the highest risk is called the "risk driver," in the case of oil petroleum the driver is usually benzene.

2.2 EXPOSURE ASSESSMENT

An exposure assessment first determines if a person is exposed, and whether that exposure occurs by contacting air, water or soil. Four elements must be in place for exposure to be complete:

- A source of pollutant
- A transport mechanism to get the pollutant to the individual
- A point of exposure
- A route of exposure into the body

If any one of these elements is missing, there is no exposure, and therefore no risk. This is important because if one does not contact fracturing fluids there is no risk from fracturing fluids.

Figure 2-2 is a simple Conceptual Site Model (CSM) that allows for a systematic determination of chemical concentrations at important points in the process. This model is expanded as a picture of the multiple exposure pathways is developed. By understanding the location of chemical release points, and the media the chemicals are released into, it is possible to answers questions about which media should be monitored, at which exposure point, and what media action levels form the basis for regulatory enforcement and potentially legal actions.

Figure 2-3 shows a typical diagram of how the EPA pictures potential exposures. Specific exposure pathways are discussed in Section 4. Because exposure depends on the properties of the chemical released (oil or gas), the medium they are released into (water or air) and their persistence in the environment (i.e., gas will quickly disperse, whereas radioactive material may be present for many years), a more detailed analysis is needed. If an exposure pathway is complete, quantification of exposure is often measured at the point of exposure. For example, measuring benzene in air at a residence or in groundwater at a residential well provides data that can be utilized to quantify the exposure to a receptor.

Figure 2-4 shows how the exposure diagram would translate into the Conceptual Site Model for air and Figure 2-5 shows a diagram of typical ways for a receptor to be exposed to all media (e.g., inhalation of contaminated air and ingestion of and dermal contact with contaminated groundwater).

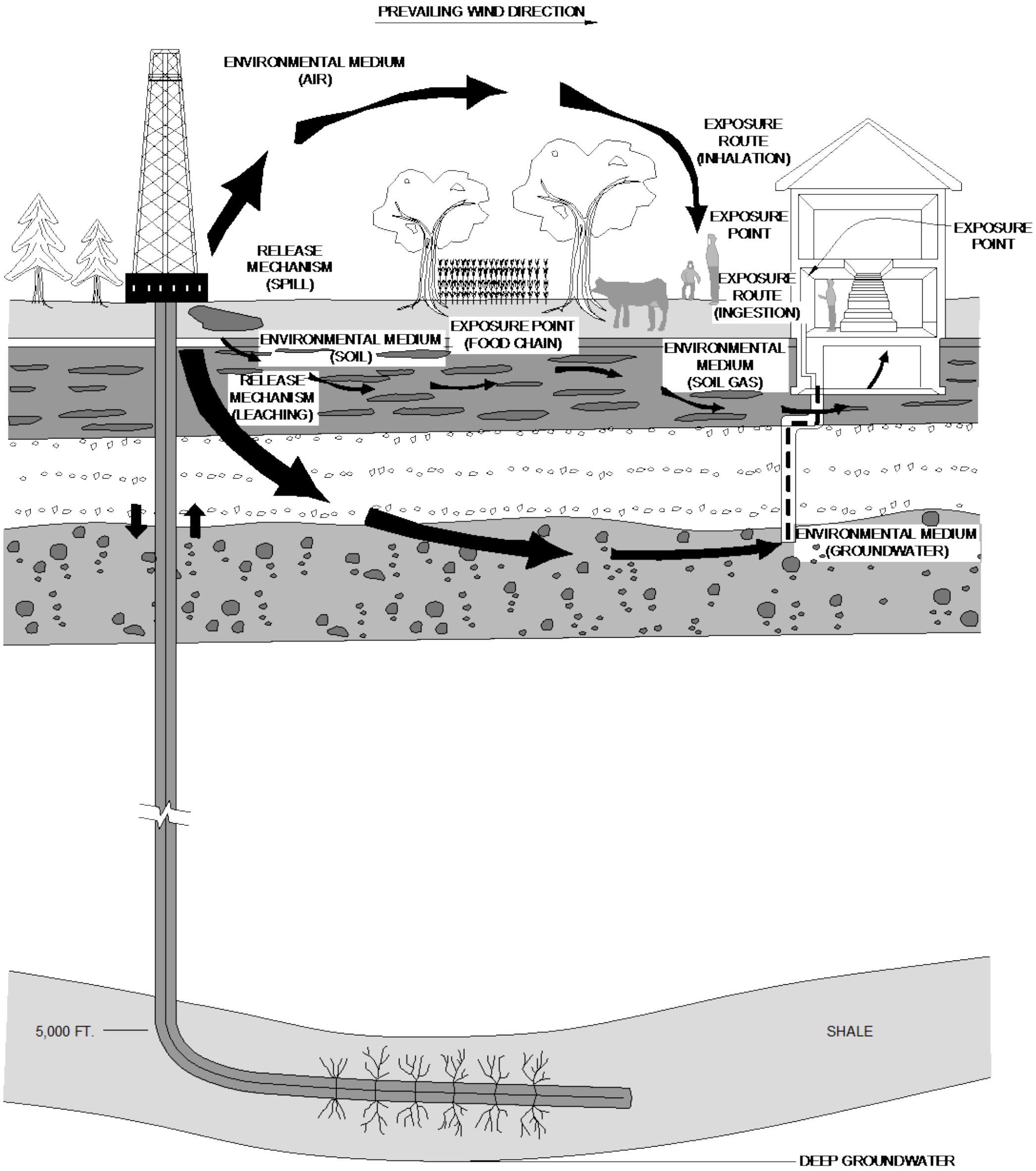


FIGURE 2-3
MODEL OF POTENTIAL EXPOSURES FROM OIL AND GAS EXTRACTION

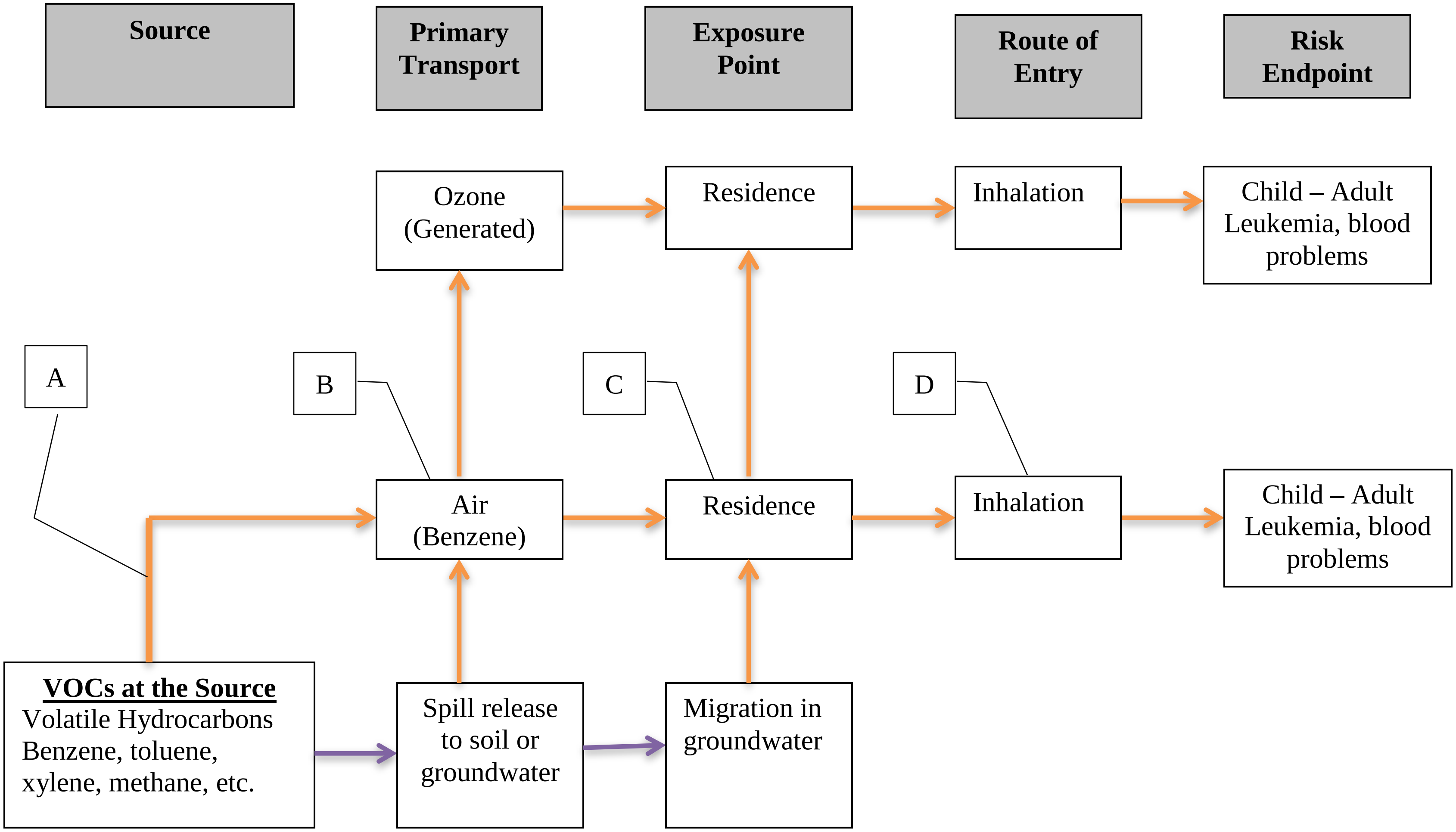


FIGURE 2-4 CONCEPTUAL SITE MODEL FOR RELEASES TO AIR

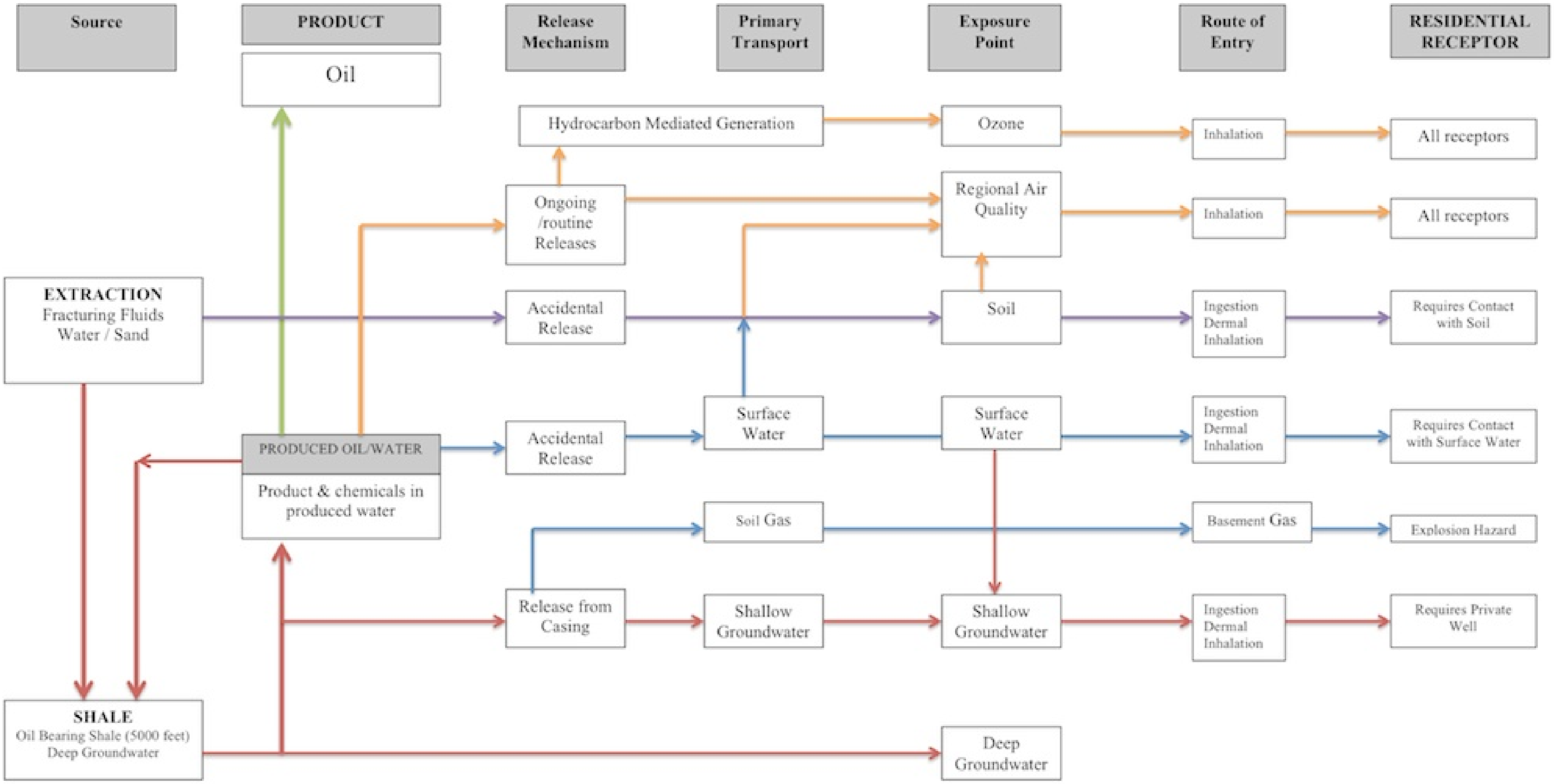
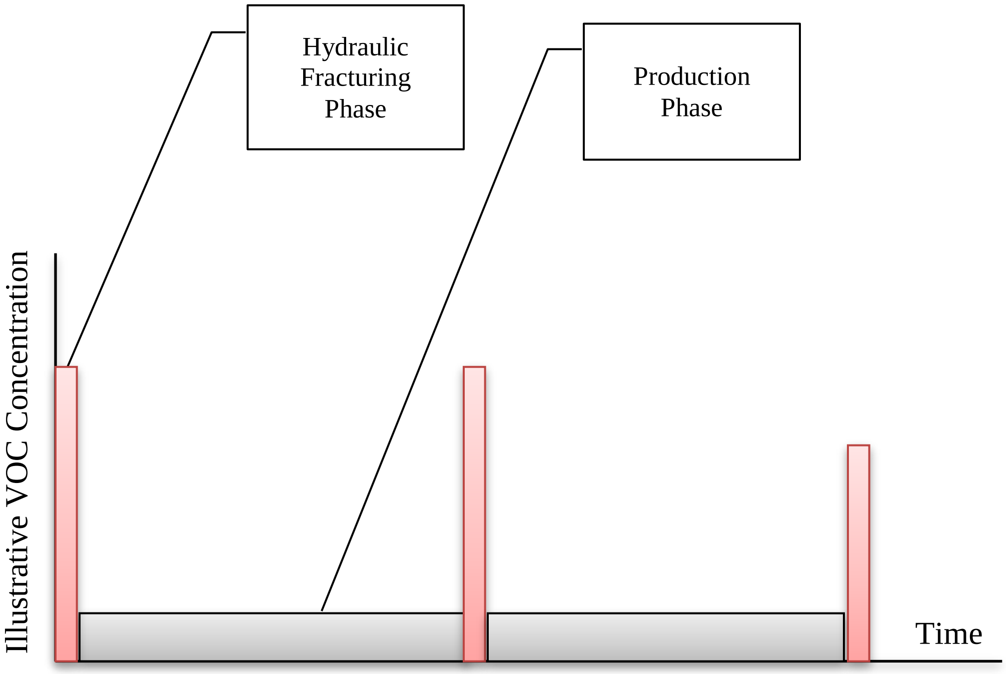


FIGURE 2-5
GENERIC CONCEPTUAL SITE MODEL FOR OIL EXTRACTION

FIGURE 2-6
GRAPH REPRESENTING VOLATILE ORGANIC CHEMICAL RELEASES DURING HYDRAULIC FRACTURING VERSUS PRODUCTION



The risk assessment process might cover different exposure timeframes, such as a few days, or a lifetime. When collecting environmental data, the time period should be representative of the length of exposure, where possible. For long term, or chronic, exposures long-term average exposure concentrations are important, but the environmental data are often not available and health protective assumptions have to be made.

For example, when considering hydraulic fracturing, current air benzene concentrations can be used to predict future potential concentrations by assuming that future concentrations will be the same as current concentrations. Or they might be assumed to increase if the number of wells increases, and vice versa. However, air COPC concentrations vary with activity at the well. Figure 2-6 is a diagram that represents hypothetical benzene concentrations over time, based on activity, and it shows that benzene concentrations are highest during the hydraulic fracturing phase, and that concentrations will decrease after the production phase is over.

Risk assessments are driven by environmental and toxicological data. The concentration of a chemical in an environmental medium can be measured at any point in the transport pathway from the source (in the case of oil and gas, the well), to the target organ of the exposed individual. However, there are a number of important factors that must be considered including:

- Access to the medium where concentrations should be measured
- The cost of sample collection, analysis, data validation, reporting and storage
- The number of samples needed to provide a valid and statistically significant representation of exposure to the medium of interest
- An understanding of how environmental concentrations change with fluctuations at the source, time, geological and meteorological conditions, and the location of the exposure point
- An understanding of chemical mobility, persistence and bioaccumulation
- Absorption into the body
- Biological markers for exposure and the relationship between these markers and the toxicological effect

It is impracticable to measure chemical concentrations in all media at all times. It would be prohibitively expensive. To reduce the need for actual physical data, mathematical models are used to estimate environmental chemical concentrations that represent exposure point concentrations. Modeling is cheaper, but still expensive.

To complicate these points, not all data are equal. The method of collection, chain-of-custody, sample holding times, analytical detection limit, and analytical problems (interferences, cross contamination, equipment failures) can render the data of poor quality or unusable. Before data are collected, data quality objective (DQO) should be established (EPA, 1994), and after collection a data quality assessment is employed to verify data quality (EPA, 2006). The EPA provides a ranking system to indicate data quality, and for litigation, or enforcement it is advisable to have data of high quality. High quality data is often the most expensive to collect. All data may serve a purpose, but the purpose should be established prior to data collection.

For oil and gas issues related to hydraulic fracturing, air data are the most relevant and important because VOC releases to air are more routine, and this pathway might represent common exposure to a resident. Whereas releases of fracturing fluids and petroleum hydrocarbons to soil, groundwater and surface water require leaks from piping and equipment, and spills, which may also occur, but may be harder to detect if they are below the ground.

Volatile chemical releases to air stem from both routine and fracturing specific activities, and they represent actual chemical concentrations being inhaled by a resident. However, air chemical concentrations will change with time of day, distance from the source, meteorological conditions such as wind speed and direction, and sample collection duration and location. Serious consideration should be given to data collection efforts because these complicating factors can compromise data quality and usefulness.

Using Figure 2-4 as an example for an oil well, to prove an individual is exposed to chemicals from hydraulic fracturing at a well, it must be shown that the chemicals at the source are transported through air in the direction of the resident for a sufficient duration to exceed either average or specific regulatory concentrations, or at levels sufficient to cause harm. For example, in Figure 2-4, Box A answers the question - What is the concentration of a chemical at its source? Box B describes the transport media that might be affected. In this example, soil and/or groundwater become contaminated, and there is the potential for benzene to migrate into ambient or indoor air. The distance from various receptors to the source may vary and the chemical concentration in air would typically decrease with increased distance to the point of exposure for a resident (represented in Figure 2-4 in Box C). Box D represents the air concentration at the route of entry into a resident’s body.

Simply measuring chemical concentrations at the point of exposure might show the resident was exposed but does not show the well is the source; exposure might be due to background sources such as a gas station, or car in a garage. If a site were regulated under a hazardous waste program, such as the Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA) or a voluntary remediation program, data would be collected under EPA data collection protocols, and environmental characterization would establish DQOs for each medium. At this point in time, there are few or no air data characterizing potential exposures to releases from Fort Collins oil wells over time. Residential exposure from a well might be suspected, due to the presence of hydrogen sulfide in the air at a residence next to a well, but to adequately prove exposure from the well all four elements must be shown, and the exposure must be quantified.

When environmental data are available they could be used in the risk assessment process. For example, when calculating the risks to a resident from a chemical like benzene the time span of data collection should be sufficient to be representative of a lifetime of exposure. A year of data would show seasonal variability within a year, but not year-to-year variability. Five years of data could provide year-to-year variability, and it would allow an estimation of exposure over the 30-year lifetime assumed by EPA. Chemical concentration data may vary with wind direction, distance from the source, etc., and each variable might require the collection of additional data. With each location, it may be necessary to collect background measurement with the goal of separating well-related benzene concentrations from benzene derived from other sources. The quality of the data for each variable should also be considered; the cost of collecting and analyzing data for each variable will be impacted by data quality requirements.

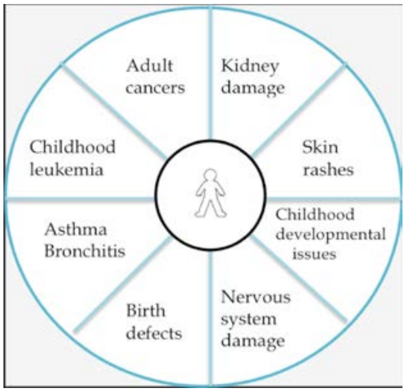
2.3 TOXICITY ASSESSMENT

A toxicity assessment provides information on the potential adverse health effects of the chemicals involved with hydraulic fracturing or the resulting petroleum hydrocarbons. In general human health dose-response data are unavailable except from epidemiological studies. In the absence of human data, toxicologists rely on animal studies.

Cancer development in humans is a complex process; cancer may take many years to develop after initial exposures, or may take multiple exposures for certain cancers to develop. In rare cases, with benzene for example, there is evidence that exposing the pregnant mother may result in childhood cancer after the infant is born. Because cancer development is a complex process, some simple assumptions are made in the interest of being health protective. In this case EPA assumes that any exposure will increase the risk of developing cancer. This is called a zero risk, non-threshold assumption.

Evaluating non-cancer effects in humans is also a complex process because each chemical may have different effects. Also, a chemical may have different effects based on the length of exposure or the exposure concentration. For hydraulic fracturing and oil and gas these are also discussed in Section 4. Figure 2-7 shows how these dose-response curves appear on a graph. The EPA dose-response process adds safety factors to the actual response found in animal experiments to account for uncertainties when extrapolating from animal studies to human responses. These uncertainty factors are conservative, meaning they lower the acceptable concentrations, but they are protective of sensitive sub-populations, like children or health-compromised individuals.

Health Effects: For petroleum compounds many of the adverse health effects are known. For some compounds, such as fracturing fluids, toxicological information is unavailable. This leads to uncertainty in the risk assessment process.



2.4 RISK CHARACTERIZATION

The EPA's risk assessment process considers both cancer and non-cancer effects. For cancer effects, because of the zero risk approach, a chemical that can cause cancer is considered to have risk, and the US National Contingency Plan provides an acceptable risk range against which risks are assessed. Cancer risks are expressed as a probability, and the acceptable excess cancer risk range is one in ten thousand (1 in 10,000 or 10^{-4}) to one in one million (1 in 1,000,000 or 10^{-6}).

Risks are calculated as the product of the exposure multiplied by the dose-response factor.

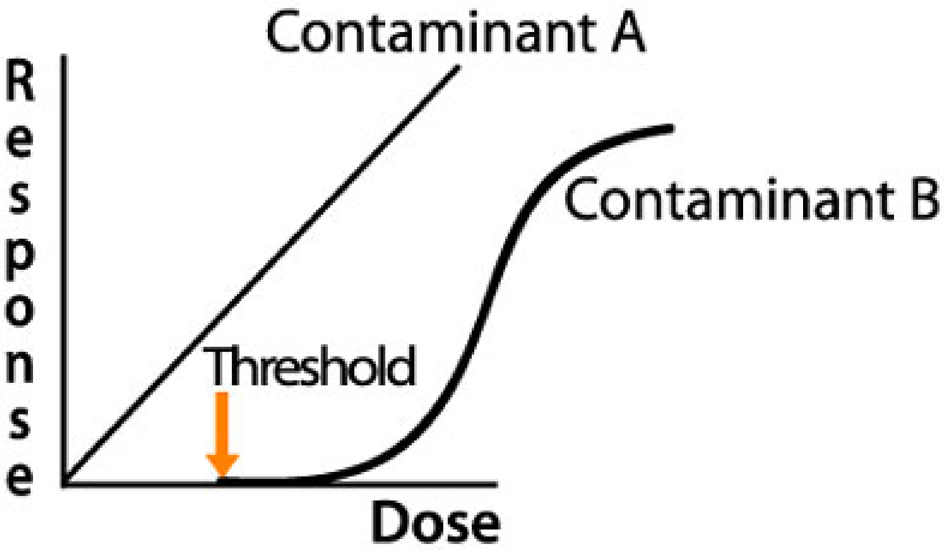


FIGURE 2-7
DOSE-RESPONSE CURVES FOR TWO TYPES OF HEALTH EFFECT

Curve A represents potential cancer effects and has no threshold (i.e., any exposure has a risk), and curve B represents non-cancer effects and has a threshold for its effect (i.e., there is a level of exposure that will not cause harm).

Chemicals with non-cancer effects are assumed to have a safe threshold (see Figure 2-7) meaning there is an exposure level that has no risk. The threshold may be different for each chemical. Once the threshold is exceeded there is the potential for an increased hazard. Hazards can be determined for short-term (hours to a few days of exposure), intermediate-term exposure (a few days to few months of exposure) or long-term exposures (greater than a few months). Non-cancer hazards are determined by comparing (dividing) the dose for the exposure period to the acceptable dose for the same period. The resulting ratio is called a Hazard Quotient and it is used to quantify the non-cancer exposure to a receptor. The value of the Hazard Quotient that is equal to or below one (1) is considered acceptable in the Superfund Program (EPA 1989). The sum of Quotients is called the Hazard Index, and for chemical mixtures, a Hazard Index summing the actions of chemical mixtures affecting the same target organ that is equal to or below one (1) is considered acceptable.

The risk assessment process calculates risks and hazards for each chemical individually, and then sums those for an estimate of total risk. Oil and gas chemicals are usually present as mixtures and not singly or individually; therefore, the risks and hazards from each chemical are added together to provide a cumulative total risk estimate.

2.5 UNCERTAINTY

All risk assessments have uncertainty. Often the uncertainty can be factors of 100 or 1000, depending on the medium sampled or the type of risks being calculated. In most, if not all, cases the uncertainty cannot be estimated because the actual risk cannot be known. The two main sources of uncertainty are environmental data and dose-response information.

Data Uncertainty When dealing with environmental data there is uncertainty because all data represent a "snap shot," or data collected from a short timeframe that is used to represent a longer time period. This is particularly true for air data because atmospheric conditions will act to disperse, and move contamination either towards or away from a fixed receptor. When the chemicals under consideration are common, background concentrations should be established, and for benzene the background range may have a measureable and significant risk.

Toxicological Uncertainty Toxicological dose-response factors are highly uncertain and because they are often based on high dose animal toxicology or epidemiologic studies and extrapolated to effects in humans exposed at low doses, the extrapolations include health protective assumptions. Extrapolating from high doses (often in animals), where effects are clear, to low levels where responses may be different due to the lack of data, leads to high uncertainty in cancer dose-response factors. Similarly, uncertainty factors for non-cancer effects can range from ten to 3000 depending on the chemical and the study used as the basis for the dose-response factor.

Risk Uncertainty When calculations are performed by combining data uncertainty with dose-response uncertainty the overall uncertainty in the risk estimates is increased.

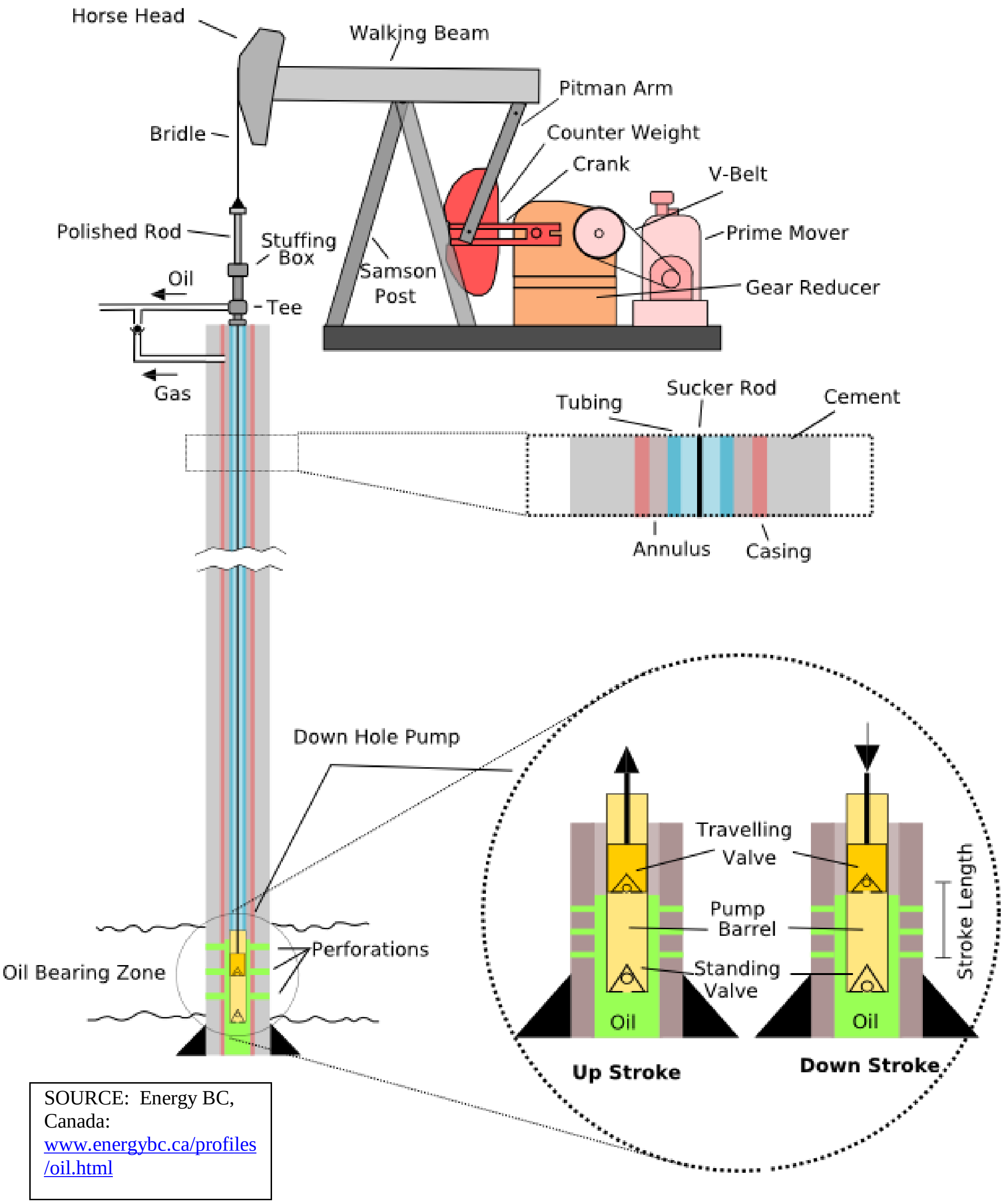
3. MECHANICAL ELEMENTS OF OIL AND GAS EXTRACTION

This section provides a brief overview of the mechanical and engineering aspects of the unconventional oil and natural gas development process, the type of mechanical equipment used and the components where hydrocarbons might be released.

3.1 MECHANICAL EQUIPMENT

Mechanical elements associated with oil and gas development produce pollutants as a by-product of their function. This includes diesel emissions, particulate matter, and/or volatile organic chemicals (VOCs) either through engine emissions, the evaporation of lubricants, solvents, etc., and the release of product. Mechanical elements are also susceptible to leakage from pipes, flanges, valves and malfunction of moving parts that can result in larger scale spills.

Diesel trucks provide transport for all elements used on the well site; this includes but is not limited to concrete for pad construction, hauling water, heavy machinery, storage tanks, and pipelines. Drilling rigs are used during the drill process to drill the borehole to the hydrocarbon-containing deposits. Power generators may be used throughout the well’s life to provide electricity to power the oil and gas pumps and to run compressors and other on-site machinery. Phase separators are used throughout the production of the well to separate the hydrocarbons produced from a well. Dehydrators are used to remove water from the produced hydrocarbons, and compressors are used to create liquid natural gas from the gas produced in the well. This is an easier way to store methane and transport it to offsite facilities. Well equipment and a sample oil well site are shown in Figure 3-1.



SOURCE: Energy BC, Canada: www.energybc.ca/profiles/oil.html

FIGURE 3-1
EXAMPLE OIL WELL: A COMMON DESIGN

3.2 SEDENTARY EQUIPMENT

Some mechanical elements have few to no moving parts and are therefore unable to malfunction as such. However, this equipment is still able to leak or rupture causing spills. Well casing and the cement that surrounds it are used to separate the chemicals going in and out of the well from the environment around it. As shown in Figure 3-1, sealed casing is particularly important to separate groundwater aquifers from the well. The wellhead is the cap and access point at the surface of the well for ongoing production and future re-fracturing (Figure 3-1). Storage tanks and condensate tanks are used on site to store fracturing fluid, produced water, and produced hydrocarbons (oil, volatile gas condensate, or liquid gas). Venting is a protocol used in situations where “low VOC emission completion” is not used. Tank vents are currently a significant source of VOCs in the Denver-Julesberg Basin. Pipeline is used in some cases to transport produced hydrocarbons and other materials off-site when the use of trucks is less economically viable.

Green completion practices are required on most oil and gas wells in Colorado except where the wells are not sufficiently proximate to sales lines, or where green completion practices are otherwise not technically and economically feasible. Prior practices relied on flowback ponds, or lined open pits, used to evaporate volatile chemicals and contain the liquid until it can be reused or removed. Flowback ponds have largely been replaced by low VOC emission completion technology that uses tanks to collect all flowback water, not allowing as much evaporation as before.

3.3 TIMELINE IN THE LIFE OF A WELL

Well activity can last as long as a few months from pad development to the steady production of hydrocarbons over several years or decades. Once a well is drilled, it can be fractured multiple times to maintain hydrocarbon production for several decades. See Figure 2-6 for a representation of this process.

3.3.1 Road and Drill Pad Development

Once the location of a well has been selected, a concrete well pad is constructed. The well pad consists of several acres of land where all the future staging, drilling, and storage will take place. The size of well pads depends on the depth and number of wells drilled (ANL, 2013). To prepare the well pad, the ground must be leveled and cleared of vegetation using chemicals and heavy machinery. Cement well bases are then poured to provide stable drill pads. Access roads will also be constructed where necessary to allow for the truck traffic required to transport materials to and from the well site to public roads.

3.3.2 Drilling and Casing

The well is drilled down to near the level of the hydrocarbon containing formation (roughly 900 feet before the level of the formation) (ANL, 2013) and the borehole is then gradually curved at a 90-degree angle to allow for horizontal access into the formation layer. As drilling advances, casing is inserted to protect the well from the aquifers and leakage of other materials into the well. Cement is pumped into the annulus (the space between the ground and the well casing) to further protect the well (Figure 3-1). The horizontal portion of the well and the casing is perforated with small explosives to allow the future flow of fracturing fluid out and oil or gas to flow into the well for collection. The horizontal portion of the wellbore can extend for more than 5,000 feet below ground surface (ft. bgs) (ANL, 2013). In Fort Collins the oil wells are between 5,000 and 7,500 feet bgs (FracFocus, 2014). Typical shale depths in Larimer and Weld Counties are discussed in Appendix A.

3.3.3 Well Stimulation and Completion

Hydraulic fracturing “describes the process of fracturing low permeability rocks using water mixed with sand and proprietary chemicals pumped into the borehole under high pressure.” (Moore *et al.*, 2014) Only a limited length of a horizontal well can be fractured at any one time, resulting in the need for fracturing in multiple “stages” by separating the well with cement plugs and then removing these plugs after fracturing a stage is complete. The overall process might vary for oil versus gas production, or for new wells versus enhancing production in older well, and the process can last a few days to a several weeks depending on the number of stages being fractured and the number of wells on a single well pad (Moore *et al.,* 2014).

During the fracturing process, fracturing fluid is pumped into the well at high pressure (e.g., greater than 3,500 psi) to break up the shale (or other geologic strata) pockets that trap the oil and gas. Fracturing fluid is composed predominantly of water (approximately 90 percent) with added proppant (~8-9 percent) to hold the formation open after the fluid has left. Proppant usually consists of fine sand (silica), meta basalt, or synthetic chemicals) (Vengosh *et al.*, 2014). The remaining elements in the fracking fluid are chemicals (~0.5 to 2 percent), usually proprietary, with a range of functions including acids, lubricants, biocides, corrosion inhibitor, pH adjusting agents, and scale inhibitors (See Appendix B for a list of chemicals in hydraulic fracturing fluids).

After pressure is removed from the well, the fracturing fluid and natural fluids previously trapped in the formation return to the surface. The water that returns to the surface of the well immediately following hydraulic fracturing is referred to as flowback water which consists of the dozens of chemical constituents present in hydraulic fracturing fluids, but it is also mixed with the fluids that were originally present with the hydrocarbons in the formation (referred to as produced water). The produced water may also contain hydrocarbons, dissolved minerals (total dissolved solids, TDS), trace elements, and naturally occurring radioactive materials (NORMs). The volumes of flowback water are extremely small relative to the volumes of produced water. Flowback water is directly attributed to hydraulic fracturing, whereas produced water is an indirect effect of hydraulic fracturing enabled production. After a hydraulic fracturing event, the fluid that comes out of the well changes from flowback water to produced water, but there is no formal distinction between the two fluids. The injected fracturing fluid continues to return in small quantities throughout well production with between 10 and 40 percent of injected fracturing fluids returning to the surface (Vengosh *et al*., 2014). Produced water can be reused for further hydraulic fracturing, disposed of in Class II deep injection wells, or treated using either municipal or industrial wastewater treatment facilities (Vengosh *et al*., 2014; COGCC, 2014).

3.3.4 Storage and Distribution

Well pads include storage tanks that perform a number of holding functions including storage of fracturing fluid, produced water, and produced hydrocarbons. Storage of hydrocarbons is required on-site for as long as it takes to remove water and separate crude oil from natural gas. Once this occurs, the crude oil or liquid gas is either stored on-site until retrieved by a transport truck, or is sent off-site via a pipeline. According to data provided by the current operator within the City, reviewed by City staff and provided to the authors, the existing wells in Fort Collins currently pass over 98% of gas through a thermal oxidizer; however, in some cases gas is simply vented.

3.3.5 Production, Abandonment and Reclamation

The life of an oil or gas well can be approximately 20-30 years (Adgate *et al*., 2014; Moore *et al*., 2014). As production decreases below profitability, hydraulic fracturing can be performed again to re-stimulate the well. Wells that have unconventional production methods (horizontal drilling and hydraulic fracturing) decline much more rapidly than conventional wells (Adgate *et al*., 2014). After a well has stopped producing at a profitable rate, the well can be capped, and the land can be returned to non-oil usage, depending on local regulations. Colorado allows for the return to regular usage by the landowner, with the responsibility of re-vegetating the well pad resting with the well operator.

4. MEDIA SPECIFIC ANALYSIS FOR CURRENT CONDITIONS

This section builds on the information provided in Section 2 to address the potential human health risks and hazards associated with the chemicals released during oil extraction and storage at well sites in Fort Collins. The more general risks and hazards potentially associated with the chemicals released during the process of hydraulic fracturing and the extraction of oil and gas that might occur in the future are also briefly discussed.

In risk assessment practice two aspects are typically considered: 1) the probability that an event will occur, and 2) the potential adverse outcomes should that event occur. A good example might be the storage of oil at a well site. There is typically a low probability that a storage tank will rupture due to failures in engineered systems, but there is always the possibility of a "*force majeure*," or a major catastrophic destructive force that might rupture the tank or wash it away. Should this occur, there would be potential impacts to human health and the environment. The risk assessment process described in Section 2 addresses the risk of possible adverse outcomes should a rupture event occur.

To evaluate the potential risk to human health and the environment, the EPA's Superfund program has developed a systematic evaluation process described in a number of guidance documents, starting with the *Risk Assessment Guidance for Superfund* (EPA, 1989). The starting framework for this process is a Conceptual Site Model Site (CSM) that identifies sources of contamination, the transport mechanisms by which these COPCs can migrate to exposure points where individuals may come in contact with them, and routes of entry into the body. Figure 4-1 shows a CSM for a hypothetical oil well in Fort Collins; the area with the red background indicates the production areas. At first glance this diagram appears complicated, but when broken down into media it shows where a source might impact water, soil, and air, and where humans might be impacted.

Hydraulic fracturing pumps fluids, proppants and water in to the well. The chemicals that return from the well are fracturing fluids, produced water and any additional chemicals dissolved in the water (e.g., naturally occurring radioactive material or NORMS), oil and gas.

Potential releases of these chemicals to water (surface water and shallow groundwater) are diagramed in Figure 4-1 with a blue background. This diagram indicates that deep groundwater (5000 feet bgs) is not accessed for drinking water. Releases from a well or well casing might impact shallow groundwater, which could act as a carrier to a residence. Releases to surface water might impact surface water bodies.

Potential releases to soil are shown in Figure 4-1 with a brown background, and this exposure mechanism would require a spill and access to the site. Potential releases to air are shown in Figure 4-1 with a green background. This is the most common exposure pathway, and releases are both routine and would occur if there was a spill.

For the purposes of this analysis, current exposures in Fort Collins are for oil wells only, and are discussed in this section (Section 4).

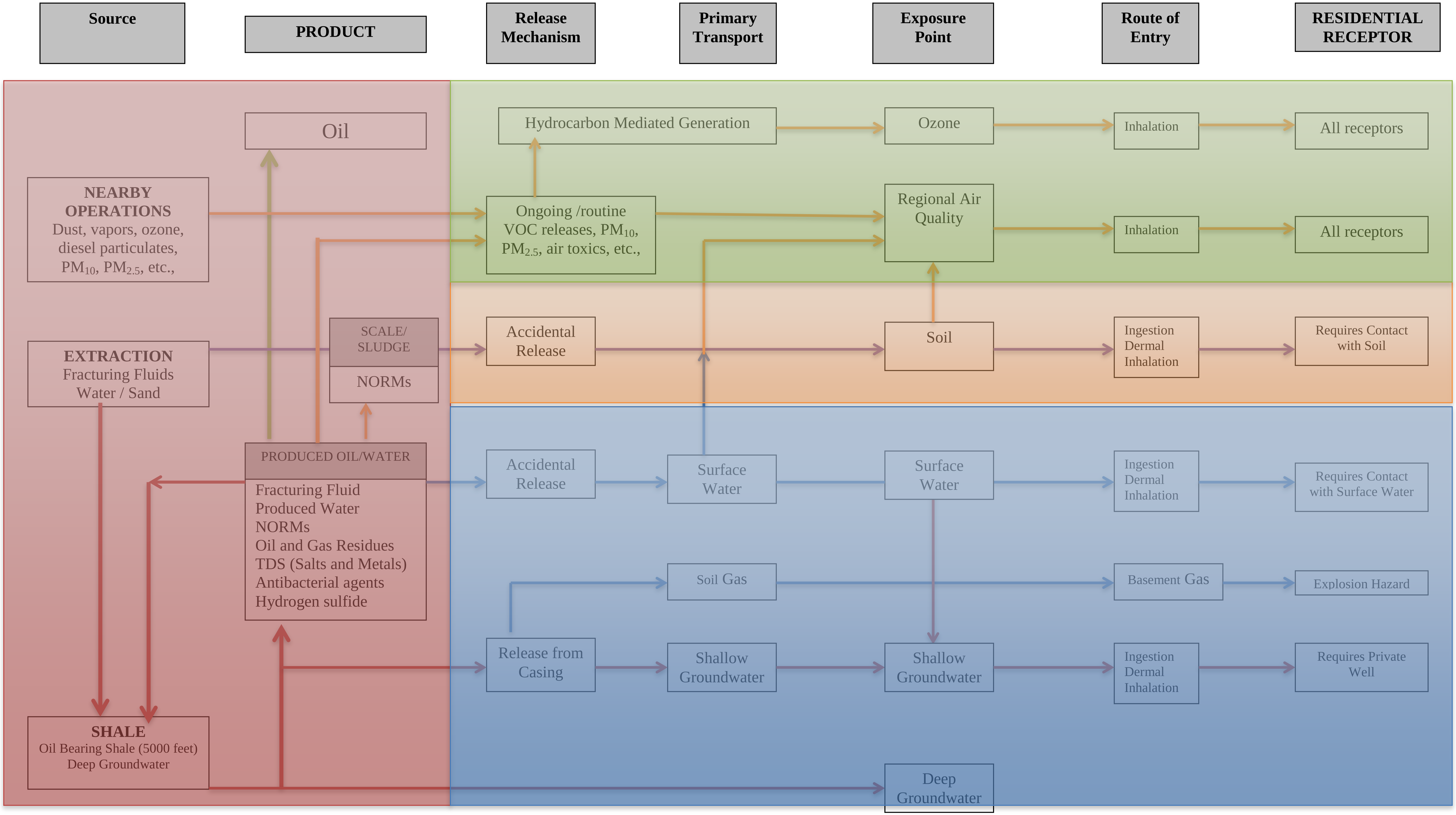
4.1 FORT COLLINS WATER SYSTEMS

Drinking water is one of the most valued resources in Colorado, and the drinking water systems in Fort Collins are no exception. Drinking water is not used, nor is it impacted by oil extraction in Fort Collins; however, an upset condition could contaminate surface and ground water locally.

4.1.1 Drinking Water

The drinking water in Fort Collins comes from the Cache la Poudre River watershed and the Colorado-Big Thompson watershed via Horsetooth Reservoir to the west. Drinking water is currently uncontaminated by oil extraction, as the wells are located east and north of Fort Collins. Well development is also unlikely to occur on the west side of Fort Collins, as the oil and shale plays do not continue into the foothills and are not beneath the watersheds. The facilities that treat the water for Fort Collins consumption are the Fort Collins Utilities' Water Treatment Facility and the Soldier Canyon Filter Plant. These facilities do not provide water for oil and gas production or hydraulic fracturing at the current time. The drinking water in Fort Collins is also treated and monitored due to recent fires and floods that increased particulate matter and chemical contamination.

FIGURE 4-1
CONCEPTUAL SITE MODEL FOR THE OIL EXTRACTION PROCESS (FT COLLINS)



Current reports show that the City's drinking water has recovered from recent natural disasters and is free of associated contaminants. The Prospect and Mulberry Water Reclamation Facilities are the Fort Collins two-wastewater processing facilities. Currently, these facilities do not treat wastewater from hydraulic fracturing or provide water for use in the Oil and Gas Industry.

4.1.2 Future Water Usage from Fort Collins

As Fort Collins develops the need for water for residential uses will also increase. And, if further oil well development occurs or if natural gas exploration and production occurs, the demand for water will rise. This requires consideration by the City of Fort Collins especially as Colorado frequently has drought conditions. The distribution of water should be managed by the City and allocated as needed.

4.1.3 Surface Water

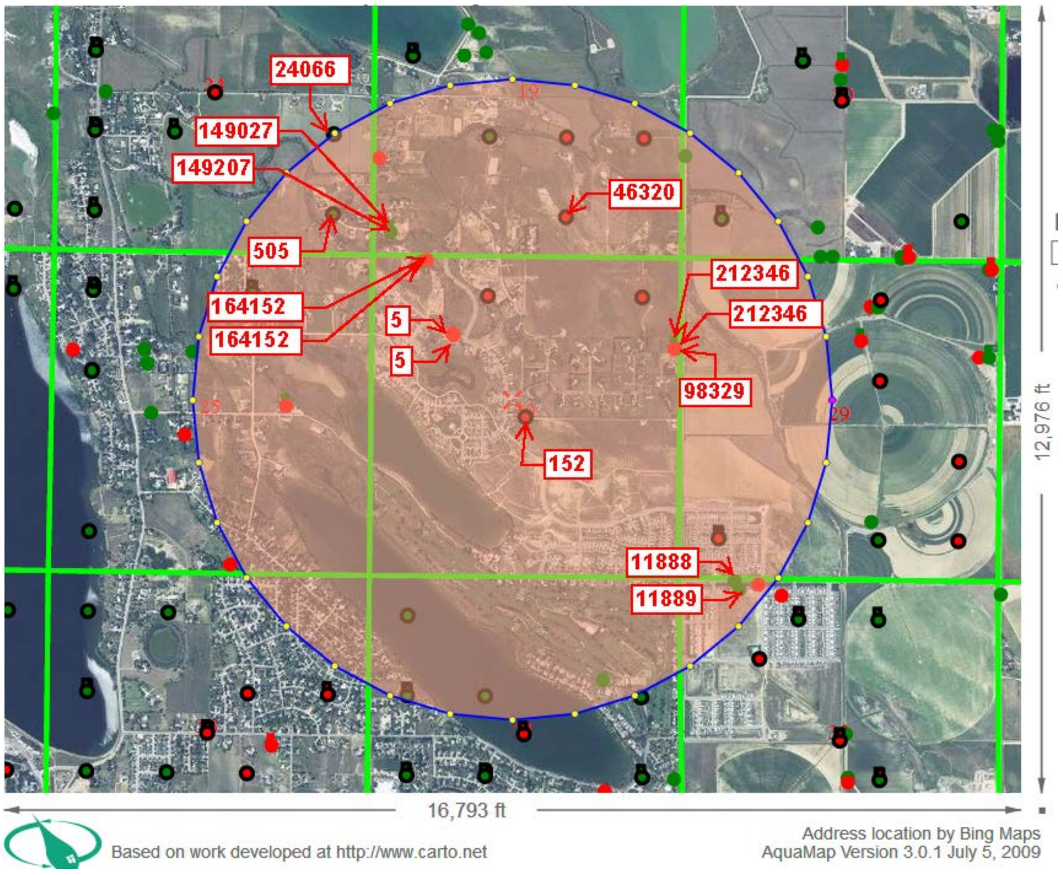
Uses for surface water in the City of Ft Collins include recreation, fishing, irrigation, and drinking water. Human contact with surface water is moderate to high depending on the location and season. Horsetooth Reservoir in particular is of critical importance as it is a source of drinking water for the City of Fort Collins and a popular recreation area; however, the reservoir is under a low chance of influence from hydraulic fracturing. The accessible shale and sandstone plays in the region are to the east of the reservoir and water runs west to east. If development occurs west of Fort Collins, there would be need for concern regarding two water basins in the foothills to the west, and the surface water of Horsetooth Reservoir to the west. The likelihood of the development to the west of the City is low due to the geographic formation and the location of the hydrocarbon bearing formations and oil plays.

4.1.4 Groundwater: Shallow Versus Deep

Shallow groundwater is a term used to describe the groundwater aquifers that are located immediately below the earth's surface. Groundwater in Fort Collins begins at ground level and goes as deep as 160 ft. bgs (USGS). Deep groundwater is a term used to describe the groundwater at the depth of shale (from 5,000 to 8,000 ft. bgs), which is where untreated wastewater from previously exploited wells is injected via Class II injection wells. This is contaminated water and is not fit for human or animal consumption. The goal of deep well injection is to remove the wastewater from the water system completely and prevent the impacts caused by contaminants. Further hazards of deep well injection are discussed in Section 5.

4.1.5 Active Groundwater Wells

There are currently 15 active groundwater wells within one mile of the current oil well sites in Fort Collins (Figure 4-2). The depths of these wells range from 20 to 350 feet (as permitted) and are located in the shallow unconfined aquifer of the groundwater system. The uses of these wells include domestic, irrigation and livestock, and monitoring wells. There is a plethora of other groundwater wells located around Fort Collins including in areas outlined previously as possible locations for further oil development. These wells should be considered when planning all future development within and around the city.



Based on work developed at http://www.carto.net

Address location by Bing Maps
AquaMap Version 3.0.1 July 5, 2009

FIGURE 4-2
GROUNDWATER WELLS WITHIN 1-MILE RADIUS AROUND FORT COLLINS WELLS

4.1.6 Fort Collins Water Use by Oil and Gas

Currently, Fort Collins does not supply water to the oil and gas industry for hydraulic fracturing. The source of water for hydraulic fracturing by the current local operator is not known, nor is it known how the water used in fracking is supplemented. The operator does recycle it’s produced water following onsite treatment, and reuses it as fracking fluid. The future use of Fort Collins water by the oil and gas industry also requires further consideration.

4.2 HUMAN EXPOSURE TO COPCS: IMPACTED MEDIA

In general, Fort Collins’ resident exposure to the hazardous components from oil production in water and soil is very limited, or non-existent. Direct contact is possible should chemicals be released during an upset such as a spill, accident, catastrophic incident or well failure.

Exposure to the chemicals released to air is much more likely. Methane, hazardous air pollutants (HAPs), hydrogen sulfide (H_2S), volatile organic compounds (VOCs) and other chemical releases to air are routine and on-going at most wells; both oil and gas. However, the amount of methane gas released is higher for gas wells. This section first describes the nature of potential releases from oil wells, followed by a discussion of the potential health effects.

4.2.1 Potential Surface Water Contamination [Fort Collins, Current Conditions]

Surface water bodies within Fort Collins’ city limits have a low probability of being contaminated as current streams, lakes, and reservoirs are not located near active wells. Contamination of surface water would require a catastrophic release or malfunction in combination with environmental circumstances, such as heavy rainfall, to transport an aqueous spill from the well site to public surface water. Currently three reservoirs are located down gradient from and within meters of active wells. Surface water is not used for human consumption; however, spills that affect surface water will migrate to groundwater. A surface water impact would potentially affect ecological receptors, but this report only covers human health impacts, not impacts to environmental receptors. Spilled liquids would contaminate soil and could migrate to groundwater if not properly remediated.

4.2.2 Surface Water Contamination [Fort Collins, Future Potential]

The potential for surface water to be contaminated due to future oil production in Fort Collins would depend on the location of a well relative to surface water bodies. The closer the well the higher the likelihood surface water might be impacted in the event of a release. Berms and engineering controls would decrease the possibility of contaminant migration in the event of a release.

4.2.3 Potential Groundwater Contamination [Fort Collins, Current Conditions]

Groundwater could be contaminated in multiple ways. The mechanics of oil extraction are designed to avoid the interactions of produced fluids with aquifers; therefore, groundwater contamination will only occur in the case of a malfunction or spill. First and more likely, if a drill casing bursts within the 160 feet bgs (USGS), it would cause direct contact between fracturing fluid, produced water, and produced oil and the shallow groundwater aquifer. This could contaminate drinking water for those water wells in the proximity of a burst casing.

The second potential human health impact, which is less likely for this pathway, is contaminant migration to groundwater from a fracture. Hydraulic fracturing is known to cause fissures up to 600 feet (183 meters) from the point of fracture, making groundwater contamination from fracturing in Fort Collins unlikely due to the distance between the fractures and shallow groundwater. However, when a fracture occurs near a previously existing fault line or previous well boring, fracturing fluid or trapped methane can flow freely to a much greater distance, even returning to the surface (ANL, 2013). Given the depth of the sandstone layer being extracted this too is unlikely.

The final potential human health impact is from surface to groundwater migration. If there is a surface spill that is unnoticed or improperly mitigated, whether the spill is fracking fluid, produced water or crude oil, the fluids could migrate down into the shallow groundwater table. Fort Collins well sites are currently required to berm around storage tanks and to line the ground under areas of potential concern; however, unless sites are monitored consistently, spills and leaks could go unnoticed and cleanup operations may not happen within an effective time period to prevent migration to groundwater.

4.2.4 Groundwater Contamination [Fort Collins, Future Potential]

The potential for groundwater to be contaminated due to future oil production in Fort Collins would be similar to that for current groundwater and is dependent on accidents, spills or releases. Berms and engineering controls to decrease the possibility of contaminant migration in the event of a release would reduce risk.

4.2.5 Potential Soil Contamination [Fort Collins, Current Conditions]

Potential releases to soil can occur, but would be localized and the potential for human health risk is proportional to contact with contaminated soil, which would require entering a well site, or migration of COPCs off site. Therefore, fencing and labeling of potential health dangers could mitigate any contact with site soils. Mishandling of wastes, especially sludges containing NORMS and oily residues represents a potential health risk. An awareness of residual contamination and remediation would prevent future potential risks. Contact with un-remediated wastes would represent a higher risk after the removal of fences and other barriers to direct contact.

4.2.6 Soil Contamination [Fort Collins, Future Potential]

The future potential for risks from contamination of soil at oil sites is the same as described above. Assuming current fencing regulations remain, contact with contaminated soil would require entering a well site, or migration of COPCs off site. Therefore, fencing and labeling of potential health dangers could mitigate any direct contact with site soils.

4.2.7 Air Contamination [Fort Collins, Current Conditions]

The existing Fort Collins oil wells have the potential to release methane, H_2S and VOCs to air from continuous, routine operations such as ongoing production and processing, product storage, and loading and unloading activities. Emissions may also be released from short-term operations such as repairs, work-overs and well stimulation. According to data provided by the site operator to the State of Colorado, the amount of gas produced by the Fort Collins wells is approximately 475 Mcf (457,000 cubic feet) per year. The gas emitted from processing operations, storage tanks, and truck loading operations at the Fort Collins tank battery is captured and routed through a thermal oxidizer control system. Residents could potentially be affected by chronic exposure to emissions from routine operations or by chronic and acute exposure to short-term emissions. The exposure is likely to be low due to the control efficiency of air pollution equipment and the short duration of non-routine operations. However, there are currently no publically available data quantifying VOC concentrations in the vicinity of nearby residences. The operator has conducted air monitoring for hydrogen sulfide.

The potential health risks associated to exposed residents are dose-dependent, meaning they would increase with increasing exposure, or decrease with or decreasing exposure.

4.2.8 Air Contamination [Fort Collins, Future Potential]

It is assumed that future potential oil development in and around Fort Collins would be similar to current oil extraction and gas extraction would be less prevalent because the primary deposit beneath Fort Collins is the oil bearing Muddy J. Gas exploration might occur on the southern and eastern boundaries of the city. The releases described above for oil development would be the same. An increase in the number of wells will potentially increase releases of volatile hydrocarbons, such as benzene, toluene, ethylbenzene and xylenes (also called BTEX), trimethylbenzenes and a host of aliphatic (straight chain) hydrocarbons.

4.3 HUMAN EXPOSURE TO COPCS: COMPLETE EXPOSURE PATHWAYS

As noted earlier, for a risk to be present the exposure pathway from the source to the receptor must be complete. Figure 4-1 shows the potentially complete exposure pathways. The following sub-sections discuss the types of COPCs in the hydraulic fracturing process, and oil well products. These are sub-divided by receiving medium.

4.3.1 Potential COPC Releases to Water

Under normal oil extraction procedures COPC releases to groundwater are less likely, and would require the failure of a well casing, or the rupture of a well or tank that discharges to ground- or surface water. This section discusses each of the COPCs that might be released to water in the event of an accident.

4.3.1.1 Fracturing Fluid

Fracturing fluid consists predominantly of water and proppants (such as fine sand), which are not significant sources of concern. Fracturing fluids contain chemicals (Appendix B) that are typically propriety formulations with confidential compositions, although in accordance with an agreement with the Fort Collins, the operator has released their fluid compositions. The typical types of chemicals found in fracturing fluid and their potential health effects are discussed below.

4.3.1.2 Flowback and Produced Water

After a well has been drilled and the oil or gas bearing formation has been opened using the hydraulic fracturing process, the pressure of the liquid in the shale forces the oil or gas to flow back up the well to the well head. The chemicals in this “flowback” liquid is a mix of dissolved fracturing fluid, proppants, and the produced water from the deep aquifer that contains chemicals previously trapped in the geologic formation. This water will potentially also contain increased total dissolved solids (TDS, brine, or salt water), naturally occurring radioactive materials (NORMs), and hydrocarbons (oil and gas).

Historically, flowback water was flushed from a well into a holding pond or pit, which may or may not be lined where gases and VOCs were allowed to freely vent to the atmosphere. In Colorado, this practice is permitted under COGCC Rule 907. Generally, operators are not placing pits near residences, and low VOC emission completion technology is currently available to process flowback water (COGCC, 2014). After hydraulic fracturing, and the initial flowback period, the oil wells enter the production period. During this phase, volatile organic compounds may be vented to the atmosphere or captured and thermally oxidized (i.e., burned). Produced water is reused in fracturing other wells and/or re-injected back into Class II deep groundwater wells for disposal. Produced water can contain sulphide-producing bacteria that generate hydrogen sulphide (H_2S) sometimes called “sour gas,” which is a toxic gas with an offensive odor. It can be a nuisance to residents near oil and gas operations.

In the event of an accidental release, flowback or produced water would come into contact with soil at the drill site, surface water, and potentially shallow groundwater. These media are likely to be remediated. Groundwater remediation would be mandated under groundwater regulations for benzene and other toxic volatile compounds. However, there are no regulations or cleanup standards for fracturing fluids, and the toxicity of some fracturing fluid components are unknown.

The volatile constituents in flowback or produced water can migrate from holding lagoons and tanks to the atmosphere. These VOCs include methane, volatile aromatic hydrocarbons, such as benzene, toluene, ethyl benzene, and xylenes (BTEX), trimethylbenzenes (TMBs) and aliphatic (straight chain) hydrocarbons. Fort Collins oil does not contain sour gas, which is more commonly associated with natural gas than crude petroleum, but it may be generated from the presence of sulfate-reducing bacteria. If these chemicals are released to the atmosphere they will disperse in air. Chemical concentrations at a residence will depend on the initial amount and concentration of the chemical released and atmospheric conditions such as wind speed and direction, temperature, humidity, atmosphere stability, and distance from the source. Releases to air are discussed below.

Petroleum hydrocarbons are familiar because we use them every day to fuel engines. As such, we often forget they can have a wide range of adverse human health effects when inhaled, ingested or when they contact skin. In short, petroleum hydrocarbons can cause leukemia, cancers of the liver and kidney, and non-cancer health effects of the blood, liver, kidney, skin and neurological system. Summaries of the adverse health effects of petroleum hydrocarbons are available from regulatory and governmental agencies such as the Agency for Toxic Substances and Disease Registry (ATSDR, 2014), the International Agency for Cancer Research (IARC, 2014), the US Environmental Protection Agency's (EPA's) Integrated Risk Information System (EPA, 2014b), and many State agencies, such as the California's Office of Environmental Health Hazard Assessment (OEHHA, 2104), and are not provided here.

<u>4.3.1.3 Oil and Volatile Hydrocarbons</u>

Crude oil contains hydrocarbons with different structures, and aromatic and aliphatic carbon molecules of different length. The number of carbons in the carbon chain is typically used to evaluate oil's physical characteristics. Crude oil also contains VOCs. In the event of an accidental release from an oil tank, the oil might contaminate soil, surface water, and potentially shallow groundwater. These media are likely to be remediated. Groundwater remediation would be mandated under groundwater regulations for benzene and other toxic volatile compounds.

4.3.1.4 Methane Releases to Water

Methane is the primary target of natural gas production. Relative to Fort Collins oil production, gas is a by-product that may be released to water at a number of points in the oil production and storage process, from leaking flanges, piping, cracked casing, and cement containment at the well head below the ground surface. The EPA is conducting an on-going study of the issue that is titled, "*Numerical modeling of subsurface fluid migration scenarios that explore the potential for gases and fluids to move from the fractured zone to drinking water aquifers.*" A progress report called, "*Study of the Potential Impacts of Hydraulic Fracturing on Drinking Water Resources, Progress Report*," was issued in 2012 (EPA, 2012). The results of this work will provide more information on the probability of this being a complete and significant pathway.

Methane is of low human health risk, but represents a risk of explosion at levels over its Lower Explosive Limit (LEL) (five percent (5 %) in air). If methane were to migrate into a confined space and reach this level there is a potential danger of explosion. No wellhead screening process is currently required by the COGCC (COGCC, 2014).

Methane gas migration has been shown to impact drinking water wells and in some historical situations local oil producers have been found responsible and were required to provide clean drinking water. However, this has only occurred in cases where groundwater methane was previously established or large amounts of methane were produced. Methane can migrate and accumulate as soil gas, and has led to home explosions. The EPA has previously stepped into situations where methane proves immediately dangerous to structural safely.

4.3.1.5 Naturally Occurring Radioactive Material Releases to Water

Naturally occurring radioactive materials (often called NORMs) are found in oil and gas deposits and therefore in oil and gas production. The water pumped into the well during hydraulic fracturing, and subsequently pumped from the well will bring dissolved NORMS to the surface. The EPA has a website devoted to NORMs from oil and gas production, which was the source of the text below. The EPA identifies thorium, uranium (and its daughter products including radium, radon (a gas), polonium and lead). The following excerpts are taken from the EPA's website: (EPA, 2014a).

Much of the petroleum in the earth's crust was created at the site of ancient seas by the decay of sea life. As a result, petroleum deposits often occur in aquifers containing brine (salt water). Radionuclides, along with other minerals that are dissolved in the brine, precipitate (separate and settle) out forming various wastes at the surface:

- Scale (or mineral deposits, mainly the insoluble salts of barium, calcium and strontium), that precipitate out as scaly deposits inside pipes, tanks, heater treaters and gas dehydrators (that can have up to four inch think deposits).
- Sludges (or scaly precipitated deposits from produced water that precipitate out barium salts with oil, often with silica).
- Contaminated equipment or components (technologically enhanced naturally occurring radioactive materials (TENORM) radioactivity levels tend to be highest in water handling equipment. Average exposure levels for this equipment were between 30 and 40 micro Roentgens per hour (µR/hr), which is about 5 times background. Gas processing equipment with the highest levels include the reflux pumps, propane pumps and tanks, other pumps, and product lines. Average radiation levels for this equipment are between 30 to 70 µR/hr. Exposures from some oil production and gas processing equipment exceeded 1 mR/hr, (EPA, 2014a) (or 125 times background).
- Produced waters (The radioactivity levels in produced waters are generally low, but the volumes are large. The ratio of produced water to oil is approximately 10 barrels of produced water per barrel of oil. According to the American Petroleum Institute (API), more than 18 billion barrels of waste fluids from oil and gas production are generated annually in the United States. (EPA, 2014a) However, according to the USGS (1999), Radium tends to be more abundant in the more saline and chloride-rich varieties of produced waters. The maximum concentration of dissolved $_{226}$Ra in a limited data set provided by Fisher (1998) was several thousand picocuries per liter (pCi/L), but concentrations above 10,000 pCi/L have been reported in the U.S. Produced water also contains dissolved $_{228}$Ra, which is typically one-half to twice the

concentration of $_{226}$Ra. For comparison, the U.S. EPA maximum contaminant level for drinking water is 5 pCi/L for total dissolved radium).

Because the extraction process concentrates the naturally occurring radionuclides and exposes them to the surface environment and human contact, these wastes are classified as technologically enhanced naturally occurring radioactive materials (or TENORMs). (EPA, 2014a)

Because TENORM contaminated wastes in oil and gas production operations were not properly recognized in the past, disposal of these wastes may have resulted in environmental contamination in and around production and disposal facilities. Surface disposal of radioactive sludge/scale, and produced water (as practiced in the past) may lead to ground and surface water contamination.

Those at risk include oil/radiation waste disposal workers, and nearby residents/office workers. Risks evaluated for members of the public working or residing within 100 meters (980 feet) of a disposal site are similar to those of disposal workers. They include: direct gamma radiation, inhalation of contaminated dust, inhalation of downwind radon, ingestion of contaminated well water, ingestion of food contaminated by well water, and ingestion of food contaminated by dust deposition.

Risks analyzed for the general population within a 50-mile radius of the disposal site include exposures from the downwind transport of re-suspended particulates and radon, and exposures arising from ingestion of river water contaminated via the groundwater pathway and surface runoff. Downwind exposures include inhalation of re-suspended particulates, ingestion of food contaminated by deposition of re-suspended particulates, and inhalation of radon gas.

Many states with oil and gas production facilities are currently creating their own NORM regulations. For example, the State of Louisiana has regulations for NORM in scales and sludges from oil and gas production that differ from the Part N model regulations, where the State of Texas has NORM regulations similar to Part N regulations (EPA, 2014a).

4.3.2 Potential Risks of COPCs to Air

As noted above, the majority of releases from the oil and gas extraction process are to air. This section discusses each of the COPCs that might be released to air from normal operations, from spills and in the event of accidents.

When evaluating releases from the oil and gas extraction process that uses hydraulic fracturing it is important to differentiate between how VOCs might be released. In oil production, volatile hydrocarbons are released as an uncaptured fraction of the hydrocarbon (oil) collection process. However, in gas production the EPA estimates that a gas well releases 1 to 7 percent of the hydrocarbons taken from the well as VOCs (C&EN, 2014).

The predominant point source of pollution from oil production is from storage tanks used to store produced water and produced oil. VOCs and methane may evaporate or leak from piping, tanks, flanges, and other connections. The active wells in Fort Collins currently produce as much as 475 Mcf (475,000 cubic feet) of methane annually, along with the oil it produces (COGCC, 2014). The current operator processes emissions through a thermal oxidizer, but product transfer provides an opportunity for methane and VOCs to vent to the atmosphere.

Current development in the City of Fort Collins produces predominantly oil. If additional oil production did occur within the City limits, it would lead to an increase in VOC emission but on a larger scale. Health concerns are based on the presence of petroleum VOCs and natural gas.

Releases to air from future gas development are discussed in Section 5.0.

4.3.3 Potential COPC Releases to Soil

The potential for releases to soil are discussed above. The chemicals identified for water are the same set of chemicals that might be released to soil, and because contaminants in soil are less mobile than in water, contamination is less likely to migrate except as wind-borne dust. However, soil might represent a source of contamination for groundwater.

4.4 RELEVANCE OF EXPOSURE PATHWAYS TO RISK ASSESSMENT

As noted in Section 2.0, risk requires that all four elements of exposure be complete. Figure 4-3 provides an example CSM for potential petroleum VOCs being released from a wellhead or storage tank, its transport medium, in this case air, and the point of exposure at the receptor. The letters in the square callout box show potential monitoring points, as follows:

A. Air monitoring at the source
B. Air monitoring at some distance from the source
C. Air monitor at the residence
D. Personal air monitoring on the resident
E. Blood, urine or tissue sample monitoring (bio-assay)

The closer to the source of VOCs the higher the concentration, and using benzene as an example, the following points are important to note. The concentration of benzene at point A would be higher than at point B because of dispersion. Higher benzene concentrations are generally easier to measure and easier to obtain better detection limits. Benzene will disperse in air and concentrations would be lower at the residence. Although the benzene concentration at the residence (point C) would provide better information on the level of benzene the resident might actually be exposed to, the source of the benzene at the residence might not be the source at point “A” but another source. Monitoring point D represents a personal monitor, where the air the resident actually breathes is measured by equipment worn by the resident. Due to the low level of chemicals generally found in air, detection limits should be established prior to sampling to make sure they are adequate for the project.

For a limited number of chemicals it is possible to characterize exposure by monitoring particular biomarkers in blood, and other bodily tissues or fluids (point E). For benzene, for example it is possible to measure the biomarker, such as S-phenylmercapturic acid (Weisel, *et al*. 1996), but exposure must be at high levels for long periods of time to accumulate biomarkers at a measurable level. These biomarkers are generated by benzene from any source, not just the source in question.

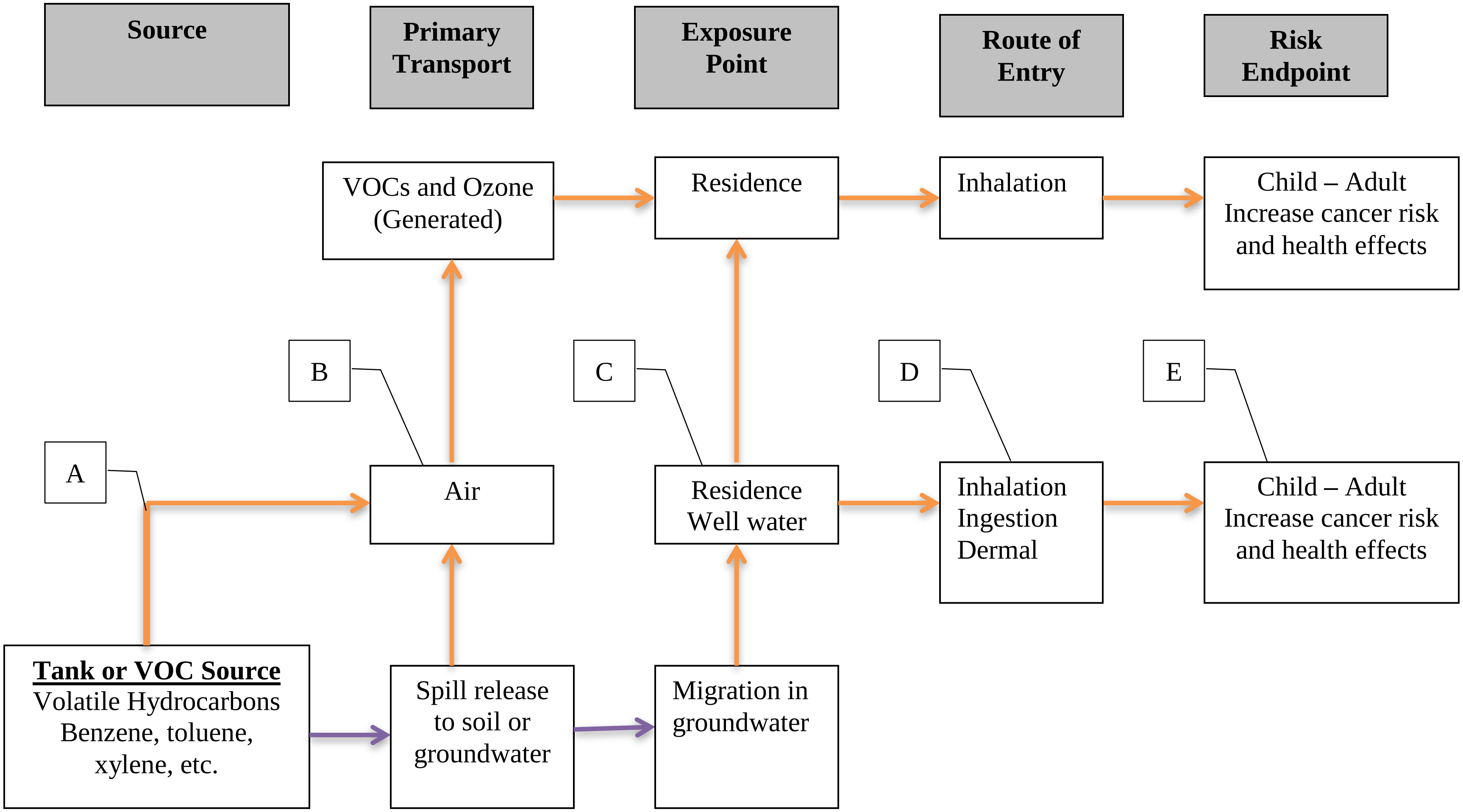


FIGURE 4-3 CONCEPTUAL SITE MODEL FOR VOC RELEASES TO AIR

A similar CSM can be drawn up for each medium, and a similar inverse relationship between the distance from the source and concentration would also apply. The concentration of COPCs will decrease with distance.

The higher the concentration the greater the risk associated with exposure.

In addition, petroleum is a mixture of many compounds. To fully assess the risks, all of the COPCs (or at least all of the most toxic COPCs) should be monitored and quantified. The risk from each of these COPCs would then be added together.

4.5 SPECIFIC HEALTH EFFECTS OF COPCS

The COPCs at oil and gas sites are predominantly hydrocarbons. Figure 4-1 indicates that inhalation is the primary pathway by which residents would be exposed, and Figure 4-3 indicates potential monitoring points. Benzene, toluene, ethylbenzene and xylene (BTEX) are the hydrocarbons that have been shown to have adverse health effects, and are the COPC regulated by oil and gas regulating agencies. US EPA Superfund programs use Regional Screening Levels (RSLs) to evaluate these constituents in a residential setting. These RSLs are based on adverse health effects, and are noted for both non-cancer, and cancer effects if appropriate. Typically there are one or two chemicals that “drive” the risk assessment, meaning they have the highest risk, and if the risks are understood, they can be used as a surrogate, or marker for exposure and risk. RSLs are health based and are generally established to be protective for long-term exposure. They are not based on what is achievable by engineering controls, or other technologies.

The EPA has established RSLs for residential and industrial receptors.

For comparison purposes the EPA’s Regional Screening Levels (EPA, 2014d) for BTEX are shown in Table 4-1 at the EPA and State of Colorado’s Point of Departure acceptable risk level of one in one million (10^{-6}). At the excess risk level of 10^{-5} and a Hazard Index of 1.0 the Colorado Department of Public Health and Environment (CDPHE) requires sites in hazardous waste programs to undergo remediation, that is, implement active cleanup measures. However, there are no similar regulatory limits for cleanup concerning the emissions of BTEX from oil and gas production sites.

“Why are industrial goals not applicable?”

A number of organizations have benzene goals or action levels, air thresholds for worker safety, including the Occupational Safety and Health Agency (OSHA), National Institute of Occupational Safety and Health (NIOSH), American Conference of Governmental and Industrial Hygienists (ACGIH). Industrial action levels are applicable to workers only and not to residents for a number of reasons. Industrial workers are educated about the chemicals to which they might be exposed, they are provided protective equipment and are paid to understand and prevent exposure, while residents are not. Workers are generally healthy and typically do not have compromised health. Some residents may have compromised health or may be more susceptible (such as children).

EPA also has RSLs for soil and tap water. These are also different from industrial soil contact levels for the same reason. Therefore, industrial levels may be cited, but they are inappropriate for residents.

Cleanup levels exist for water and soil, but inhalation is the primary potential chronic exposure pathway.

Two types of adverse health effect are considered: cancer and non-cancer effects. For inhalation risk assessments two elements are important:

- The concentration of the chemical inhaled, and
- The length of the exposure.

The EPA has standard exposure parameters for residential exposure, which have been recently updated, and which are used at all sites across the US.

Table 4-1
EPA Residential Inhalation Screening Levels1 for Petroleum Related Chemicals

Chemical Name	**Residential Goal (10^{-6}) (μg/m^3)**	**Type of Cancer[2]**	**Residential Goal (HI=0.1) (μg/m^3)**	**Target Organ**
Volatile Hydrocarbons				
1,3-Butadiene	0.41	Leukemia in humans	0.88	Reproductive effects
Benzene	0.36	Leukemia in humans	3.1	Lymphocyte Count
Toluene	NC	NA	520	Neurological effects
Ethylbenzene	1.1	Kidney cancer	100	Developmental toxicity
Xylene(s)	NC	NA	100	Impaired coordination
Trimethylbenzene	NC	NA	0.73	Blood clotting time
Polynuclear Aromatic Hydrocarbons (Less Volatile)				
Benz[a]anthracene	0.11	Stomach cancer	NA	--
Benzo[a]pyrene	0.011	Stomach cancer	NA	--
Chrysene	1.1	Lung and Liver Tumors	NA	--
Naphthalene	0.36	Nasal Tumors	1.3	Nasal Effects

μg/m^3	Micrograms per cubic meter
NA	Not applicable
NC	Non-carcinogenic

1. EPA Regional Screening Levels, EPA, 2014d
2. EPA IRIS files (EPA, 2014b)

4.5.1 Benzene Air Concentrations Near Gas Hydraulic Fracturing Wells

There are a limited number of studies in Colorado measuring the concentrations of benzene in air near Gas Hydraulic Fracturing Wells. Benzene is considered a “driver” or critical chemical for petroleum VOCs, because it has the highest ability to cause cancer of all petroleum VOCs.

In November 2014, Thompson *et al.,* (2014) published a paper titled; "Influence of oil and gas emissions on ambient atmospheric non-methane hydrocarbons in residential areas of Northeastern Colorado," which provides data showing that benzene is higher in Platteville (a rural area) than in Denver (an urban area). And that non-methane hydrocarbon compounds are elevated across the Northern Front Range, with the highest levels found within the Greater Wattenberg Gas Field. The authors state: "This represents a large area source for ozone precursors in the Northern Front Range." The study does not discuss the health risks associated with elevated ozone precursors, or the cancer and non-cancer health risks, as calculated using EPA's methods.

One key study by McKenzie *et al*., (2012) provided BTEX (and other hydrocarbon) concentrations at gas wells in Garfield County. Two types of data were collected: 1) samples from less than or equal to one-half mile from the well and samples from greater than one-half mile from the site. Benzene air concentrations closer to the flowback ponds ranged from 1 to 69 micrograms per cubic meter (μg/m^3), and benzene air concentrations further from the well site (greater than one-half mile) following well completion ranged from 0.1 to 14 μg/m^3. Other hydrocarbon concentrations are also elevated, and summary statistics were provided. A comparison of the range of concentrations and the average concentration to the benzene screening levels shown in Table 4-1 indicated that some benzene concentrations were in excess of the 10^{-5} risk level (should the exposure be for 30 years), where CDPHE requires sites in hazardous waste programs to undergo remediation for potential cancer impacts.

The EPA's acceptable risk range is one in ten thousand ($1x10^{-4}$) to one in one million ($1x10^{-6}$) and is difficult to conceptualize. Most State regulatory agencies require that hazardous waste sites achieve cleanup for single chemicals at a risk level of $1x10^{-6}$, and chemical mixtures at a risk level of $1x10^{-5}$. For benzene, this gives a risk equivalent to a benzene level of 0.36 μg/m^3, alone. Typical indoor background benzene concentrations range from 1.9 to 7.0 μg/m^3 (75th percentile range) (EPA, 2011). Indoor air benzene concentrations are provided as examples because they may include background benzene from an attached garage that would complicate benzene interpretation.

The McKenzie *et al*., (2012) study has been criticized for using data from before Colorado regulations changed to require contained treatment technologies to manage flowback pond emissions (COGCC, 2014), and the data do not appear to have been republished with 2010 data. However, there is also no information showing the wells studied were in compliance with the 2009 regulations. Furthermore, on-going emissions would be unaffected by the contained treatment technologies.

The McKenzie study also calculated non-cancer inhalation Hazard Indices (HIs) (hazards to blood) for the two data sets, and showed chronic HIs of 1.0 and 0.4 for close in and more distant data sets, respectively. Sub-chronic HIs, or an index of the chemical's hazards for short-term exposure were higher, and also above one. Sub-chronic exposure represents a potential adverse health reaction to short duration exposures.

The data in the McKenzie study were collected in 2008 and 2010, and might represent data at a residence located at the distances indicated. These distances (>0.5 miles, 800 meters) are considerably greater than the current range of setback distances of 500 feet (0.094 miles, 152.4 meters) to 1,000 feet (0.1894 miles, 304.8 meters). Chemical concentration decreases by dispersion with distance from the well so BTEX concentrations at the setback distance are likely to be higher than those reported in McKenzie *et al*., (2012). On a local level the concentration of air COPCs from a well will decrease with distance from the well due to air dispersion. Airflow patterns mean that air COPC concentrations will also vary with wind speed and direction carrying COPCs to or away from a particular receptor. This does not apply to situations where a well is in the center of a residential sub-division; this is a location where a residential receptor is always down wind.

In a more recent study by Macy, *et al*. ((2014), which used a community-based sampling program where trained volunteers collected air data at locations suggested by residents near gas wells, benzene concentrations in Wyoming air as high as 110,000 $\mu g/m^3$ and toluene as high as 240,000 $\mu g/m^3$ were found at selected locations. These samples were taken 30 to 350 yards from the well, or from farmland along the perimeter of the well pad. A significant number of compounds were analyzed and detected, and one sample contain up to 1.6 million $\mu g/m^3$ total VOCs (excluding methane) suggesting that the sampling location is very important in any monitoring program, and that community involvement may also be important when considering a sampling program.

4.5.2 Benzene Childhood Cancers and Birth Defects

The US EPA's (2009) Benzene TEACH Summary states, "Two studies have shown a significantly increased risk of childhood leukemia associated with paternal exposure to benzene (Buckley, *et al*., 1989; McKinney *et al*., 1991), while another showed no such association (Shaw, *et al*., 1984). A case control interview study showed that acute non-lymphocytic leukemia was significantly associated with maternal occupational exposure to benzene during pregnancy (Xiao, *et al*. 1988).

The EPA's toxicological update on benzene states:

"The effects from exposure to benzene can be quite different among subpopulations. Children may have a higher unit body weight exposure because of their heightened activity patterns, which can increase their exposures, as well as different ventilation tidal volumes and frequencies, factors that influence uptake. This could entail a greater risk of leukemia and other toxic effects to children if they are exposed to benzene at similar levels as adults. Infants and children may be more vulnerable to leukemogenesis because their hematopoietic cell populations are differentiating and undergoing maturation. Many confounding factors may affect the susceptibility of children to leukemia (e.g., nutritional status, lifestyle, ethnicity, and place of residence) (EPA, 1998)."

"Some recent research has shown, with limited consistency, that parental occupational exposure to benzene plays a role in causing childhood leukemia. Shu *et al*. (1988) conducted a case-control study of acute childhood leukemia in Shanghai, China, and found a significant association between acute nonlymphocytic leukemia (ANNL) and maternal occupational exposures to benzene during pregnancy (OR = 4.0). These excesses occurred among second- or later-born children rather than firstborn children. In addition, Mckinney *et al.*, (1991) conducted a case-control study to determine whether parental occupational, chemical, and other specific exposures are risk factors for childhood leukemia. They found a significant association between childhood leukemia and reported preconceptional exposures of fathers to benzene (OR = 5.81, 95% confidence intervals 1.67

to 26.44) and concluded that the results should be interpreted cautiously because of the small numbers, overlap with another study, and multiple exposures of some parents. Furthermore, Buckley *et al*. (1989) conducted a case-control study of occupational exposures of parents of 204 children (under 18 years of age) with ANNL. They found a significant association between ANNL and maternal exposure to pesticides, petroleum products, and solvents. Among many chemicals, benzene was identified as one of the solvents. These studies, however, have not provided data to indicate how the occupational exposures might affect offspring. Some possible mechanisms include a germ-cell mutation prior to conception, transplacental fetal exposures, exposures through breast milk, or direct exposures postnatally to benzene from the environment." (EPA, 1998)

Recent studies have found similar results linking the presence of leukemia in children to residing in close proximity to gasoline stations and roads.

A 2004 Italian study (Crosignani *et al.*, 2004) that looked at 120-childhood leukemia cases in relation to traffic exhaust found a strong correlation between estimated benzene concentration above 10 micrograms per cubic meter ($\mu g/m^3$) with childhood leukemia, and in particular acute non-lymphocytic leukemia. However, benzene concentrations were estimated using a model and proximity to a highway. Three benzene levels were used and there was a dose-related correlation. At 300 meters (984 feet) impact was assumed to be negligible, based on an EPA (2001) model.

A 2004 French study (Steffen *et al*, 2004) that looked at 280 childhood leukemia cases in relation to gas stations or repair garages found a strong correlation of location with leukemia, and in particular acute non-lymphocytic leukemia. However, the dose to child is not provided, and the level of benzene linked to the childhood leukemia is unclear. These findings were supported by a 2009, 765 leukemia case-study (Brosselin, 2009).

A 2006 US study (Utah, 2006) identified that children living in close proximity to roads (< 150 meters, 492 feet) appear to have an increased risk for all types of childhood leukemia and for myelogenous leukemia. Benzene levels were estimated using a model to be >5 $\mu g/m^3$. The study did not account for confounding factors.

The above findings suggest that a pregnant woman exposed to high levels of benzene during pregnancy, especially during the stage of fetal blood system development, would have higher risks of birthing a child with childhood leukemia, and children exposed to benzene (or gasoline) have a higher risk of acute non-lymphocytic leukemia. The benzene concentrations, the associated exposure duration, and the sensitive period duration during pregnancy are unclear. However, benzene exposure concentrations are within the range of those measured by McKenzie (2012).

McKenzie, *et al*., (2013) examined the relationship between birth outcomes and maternal residential proximity to natural gas development in rural Colorado and in a large cohort, observed an association between the density and proximity of natural gas wells (in a 10 mile radius) and the teratogenic effects of congenital heart defects and possible neural tube defects. Childhood leukemia was not studied.

There are limited studies measuring benzene levels near oil and gas operations, and the studies that currently exist indicate that benzene concentrations vary when containment or evaporation pits are used versus under low VOC emission completion techniques, as shown by the McKenzie study (2012). Typical benzene concentrations are shown in Table 4-2.

TABLE 4-2
TYPICAL ENVIRONMENTAL BENZENE CONCENTRATIONS

Type of Study and Location	Benzene Concentration (μg/m^3)	Toluene Concentration (μg/m^3)
Service station attendant	910 ± 140	1580 ± 180
Mechanic repairing gas pump	233 ± 165	2218 ± 1736
Air within service station	4 ± 2	47.7 ± 27.4
Worker air within service station	5 ± 6	330 ± 393
Customer refueling car	1767 ± 1595	27,878 ± 28,337
Air external to service station	17 ± 3 27 ± 38	23 ± 4

Source: Edokpolo, *et al*., 2014

4.5.3 Other Petroleum Hydrocarbons

Petroleum contains a host of organic molecules that have adverse health effects, and benzene is only one of many that are potentially carcinogenic (will cause cancer). It was evaluated in greater detail due to its more well-known and severe toxic effects.

Ethylbenzene has been shown to cause kidney cancer in mice (Cal EPA, 2007), and it was listed under California's Proposition 65 as a cancer-causing agent in 2004. The EPA considers the potential effects of two or more carcinogenic chemicals to be additive, so the cancer risks from benzene and ethylbenzene and other chemicals would give an added risk.

1,3-Butadiene has been shown in epidemiological studies to cause leukemia (EPA, 2002).

The EPA considers the potential effects of two or more carcinogenic chemicals to be additive, so the cancer risks from 1,3-butadiene, benzene, ethylbenzene and other cancer causing chemicals would be added together in a risk assessment. The McKenzie study provides summed risks, which is the appropriate approach for carcinogenic chemicals under US EPA risk assessment guidance.

Other less volatile petroleum chemicals that cause cancer in animals, and that are suspected of causing cancer in humans are polynuclear aromatic hydrocarbons. These chemicals are more associated with oil than gas, but could be present in all petroleum products and gases at low levels. They can often have a greater ability to cause cancer in children because the mechanism of cancer development is more active in the rapidly developing DNA of a child.

All chemicals can have adverse health effects and because petroleum hydrocarbons are a mixture of many chemicals; each can be evaluated individually, or the total petroleum hydrocarbon (TPH) suite can be evaluated as a whole. A number of government agencies have issued toxicological reviews of TPH especially, the Agency for Toxic Substances and Disease Registry (ATSDR, 2011). The State of Massachusetts has developed health-based toxicity values for petroleum hydrocarbons (MassDEQ, 2003).

The important fact is that all of the chemicals in petroleum hydrocarbons can act together to have potential additive adverse health effects, and for volatile hydrocarbons that can migrate in air to a resident, and the potential effects depend on the level of exposure, which is dependent on the release concentration, and the distance to the source.

4.5.4 Hydrogen Sulfide (H_2S) (7783-06-4)

Hydrogen sulfide is the toxic gas found in sour gas, but in Fort Collins oil well bacteria within the wells may produce it. If inhaled at high concentrations hydrogen sulfide is toxic by many mechanisms including the prevention of cellular respiration, but at low concentrations it is more of an unpleasant nuisance because it has the smell of rotten eggs. The odor threshold also known as the recognition is 0.00047 parts per millions (ppm) or 0.47 parts per billion (ppb) (Iowa, 2004). The EPA's RSL for H_2S is 0.2 $\mu g/m^3$ (0.0001 ppm) (HQ = 0.1), and the OSHA Immediately Dangerous to Life and Health level is 100 ppm. High concentrations may be encountered by oil and gas workers but generally not encountered by the general public. H_2S may prove a problem to those living within close proximity to active wells.

4.5.6 Particulate Matter (PM)

Particulate matter (PM) is the term used for small particles of dust, and smoke in the air, and it can prove a concern at oil and gas sites. Particles in the air can range in size, and the small particles are of more concern than large ones because they can penetrate deeper into the lung, by passing the lung's protective mechanisms. Two types of PM are often monitored: particulate matter that has a diameter of ten micrometers (PM_{10}), and particulate matter that has a diameter of two and a half micrometers ($PM_{2.5}$). PM may be produced in the fracturing process by the diesel engines used to run drill rigs, compressors, pumps and other equipment or through the dirt kicked up by heavy truck traffic. Both of these concerns are temporary and unique to specific parts of the hydraulic fracturing process and can last for weeks in the life of a well. These are only issues for residences located in very close proximity to unpaved roads and/or the drill pad. It is more of a concern for workers, and no significant hazards are likely due to current Fort Collins operations. $PM_{2.5}$ emissions from oil and gas development can be a significant concern both locally and regionally when emissions contribute to ozone formation or acid deposition or form toxic or contain carcinogenic compounds that can be inhaled. These emissions can be emitted from fuel combustion for processing equipment and vehicles as well as emitted product and wastes generated during the extraction and production process.

4.5.7 Ozone (O_3) (10028-15-6)

Ozone is an invisible gas made of three oxygen atoms (O_3). Ozone is often referred to as smog, and is formed when two groups of gases, VOCs and nitrogen oxides, undergo a chemical reaction in the air in the presence of sunlight. Ozone reacts chemically ("oxidizes") with internal body tissues, such as those in the lung, where it irritates and inflames the respiratory system at levels frequently found across the nation during the summer months. Breathing ozone may lead to:

- Shortness of breath, chest pain
- Inflammation of the lung lining, wheezing and coughing
- Increased risk of asthma attacks
- Make lungs more susceptible to infection

People with lung diseases, such as asthma or chronic obstructive pulmonary disease (COPD), often need medical treatment or hospitalization. These diseases can lead to premature death. The EPA has a good body of information on the adverse health effects of ozone (EPA, 2014c).

4.5.8 Nitrogen Oxides (NO_x)

Oxides of nitrogen are nitrous oxide (NO), nitrogen dioxide (NO_2) and nitrogen trioxide (NO_3). They are all gases. When they contact water, either in the environment or in the lung, they can form acids and can irritate or burn lung tissue causing irritation, asthma, and other lung problems.

4.6 SUMMARY OF MAJOR SOURCES OF AIR POLLUTION

In summary, barring spills, the major exposure pathway to COPCs from hydraulic fracturing is the inhalation of pollutants released to air. The COPCs discussed above typically come from the following processes:

Drilling:	NO_x from engines, thermal oxidation; VOCs, PM from engines; VOCs and HAPs from well venting and flowback
Completion:	VOCs and HAPs from hydraulic fracturing; NO_x from engines, thermal oxidation
Production:	VOCs, HAPs and H_2S from production equipment, work overs, blowdowns, pipelines, leaks from components, flanges, tanks and trucks; NO_x from engines and heaters; PM from engines

5. AIR, SOIL AND WATER ANALYSES FOR FUTURE POTENTIAL CONDITIONS

This section provides a brief description of the COPCs that might potentially be released to air, soil and water under the future scenario of hydraulic fracturing during oil and gas production in the City of Fort Collins.

Currently, hydraulic fracturing in Fort Collins is used for oil extraction. Given the type of oil and gas resources beneath Fort Collins, oil extraction is more likely in the future. However, hydraulic fracturing for gas extraction near Fort Collins is increasing, especially in Weld County, which borders the City. While the same process may be used, leading to the release of the same COPCs, gas extraction typically leads to a different mix of COPCs.

5.1 RELEASES TO AIR FROM GAS EXTRACTION

Methane, hazardous air pollutants (HAPs) such as benzene, toluene, ethylbenzene and xylenes (BTEX), trimethylbenzenes and a host of aliphatic (straight chain) hydrocarbons, and other chemical releases to air are routine and on-going at most oil and gas wells. Methane releases are more common with gas wells. Methane is released primarily from venting during drilling, workovers, and blowdowns; tanks, process equipment and component leaks, and has been shown to represent a loss of up to seven percent (7%) of a well's gas production (Howarth *et al*, 2012). In their statement of basis for Colorado's Regulation Number 7, concerning, "*The control of ozone via ozone precursors and control of hydrocarbons via oil and gas emissions*," Section XIX indicates that 1996 estimated annual nationwide methane emissions are approximately 31 billion cubic feet (Bcf) from the production sector, 16 Bcf from the processing sector, and 14 Bcf from the transmission sector (5 CCR 1001-9). Released methane will migrate from the well into the atmosphere. Methane is a naturally occurring hydrocarbon found at low levels in marshes, surface water and groundwater. Methane is of low human health risk, but it is of concern in ozone nonattainment areas because it is an ozone precursor. Methane represents a risk of explosion at levels over its Lower Explosive Limit (LEL) (five percent (5 %) in air). If release rates reach levels that are too high, remediation of the well is required, although no wellhead screening process is currently required by the COGCC (COGCC, 2014).

While this document does not address regulations, it should be noted that Colorado Regulation Number 7 (5 CCR 1001-9) has provisions that require reporting of methane and VOCs emissions, with the goal of reducing ozone precursor chemicals because of ozone nonattainment in parts of Denver, Boulder, Weld and Larimer Counties. These reporting requirements will provide general data on methane and VOC releases, but will not provide location specific methane or VOC concentration data for the area subject to reporting.

5.2 RELEASES TO WATER FROM GAS EXTRACTION

In historical situations and in other States, methane gas migration has been shown to impact drinking water wells; local oil producers have been found responsible and were required to provide clean drinking water. However, this has only occurred in cases where groundwater methane was previously established or large amounts of methane were released, and groundwater is relatively close to methane producing zones. VOCs can migrate with methane and may contaminate groundwater aquifers under specific conditions of close proximity, leaking or ruptured well casings, and spills.

5.3 RELEASES TO SOIL FROM GAS EXACTION

Methane can migrate and accumulate as soil gas, and historically has led to home explosions. The EPA has previously stepped into situations where methane proves immediately dangerous to structural safely. VOCs can migrate with methane and may contaminate soil under specific conditions of leaking or ruptured well casings, and spills.

6. FURTHER CONCERNS

As oil and gas development comes closer to urban centers and residential areas, other concerns need to be considered besides the ingestion of and contact with dangerous chemicals. Increased truck traffic through neighborhoods and on city roads can increase noise, pollution and utility wear. The increased contact between citizens and wells can have a direct effect on social cohesion within a community and aesthetic concerns of neighboring citizens. Recent increases in earthquakes in Colorado have also prompted public concern for the connections between oil and gas and induced seismicity. Finally, recent drought conditions in Colorado and around the United States have highlighted concerns by citizens as to the amount of water that is used by the oil and gas industry, especially during seasons when water is scarce.

6.1 TRUCK TRAFFIC

The process of fracking can require a large number of trucks to bring equipment onto the well site. This can be as many at 400 truck trips per site, which varies depending on whether fracturing is occurring, how productive the wells might be, and the methods by which oil is moved from the site (ANL, 2013). At the current locations of the Fort Collins oil wells, heavy truck traffic is not common because they have already been constructed and fractured. However, the wells are located within residential areas and heavy truck traffic may prove to be a noise nuisance and a heavy diesel pollutant source if further fracturing or new development occurs. As a health concern these are low as the levels of both PM and emissions from diesel combustion should not be regularly occurring and should be in levels lower than other pollutants within the City of Fort Collins.

6.2 SOCIAL DIMENSIONS

The oil and gas work can affect the social fabric of communities that have fracking. This is due to several factors. First, the proximity to oil and gas can cause personal views on oil and gas development to be a dominating issue of discussion and dissension between neighbors. These issues can highlight differences and conflicts within neighborhoods. Secondly, increased oil and gas activity can cause unrest with the proximity of the wells to individual houses. These proximities can have effects on quality of life and housing prices. In most cases housing prices will decrease due to proximity to wells due to the recent publicity of health concerns related to fracking. House worth can be directly connected to personal satisfaction and happiness due to the connection many draw between personal assets and success.

6.3 AESTHETIC ASPECTS

Aesthetic aspects of oil and gas drilling must be considered due to the importance of issues such as noise and light pollution, which can be a major concern to citizens. Current regulations require the mitigation of aesthetic concerns by painting the equipment to match the landscape, high fences to hide equipment, and the addition of natural obstacles (trees or shrubs) in locations near to residences. However, it is unreasonable to expect the complete camouflage of a multi-acre well pad.

Besides the visual aesthetics of natural gas, bacteria within a well produce hydrogen sulfide and can cause a detectable and irritating smell to those who reside near a well or well activities. This can negatively affect the resident's enjoyment of their property and the outdoors. This is also a driver of housing cost decreases.

A positive nascence, industrial sites may provide incentive for young children to visit the site when located near residences. For instance heavy machinery, especially pump jacks can prove attractive to children and adolescents. It is therefore important to close off areas that may be of interest to children, and post signs warning adults of dangers.

6.4 INDUCED SEISMICITY

Induced seismicity is a prominent concern, especially in Fort Collins and neighboring cities like Greeley. As research stands currently, induced seismicity has not been linked to the process of hydraulic fracturing (Keranen *et al*., 2014). However, it has been linked to Class II deep well injection. This utilizes the process of injecting wastewater into deep wells at high pressure to dispose of wastewater. There has been seismic activity measured in Colorado and near Fort Collins. There has also been increased seismic activity in other parts of the country connected to the disposal of water at high pressures (Keranen *et al*., 2014). The nearest injection wells are located in Weld County and have been under heavy scrutiny as of May 2014 due to recent earthquakes in the region (Magnitude 3.4 on May 31st, 2014). Earthquake censors were installed in June 2014 to measure quakes as they happen (KUNC, 2014).

6.5 DROUGHT CONDITIONS

Colorado frequently deals with drought conditions. Currently, water for active wells in Fort Collins is drawn from groundwater (Walsh, 2013). If drought conditions occur, oil and gas developers are not required to limit their usage of water due to shortages. This may cause a depletion of groundwater aquifers, depending on withdrawal volumes. This could take water from citizens but more likely from other industries such as ranching or farming. Another issue to consider is the potential future use of municipal or surface water sources for oil and gas development.

7. ENVIRONMENTAL CONSIDERATIONS

This section briefly discusses the release of Greenhouse Gases (GHGs) and their potential impact on the environment.

Greenhouse Gas emissions have been tied to climate change and transitively to increases in environmental hazards. As a progressive city, GHG is a major concern for the City of Fort Collins. Maintaining and enhancing the practices of a sustainable city depends on reducing emissions of GHGs. Fort Collins is currently investigating setting new goals on greenhouse emissions to 80 percent below 2005 levels by 2030 and carbon neutrality by 2050. These goals are aggressive in the face of a 4.9 percent population increase since 2011 and two consecutive years of increased carbon emissions. Despite 2013 increases, Carbon emissions have been reduced overall by 4.9 percent from the 2005 level but further steps must be taken to reach the 2030 goal.

Oil and gas wells will produce varying amounts of GHGs throughout their lifetime. In the early stages of the lifetime of wells, diesel trucks, generators, and other heavy machinery will produce CO_2 at levels similar to construction sites. The heavy truck traffic can contribute to city transportation emissions. Methane leakage from wells is a major concern for GHG release. Methane is between 105 and 108 times more effective as a GHG for the first 20 years (referred to as global warming potential (GWP)) (Howarth *et al*., 2012; C&EN, 2014). This high potential for global warming makes methane “the second largest contributor to human-caused global warming after carbon dioxide” (Howarth *et al*., 2012).

One of the largest conflicts between researchers is the percentage of methane released from upstream well sites. Current estimates of the percentage of methane produced that ends up as fugitive methane emissions range from 0.6 to 4.0 percent with the EPA level set at 3.0 percent (Stephenson *et al*., 2011; Petron *et al*., 2012, Howarth *et al*., 2012). The most robust and applicable study is Petron *et al*. (2012 and 2013), which took place over a year and focuses on the Weld County wells and the Colorado Front Range. This study found that a range of 2.7 to 7.7 percent of natural gas is emitted from well sites with a best estimate at 4 percent. The study does not include any emissions that may result from transport and processing of natural gas off-site.

The added GHG from current Fort Collins wells is considerably low, as they produce no more than 500 Mcf of methane a month. The percentage of produced natural gas that is released is important to consider if natural gas was ever produced within city limits. Considering the possibility that each well leaks 3 percent of its total produced methane (EPA estimation and middle of applicable study ranges) then a single well producing 100,000 Mcf of natural gas annually can expect to release 3,000 Mcf of gas in emissions. Some wells in Larimer County produce as much as 200,000 Mcf of natural gas in a year (COGCC, 2014). As the number of wells increases and the target of drilling includes natural gas, the amount of annual methane will significantly increase.

The GHG emission goals of Fort Collins do not coincide with the prospect of increased natural gas drilling. With methane's higher GWP over the short term, carbon reduction goals for 2030 and 2050 will be significantly affected.

As noted above, the recent study by Thompson *et al*., 2014, has quantified air concentrations for urban and rural areas of Northern Colorado, in particular, Platteville was shown to have benzene levels greater than Denver (an urban setting) and non-methane hydrocarbon concentrations are also high.

8. ONGOING RESEARCH

This section provides a brief overview of some of the key studies in Colorado, and other States, that are evaluating the amounts and types of chemicals in air due to oil and gas extraction (that might use hydraulic fracturing) and other sources, the risks associated with airborne chemicals, and other health-related studies.

There are a number of ongoing scientific research projects that are applicable to the city of Fort Collins, either directly or indirectly. The authors are aware of the larger scale studies described below. Smaller scale studies, conducted by individual researchers of which the authors are unaware, may also be on-going. From a risk assessment perspective, the studies described below are designed to gather data for exposure assessment (i.e., how individuals or communities may be exposed to chemicals released during hydraulic fracturing), and for toxicity assessment (i.e., how these chemicals may adversely affect individuals or communities). Local studies are presented first, followed by national studies. Due to the on-going nature of these studies it is difficult to determine what the results might show.

8.1 NATIONAL AERONAUTICS AND SPACE ADMINISTRATION, COLORADO FRONT RANGE

The Frappé Study (Front Range Air Pollution and Photochemistry Éxperiment; NCAR, 2014) is a collaborative effort between the Colorado Department of Public Health, CU-Boulder, CSU, UC Berkeley, and other universities, local agencies, National Center for Atmospheric Research (NCAR), National Aeronautics and Space Administration (NASA), and NOAA. The study uses aircrafts to measure tracers, methane and non-methane hydrocarbons at atmospheric levels, collect photochemical data via flyovers and measure ground concentrations throughout the flight area. The Flights began on July 16th, 2014 and continued through August, 2014. The availability of the results and timeline for publication of the results are currently unknown.

8.2 NORTH FRONT RANGE EMISSIONS AND DISPERSION STUDY, COLORADO FRONT RANGE

The North Front Range Emissions and Dispersion Study is a research project spearheaded by the Collett Research Group from the Department of Atmospheric Science at Colorado State University. Professor Jeffrey L. Collett, Jr. leads this research group, and the CDPHE funds the project. The research project focuses on oil and gas emissions using mobile air quality laboratories and high sensitivity air analysis equipment. This study is expected to be completed in 2016 (CSU, 2014) (Table 8-1).

8.3 NATIONAL SCIENCE FOUNDATION, ROCKY MOUNTAIN FRONT RANGE, COLORADO AND WYOMING

The National Science Foundation is funding studies with scientists in the Front Range to study "Routes to Sustainability for Natural Gas Development and Water and Air Resources in the Rocky Mountain Region." These studies focus on air quality impacts from methane and ozone, health effects related to proximity to wells, and methods and technologies of wastewater treatment. Research locations are focused on Colorado, Utah, and Wyoming. Professor Joseph Ryan of CU-Boulder coordinates these ongoing studies and results and papers associated with the research are released online as they become available (airwatergas.org). This meta-study in its entirety is expected to be completed at the end of 2018 (Table 8-1).

8.4 ENVIRONMENTAL DEFENSE FUND, COLORADO AND NATIONAL METHANE STUDY

In 2012, The Environmental Defense Fund (EDF) provided support for 16 methane studies around the United States. These studies are targeted at understanding methane emissions in the context of climate change. Of the 16 studies, six of them target Colorado and the methane emissions from Colorado gas development. These studies work with CSU, CU-Boulder and National Oceanic and Atmospheric Association (NOAA) to provide a complete picture of methane emissions from the industry from production to distribution. The majority of the studies will use air-sampling data both upstream and downstream of leakage points (wells, storage facilities, processing plants, etc.). These studies will rely on atmospheric measurements and tracer gas to track ambient methane release as well as point source release. These studies are expected be published by the end of 2014 (EDF, 2014) (Table 8-1).

8.5 ENVIRONMENTAL PROTECTION AGENCY, NATIONAL DRINKING WATER STUDY

An EPA Study is currently under way as the EPA portion of a Multi-Agency (EPA, DOE, and DOI) collaboration on unconventional oil and gas research. The EPA Study entitled “The Potential Impacts of Hydraulic Fracturing on Drinking Water Resources,” will focus on the interaction between hydraulic fracturing and drinking water. It will cover the stages of water acquisition, chemical mixing, well injection, wastewaters, and wastewater treatment and disposal. This study is done with the cooperation of industry partners and will include a case study location. This investigation will not create toxicity data for chemicals used in hydraulic fracturing, but will evaluate existing chemical profiles. A draft report of the findings is expected for public comment and review in early 2015 (Table 8-1).

8.6 HYDRAULIC FRACTURING AND ENDOCRINE DISRUPTERS IN GARFIELD COUNTY, COLORADO

Dr. Susan Nagel, an associate professor of Obstetrics Gynecology and Women’s Health at the University of Missouri, has been studying hormones and endocrine-disrupting chemicals associated with water from hydraulic fracturing in Garfield County, Colorado. An abstract published in 2013, “hypothesized that a selected subset of chemicals used in natural gas drilling operations and also surface and ground water samples collected in a drilling-dense region of Garfield County, Colorado, would exhibit estrogen and androgen receptor activities. Water samples were collected, solid-phase extracted, and measured for estrogen and androgen receptor activities using reporter gene assays in human cell lines. Of the 39 unique water samples, 89%, 41%, 12%, and 46% exhibited estrogenic, antiestrogenic, androgenic, and antiandrogenic activities, respectively.” (Kassotis, *et al.,* 2013). According to a community website update on July 7, 2014, Dr. Nagel has received additional funding and plans to continue her research in Garfield County. (Styx, 2014).

8.7 FLOWER MOUND'S CANCER CLUSTER, TEXAS HEALTH STUDY

In response to residents' concerns about the health effects of natural gas drilling in the vicinity of Flower Mounds Texas, the health department conducted an analysis of cancer cases in two zip codes to address concerns after tests found cancer-causing benzene in the air around some drilling sites. The study reviewed cases of leukemia in children and adults, non-Hodgkin's lymphoma, childhood brain cancer and female breast cancer from 1998 to 2007 in two ZIP codes covering most of Flower Mound, TX. Texas State health officials found no evidence of a cancer cluster in Flower Mound, according to a study released in 2010. Researchers compared the findings with the number of expected cases based on statewide rates.

The number of cases was within the statistically normal range except for breast cancer, the researchers found. Breast cancer cases were slightly higher than the number of expected cases.

However, a review by a University of Texas at Austin researcher in the Virginia Environmental Law Journal (Rawlins, 2013) said the state was too quick to dismiss the study and that the State was doing little to identify "Hotspots." Dr. Maria Morandi, a faculty affiliate and former research professor from the Center for Environmental Health Sciences at the University of Montana reanalyzed the data and found, with 95 percent certainty, that rates of childhood leukemia and childhood lymphoma in Flower Mound are significantly higher than expected; there is only a 1 in 20 chance that the difference is random. The discussions concerning the additional cases of cancer continue.

8.8 HOUSEHOLD SURVEY IN WASHINGTON COUNTY, PENNSYLVANIA HEALTH STUDY

Dr. Peter Rabinowitz, formally of Yale University School of Medicine, New Haven, Connecticut, and now with the University of Washington, Seattle, Washington, recently published a study of health effects in the proximity of natural gas wells in Pennsylvania (Rabinowitz, *et al.*, 2014). The conclusion of the study states:

> "The results of this study suggest that natural gas drilling activities could be associated with increased reports of dermal and upper respiratory symptoms in

> nearby communities and support the need for further research into health effects of natural gas extraction activities. Such research could include longitudinal assessment of the health of individuals living in proximity to natural gas drilling activities, medical confirmation of health conditions, and more precise assessment of contaminant exposures."

8.9 HOW THESE STUDIES MIGHT AFFECT FORT COLLINS

The studies described in Section 8.1 through Section 8.4 will provide data on hydrocarbons released, and air quality data on the Colorado Front Range air shed. They are also designed to explore relationships between hydraulic fracturing, hydrocarbon releases and ozone, which exceeds EPA's acceptable concentration in the Front Range. While Fort Collins is affected by this air shed, and ozone non-attainability is an issue for Fort Collins residents, current oil extraction is expected to have an insignificant effect on air quality compared with hydraulic fracturing and gas extraction in Weld County. The results of these studies may be incorporated into an area-wide plan that might include Fort Collins.

The EPA study described in Section 8.5 will provide data on hydraulic fracturing and groundwater, and would only be applicable to Fort Collins in a general sense.

The studies described in Section 8.6 through Section 8.8 will provide data on the potential adverse health effects from hydrocarbons released during hydraulic fracturing. They are specifically relevant to Fort Collins because they investigate the relationship between chemicals released during hydraulic fracturing and potential adverse health effects. These data, with other health related data, might be used to establish the risks from a hydraulic fracturing chemical under investigation (e.g., benzene) at a particular concentration. This concentration might then be used to determine a level of acceptable exposure for the City of Fort Collins.

TABLE 8-1
TIMELINE FOR ONGOING STUDIES RELATED TO OIL AND GAS DEVELOPMENT

Study	Task	2013				2014				2015				2016				2017				2018			
Front Range (Section 8.1)	Data Collection					🟩	🟩	🟩																	
	Data Publication									🟨	🟨	🟨	🟨												
CSU (Section 8.2)	Funding Procurement			🟩															░	░					
	Study Design				🟩	🟩	🟩														░				
	Data Collection							🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩						
	Results																			🟩	🟩				
	Health Impacts Analysis																					🟨	🟨	🟨	🟨
NSF (Section 8.3)	Funding Procurement	🟩																							
	Study Design		🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩												
	Data Collection			🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩		
	Results					🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩
	Health Impacts Analysis							🟨	🟨	🟨	🟨	🟨	🟨	🟨	🟨	🟨	🟨	🟨	🟨	🟨	🟨	🟨	🟨	🟨	🟨
EDF (Section 8.4)	Funding Procurement	🟩																							
	Study Design	🟩																							
	Data Collection		🟩	🟩	🟩	🟩	🟩	🟩																	
	Results				🟩	🟩	🟩	🟩	🟩																
	Health Impacts Analysis									🟨	🟨	🟨	🟨												

TABLE 8-1 (CONTINUED)
TIMELINE FOR ONGOING STUDIES RELATED TO OIL AND GAS DEVELOPMENT

Study	**Task**	**2013**				**2014**				**2015**				**2016**				**2017**				**2018**			
EPA (Section 8.5)	Funding Procurement	🟩																							
	Study Design	🟩																							
	Data Collection	🟩	🟩	🟩	🟩																				
	Results			🟩	🟩	🟩	🟩	🟩	🟩																
	Health Impacts Analysis								🟨	🟨	🟨	🟨	🟨												
	Data Collection		🟩	🟩	🟩	🟩	🟩	🟩																	
University of Missouri (Section 8.6)	Results				🟩	🟩	🟩	🟩	🟩																
	Health Impacts Analysis			🟨	🟨	🟨	🟨	🟨	🟨	🟨	🟨	🟨													
	Publications-Ongoing																								
Texas Health Study	Ongoing																								
Pennsylvania Health Study	Ongoing																								

9. FINDINGS AND CONCLUSION

The findings and conclusions presented in this sub-section were developed based on the material presented in this report, and the literature from which the facts were taken. Findings specific to the City of Fort Collins are presented first, followed by findings related to hydraulic fracturing in general.

9.1 FRAMEWORK FOR THE PROCESS AND FINDINGS

The US EPA's risk assessment process provides a framework for this support document because it uses a process accepted by regulatory agencies since the 1980s, it systematically considers all aspects of exposure, it evaluates potential adverse cancer and non-cancer health effects, and there are promulgated acceptable risk levels that are applicable in a public health setting. The EPA's risk assessments have four parts: site characterization, exposure assessment, toxicity assessment and risk characterization. The use of this framework is directly applicable when considering exposure to chemicals from hydraulic fracturing in Fort Collins.

9.1.1 Site Characterization and the Hydraulic Fracturing Process

Site characterization provides a summary of the site settings, and discusses chemicals present in air, surface water, groundwater and soil under background (unaffected) and under impacted conditions at a site where hydraulic fracturing might take place. Findings specific to Fort Collins:

a. There are no published background site characterization data for air, groundwater, and soil around the existing Fort Collins oil wells.
b. There are no published site characterization data for potential public health impacts from Fort Collins oil wells.
c. Available COGC data suggest that current hydraulic fracturing practices in the Muddy J formation (extraction from sandstone, which is similar geology to that beneath Fort Collins) are significantly different from hydraulic fracturing practices used to extract natural gas from the surrounding Niobrara shale formation (Weld and Larimer County).

d. Substantially lower volumes of fracturing fluid are used in the Muddy J (similar to Fort Collins) compared with the Niobrara formation (Weld and Larimer County).
e. The lower volumes of fracturing fluids and pressures would likely result in lower volumes of flow-back water, and low emissions during fracturing and well completion at current and future potential oil wells developed in Fort Collins.

Site Characterization and the Hydraulic Fracturing Process General Findings:

f. Site characterization data at locations where hydraulic fracturing is used at oil and gas wells in Weld and Larimer County are generally poor.
g. There are no site-specific studies that compare the magnitude of emissions from hydraulic fracturing in different geologic formations.
h. There are studies showing that chemicals are routinely released to air from gas wells during and after hydraulic fracturing. And this is the primary exposure pathway for human health.

9.1.2 Exposure Pathways and Chemicals of Concern

An exposure pathway is the means by which a chemical moves from it source (e.g., a well) to the exposed receptor (e.g., a resident). The chemicals of concern for hydraulic fracturing are a complex mixture of petroleum compounds and fracturing-fluids extracted or used in the oil and gas extraction process. Findings specific to Fort Collins:

a. There are many factors influencing chemical exposures to a Fort Collins resident from an existing or future potential oil extraction well, these are uncharacterized at this time.
b. Air related exposures are the most relevant exposure pathways for a resident; the point of exposure for quantifying an unacceptable exposure to fracturing-related chemicals is both undefined and uncharacterized at this time. However, in general, the closer the well is located to a resident the higher the exposure.
c. Contamination of soil and water from a Fort Collins oil well would require a spill, leak or catastrophic failure to present a significant risk to human health.

Exposure Pathways and Chemicals of Concern General Findings:

d. Air exposure pathways are the primary exposure pathways for human health, and there are limited data characterizing this pathway.
e. When uncontrolled, chemical emissions to air can be higher during the back-flow stage of hydraulic fracturing than during routine operations.
f. Contamination of soil and water from oil and gas production would require a spill, leak or catastrophic failure to present a significant risk to human health.
g. Exposure pathways relative to well decommissioning have not been characterized at this time.

9.1.3 Dose-response of Chemicals of Concern

In the risk assessment process, the dose-response section describes a chemical's adverse effect in humans, and quantifies the causal relationship for the effect. Two type of health effect are considered: potential cancer effects (such as benzene causing leukemia), and non-cancer effects (such as xylene causing nerve damage). Also, when two or more chemicals with the same effect are present, the effects are considered additive, and the toxicity of chemical mixtures is considered cumulative. Findings specific to Fort Collins:

a. The types of chemicals released from a Fort Collins oil well are generally known, but data on the specific mix of chemicals is unavailable at this time.
b. The petroleum chemicals benzene and 1,3-butadiene are present in emissions and have the potential to cause cancer in humans. These chemicals are likely to be the most important chemicals for long-term human health in Fort Collins, but data on these chemicals in background air, and from Fort Collins oil wells are unavailable at this time.
c. The petroleum chemicals trimethylbenzenes, ethyl benzene and xylenes are likely to be the most important chemicals for non-cancer and short-term human health in Fort Collins, but data on these chemicals in background air and from Fort Collins oil wells are unavailable at this time.
d. Fort Collins is located in an ozone non-attainment area, with respect to air quality. Ozone is known to cause respiratory problems including asthma, and

decreased lung functioning in sensitive individuals, and children. The contribution of current and future potential oil and gas production in the Front Range is significant and several ongoing studies are assessing the impacts to air quality degradation and health. Contributions to regional ozone levels from oil and gas development specific to Fort Collins is a complex issue and cannot be assessed at this time.

Dose-response of Chemicals of Concern General Findings:

e. Studies at gas wells in Colorado (and other places) have shown that benzene, 1,3-butadiene and ethyl benzene potentially contribute significantly to human health risks during hydraulic fracturing, particularly the back-flow stage of well development.
f. Benzene has been linked to an increase in childhood leukemia when the mother is exposed to benzene; however, an acceptable level of exposure for this sensitive health end-point has not been developed by health regulatory agencies.
g. Studies at gas wells in Colorado (and other places) have shown that trimethyl benzenes, ethyl benzene and xylenes contribute significantly to human health risks during hydraulic fracturing, particularly the back-flow stage of well development.
h. The toxicological dose-response of many of the chemical in hydraulic fracturing fluid are unknown at this time. However, many of these chemicals have low volatility and exposure to residents would be insignificant, except potentially, in the event of exposure to contaminated soil or water.
i. Air emission sources in Weld and Larimer Counties have known releases of ozone producing gases. The degree to which these contribute to ozone non-attainment in Fort Collins cannot be assessed at this time.

9.1.4 Cancer Risks and Non-cancer Hazards

In the risk assessment process, potential cancer risks are calculated as the probability of developing cancer over a lifetime due to long-term exposure to the chemicals in question. It is assumed that any level of exposure has a risk, and so Congress has agreed an acceptable risk range of one-in-ten thousand (1 in 10,000) to one-in-one million (1 in 1,000,000); the added probability of developing cancer over a lifetime. Non-cancer hazards are assumed to have an acceptable level of exposure, and the probability of an adverse effect is the ratio of the level of exposure to this acceptable level. It is presented as a fraction, or index with an acceptable Hazard Index of 1.0. Findings specific to Fort Collins:

a. There are no cancer risk assessments available for Fort Collins background, or oil well-related exposures for potentially carcinogenic fracturing-related compounds at this time.
b. Non-cancer hazard assessments are unavailable for Fort Collins background, or oil well-related exposures to trimethylbenzenes or other petroleum compounds at this time.

Cancer Risks and Non-cancer Hazards General Findings:

c. Studies at gas wells in Colorado (and other places) have shown that benzene, 1,3-butadiene and ethyl benzene, and other potential carcinogens increase the risks of developing cancer due to exposure to hydraulic fracturing chemicals, particularly the back-flow stage of well development.
d. The US EPA has provided ranges of acceptable risks for chemical in air, soil and drinking water (called Regional Screening Levels). However, these have not been applied to hydraulic fracturing at this time.
e. Therefore, there is a lack of agreement in the literature on the cleanup levels that might be used to determine what constitutes a contaminated medium for hydraulic fracturing related chemicals, and oil and gas extraction.
f. There is also no recognized process for determining where and when goals for air, surface water and groundwater might be applied to hydraulic fracturing.

9.1.5 General Risk Factors

There are other potential risk factors that might be considered when evaluating the risks from hydraulic fracturing and the chemicals used or produced by oil and gas extraction. Findings specific to Fort Collins:

a. Fort Collins city water is not used for fracturing at this time.

b. Fort Collins does not accept oil extraction wastewaters for waste disposal at this time.

c. Apart from the moratorium, there are few restrictions preventing hydraulic fracturing in the City of Fort Collins.

General Risk General Findings:

d. The use of municipal and special district water for hydraulic fracturing is a common practice in Colorado's Front Range.

e. Publically Owned Treatment Works (POTW) accept waste waters from hydraulic fracturing, although the amount varies for each POTW based on the volume and toxicity of the oil and gas waste water.

f. Even though the practice of disposing of oil and gas wastes (including the co-mingled well stimulation fluids) for land treatment and application, and for road spreading is not currently used in the City of Fort Collins, Colorado State law allows for these practices.

   There is little data available to evaluate if these practices pose a risk to surface water or groundwater aquifers, or residents living on the roads where this disposal method is a common practice.

9.2 CONCLUSIONS AND ENVIRONMENTAL STUDIES

The primary conclusions from the body of data presented in the previous section of this report are that there are little environmental data characterizing background and/or potential impacts from the chemical released during hydraulic fracturing and oil extraction in Fort Collins. Therefore, it is not possible to predict potential human health impacts from current and future potential hydraulic fracturing, for the purpose of oil and gas extraction, within the City. Areas where there are little or no published environmental data include:

- The characterization of background conditions (for air, water and soil) at well sites.
- The characterization of current releases of chemicals (to air, water and soil) at well sites.

- The concentrations of cancer and non-cancer causing chemicals at resident's homes from wells.
- The risks from these cancer and non-cancer causing chemicals at resident's homes.
- Acceptable levels of exposure and risk at resident's homes.
- The contribution of well releases to ozone concentrations.
- The contribution of cancer and non-cancer causing chemicals to adverse health outcomes in Fort Collins from exposure to chemicals released during hydraulic fracturing in nearby Counties.

As noted, there are data for sites in Colorado that may be applicable.

This sub-section uses the risk assessment steps (described earlier) to identify areas where environmental and health studies might be conducted to answer some of the unresolved questions concerning exposure to chemicals from the hydraulic fracturing process. This is not a list of recommended studies. The scientific process requires that the objectives of any study be clearly identified at the outset, and the data collected be targeted to the goals of that study. The studies identified here could be undertaken to answer specific questions related to citizen exposure to chemicals from hydraulic fracturing. Some of the studies on the health effects of chemicals of concern would be prohibitively expensive and would normally be undertaken on a federal level.

9.2.1 Characterizing the Environmental Setting

Characterizing the background environmental setting of current and future oil and gas extraction is important because it allows for a comparison of conditions before and after. If a moratorium on hydraulic fracturing is in effect, it would prove an ideal time period to collect data before making decisions related to local oil and gas and hydraulic fracturing regulations.

Air

As the primary route of exposure to chemicals released during hydraulic fracturing is to air, this is an important pathway of study.

- Background air quality studies could be conducted at locations in and around Fort Collins to determine background air quality. Concurrent meteorological data might indicate background air chemical sources in the regional air shed. Ideally this would be a multi-year study that would characterize potential impacts from nearby gas extraction fields. Chemicals of interest might include markers for petroleum, natural gas, fracturing fluids; ozone and greenhouse gases; and particulate matter. The cost would range based on the study duration, the number of monitoring locations, the chemical analyte list and the level of reporting: An approximate cost might be $60,000 to $240,000 per 12 month period.
- Oil well-related canister studies could be conducted at locations in and around Fort Collins oil wells to determine air quality impacts near sources of air pollutants in relation to the houses nearest to the existing wells. Representative residential exposure points would be selected in conjunction with meteorological monitoring locations and representative chemicals of concern. The cost would range based on the months of study, the number of location monitored, the chemical analyte list and the level of reporting: An approximate cost might be $60,000 to $240,000 per 12 month period.

Groundwater

- Groundwater monitoring is necessary to determine the baseline water quality of the shallow groundwater aquifer in locations near current oil extraction, and in locations where future potential oil and gas extraction may take place. Representative exposure points would be selected in conjunction with existing wells, city zoning and known oil and gas reserves. Representative groundwater physical chemistry parameters and chemicals of concern analyte lists would include markers for petroleum, fracturing fluids and natural minerals. The cost would vary based on the months of study, the number of locations/depths monitored, the chemical analyte list and the level of reporting: $120,000 to $240,000 per 12 month period. Subsequent years would be cheaper because of prior well construction.

Soil

- The monitoring of releases to soil would be unnecessary if a spill reporting requirement is implemented.

9.2.2 Environmental Exposure Pathways

Air

- Monitoring to characterize the environmental settings would provide a background data set against which releases to the environment might be measured. Monitoring routine and periodic releases to air is important and the monitoring program identified above could be used to monitor potential releases.

Groundwater

- Monitoring to characterize the environmental groundwater settings would provide a background data set against which releases to the environment might be measured. Potential releases to groundwater could only be effectively detected through a monitoring program. The program identified above could be used to monitor for these releases.

Surface water

- The monitoring of releases to surface water is likely unnecessary because the existing oil wells are not located near surface water and a spill reporting requirement would be adequate for this medium. However, future wells might be located near surface water and a monitoring program would help identify releases to surface water. The cost of such a program would be well-specific.

9.2.3 Production and Decommissioning Related Pathways

- There is currently no published data on the levels of Naturally Occurring Radioactive Materials (NORMS) produced by groundwater from the oil-bearing formations beneath Fort Collins, and the degree to which equipment becomes “scaled” with precipitated NORMS. A study of this issue would allow the City to determine if special handling and disposal procedures are appropriate when dealing with scaled equipment from oil and gas wells. A study of NORMS would require industry participation, and would best be designed and conducted in conjunction with COGC and the CDPHE. The cost would range based on the number of sites and wells per site, the number of locations, the age, depth and equipment used at each well, the chemical analyte list and the level of reporting: An approximate cost might be $5,000 to $10,000 per site.

9.2.4 Toxicology and Health Studies

At a minimum, the City's First Responders should have information on the toxicity and dangers related to chemical that might be released in the event of a spill that might contaminate air, soil, surface water and groundwater.

Additional toxicological studies are needed to understand the health effects of specific COPCs associated with fracturing fluids. This area of investigation falls to State and Federal Agencies and the oil and gas industry to prioritize research. The cost of an animal dose-response study might vary based on the duration, the number of animals/species, the route of administration and the number of chemicals tested: a typical long-term study on one chemical in one species is $1,000,000 to $5,000,000.

- There are uncertainties in the long-term health effects of oil and gas chemicals such as benzene; especially, the potential health effect of maternal benzene exposure on childhood leukemia, a potentially sensitive human receptor. For a human study to provide information with sufficient statistical power and confidence for decision making, the design would include a large population of affected individuals, and a control population. This type of animal teratology study and/or human epidemiological study falls in the purview of the oil and gas industry or Federal regulatory agencies, and might cost $1,000,000 to $5,000,000.

9.3 OTHER OIL AND GAS QUESTIONS

In addition to the collection of monitoring data, questions City managers might consider in the process of reviewing hydraulic fracturing for oil and gas development include:

- Are there specific practices that could be employed to minimize, prevent or eliminate releases from wells with the goal of eliminating public exposure to COPCs? What power does the City have to implement these types of measures?
- If the City has limited power, can the City bring these issues to the attention of the appropriate regulatory authority, and/or pursue alternative action/recourse?
- Should any new application require a full background characterization prior to the City allowing for the construction of a new well?
- When a well is decommissioned, are there data required before disposal in Fort Collins landfills is allowed? Has a level of “natural background” been defined along with an appropriate cleanup standard?
- Are the measures in place sufficient to ensure local concerns are addressed, and adequate protections are available to residents adjacent to a well?
- Should the City conduct a survey of existing private water supply wells to help identify potential areas of concern for exposure should new oil or gas exploration or production occur within City limits?
- Emissions from flaring or venting are uncertain due to a lack of information regarding the frequency of occurrence. Would it be important to request this information from an operator as a part of an operator agreement?
- Would it be worth requiring vapor controls on the temporary tanks to which flowback water is stored, thus preventing emissions from evaporative sources related to hydraulic fracturing?

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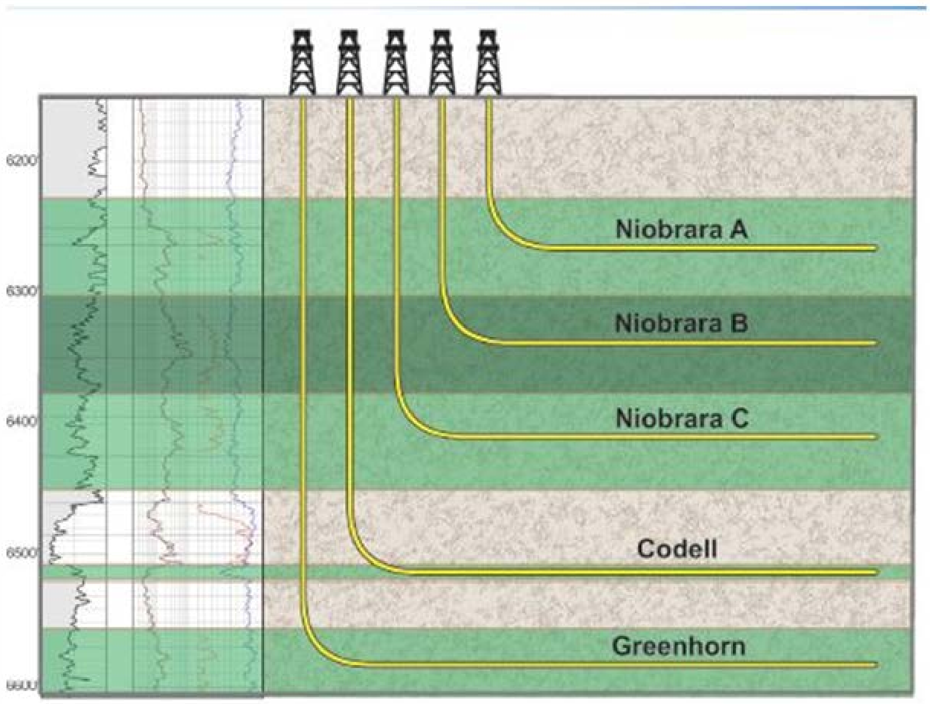
APPENDICES

APPENDIX A:

FORT COLLINS OIL AND NORTHERN COLORADO GEOLOGIC FORMATIONS

A. FORT COLLINS OIL AND NORTHERN COLORADO GEOLOGIC FORMATIONS

Oil and gas extraction can only occur where there are hydrocarbon reserves contained in the underlying geology. Even though hydrocarbon extraction technologies are constantly improving, the reserves have to be present for wells to exist. This section provides a brief overview of the resources available. The Niobrara Shale is a shale rock formation underlying parts of Colorado and Wyoming. Oil and natural gas can be found at depths from 3,000 to 14,000 feet. Figure A-1 is a representation of depths within the Niobrara shale formation.



Source: Bonanza Creek

SOURCE: www.naturalgasintel.com/niobraradjinfo

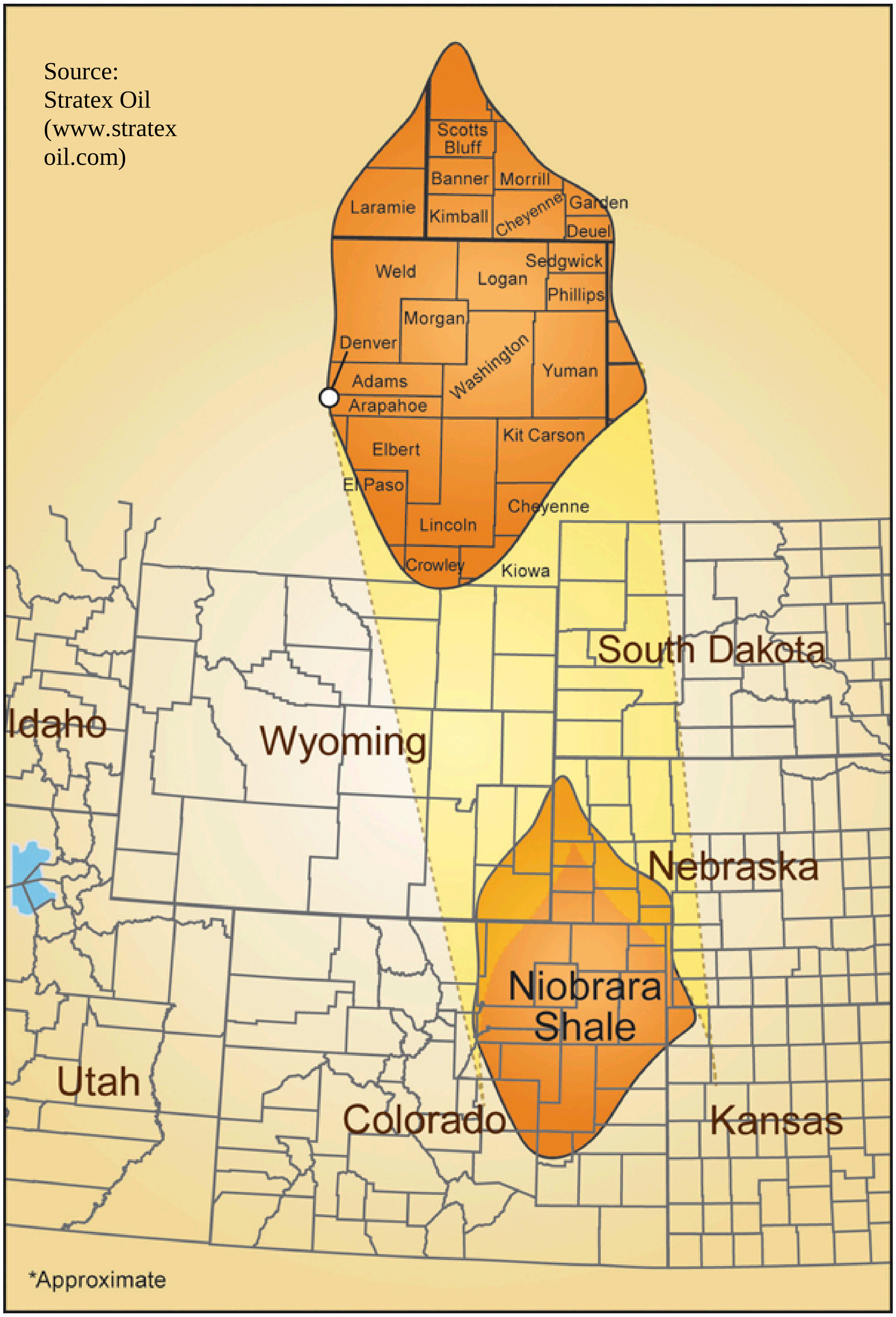
FIGURE A-1
DIAGRAM OF DRILLING TO VARIOUS DEPTHS WITHIN NIOBRARA FORMATION

The Niobrara is a new oil formation that is part of the Denver-Julesburg basin. It is an early oil formation that is being compared to the Bakken Shale. It can be seen from Figure A-2 that it is beneath Weld County and part of Larimer County.

Currently there is only oil production within Fort Collins City limits in the Fort Collins Field, located in the northeast portion of the city, where oil extraction is from the Muddy J formation. Sandstone is the reservoir rock for petroleum generated by overlying source rocks, and generally the Muddy J formation is located between 7,600 to 8,400 ft. bgs and varies in thickness from 75 to 150 feet. The current oil extraction operations in the Fort Collins City limits are identified on Figure A-3 and Figure A-4 showing the four residential subdivisions that have been developed around the Fort Collins field. There are options available for further development, as shown in Figure A-4 and Figure A-5. In addition, north of Fort Collins, further development of the Muddy J formation has occurred.

A.1 OIL AND GAS INFRASTRUCTURE

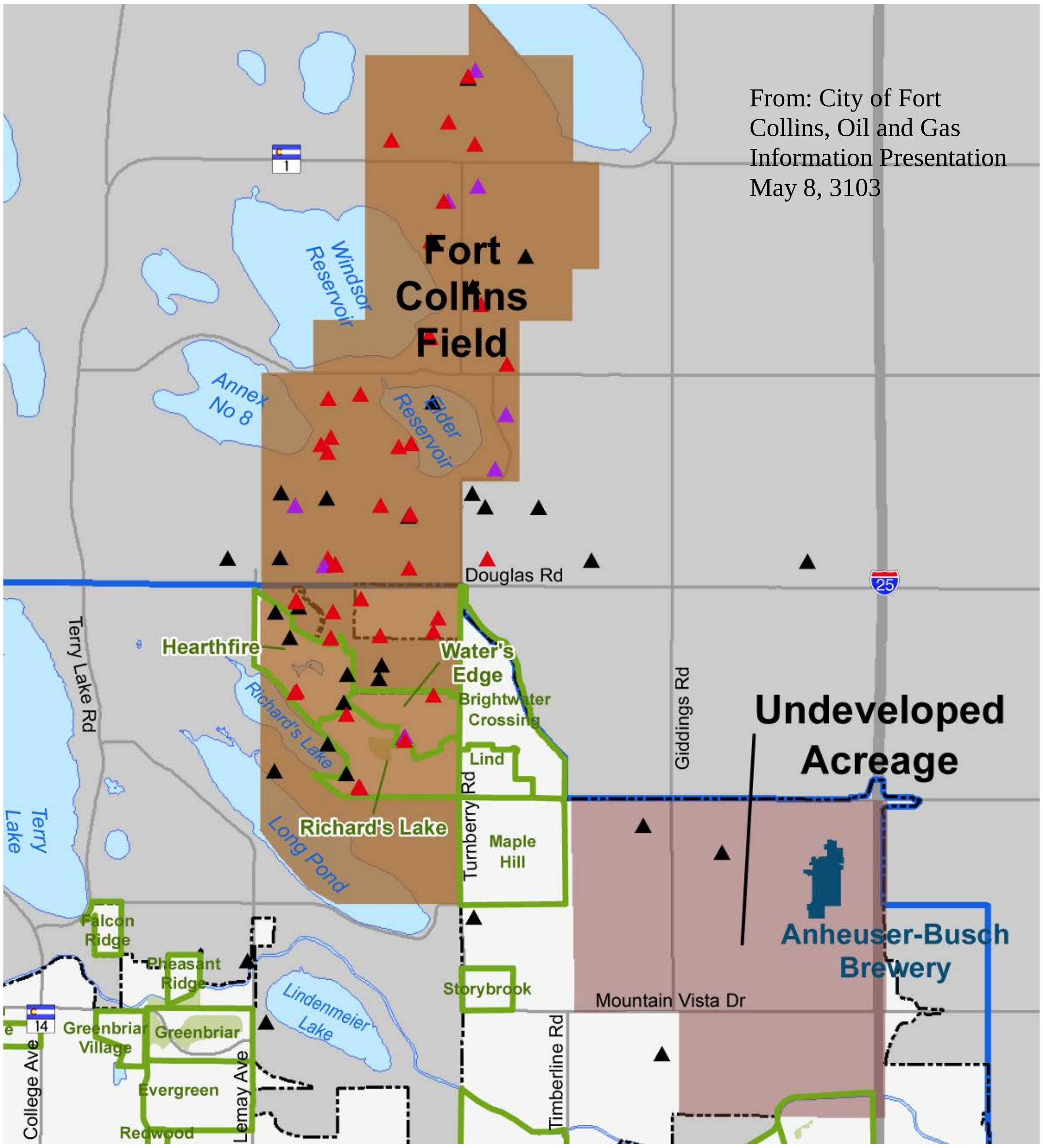
Oil and gas are produced by drilling into shale or sandstone that contain hydrocarbon deposits. Shale is a tightly compacted geologic formation that does not easily allow the passage of gases or liquids and requires stimulation to release hydrocarbons. Permeability and porosity are generally much higher in sandstone than in shale. Fracturing is used to break open fractures in the shale or sandstone to allow better oil or gas passage and higher extraction rates. Fort Collins sits atop two major oil and gas producing layers, the Muddy J sandstone (7,600 feet bgs) and the Niobrara Shale formation (6,800 to 7,100 feet bgs) both contained within the Denver-Julesburg Basin area (Polzin, 2012). These layers of the Denver-Julesburg basin are outlined in Figure A-6. In Colorado, these formations produce around 66 million barrels (bbl.) of oil and 1.7 trillion cf (cubic feet) of gas a year (EIA, 2014).



Source:
Stratex Oil
(www.stratex
oil.com)

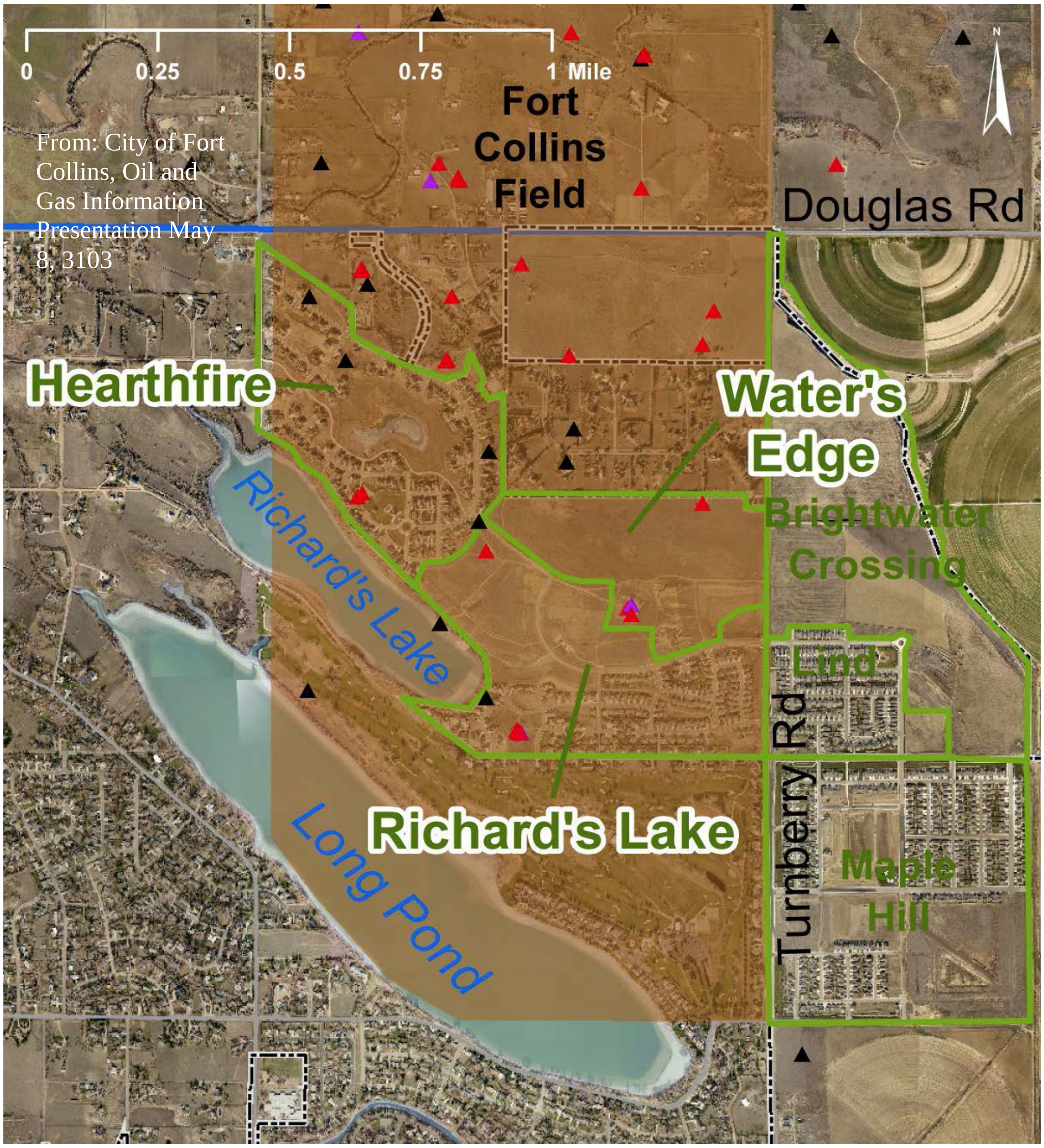
*Approximate

FIGURE A-2
THE NIOBRARA SHALE FORMATION IN COLORADO



From: City of Fort Collins, Oil and Gas Information Presentation May 8, 3103

FIGURE A-3
FORT COLLINS OIL EXTRACTION FIELDS AND NEIGHBORHOODS



From: City of Fort Collins, Oil and Gas Information Presentation May 8, 3103

Figure A-4
Fort Collins Oil Extraction Fields and Residential Subdivisions

(Active wells- Red, inactive wells-Black)

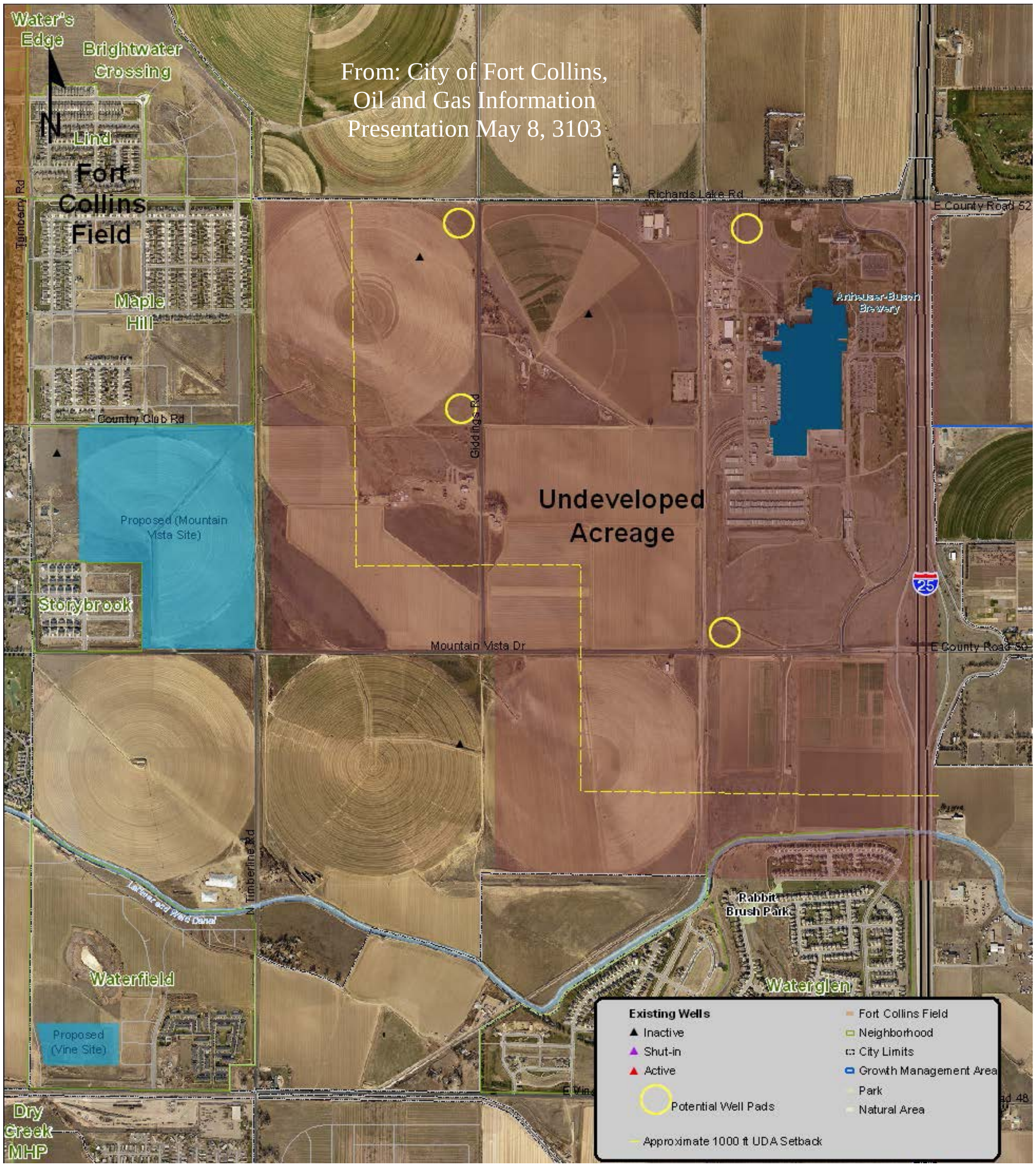

From: City of Fort Collins,
Oil and Gas Information
Presentation May 8, 3103

FIGURE A-5
FORT COLLINS UDA NEIGHBORHOOD & ZONING MAP

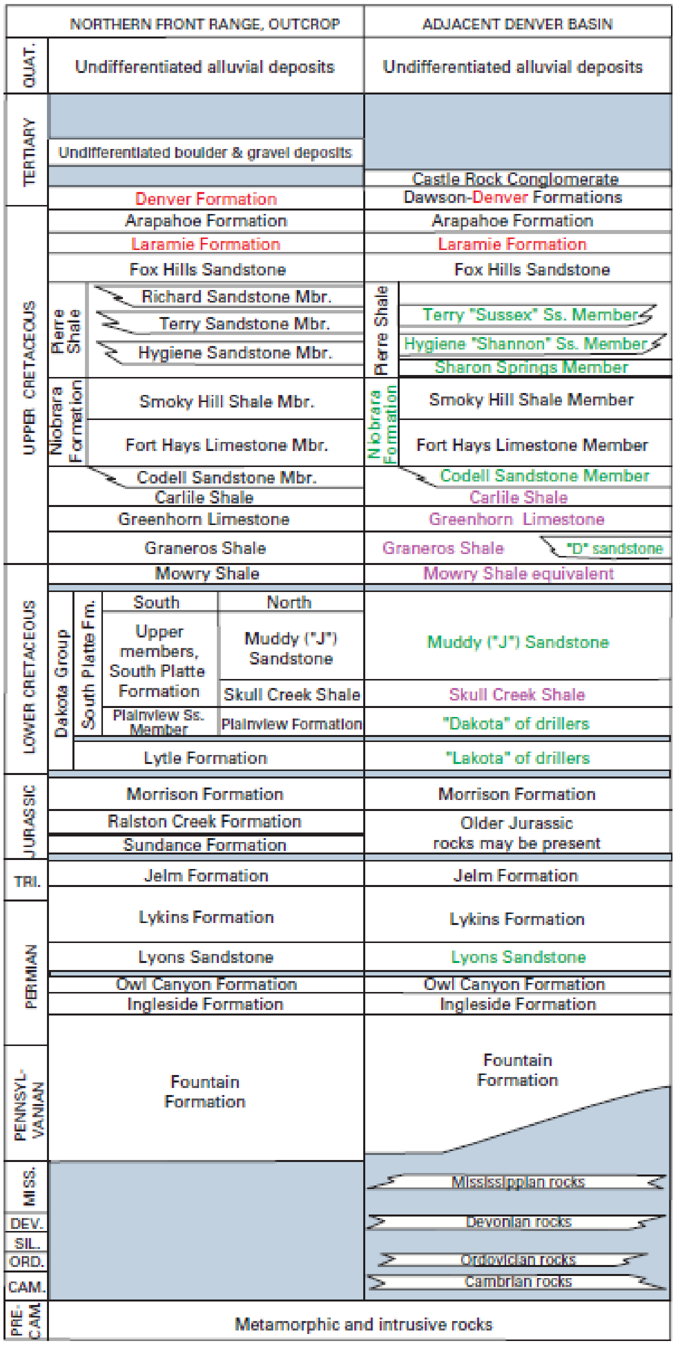


Figure 2. Stratigraphic section of rock units in outcrop and the adjacent Denver Basin. Light blue zones are periods of erosion or nondeposition. Green text marks formations that produce oil and (or) gas. Red text marks formations that have the potential to produce coal-bed methane. Hydrocarbon source rocks are marked with purple text. Question marks label unclear boundaries. Sources of information include Hoyt (1963), Momper (1963), Irwin (1976), Sonnenberg and Weimer (1981), Higley and Schmoker (1989), Hjellming (1993), and MacLachlan and others (1996).

FIGURE A-6
DENVER-JULESBURG SHALE LAYERS

(Highlighting depths of Niobrara and Muddy J Sandstone)

A.1.1 Current City Well Locations

Oil development has occurred in Fort Collins since around 1925. There are seven producing wells and seven injection wells all managed by one operator located in northeast Fort Collins (Figure A-3 and A- 4). The wells in Fort Collins access the Muddy J sandstone and the Niobrara Shale. The wells in Fort Collins are targeted to produce oil and only produce a limited amount of natural gas as a by-product. These wells produce around 780,000 barrels (bbl.) (average) of oil and 4,200 Mcf (4,200,000 cubic feet) (average) of gas a year (COGCC, 2014; COGIS, 2014). The gas is either vented or flared and the oil is sold. The Fort Collins wells are fractured infrequently, most recently in 2012.

A.1.2 Neighboring Extraction Fields

Larimer County contains active wells outside of Fort Collins. Thirty-three of the 42 total wells in Larimer County are south of Fort Collins, near the city of Johnstown. Two other wells are located east of Fort Collins. These wells are on the other side of I-25 but within the county limits (FracFocus, 2014).

Weld County contains one of the largest densities of wells in the country, containing around 18,000 total wells. These wells range in distance from Fort Collins. Within a 30-mile radius there are 542 wells located between Greeley and Fort Collins. Twenty of these wells are located between Windsor and Larimer County (within 8 miles) (FracFocus, 2014).

Laramie County, Wyoming, borders Larimer County, Colorado to the north. There are a total of 21 wells between Cheyenne and the border of Colorado; however, all of these wells are located to the east of I-25. It is approximately 28 miles from Fort Collins to the Wyoming border and approximately 41 miles from Fort Collins to Cheyenne, Wyoming.

A.1.3 Future Exploration

Future exploration in and around Fort Collins depends greatly on any possible regulations set forward by the city of Fort Collins as well as on technological advances. The oil and gas plays in Larimer County extend from the eastern border to the western border of Fort Collins (EIA, 2014). The basins extend even further to the other side of the divide to the west of Fort Collins. Current technology would allow the drilling and access of hydrocarbons in the Julesburg-Denver Basin within and around the city of Fort Collins, however, this paper does not evaluate whether this is an economically viable option for an operator. Areas of moderate or high potential for exploration are shown in Figure A-7. If technologies allow for easier access and economic viability of drilling in the mountains it is possible development would occur to the west of Fort Collins, putting water resources under greater danger. The likelihood of this is also low because it is current practice not to drill on fault lines including mountains.

Oil and gas industry officials have already shown interest in some areas of Fort Collins properties, mainly the Soapstone Prairie Natural Area and the Meadow Springs Ranch (Figure A-5). These areas are owned by the City and are located to the north outside of the City proper. These are flat, easily accessible lands that are sparsely populated to unpopulated making them ideal for oil and gas developers. Historically development has also been greatest around the I-25 corridor. This location makes it easy for trucks to access sites and is nearby to local pipelines. The Fort Collins Natural Areas program participated in the Mountains to Plains Energy by Design process developed by the State Land Board and other stakeholders to design an oil and gas leasing plan that would allow for reasonable energy development at these properties while achieving the biological, cultural, scenic and recreational resource conservation goals of local governments.

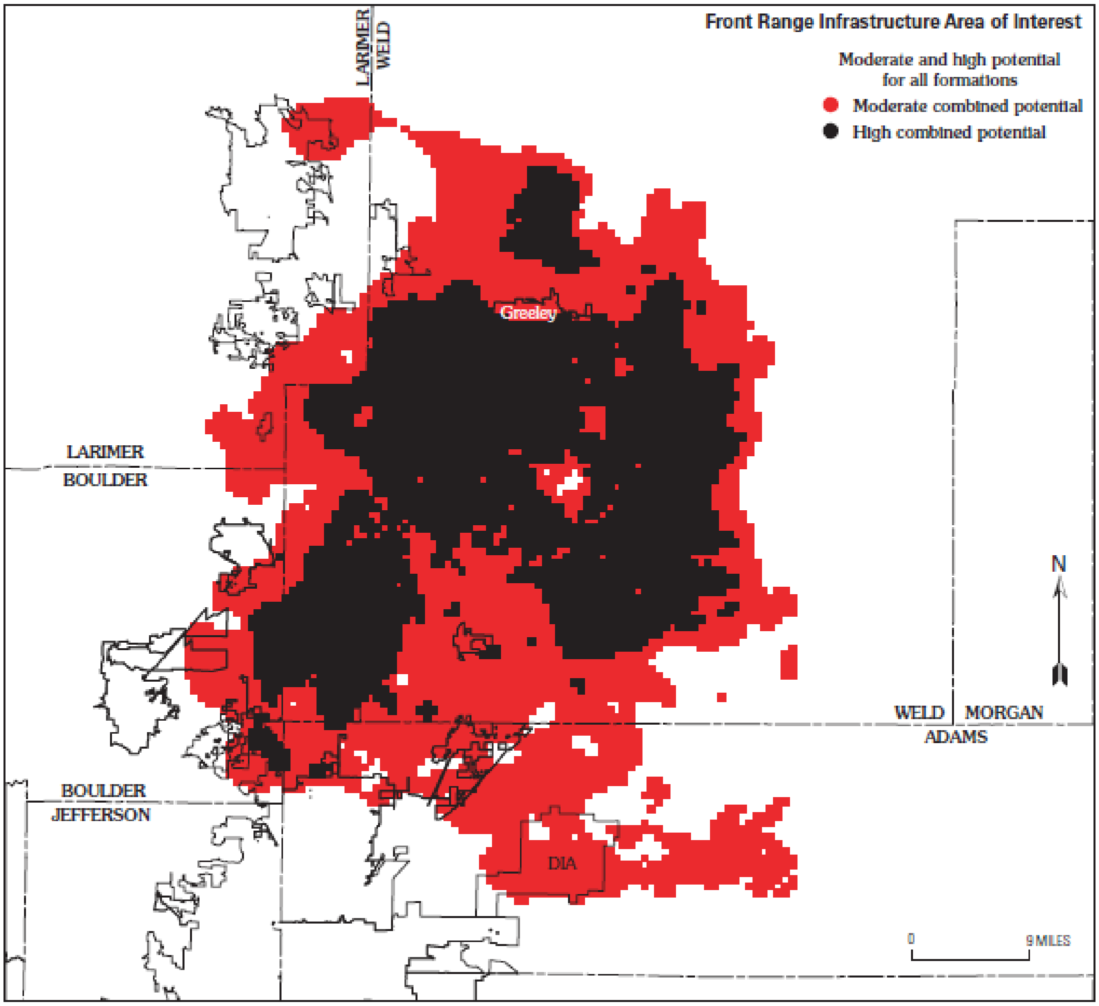


Figure 9. Combined potential development for all formations.

Figure A-7
Moderate and High Potential of Oil and Gas Development of all formations

APPENDIX B:

HYDRAULIC FRACTURING CHEMICALS AND THEIR USES

Appendix B-1 Fracturing Fluid Chemicals and their Uses

Table B-1
Fracking Fluid Chemicals and Their Uses

Chemical Name	**CAS**	**Chemical Purpose**	**Product Function**
Hydrochloric Acid	007647-01-0	Helps dissolve minerals and initiate cracks in the rock	Acid
Glutaraldehyde	000111-30-8	Eliminates bacteria in the water that produces corrosive by-products	Biocide
Quaternary Ammonium Chloride	012125-02-9	Eliminates bacteria in the water that produces corrosive by-products	Biocide
Quaternary Ammonium Chloride	061789-71-1	Eliminates bacteria in the water that produces corrosive by-products	Biocide
Tetrakis Hydroxymethyl-Phosphonium Sulfate	055566-30-8	Eliminates bacteria in the water that produces corrosive by-products	Biocide
Ammonium Persulfate	007727-54-0	Allows a delayed break down of the gel	Breaker
Sodium Chloride	007647-14-5	Product Stabilizer	Breaker
Magnesium Peroxide	014452-57-4	Allows a delayed break down the gel	Breaker
Magnesium Oxide	001309-48-4	Allows a delayed break down the gel	Breaker
Calcium Chloride	010043-52-4	Product Stabilizer	Breaker
Choline Chloride	000067-48-1	Prevents clays from swelling or shifting	Clay Stabilizer
Tetramethyl ammonium chloride	000075-57-0	Prevents clays from swelling or shifting	Clay Stabilizer
Sodium Chloride	007647-14-5	Prevents clays from swelling or shifting	Clay Stabilizer
Isopropanol	000067-63-0	Product stabilizer and / or winterizing agent	Corrosion Inhibitor
Methanol	000067-56-1	Product stabilizer and / or winterizing agent	Corrosion Inhibitor
Formic Acid	000064-18-6	Prevents the corrosion of the pipe	Corrosion Inhibitor
Acetaldehyde	000075-07-0	Prevents the corrosion of the pipe	Corrosion Inhibitor
Petroleum Distillate	064741-85-1	Carrier fluid for borate or zirconate crosslinker	Crosslinker
Hydrotreated Light Petroleum Distillate	064742-47-8	Carrier fluid for borate or zirconate crosslinker	Crosslinker
Potassium Metaborate	013709-94-9	Maintains fluid viscosity as temperature increases	Crosslinker
Triethanolamine Zirconate	101033-44-7	Maintains fluid viscosity as temperature increases	Crosslinker
Sodium Tetraborate	001303-96-4	Maintains fluid viscosity as temperature increases	Crosslinker
Boric Acid	001333-73-9	Maintains fluid viscosity as temperature increases	Crosslinker
Zirconium Complex	113184-20-6	Maintains fluid viscosity as temperature increases	Crosslinker
Borate Salts	N/A	Maintains fluid viscosity as temperature increases	Crosslinker
Ethylene Glycol	000107-21-1	Product stabilizer and / or winterizing agent.	Crosslinker
Methanol	000067-56-1	Product stabilizer and / or winterizing agent.	Crosslinker
Polyacrylamide	009003-05-8	“Slicks” the water to minimize friction	Friction Reducer
Petroleum Distillate	064741-85-1	Carrier fluid for polyacrylamide friction reducer	Friction Reducer
Hydrotreated Light Petroleum	064742-47-8	Carrier fluid for polyacrylamide friction reducer	Friction Reducer

TABLE B-1
FRACKING FLUID CHEMICALS AND THEIR USES

Distillate			
Methanol	000067-56-1	Product stabilizer and / or winterizing agent.	Friction Reducer
Ethylene Glycol	000107-21-1	Product stabilizer and / or winterizing agent.	Friction Reducer
Guar Gum	009000-30-0	Thickens the water in order to suspend the sand	Gelling Agent
Petroleum Distillate	064741-85-1	Carrier fluid for guar gum in liquid gels	Gelling Agent
Hydrotreated Light Petroleum Distillate	064742-47-8	Carrier fluid for guar gum in liquid gels	Gelling Agent
Methanol	000067-56-1	Product stabilizer and / or winterizing agent.	Gelling Agent
Polysaccharide Blend	068130-15-4	Thickens the water in order to suspend the sand	Gelling Agent
Ethylene Glycol	000107-21-1	Product stabilizer and / or winterizing agent.	Gelling Agent
Citric Acid	000077-92-9	Prevents precipitation of metal oxides	Iron Control
Acetic Acid	000064-19-7	Prevents precipitation of metal oxides	Iron Control
Thioglycolic Acid	000068-11-1	Prevents precipitation of metal oxides	Iron Control
Sodium Erythorbate	006381-77-7	Prevents precipitation of metal oxides	Iron Control
Lauryl Sulfate	000151-21-3	Used to prevent the formation of emulsions in the fracture fluid	Non-Emulsifier
Isopropanol	000067-63-0	Product stabilizer and / or winterizing agent.	Non-Emulsifier
Ethylene Glycol	000107-21-1	Product stabilizer and / or winterizing agent.	Non-Emulsifier
Sodium Hydroxide	001310-73-2	Adjusts the pH of fluid to maintains the effectiveness of other components, such as crosslinkers	pH Adjusting Agent
Potassium Hydroxide	001310-58-3	Adjusts the pH of fluid to maintains the effectiveness of other components, such as crosslinkers	pH Adjusting Agent
Acetic Acid	000064-19-7	Adjusts the pH of fluid to maintains the effectiveness of other components, such as crosslinkers	pH Adjusting Agent
Sodium Carbonate	000497-19-8	Adjusts the pH of fluid to maintains the effectiveness of other components, such as crosslinkers	pH Adjusting Agent
Potassium Carbonate	000584-08-7	Adjusts the pH of fluid to maintains the effectiveness of other components, such as crosslinkers	pH Adjusting Agent
Copolymer of Acrylamide and Sodium Acrylate	025987-30-8	Prevents scale deposits in the pipe	Scale Inhibitor
Sodium Polycarboxylate	N/A	Prevents scale deposits in the pipe	Scale Inhibitor
Phosphonic Acid Salt	N/A	Prevents scale deposits in the pipe	Scale Inhibitor
Lauryl Sulfate	000151-21-3	Used to increase the viscosity of the fracture fluid	Surfactant
Ethanol	000064-17-5	Product stabilizer and / or winterizing agent.	Surfactant
Naphthalene	000091-20-3	Carrier fluid for the active surfactant ingredients	Surfactant
Methanol	000067-56-1	Product stabilizer and / or winterizing agent.	Surfactant
Isopropyl Alcohol	000067-63-0	Product stabilizer and / or winterizing agent.	Surfactant
2-Butoxyethanol	000111-76-2	Product stabilizer	Surfactant

APPENDIX B-2 CHEMICALS USED IN FRACKING HYDRAULIC FRACTURING: US HOUSE OF REPRESENTATIVES, COMMITTEE ON ENERGY AND COMMERCE

UNITED STATES HOUSE OF REPRESENTATIVES
COMMITTEE ON ENERGY AND COMMERCE
MINORITY STAFF
APRIL 2011

CHEMICALS USED IN HYDRAULIC FRACTURING

PREPARED BY COMMITTEE STAFF FOR:

Henry A. Waxman **Ranking Member** **Committee on Energy and Commerce**	**Edward J. Markey** **Ranking Member** **Committee on Natural Resources**	**Diana DeGette** **Ranking Member** **Subcommittee on Oversight and Investigations**

TABLE OF CONTENTS

I. EXECUTIVE SUMMARY

Hydraulic fracturing has helped to expand natural gas production in the United States, unlocking large natural gas supplies in shale and other unconventional formations across the country. As a result of hydraulic fracturing and advances in horizontal drilling technology, natural gas production in 2010 reached the highest level in decades. According to new estimates by the Energy Information Administration (EIA), the United States possesses natural gas resources sufficient to supply the United States for approximately 110 years.

As the use of hydraulic fracturing has grown, so have concerns about its environmental and public health impacts. One concern is that hydraulic fracturing fluids used to fracture rock formations contain numerous chemicals that could harm human health and the environment, especially if they enter drinking water supplies. The opposition of many oil and gas companies to public disclosure of the chemicals they use has compounded this concern.

Last Congress, the Committee on Energy and Commerce launched an investigation to examine the practice of hydraulic fracturing in the United States. As part of that inquiry, the Committee asked the 14 leading oil and gas service companies to disclose the types and volumes of the hydraulic fracturing products they used in their fluids between 2005 and 2009 and the chemical contents of those products. This report summarizes the information provided to the Committee.

Between 2005 and 2009, the 14 oil and gas service companies used more than 2,500 hydraulic fracturing products containing 750 chemicals and other components. Overall, these companies used 780 million gallons of hydraulic fracturing products – not including water added at the well site – between 2005 and 2009.

Some of the components used in the hydraulic fracturing products were common and generally harmless, such as salt and citric acid. Some were unexpected, such as instant coffee and walnut hulls. And some were extremely toxic, such as benzene and lead. Appendix A lists each of the 750 chemicals and other components used in hydraulic fracturing products between 2005 and 2009.

The most widely used chemical in hydraulic fracturing during this time period, as measured by the number of compounds containing the chemical, was methanol. Methanol, which was used in 342 hydraulic fracturing products, is a hazardous air pollutant and is on the candidate list for potential regulation under the Safe Drinking Water Act. Some of the other most widely used chemicals were isopropyl alcohol (used in 274 products), 2-butoxyethanol (used in 126 products), and ethylene glycol (used in 119 products).

Between 2005 and 2009, the oil and gas service companies used hydraulic fracturing products containing 29 chemicals that are (1) known or possible human carcinogens, (2) regulated under the Safe Drinking Water Act for their risks to human health, or (3) listed as hazardous air pollutants under the Clean Air Act. These 29 chemicals were components of more than 650 different products used in hydraulic fracturing.

The BTEX compounds – benzene, toluene, xylene, and ethylbenzene – appeared in 60 of the hydraulic fracturing products used between 2005 and 2009. Each BTEX compound is a regulated contaminant under the Safe Drinking Water Act and a hazardous air pollutant under the Clean Air Act. Benzene also is a known human carcinogen. The hydraulic fracturing companies injected 11.4 million gallons of products containing at least one BTEX chemical over the five year period.

In many instances, the oil and gas service companies were unable to provide the Committee with a complete chemical makeup of the hydraulic fracturing fluids they used. Between 2005 and 2009, the companies used 94 million gallons of 279 products that contained at least one chemical or component that the manufacturers deemed proprietary or a trade secret. Committee staff requested that these companies disclose this proprietary information. Although some companies did provide information about these proprietary fluids, in most cases the companies stated that they did not have access to proprietary information about products they purchased "off the shelf" from chemical suppliers. In these cases, the companies are injecting fluids containing chemicals that they themselves cannot identify.

II. BACKGROUND

Hydraulic fracturing – a method by which oil and gas service companies provide access to domestic energy trapped in hard-to-reach geologic formations — has been the subject of both enthusiasm and increasing environmental and health concerns in recent years. Hydraulic fracturing, used in combination with horizontal drilling, has allowed industry to access natural gas reserves previously considered uneconomical, particularly in shale formations. As a result of the growing use of hydraulic fracturing, natural gas production in the United States reached 21,577 billion cubic feet in 2010, a level not achieved since a period of high natural gas production between 1970 and 1974.[1] Overall, the Energy Information Administration now projects that the United States possesses 2,552 trillion cubic feet of potential natural gas resources, enough to supply the United States for approximately 110 years. Natural gas from shale resources accounts for 827 trillion cubic feet of this total, which is more than double what the EIA estimated just a year ago.[2]

Hydraulic fracturing creates access to more natural gas supplies, but the process requires the use of large quantities of water and fracturing fluids, which are injected underground at high volumes and pressure. Oil and gas service companies design fracturing fluids to create fractures and transport sand or other granular substances to prop open the fractures. The composition of these fluids varies by formation, ranging from a simple mixture of water and sand to more complex mixtures with a multitude of chemical additives. The companies may use these

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[1] Energy Information Administration (EIA), *Natural Gas Monthly (Mar. 2011)*, Table 1, U.S. Natural Gas Monthly Supply and Disposition Balance (online at www.eia.gov/dnav/ng/hist/n9070us1A.htm) (accessed Mar. 30, 2011).

[2] EIA, *Annual Energy Outlook 2011 Early Release* (Dec. 16, 2010); EIA, *What is shale gas and why is it important?* (online at www.eia.doe.gov/energy_in_brief/about_shale_gas.cfm) (accessed Mar. 30, 2011).

chemical additives to thicken or thin the fluids, improve the flow of the fluid, or kill bacteria that can reduce fracturing performance.[3]

Some of these chemicals, if not disposed of safely or allowed to leach into the drinking water supply, could damage the environment or pose a risk to human health. During hydraulic fracturing, fluids containing chemicals are injected deep underground, where their migration is not entirely predictable. Well failures, such as the use of insufficient well casing, could lead to their release at shallower depths, closer to drinking water supplies.[4] Although some fracturing fluids are removed from the well at the end of the fracturing process, a substantial amount remains underground.[5]

While most underground injections of chemicals are subject to the protections of the Safe Drinking Water Act (SDWA), Congress in 2005 modified the law to exclude "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" from the Act's protections.[6] Unless oil and gas service companies use diesel in the hydraulic fracturing process, the permanent underground injection of chemicals used for hydraulic fracturing is not regulated by the Environmental Protection Agency (EPA).

Concerns also have been raised about the ultimate outcome of chemicals that are recovered and disposed of as wastewater. This wastewater is stored in tanks or pits at the well site, where spills are possible.[7] For final disposal, well operators must either recycle the fluids for use in future fracturing jobs, inject it into underground storage wells (which, unlike the fracturing process itself, are subject to the Safe Drinking Water Act), discharge it to nearby surface water, or transport it to wastewater treatment facilities.[8] A recent report in the *New York*

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[3] U.S. Environmental Protection Agency, *Evaluation of Impacts to Underground Sources of Drinking Water by Hydraulic Fracturing of Coalbed Methane Reservoirs* (June 2004) (EPA 816-R-04-003) at 4-1 and 4-2.

[4] For instance, Pennsylvania's Department of Environmental Protection has cited Cabot Oil & Gas Corporation for contamination of drinking water wells with seepage caused by weak casing or improper cementing of a natural gas well. *See Officials in Three States Pin Water Woes on Gas Drilling*, ProPublica (Apr. 26, 2009) (online at www.propublica.org/article/officials-in-three-states-pin-water-woes-on-gas-drilling-426) (accessed Mar. 24, 2011).

[5] John A. Veil, Argonne National Laboratory, *Water Management Technologies Used by Marcellus Shale Gas Producers*, prepared for the Department of Energy (July 2010), at 13 (hereinafter "*Water Management Technologies*").

[6] 42 U.S.C. § 300h(d). Many dubbed this provision the "Halliburton loophole" because of Halliburton's ties to then-Vice President Cheney and its role as one of the largest providers of hydraulic fracturing services. *See The Halliburton Loophole*, New York Times (Nov. 9. 2009).

[7] *See* EPA, *Draft Hydraulic Fracturing Study Plan* (Feb. 7, 2011), at 37; *Regulation Lax as Gas Wells' Tainted Water Hits Rivers*, New York Times (Feb. 26, 2011).

[8] *Water Management Technologies*, at 13.

Times raised questions about the safety of surface water discharge and the ability of water treatment facilities to process wastewater from natural gas drilling operations.[9]

Any risk to the environment and human health posed by fracturing fluids depends in large part on their contents. Federal law, however, contains no public disclosure requirements for oil and gas producers or service companies involved in hydraulic fracturing, and state disclosure requirements vary greatly.[10] While the industry has recently announced that it soon will create a public database of fluid components, reporting to this database is strictly voluntary, disclosure will not include the chemical identity of products labeled as proprietary, and there is no way to determine if companies are accurately reporting information for all wells.[11]

The absence of a minimum national baseline for disclosure of fluids injected during the hydraulic fracturing process and the exemption of most hydraulic fracturing injections from regulation under the Safe Drinking Water Act has left an informational void concerning the contents, chemical concentrations, and volumes of fluids that go into the ground during fracturing operations and return to the surface in the form of wastewater. As a result, regulators and the public are unable effectively to assess any impact the use of these fluids may have on the environment or public health.

III. METHODOLOGY

On February 18, 2010, the Committee commenced an investigation into the practice of hydraulic fracturing and its potential impact on water quality across the United States. This investigation built on work begun by Ranking Member Henry A. Waxman in 2007 as Chairman of the Committee on Oversight and Government Reform. The Committee initially sent letters to eight oil and gas service companies engaged in hydraulic fracturing in the United States. In May 2010, the Committee sent letters to six additional oil and gas service companies to assess a

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[9] *Regulation Lax as Gas Wells' Tainted Water Hits Rivers*, New York Times (Feb. 26, 2011).

[10] Wyoming, for example, recently enacted relatively strong disclosure regulations, requiring disclosure on a well-by-well basis and "for each stage of the well stimulation program," "the chemical additives, compounds and concentrations or rates proposed to be mixed and injected." *See* WCWR 055-000-003 Sec. 45. Similar regulations became effective in Arkansas this year. *See* Arkansas Oil and Gas Commission Rule B-19. In Wyoming, much of this information is, after an initial period of review, available to the public. *See* WCWR 055-000-003 Sec. 21. Other states, however, do not insist on such robust disclosure. For instance, West Virginia has no disclosure requirements for hydraulic fracturing and expressly exempts fluids used during hydraulic fracturing from the disclosure requirements applicable to underground injection of fluids for purposes of waste storage. *See* W. Va. Code St. R. § 34-5-7.

[11] *See Ground Water Protection Council Calls for Disclosure of Chemicals Used in Shale Gas Exploration*, Ground Water Protection Council (Oct. 5, 2010) (online at www.wqpmag.com/Ground-Water-Protection-Council-Calls-for-Disclosure-of-Chemicals-in-Shale-Gas-Exploration-newsPiece21700) (accessed Mar. 24, 2011).

broader range of industry practices.[12] The February and May letters requested information on the type and volume of chemicals present in the hydraulic fracturing products that each company used in their fluids between 2005 and 2009.

The 14 oil and gas service companies that received the letter voluntarily provided substantial information to the Committee. As requested, the companies reported the names and volumes of the products they used during the five-year period.[13] For each hydraulic fracturing product reported, the companies also provided a Material Safety Data Sheet (MSDS) detailing the product's chemical components. The Occupational Safety and Health Administration (OSHA) requires chemical manufacturers to create a MSDS for every product they sell as a means to communicate potential health and safety hazards to employees and employers. The MSDS must list all hazardous ingredients if they comprise at least 1% of the product; for carcinogens, the reporting threshold is 0.1%.[14]

Under OSHA regulations, manufacturers may withhold the identity of chemical components that constitute "trade secrets."[15] If the MSDS for a particular product used by a company subject to the Committee's investigation reported that the identity of any chemical component was a trade secret, the Committee asked the company that used that product to provide the proprietary information, if available.

IV. HYDRAULIC FRACTURING FLUIDS AND THEIR CONTENTS

Between 2005 and 2009, the 14 oil and gas service companies used more than 2,500 hydraulic fracturing products containing 750 chemicals and other components.[16] Overall, these companies used 780 million gallons of hydraulic fracturing products in their fluids between 2005 and 2009. This volume does not include water that the companies added to the fluids at the well site before injection. The products are comprised of a wide range of chemicals. Some are seemingly harmless like sodium chloride (salt), gelatin, and citric acid. Others could pose a severe risk to human health or the environment.

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[12] The Committee sent letters to Basic Energy Services, BJ Services, Calfrac Well Services, Complete Production Services, Frac Tech Services, Halliburton, Key Energy Services, RPC, Sanjel Corporation, Schlumberger, Superior Well Services, Trican Well Service, Universal Well Services, and Weatherford.

[13] BJ Services, Halliburton, and Schlumberger already had provided the Oversight Committee with data for 2005 through 2007. For BJ Services, the 2005-2007 data is limited to natural gas wells. For Schlumberger, the 2005-2007 data is limited to coalbed methane wells.

[14] 29 CFR 1910.1200(g)(2)(i)(C)(1).

[15] 29 CFR 1910.1200.

[16] Each hydraulic fracturing "product" is a mixture of chemicals or other components designed to achieve a certain performance goal, such as increasing the viscosity of water. Some oil and gas service companies create their own products; most purchase these products from chemical vendors. The service companies then mix these products together at the well site to formulate the hydraulic fracturing fluids that they pump underground.

Some of the components were surprising. One company told the Committee that it used instant coffee as one of the components in a fluid designed to inhibit acid corrosion. Two companies reported using walnut hulls as part of a breaker—a product used to degrade the fracturing fluid viscosity, which helps to enhance post-fracturing fluid recovery. Another company reported using carbohydrates as a breaker. One company used tallow soap—soap made from beef, sheep, or other animals—to reduce loss of fracturing fluid into the exposed rock.

Appendix A lists each of the 750 chemicals and other components used in the hydraulic fracturing products injected underground between 2005 and 2009.

A. Commonly Used Chemical Components

The most widely used chemical in hydraulic fracturing during this time period, as measured by the number of products containing the chemical, was methanol. Methanol is a hazardous air pollutant and a candidate for regulation under the Safe Drinking Water Act. It was a component in 342 hydraulic fracturing products. Some of the other most widely used chemicals include isopropyl alcohol, which was used in 274 products, and ethylene glycol, which was used in 119 products. Crystalline silica (silicon dioxide) appeared in 207 products, generally proppants used to hold open fractures. Table 1 has a list of the most commonly used compounds in hydraulic fracturing fluids.

Table 1. Chemical Components Appearing Most Often in Hydraulic Fracturing Products Used Between 2005 and 2009

Chemical Component	No. of Products Containing Chemical
Methanol (Methyl alcohol)	342
Isopropanol (Isopropyl alcohol, Propan-2-ol)	274
Crystalline silica - quartz (SiO2)	207
Ethylene glycol monobutyl ether (2-butoxyethanol)	126
Ethylene glycol (1,2-ethanediol)	119
Hydrotreated light petroleum distillates	89
Sodium hydroxide (Caustic soda)	80

Hydraulic fracturing companies used 2-butoxyethanol (2-BE) as a foaming agent or surfactant in 126 products. According to EPA scientists, 2-BE is easily absorbed and rapidly distributed in humans following inhalation, ingestion, or dermal exposure. Studies have shown that exposure to 2-BE can cause hemolysis (destruction of red blood cells) and damage to the spleen, liver, and bone marrow.[17] The hydraulic fracturing companies injected 21.9 million gallons of products containing 2-BE between 2005 and 2009. They used the highest volume of products containing 2-BE in Texas, which accounted for more than half of the volume used. EPA recently found this chemical in drinking water wells tested in Pavillion, Wyoming.[18] Table 2 shows the use of 2-BE by state.

Table 2. States with the Highest Volume of Hydraulic Fracturing Fluids Containing 2-Butoxyethanol (2005-2009)

State	Fluid Volume (gallons)
Texas	12,031,734
Oklahoma	2,186,613
New Mexico	1,871,501
Colorado	1,147,614
Louisiana	890,068
Pennsylvania	747,416
West Virginia	464,231
Utah	382,874
Montana	362,497
Arkansas	348,959

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[17] EPA, *Toxicological Review of Ethylene Glycol Monobutyl Ether* (Mar. 2010) at 4.

[18] EPA, *Fact Sheet: January 2010 Sampling Results and Site Update, Pavillion, Wyoming Groundwater Investigation* (Aug. 2010) (online at www.epa.gov/region8/superfund/wy/pavillion/PavillionWyomingFactSheet.pdf) (accessed Mar. 1, 2011).

B. Toxic Chemicals

The oil and gas service companies used hydraulic fracturing products containing 29 chemicals that are (1) known or possible human carcinogens, (2) regulated under the Safe Drinking Water Act for their risks to human health, or (3) listed as hazardous air pollutants under the Clean Air Act. These 29 chemicals were components of 652 different products used in hydraulic fracturing. Table 3 lists these toxic chemicals and their frequency of use.

Table 3. Chemicals Components of Concern: Carcinogens, SDWA-Regulated Chemicals, and Hazardous Air Pollutants

Chemical Component	Chemical Category	No. of Products
Methanol (Methyl alcohol)	HAP	342
Ethylene glycol (1,2-ethanediol)	HAP	119
Diesel[19]	Carcinogen, SDWA, HAP	51
Naphthalene	Carcinogen, HAP	44
Xylene	SDWA, HAP	44
Hydrogen chloride (Hydrochloric acid)	HAP	42
Toluene	SDWA, HAP	29
Ethylbenzene	SDWA, HAP	28
Diethanolamine (2,2-iminodiethanol)	HAP	14
Formaldehyde	Carcinogen, HAP	12
Sulfuric acid	Carcinogen	9
Thiourea	Carcinogen	9
Benzyl chloride	Carcinogen, HAP	8
Cumene	HAP	6
Nitrilotriacetic acid	Carcinogen	6
Dimethyl formamide	HAP	5
Phenol	HAP	5
Benzene	Carcinogen, SDWA, HAP	3
Di (2-ethylhexyl) phthalate	Carcinogen, SDWA, HAP	3
Acrylamide	Carcinogen, SDWA, HAP	2
Hydrogen fluoride (Hydrofluoric acid)	HAP	2
Phthalic anhydride	HAP	2
Acetaldehyde	Carcinogen, HAP	1
Acetophenone	HAP	1
Copper	SDWA	1
Ethylene oxide	Carcinogen, HAP	1
Lead	Carcinogen, SDWA, HAP	1
Propylene oxide	Carcinogen, HAP	1
p-Xylene	HAP	1
Number of Products Containing a Component of Concern		**652**

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[19] According to EPA, diesel contains benzene, toluene, ethylbenzene, and xylenes. *See* EPA, *Evaluation of Impacts to Underground Sources of Drinking Water by Hydraulic Fracturing of Coalbed Methane Reservoirs* (June 2004) (EPA 816-R-04-003) at 4-11.

1. Carcinogens

Between 2005 and 2009, the hydraulic fracturing companies used 95 products containing 13 different carcinogens.[20] These included naphthalene (a possible human carcinogen), benzene (a known human carcinogen), and acrylamide (a probable human carcinogen). Overall, these companies injected 10.2 million gallons of fracturing products containing at least one carcinogen. The companies used the highest volume of fluids containing one or more carcinogens in Texas, Colorado, and Oklahoma. Table 4 shows the use of these chemicals by state.

Table 4. States with at Least 100,000 Gallons of Hydraulic Fracturing Fluids Containing a Carcinogen (2005-2009)

State	Fluid Volume (gallons)
Texas	3,877,273
Colorado	1,544,388
Oklahoma	1,098,746
Louisiana	777,945
Wyoming	759,898
North Dakota	557,519
New Mexico	511,186
Montana	394,873
Utah	382,338

2. Safe Drinking Water Act Chemicals

Under the Safe Drinking Water Act, EPA regulates 53 chemicals that may have an adverse effect on human health and are known to or likely to occur in public drinking water systems at levels of public health concern. Between 2005 and 2009, the hydraulic fracturing companies used 67 products containing at least one of eight SDWA-regulated chemicals. Overall, they injected 11.7 million gallons of fracturing products containing at least one chemical regulated under SDWA. Most of these chemicals were injected in Texas. Table 5 shows the use of these chemicals by state.

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[20] For purposes of this report, a chemical is considered a “carcinogen” if it is on one of two lists: (1) substances identified by the National Toxicology Program as “known to be human carcinogens” or as “reasonably anticipated to be human carcinogens”; and (2) substances identified by the International Agency for Research on Cancer, part of the World Health Organization, as “carcinogenic” or “probably carcinogenic” to humans. See U.S. Department of Health and Human Services, Public Health Service, National Toxicology Program, *Report on Carcinogens*, *Eleventh Edition* (Jan. 31, 2005) and World Health Organization, International Agency for Research on Cancer, *Agents Classified by the IARC Monographs* (online at http://monographs.iarc.fr/ENG/Classification/index.php) (accessed Feb. 28, 2011).

The vast majority of these SDWA-regulated chemicals were the BTEX compounds – benzene, toluene, xylene, and ethylbenzene. The BTEX compounds appeared in 60 hydraulic fracturing products used between 2005 and 2009 and were used in 11.4 million gallons of hydraulic fracturing fluids. The Department of Health and Human Services, the International Agency for Research on Cancer, and EPA have determined that benzene is a human carcinogen.[21] Chronic exposure to toluene, ethylbenzene, or xylenes also can damage the central nervous system, liver, and kidneys.[22]

Table 5. States with at Least 100,000 Gallons of Hydraulic Fracturing Fluids Containing a SDWA-Regulated Chemical (2005-2009)

State	Fluid Volume (gallons)
Texas	9,474,631
New Mexico	1,157,721
Colorado	375,817
Oklahoma	202,562
Mississippi	108,809
North Dakota	100,479

In addition, the hydraulic fracturing companies injected more than 30 million gallons of diesel fuel or hydraulic fracturing fluids containing diesel fuel in wells in 19 states.[23] In a 2004 report, EPA stated that the "use of diesel fuel in fracturing fluids poses the greatest threat" to underground sources of drinking water.[24] Diesel fuel contains toxic constituents, including BTEX compounds.[25]

EPA also has created a Candidate Contaminant List (CCL), which is a list of contaminants that are currently not subject to national primary drinking water regulations but are known or anticipated to occur in public water systems and may require regulation under the Safe Drinking Water Act in the future.[26] Nine chemicals on that list—1-butanol, acetaldehyde, benzyl

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[21] U.S. Department of Health and Human Services, Agency for Toxic Substances and Disease Registry, *Public Health Statement for Benzene* (Aug. 2007).

[22] EPA, *Basic Information about Toluene in Drinking Water, Basic Information about Ethylbenzene in Drinking Water*, and *Basic Information about Xylenes in Drinking Water* (online at http://water.epa.gov/drink/contaminants/basicinformation/index.cfm) (accessed Oct. 14, 2010).

[23] Letter from Reps. Henry A. Waxman, Edward J. Markey, and Diana DeGette to the Honorable Lisa Jackson, Administrator, U.S. Environmental Protection Agency (Jan. 31, 2011).

[24] EPA, *Evaluation of Impacts to Underground Sources of Drinking Water by Hydraulic Fracturing of Coalbed Methane Reservoirs* (June 2004) (EPA 816-R-04-003) at 4-11.

[25] *Id.*

[26] EPA, *Contaminant Candidate List 3* (online at http://water.epa.gov/scitech/drinkingwater/dws/ccl/ccl3.cfm) (accessed Mar. 31, 2011).

chloride, ethylene glycol, ethylene oxide, formaldehyde, methanol, n-methyl-2-pyrrolidone, and propylene oxide—were used in hydraulic fracturing products between 2005 and 2009.

3. Hazardous Air Pollutants

The Clean Air Act requires EPA to control the emission of 187 hazardous air pollutants, which are pollutants that cause or may cause cancer or other serious health effects, such as reproductive effects or birth defects, or adverse environmental and ecological effects.[27] Between 2005 and 2009, the hydraulic fracturing companies used 595 products containing 24 different hazardous air pollutants.

Hydrogen fluoride is a hazardous air pollutant that is a highly corrosive and systemic poison that causes severe and sometimes delayed health effects due to deep tissue penetration. Absorption of substantial amounts of hydrogen fluoride by any route may be fatal.[28] One of the hydraulic fracturing companies used 67,222 gallons of two products containing hydrogen fluoride in 2008 and 2009.

Lead is a hazardous air pollutant that is a heavy metal that is particularly harmful to children's neurological development. It also can cause health problems in adults, including reproductive problems, high blood pressure, and nerve disorders.[29] One of the hydraulic fracturing companies used 780 gallons of a product containing lead in this five-year period.

Methanol is the hazardous air pollutant that appeared most often in hydraulic fracturing products. Other hazardous air pollutants used in hydraulic fracturing fluids included formaldehyde, hydrogen chloride, and ethylene glycol.

V. USE OF PROPRIETARY AND "TRADE SECRET" CHEMICALS

Many chemical components of hydraulic fracturing fluids used by the companies were listed on the MSDSs as "proprietary" or "trade secret." The hydraulic fracturing companies used 93.6 million gallons of 279 products containing at least one proprietary component between 2005 and 2009.[30]

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[27] Clean Air Act Section 112(b), 42 U.S.C. § 7412.

[28] HHS, Agency for Toxic Substances and Disease Registry, *Medical Management Guidelines for Hydrogen Fluoride* (online at www.atsdr.cdc.gov/mhmi/mmg11.pdf) (accessed Mar. 24, 2011).

[29] EPA, *Basic Information about Lead* (online at www.epa.gov/lead/pubs/leadinfo.htm) (accessed Mar. 30, 2011).

[30] This is likely a conservative estimate. We included only those products for which the MSDS says "proprietary" or "trade secret" instead of listing a component by name or providing the CAS number. If the MSDS listed a component's CAS as N.A. or left it blank, we did not count that as a trade secret claim, unless the company specified as such in follow-up correspondence.

The Committee requested that these companies disclose this proprietary information. Although a few companies were able to provide additional information to the Committee about some of the fracturing products, in most cases the companies stated that they did not have access to proprietary information about products they purchased "off the shelf" from chemical suppliers. The proprietary information belongs to the suppliers, not the users of the chemicals.

Universal Well Services, for example, told the Committee that it "obtains hydraulic fracturing products from third-party manufacturers, and to the extent not publicly disclosed, product composition is proprietary to the respective vendor and not to the Company."[31] Complete Production Services noted that the company always uses fluids from third-party suppliers who provide an MSDS for each product. Complete confirmed that it is "not aware of any circumstances in which the vendors who provided the products have disclosed this proprietary information" to the company, further noting that "such information is highly proprietary for these vendors, and would not generally be disclosed to service providers" like Complete.[32] Key Energy Services similarly stated that it "generally does not have access to the trade secret information as a purchaser of the chemical(s)."[33] Trican also told the Committee that it has limited knowledge of "off the shelf" products purchased from a chemical distributor or manufacturer, noting that "Trican does not have any information in its possession about the components of such products beyond what the distributor of each product provided Trican in the MSDS sheet."[34]

In these cases, it appears that the companies are injecting fluids containing unknown chemicals about which they may have limited understanding of the potential risks posed to human health and the environment.

VI. CONCLUSION

Hydraulic fracturing has opened access to vast domestic reserves of natural gas that could provide an important stepping stone to a clean energy future. Yet questions about the safety of hydraulic fracturing persist, which are compounded by the secrecy surrounding the chemicals used in hydraulic fracturing fluids. This analysis is the most comprehensive national assessment to date of the types and volumes of chemical used in the hydraulic fracturing process. It shows that between 2005 and 2009, the 14 leading hydraulic fracturing companies in the United States used over 2,500 hydraulic fracturing products containing 750 compounds. More than 650 of these products contained chemicals that are known or possible human carcinogens, regulated under the Safe Drinking Water Act, or listed as hazardous air pollutants.

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[31] Letter from Reginald J. Brown to Henry A. Waxman, Chairman, Committee on Energy and Commerce, and Edward J. Markey, Chairman, Subcommittee on Energy and Environment (Apr. 16, 2010).

[32] Letter from Philip Perry to Henry A. Waxman, Chairman, Committee Energy and Commerce, and Edward J. Markey, Chairman, Subcommittee on Energy and Environment (Aug. 6, 2010).

[33] E-mail from Peter Spivack to Committee Staff (Aug. 5, 2010).

[34] E-mail from Lee Blalack to Committee Staff (July 29, 2010).

Appendix A. Chemical Components of Hydraulic Fracturing Products, 2005-2009[35]

Chemical Component	Chemical Abstract Service Number	No. of Products Containing Chemical
1-(1-naphthylmethyl)quinolinium chloride	65322-65-8	1
1,2,3-propanetricarboxylic acid, 2-hydroxy-, trisodium salt, dihydrate	6132-04-3	1
1,2,3-trimethylbenzene	526-73-8	1
1,2,4-trimethylbenzene	95-63-6	21
1,2-benzisothiazol-3	2634-33-5	1
1,2-dibromo-2,4-dicyanobutane	35691-65-7	1
1,2-ethanediaminium, N, N'-bis[2-[bis(2-hydroxyethyl)methylammonio]ethyl]-N,N'-bis(2-hydroxyethyl)-N,N'-dimethyl-,tetrachloride	138879-94-4	2
1,3,5-trimethylbenzene	108-67-8	3
1,6-hexanediamine dihydrochloride	6055-52-3	1
1,8-diamino-3,6-dioxaoctane	929-59-9	1
1-hexanol	111-27-3	1
1-methoxy-2-propanol	107-98-2	3
2,2`-azobis (2-amidopropane) dihydrochloride	2997-92-4	1
2,2-dibromo-3-nitrilopropionamide	10222-01-2	27
2-acrylamido-2-methylpropanesulphonic acid sodium salt polymer	*	1
2-bromo-2-nitropropane-1,3-diol	52-51-7	4
2-butanone oxime	96-29-7	1
2-hydroxypropionic acid	79-33-4	2
2-mercaptoethanol (Thioglycol)	60-24-2	13
2-methyl-4-isothiazolin-3-one	2682-20-4	4
2-monobromo-3-nitrilopropionamide	1113-55-9	1
2-phosphonobutane-1,2,4-tricarboxylic acid	37971-36-1	2
2-phosphonobutane-1,2,4-tricarboxylic acid, potassium salt	93858-78-7	1
2-substituted aromatic amine salt	*	1
4,4'-diaminodiphenyl sulfone	80-08-0	3
5-chloro-2-methyl-4-isothiazolin-3-one	26172-55-4	5
Acetaldehyde	75-07-0	1
Acetic acid	64-19-7	56
Acetic anhydride	108-24-7	7
Acetone	67-64-1	3
Acetophenone	98-86-2	1
Acetylenic alcohol	*	1
Acetyltriethyl citrate	77-89-4	1
Acrylamide	79-06-1	2
Acrylamide copolymer	*	1
Acrylamide copolymer	38193-60-1	1

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[35] To compile this list of chemicals, Committee staff reviewed each Material Safety Data Sheet provided to the Committee for hydraulic fracturing products used between 2005 and 2009. Committee staff transcribed the names and CAS numbers as written in the MSDSs; as such, any inaccuracies on this list reflect inaccuracies on the MSDSs themselves.

Chemical Component	Chemical Abstract Service Number	No. of Products Containing Chemical
Acrylate copolymer	*	1
Acrylic acid, 2-hydroxyethyl ester	818-61-1	1
Acrylic acid/2-acrylamido-methylpropylsulfonic acid copolymer	37350-42-8	1
Acrylic copolymer	403730-32-5	1
Acrylic polymers	*	1
Acrylic polymers	26006-22-4	2
Acyclic hydrocarbon blend	*	1
Adipic acid	124-04-9	6
Alcohol alkoxylate	*	5
Alcohol ethoxylates	*	2
Alcohols	*	9
Alcohols, C11-15-secondary, ethoxylated	68131-40-8	1
Alcohols, C12-14-secondary	126950-60-5	4
Alcohols, C12-14-secondary, ethoxylated	84133-50-6	19
Alcohols, C12-15, ethoxylated	68131-39-5	2
Alcohols, C12-16, ethoxylated	103331-86-8	1
Alcohols, C12-16, ethoxylated	68551-12-2	3
Alcohols, C14-15, ethoxylated	68951-67-7	5
Alcohols, C9-11-iso-, C10-rich, ethoxylated	78330-20-8	4
Alcohols, C9-C22	*	1
Aldehyde	*	4
Aldol	107-89-1	1
Alfa-Alumina	*	5
Aliphatic acid	*	1
Aliphatic alcohol polyglycol ether	68015-67-8	1
Aliphatic amine derivative	120086-58-0	2
Alkaline bromide salts	*	2
Alkanes, C10-14	93924-07-3	2
Alkanes, C13-16-iso	68551-20-2	2
Alkanolamine	150-25-4	3
Alkanolamine chelate of zirconium alkoxide (Zirconium complex)	197980-53-3	4
Alkanolamine/aldehyde condensate	*	1
Alkenes	*	1
Alkenes, C>10 alpha-	64743-02-8	3
Alkenes, C>8	68411-00-7	2
Alkoxylated alcohols	*	1
Alkoxylated amines	*	6
Alkoxylated phenol formaldehyde resin	63428-92-2	1
Alkyaryl sulfonate	*	1
Alkyl (C12-16) dimethyl benzyl ammonium chloride	68424-85-1	7
Alkyl (C6-C12) alcohol, ethoxylated	68439-45-2	2
Alkyl (C9-11) alcohol, ethoxylated	68439-46-3	1
Alkyl alkoxylate	*	9
Alkyl amine	*	2

Chemical Component	Chemical Abstract Service Number	No. of Products Containing Chemical
Alkyl amine blend in a metal salt solution	*	1
Alkyl aryl amine sulfonate	255043-08-04	1
Alkyl benzenesulfonic acid	68584-22-5	2
Alkyl esters	*	2
Alkyl hexanol	*	1
Alkyl ortho phosphate ester	*	1
Alkyl phosphate ester	*	3
Alkyl quaternary ammonium chlorides	*	4
Alkylaryl sulfonate	*	1
Alkylaryl sulphonic acid	27176-93-9	1
Alkylated quaternary chloride	*	5
Alkylbenzenesulfonic acid	*	1
Alkylethoammonium sulfates	*	1
Alkylphenol ethoxylates	*	1
Almandite and pyrope garnet	1302-62-1	1
Aluminium isopropoxide	555-31-7	1
Aluminum	7429-90-5	2
Aluminum chloride	*	3
Aluminum chloride	1327-41-9	2
Aluminum oxide (alpha-Alumina)	1344-28-1	24
Aluminum oxide silicate	12068-56-3	1
Aluminum silicate (mullite)	1302-76-7	38
Aluminum sulfate hydrate	10043-01-3	1
Amides, tallow, n-[3-(dimethylamino)propyl],n-oxides	68647-77-8	4
Amidoamine	*	1
Amine	*	7
Amine bisulfite	13427-63-9	1
Amine oxides	*	1
Amine phosphonate	*	3
Amine salt	*	2
Amines, C14-18; C16-18-unsaturated, alkyl, ethoxylated	68155-39-5	1
Amines, coco alkyl, acetate	61790-57-6	3
Amines, polyethylenepoly-, ethoxylated, phosphonomethylated	68966-36-9	1
Amines, tallow alkyl, ethoxylated	61791-26-2	2
Amino compounds	*	1
Amino methylene phosphonic acid salt	*	1
Amino trimethylene phosphonic acid	6419-19-8	2
Ammonia	7664-41-7	7
Ammonium acetate	631-61-8	4
Ammonium alcohol ether sulfate	68037-05-8	1
Ammonium bicarbonate	1066-33-7	1
Ammonium bifluoride (Ammonium hydrogen difluoride)	1341-49-7	10
Ammonium bisulfate	7783-20-2	3
Ammonium bisulfite	10192-30-0	15

Chemical Component	Chemical Abstract Service Number	No. of Products Containing Chemical
Ammonium C6-C10 alcohol ethoxysulfate	68187-17-7	4
Ammonium C8-C10 alkyl ether sulfate	68891-29-2	4
Ammonium chloride	12125-02-9	29
Ammonium fluoride	12125-01-8	9
Ammonium hydroxide	1336-21-6	4
Ammonium nitrate	6484-52-2	2
Ammonium persulfate (Diammonium peroxidisulfate)	7727-54-0	37
Ammonium salt	*	1
Ammonium salt of ethoxylated alcohol sulfate	*	1
Amorphous silica	99439-28-8	1
Amphoteric alkyl amine	61789-39-7	1
Anionic copolymer	*	3
Anionic polyacrylamide	*	1
Anionic polyacrylamide	25085-02-3	6
Anionic polyacrylamide copolymer	*	3
Anionic polymer	*	2
Anionic polymer in solution	*	1
Anionic polymer, sodium salt	9003-04-7	1
Anionic water-soluble polymer	*	2
Antifoulant	*	1
Antimonate salt	*	1
Antimony pentoxide	1314-60-9	2
Antimony potassium oxide	29638-69-5	4
Antimony trichloride	10025-91-9	2
a-organic surfactants	61790-29-8	1
Aromatic alcohol glycol ether	*	2
Aromatic aldehyde	*	2
Aromatic ketones	224635-63-6	2
Aromatic polyglycol ether	*	1
Barium sulfate	7727-43-7	3
Bauxite	1318-16-7	16
Bentonite	1302-78-9	2
Benzene	71-43-2	3
Benzene, C10-16, alkyl derivatives	68648-87-3	1
Benzenecarboperoxoic acid, 1,1-dimethylethyl ester	614-45-9	1
Benzenemethanaminium	3844-45-9	1
Benzenesulfonic acid, C10-16-alkyl derivs., potassium salts	68584-27-0	1
Benzoic acid	65-85-0	11
Benzyl chloride	100-44-7	8
Biocide component	*	3
Bis(1-methylethyl)naphthalenesulfonic acid, cyclohexylamine salt	68425-61-6	1
Bishexamethylenetriamine penta methylene phosphonic acid	35657-77-3	1
Bisphenol A/Epichlorohydrin resin	25068-38-6	5
Bisphenol A/Novolac epoxy resin	28906-96-9	1

Chemical Component	Chemical Abstract Service Number	No. of Products Containing Chemical
Borate	12280-03-4	2
Borate salts	*	5
Boric acid	10043-35-3	18
Boric acid, potassium salt	20786-60-1	1
Boric acid, sodium salt	1333-73-9	2
Boric oxide	1303-86-2	1
b-tricalcium phosphate	7758-87-4	1
Butanedioic acid	2373-38-8	4
Butanol	71-36-3	3
Butyl glycidyl ether	2426-08-6	5
Butyl lactate	138-22-7	4
C10-C16 ethoxylated alcohol	68002-97-1	4
C-11 to C-14 n-alkanes, mixed	*	1
C12-C14 alcohol, ethoxylated	68439-50-9	3
Calcium carbonate	471-34-1	1
Calcium carbonate (Limestone)	1317-65-3	9
Calcium chloride	10043-52-4	17
Calcium chloride, dihydrate	10035-04-8	1
Calcium fluoride	7789-75-5	2
Calcium hydroxide	1305-62-0	9
Calcium hypochlorite	7778-54-3	1
Calcium oxide	1305-78-8	6
Calcium peroxide	1305-79-9	5
Carbohydrates	*	3
Carbon dioxide	124-38-9	4
Carboxymethyl guar gum, sodium salt	39346-76-4	7
Carboxymethyl hydroxypropyl guar	68130-15-4	11
Cellophane	9005-81-6	2
Cellulase	9012-54-8	7
Cellulase enzyme	*	1
Cellulose	9004-34-6	1
Cellulose derivative	*	2
Chloromethylnaphthalene quinoline quaternary amine	15619-48-4	3
Chlorous ion solution	*	2
Choline chloride	67-48-1	3
Chromates	*	1
Chromium (iii) acetate	1066-30-4	1
Cinnamaldehyde (3-phenyl-2-propenal)	104-55-2	5
Citric acid (2-hydroxy-1,2,3 propanetricarboxylic acid)	77-92-9	29
Citrus terpenes	94266-47-4	11
Coal, granular	50815-10-6	1
Cobalt acetate	71-48-7	1
Cocaidopropyl betaine	61789-40-0	2
Cocamidopropylamine oxide	68155-09-9	1

Chemical Component	Chemical Abstract Service Number	No. of Products Containing Chemical
Coco bis-(2-hydroxyethyl) amine oxide	61791-47-7	1
Cocoamidopropyl betaine	70851-07-9	1
Cocomidopropyl dimethylamine	68140-01-2	1
Coconut fatty acid diethanolamide	68603-42-9	1
Collagen (Gelatin)	9000-70-8	6
Complex alkylaryl polyo-ester	*	1
Complex aluminum salt	*	2
Complex organometallic salt	*	2
Complex substituted keto-amine	143106-84-7	1
Complex substituted keto-amine hydrochloride	*	1
Copolymer of acrylamide and sodium acrylate	25987-30-8	1
Copper	7440-50-8	1
Copper iodide	7681-65-4	1
Copper sulfate	7758-98-7	3
Corundum (Aluminum oxide)	1302-74-5	48
Crotonaldehyde	123-73-9	1
Crystalline silica - cristobalite	14464-46-1	44
Crystalline silica - quartz (SiO2)	14808-60-7	207
Crystalline silica, tridymite	15468-32-3	2
Cumene	98-82-8	6
Cupric chloride	7447-39-4	10
Cupric chloride dihydrate	10125-13-0	7
Cuprous chloride	7758-89-6	1
Cured acrylic resin	*	7
Cured resin	*	4
Cured silicone rubber-polydimethylsiloxane	63148-62-9	1
Cured urethane resin	*	3
Cyclic alkanes	*	1
Cyclohexane	110-82-7	1
Cyclohexanone	108-94-1	1
Decanol	112-30-1	2
Decyl-dimethyl amine oxide	2605-79-0	4
Dextrose monohydrate	50-99-7	1
D-Glucitol	50-70-4	1
Di (2-ethylhexyl) phthalate	117-81-7	3
Di (ethylene glycol) ethyl ether acetate	112-15-2	4
Diatomaceous earth	61790-53-2	3
Diatomaceous earth, calcined	91053-39-3	7
Dibromoacetonitrile	3252-43-5	1
Dibutylaminoethanol (2-dibutylaminoethanol)	102-81-8	4
Di-calcium silicate	10034-77-2	1
Dicarboxylic acid	*	1
Didecyl dimethyl ammonium chloride	7173-51-5	1
Diesel	*	1

Chemical Component	Chemical Abstract Service Number	No. of Products Containing Chemical
Diesel	68334-30-5	3
Diesel	68476-30-2	4
Diesel	68476-34-6	43
Diethanolamine (2,2-iminodiethanol)	111-42-2	14
Diethylbenzene	25340-17-4	1
Diethylene glycol	111-46-6	8
Diethylene glycol monomethyl ether	111-77-3	4
Diethylene triaminepenta (methylene phosphonic acid)	15827-60-8	1
Diethylenetriamine	111-40-0	2
Diethylenetriamine, tall oil fatty acids reaction product	61790-69-0	1
Diisopropylnaphthalenesulfonic acid	28757-00-8	2
Dimethyl formamide	68-12-2	5
Dimethyl glutarate	1119-40-0	1
Dimethyl silicone	*	2
Dioctyl sodium sulfosuccinate	577-11-7	1
Dipropylene glycol	25265-71-8	1
Dipropylene glycol monomethyl ether (2-methoxymethylethoxy propanol)	34590-94-8	12
Di-secondary-butylphenol	53964-94-6	3
Disodium EDTA	139-33-3	1
Disodium ethylenediaminediacetate	38011-25-5	1
Disodium ethylenediaminetetraacetate dihydrate	6381-92-6	1
Disodium octaborate tetrahydrate	12008-41-2	1
Dispersing agent	*	1
d-Limonene	5989-27-5	11
Dodecyl alcohol ammonium sulfate	32612-48-9	2
Dodecylbenzene sulfonic acid	27176-87-0	14
Dodecylbenzene sulfonic acid salts	42615-29-2	2
Dodecylbenzene sulfonic acid salts	68648-81-7	7
Dodecylbenzene sulfonic acid salts	90218-35-2	1
Dodecylbenzenesulfonate isopropanolamine	42504-46-1	1
Dodecylbenzenesulfonic acid, monoethanolamine salt	26836-07-7	1
Dodecylbenzenesulphonic acid, morpholine salt	12068-08-5	1
EDTA/Copper chelate	*	2
EO-C7-9-iso-, C8-rich alcohols	78330-19-5	5
Epichlorohydrin	25085-99-8	5
Epoxy resin	*	5
Erucic amidopropyl dimethyl betaine	149879-98-1	3
Erythorbic acid	89-65-6	2
Essential oils	*	6
Ethanaminium, n,n,n-trimethyl-2-[(1-oxo-2-propenyl)oxy]-,chloride, polymer with 2-propenamide	69418-26-4	4
Ethanol (Ethyl alcohol)	64-17-5	36
Ethanol, 2-(hydroxymethylamino)-	34375-28-5	1
Ethanol, 2, 2'-(Octadecylamino) bis-	10213-78-2	1

Chemical Component	Chemical Abstract Service Number	No. of Products Containing Chemical
Ethanoldiglycine disodium salt	135-37-5	1
Ether salt	25446-78-0	2
Ethoxylated 4-nonylphenol (Nonyl phenol ethoxylate)	26027-38-3	9
Ethoxylated alcohol	104780-82-7	1
Ethoxylated alcohol	78330-21-9	2
Ethoxylated alcohols	*	3
Ethoxylated alkyl amines	*	1
Ethoxylated amine	*	1
Ethoxylated amines	61791-44-4	1
Ethoxylated fatty acid ester	*	1
Ethoxylated nonionic surfactant	*	1
Ethoxylated nonyl phenol	*	8
Ethoxylated nonyl phenol	68412-54-4	10
Ethoxylated nonyl phenol	9016-45-9	38
Ethoxylated octyl phenol	68987-90-6	1
Ethoxylated octyl phenol	9002-93-1	1
Ethoxylated octyl phenol	9036-19-5	3
Ethoxylated oleyl amine	13127-82-7	2
Ethoxylated oleyl amine	26635-93-8	1
Ethoxylated sorbitol esters	*	1
Ethoxylated tridecyl alcohol phosphate	9046-01-9	2
Ethoxylated undecyl alcohol	127036-24-2	2
Ethyl acetate	141-78-6	4
Ethyl acetoacetate	141-97-9	1
Ethyl octynol (1-octyn-3-ol,4-ethyl-)	5877-42-9	5
Ethylbenzene	100-41-4	28
Ethylene glycol (1,2-ethanediol)	107-21-1	119
Ethylene glycol monobutyl ether (2-butoxyethanol)	111-76-2	126
Ethylene oxide	75-21-8	1
Ethylene oxide-nonylphenol polymer	*	1
Ethylenediaminetetraacetic acid	60-00-4	1
Ethylene-vinyl acetate copolymer	24937-78-8	1
Ethylhexanol (2-ethylhexanol)	104-76-7	18
Fatty acid ester	*	1
Fatty acid, tall oil, hexa esters with sorbitol, ethoxylated	61790-90-7	1
Fatty acids	*	1
Fatty alcohol alkoxylate	*	1
Fatty alkyl amine salt	*	1
Fatty amine carboxylates	*	1
Fatty quaternary ammonium chloride	61789-68-2	1
Ferric chloride	7705-08-0	3
Ferric sulfate	10028-22-5	7
Ferrous sulfate, heptahydrate	7782-63-0	4
Fluoroaliphatic polymeric esters	*	1

Chemical Component	Chemical Abstract Service Number	No. of Products Containing Chemical
Formaldehyde	50-00-0	12
Formaldehyde polymer	*	2
Formaldehyde, polymer with 4-(1,1-dimethyl)phenol, methyloxirane and oxirane	30704-64-4	3
Formaldehyde, polymer with 4-nonylphenol and oxirane	30846-35-6	1
Formaldehyde, polymer with ammonia and phenol	35297-54-2	2
Formamide	75-12-7	5
Formic acid	64-18-6	24
Fumaric acid	110-17-8	8
Furfural	98-01-1	1
Furfuryl alcohol	98-00-0	3
Glass fiber	65997-17-3	3
Gluconic acid	526-95-4	1
Glutaraldehyde	111-30-8	20
Glycerol (1,2,3-Propanetriol, Glycerine)	56-81-5	16
Glycol ethers	*	9
Glycol ethers	9004-77-7	4
Glyoxal	107-22-2	3
Glyoxylic acid	298-12-4	1
Guar gum	9000-30-0	41
Guar gum derivative	*	12
Haloalkyl heteropolycycle salt	*	6
Heavy aromatic distillate	68132-00-3	1
Heavy aromatic petroleum naphtha	64742-94-5	45
Heavy catalytic reformed petroleum naphtha	64741-68-0	10
Hematite	*	5
Hemicellulase	9025-56-3	2
Hexahydro-1,3,5-tris(2-hydroxyethyl)-s-triazine (Triazine)	4719-04-4	4
Hexamethylenetetramine	100-97-0	37
Hexanediamine	124-09-4	1
Hexanes	*	1
Hexylene glycol	107-41-5	5
Hydrated aluminum silicate	1332-58-7	4
Hydrocarbon mixtures	8002-05-9	1
Hydrocarbons	*	3
Hydrodesulfurized kerosine (petroleum)	64742-81-0	3
Hydrodesulfurized light catalytic cracked distillate (petroleum)	68333-25-5	1
Hydrodesulfurized middle distillate (petroleum)	64742-80-9	1
Hydrogen chloride (Hydrochloric acid)	7647-01-0	42
Hydrogen fluoride (Hydrofluoric acid)	7664-39-3	2
Hydrogen peroxide	7722-84-1	4
Hydrogen sulfide	7783-06-4	1
Hydrotreated and hydrocracked base oil	*	2
Hydrotreated heavy naphthenic distillate	64742-52-5	3
Hydrotreated heavy paraffinic petroleum distillates	64742-54-7	1

Chemical Component	Chemical Abstract Service Number	No. of Products Containing Chemical
Hydrotreated heavy petroleum naphtha	64742-48-9	7
Hydrotreated light petroleum distillates	64742-47-8	89
Hydrotreated middle petroleum distillates	64742-46-7	3
Hydroxyacetic acid (Glycolic acid)	79-14-1	6
Hydroxyethylcellulose	9004-62-0	1
Hydroxyethylethylenediaminetriacetic acid, trisodium salt	139-89-9	1
Hydroxylamine hydrochloride	5470-11-1	1
Hydroxypropyl guar gum	39421-75-5	2
Hydroxysultaine	*	1
Inner salt of alkyl amines	*	2
Inorganic borate	*	3
Inorganic particulate	*	1
Inorganic salt	*	1
Inorganic salt	533-96-0	1
Inorganic salt	7446-70-0	1
Instant coffee purchased off the shelf	*	1
Inulin, carboxymethyl ether, sodium salt	430439-54-6	1
Iron oxide	1332-37-2	2
Iron oxide (Ferric oxide)	1309-37-1	18
Iso amyl alcohol	123-51-3	1
Iso-alkanes/n-alkanes	*	10
Isobutanol (Isobutyl alcohol)	78-83-1	4
Isomeric aromatic ammonium salt	*	1
Isooctanol	26952-21-6	1
Isooctyl alcohol	68526-88-0	1
Isooctyl alcohol bottoms	68526-88-5	1
Isopropanol (Isopropyl alcohol, Propan-2-ol)	67-63-0	274
Isopropylamine	75-31-0	1
Isotridecanol, ethoxylated	9043-30-5	1
Kerosene	8008-20-6	13
Lactic acid	10326-41-7	1
Lactic acid	50-21-5	1
L-Dilactide	4511-42-6	1
Lead	7439-92-1	1
Light aromatic solvent naphtha	64742-95-6	11
Light catalytic cracked petroleum distillates	64741-59-9	1
Light naphtha distillate, hydrotreated	64742-53-6	1
Low toxicity base oils	*	1
Maghemite	*	2
Magnesium carbonate	546-93-0	1
Magnesium chloride	7786-30-3	4
Magnesium hydroxide	1309-42-8	4
Magnesium iron silicate	1317-71-1	3
Magnesium nitrate	10377-60-3	5

Chemical Component	Chemical Abstract Service Number	No. of Products Containing Chemical
Magnesium oxide	1309-48-4	18
Magnesium peroxide	1335-26-8	2
Magnesium peroxide	14452-57-4	4
Magnesium phosphide	12057-74-8	1
Magnesium silicate	1343-88-0	3
Magnesium silicate hydrate (talc)	14807-96-6	2
Magnetite	*	3
Medium aliphatic solvent petroleum naphtha	64742-88-7	10
Metal salt	*	2
Metal salt solution	*	1
Methanol (Methyl alcohol)	67-56-1	342
Methyl isobutyl carbinol (Methyl amyl alcohol)	108-11-2	3
Methyl salicylate	119-36-8	6
Methyl vinyl ketone	78-94-4	2
Methylcyclohexane	108-87-2	1
Mica	12001-26-2	3
Microcrystalline silica	1317-95-9	1
Mineral	*	1
Mineral Filler	*	1
Mineral spirits (stoddard solvent)	8052-41-3	2
Mixed titanium ortho ester complexes	*	1
Modified alkane	*	1
Modified cycloaliphatic amine adduct	*	3
Modified lignosulfonate	*	1
Monoethanolamine (Ethanolamine)	141-43-5	17
Monoethanolamine borate	26038-87-9	1
Morpholine	110-91-8	2
Mullite	1302-93-8	55
n,n-dibutylthiourea	109-46-6	1
N,N-dimethyl-1-octadecanamine-HCl	*	1
N,N-dimethyloctadecylamine	124-28-7	3
N,N-dimethyloctadecylamine hydrochloride	1613-17-8	2
n,n'-Methylenebisacrylamide	110-26-9	1
n-alkyl dimethyl benzyl ammonium chloride	139-08-2	1
Naphthalene	91-20-3	44
Naphthalene derivatives	*	1
Naphthalenesulphonic acid, bis (1-methylethyl)-methyl derivatives	99811-86-6	1
Natural asphalt	12002-43-6	1
n-cocoamidopropyl-n,n-dimethyl-n-2-hydroxypropylsulfobetaine	68139-30-0	1
n-dodecyl-2-pyrrolidone	2687-96-9	1
N-heptane	142-82-5	1
Nickel sulfate hexahydrate	10101-97-0	2
Nitrilotriacetamide	4862-18-4	4
Nitrilotriacetic acid	139-13-9	6

Chemical Component	Chemical Abstract Service Number	No. of Products Containing Chemical
Nitrilotriacetonitrile	7327-60-8	3
Nitrogen	7727-37-9	9
n-Methylpyrrolidone	872-50-4	1
Nonane, all isomers	*	1
Non-hazardous salt	*	1
Nonionic surfactant	*	1
Nonyl phenol ethoxylate	*	2
Nonyl phenol ethoxylate	9016-45-6	2
Nonyl phenol ethoxylate	9018-45-9	1
Nonylphenol	25154-52-3	1
Nonylphenol, ethoxylated and sulfated	9081-17-8	1
N-propyl zirconate	*	1
N-tallowalkyltrimethylenediamines	*	1
Nuisance particulates	*	2
Nylon fibers	25038-54-4	2
Octanol	111-87-5	2
Octyltrimethylammonium bromide	57-09-0	1
Olefinic sulfonate	*	1
Olefins	*	1
Organic acid salt	*	3
Organic acids	*	1
Organic phosphonate	*	1
Organic phosphonate salts	*	1
Organic phosphonic acid salts	*	6
Organic salt	*	1
Organic sulfur compound	*	2
Organic titanate	*	2
Organiophilic clay	*	2
Organo-metallic ammonium complex	*	1
Other inorganic compounds	*	1
Oxirane, methyl-, polymer with oxirane, mono-C10-16-alkyl ethers, phosphates	68649-29-6	1
Oxyalkylated alcohol	*	6
Oxyalkylated alcohols	228414-35-5	1
Oxyalkylated alkyl alcohol	*	1
Oxyalkylated alkylphenol	*	1
Oxyalkylated fatty acid	*	2
Oxyalkylated phenol	*	1
Oxyalkylated polyamine	*	1
Oxylated alcohol	*	1
Paraffin wax	8002-74-2	1
Paraffinic naphthenic solvent	*	1
Paraffinic solvent	*	5
Paraffins	*	1
Perlite	93763-70-3	1

Chemical Component	Chemical Abstract Service Number	No. of Products Containing Chemical
Petroleum distillates	*	26
Petroleum distillates	64742-65-0	1
Petroleum distillates	64742-97-5	1
Petroleum distillates	68477-31-6	3
Petroleum gas oils	*	1
Petroleum gas oils	64741-43-1	1
Phenol	108-95-2	5
Phenol-formaldehyde resin	9003-35-4	32
Phosphate ester	*	6
Phosphate esters of alkyl phenyl ethoxylate	68412-53-3	1
Phosphine	*	1
Phosphonic acid	*	1
Phosphonic acid	129828-36-0	1
Phosphonic acid	13598-36-2	3
Phosphonic acid (dimethlamino(methylene))	29712-30-9	1
Phosphonic acid, [nitrilotris(methylene)]tris-, pentasodium salt	2235-43-0	1
Phosphoric acid	7664-38-2	7
Phosphoric acid ammonium salt	*	1
Phosphoric acid, mixed decyl, octyl and ethyl esters	68412-60-2	3
Phosphorous acid	10294-56-1	1
Phthalic anhydride	85-44-9	2
Pine oil	8002-09-3	5
Plasticizer	*	1
Poly(oxy-1,2-ethanediyl)	24938-91-8	1
Poly(oxy-1,2-ethanediyl), alpha-(4-nonylphenyl)-omega-hydroxy-, branched (Nonylphenol ethoxylate)	127087-87-0	3
Poly(oxy-1,2-ethanediyl), alpha-hydro-omega-hydroxy	65545-80-4	1
Poly(oxy-1,2-ethanediyl), alpha-sulfo-omega-(hexyloxy)-, ammonium salt	63428-86-4	3
Poly(oxy-1,2-ethanediyl),a-(nonylphenyl)-w-hydroxy-, phosphate	51811-79-1	1
Poly-(oxy-1,2-ethanediyl)-alpha-undecyl-omega-hydroxy	34398-01-1	6
Poly(sodium-p-styrenesulfonate)	25704-18-1	1
Poly(vinyl alcohol)	25213-24-5	2
Polyacrylamides	9003-05-8	2
Polyacrylamides	*	1
Polyacrylate	*	1
Polyamine	*	2
Polyanionic cellulose	*	2
Polyepichlorohydrin, trimethylamine quaternized	51838-31-4	1
Polyetheramine	9046-10-0	3
Polyether-modified trisiloxane	27306-78-1	1
Polyethylene glycol	25322-68-3	20
Polyethylene glycol ester with tall oil fatty acid	9005-02-1	1
Polyethylene polyammonium salt	68603-67-8	2
Polyethylene-polypropylene glycol	9003-11-6	5

Chemical Component	Chemical Abstract Service Number	No. of Products Containing Chemical
Polylactide resin	*	3
Polyoxyalkylenes	*	1
Polyoxyethylene castor oil	61791-12-6	1
Polyphosphoric acid, esters with triethanolamine, sodium salts	68131-72-6	1
Polypropylene glycol	25322-69-4	1
Polysaccharide	*	20
Polyvinyl alcohol	*	1
Polyvinyl alcohol	9002-89-5	2
Polyvinyl alcohol/polyvinylacetate copolymer	*	1
Potassium acetate	127-08-2	1
Potassium carbonate	584-08-7	12
Potassium chloride	7447-40-7	29
Potassium formate	590-29-4	3
Potassium hydroxide	1310-58-3	25
Potassium iodide	7681-11-0	6
Potassium metaborate	13709-94-9	3
Potassium metaborate	16481-66-6	3
Potassium oxide	12136-45-7	1
Potassium pentaborate	*	1
Potassium persulfate	7727-21-1	9
Propanol (Propyl alcohol)	71-23-8	18
Propanol, [2(2-methoxy-methylethoxy) methylethoxyl]	20324-33-8	1
Propargyl alcohol (2-propyn-1-ol)	107-19-7	46
Propylene carbonate (1,3-dioxolan-2-one, methyl-)	108-32-7	2
Propylene glycol (1,2-propanediol)	57-55-6	18
Propylene oxide	75-56-9	1
Propylene pentamer	15220-87-8	1
p-Xylene	106-42-3	1
Pyridinium, 1-(phenylmethyl)-, ethyl methyl derivatives, chlorides	68909-18-2	9
Pyrogenic silica	112945-52-5	3
Quaternary amine compounds	*	3
Quaternary amine compounds	61789-18-2	1
Quaternary ammonium compounds	*	9
Quaternary ammonium compounds	19277-88-4	1
Quaternary ammonium compounds	68989-00-4	1
Quaternary ammonium compounds	8030-78-2	1
Quaternary ammonium compounds, dicoco alkyldimethyl, chlorides	61789-77-3	2
Quaternary ammonium salts	*	2
Quaternary compound	*	1
Quaternary salt	*	2
Quaternized alkyl nitrogenated compound	68391-11-7	2
Rafinnates (petroleum), sorption process	64741-85-1	2
Residues (petroleum), catalytic reformer fractionator	64741-67-9	10
Resin	8050-09-7	2

Chemical Component	Chemical Abstract Service Number	No. of Products Containing Chemical
Rutile	1317-80-2	2
Salt of phosphate ester	*	3
Salt of phosphono-methylated diamine	*	1
Salts of oxyalkylated fatty amines	68551-33-7	1
Secondary alcohol	*	7
Silica (Silicon dioxide)	7631-86-9	47
Silica, amorphous	*	3
Silica, amorphous precipitated	67762-90-7	1
Silicon carboxylate	681-84-5	1
Silicon dioxide (Fused silica)	60676-86-0	7
Silicone emulsion	*	1
Sodium (C14-16) olefin sulfonate	68439-57-6	4
Sodium 2-ethylhexyl sulfate	126-92-1	1
Sodium acetate	127-09-3	6
Sodium acid pyrophosphate	7758-16-9	5
Sodium alkyl diphenyl oxide sulfonate	28519-02-0	1
Sodium aluminate	1302-42-7	1
Sodium aluminum phosphate	7785-88-8	1
Sodium bicarbonate (Sodium hydrogen carbonate)	144-55-8	10
Sodium bisulfite	7631-90-5	6
Sodium bromate	7789-38-0	10
Sodium bromide	7647-15-6	1
Sodium carbonate	497-19-8	14
Sodium chlorate	7775-09-9	1
Sodium chloride	7647-14-5	48
Sodium chlorite	7758-19-2	8
Sodium cocaminopropionate	68608-68-4	2
Sodium diacetate	126-96-5	2
Sodium erythorbate	6381-77-7	4
Sodium glycolate	2836-32-0	2
Sodium hydroxide (Caustic soda)	1310-73-2	80
Sodium hypochlorite	7681-52-9	14
Sodium lauryl-ether sulfate	68891-38-3	3
Sodium metabisulfite	7681-57-4	1
Sodium metaborate	7775-19-1	2
Sodium metaborate tetrahydrate	35585-58-1	6
Sodium metasilicate, anhydrous	6834-92-0	2
Sodium nitrite	7632-00-0	1
Sodium oxide (Na2O)	1313-59-3	1
Sodium perborate	1113-47-9	1
Sodium perborate	7632-04-4	1
Sodium perborate tetrahydrate	10486-00-7	4
Sodium persulfate	7775-27-1	6
Sodium phosphate	*	2

Chemical Component	Chemical Abstract Service Number	No. of Products Containing Chemical
Sodium polyphosphate	68915-31-1	1
Sodium salicylate	54-21-7	1
Sodium silicate	1344-09-8	2
Sodium sulfate	7757-82-6	7
Sodium tetraborate	1330-43-4	7
Sodium tetraborate decahydrate	1303-96-4	10
Sodium thiosulfate	7772-98-7	10
Sodium thiosulfate pentahydrate	10102-17-7	3
Sodium trichloroacetate	650-51-1	1
Sodium tripolyphosphate	7758-29-4	2
Sodium xylene sulfonate	1300-72-7	3
Sodium zirconium lactate	174206-15-6	1
Solvent refined heavy naphthenic petroleum distillates	64741-96-4	1
Sorbitan monooleate	1338-43-8	1
Stabilized aqueous chlorine dioxide	10049-04-4	1
Stannous chloride	7772-99-8	1
Stannous chloride dihydrate	10025-69-1	6
Starch	9005-25-8	5
Steam cracked distillate, cyclodiene dimer, dicyclopentadiene polymer	68131-87-3	1
Steam-cracked petroleum distillates	64742-91-2	6
Straight run middle petroleum distillates	64741-44-2	5
Substituted alcohol	*	2
Substituted alkene	*	1
Substituted alkylamine	*	2
Sucrose	57-50-1	1
Sulfamic acid	5329-14-6	6
Sulfate	*	1
Sulfonate acids	*	1
Sulfonate surfactants	*	1
Sulfonic acid salts	*	1
Sulfonic acids, petroleum	61789-85-3	1
Sulfur compound	*	1
Sulfuric acid	7664-93-9	9
Sulfuric acid, monodecyl ester, sodium salt	142-87-0	2
Sulfuric acid, monooctyl ester, sodium salt	142-31-4	2
Surfactants	*	13
Sweetened middle distillate	64741-86-2	1
Synthetic organic polymer	9051-89-2	2
Tall oil (Fatty acids)	61790-12-3	4
Tall oil, compound with diethanolamine	68092-28-4	1
Tallow soap	*	2
Tar bases, quinoline derivatives, benzyl chloride-quaternized	72480-70-7	5
Tergitol	68439-51-0	1
Terpene hydrocarbon byproducts	68956-56-9	3

Chemical Component	Chemical Abstract Service Number	No. of Products Containing Chemical
Terpenes	*	1
Terpenes and terpenoids, sweet orange-oil	68647-72-3	2
Terpineol	8000-41-7	1
Tert-butyl hydroperoxide	75-91-2	6
Tetra-calcium-alumino-ferrite	12068-35-8	1
Tetraethylene glycol	112-60-7	1
Tetraethylenepentamine	112-57-2	2
Tetrahydro-3,5-dimethyl-2H-1,3,5-thiadiazine-2-thione (Dazomet)	533-74-4	13
Tetrakis (hydroxymethyl) phosphonium sulfate	55566-30-8	12
Tetramethyl ammonium chloride	75-57-0	14
Tetrasodium 1-hydroxyethylidene-1,1-diphosphonic acid	3794-83-0	1
Tetrasodium ethylenediaminetetraacetate	64-02-8	10
Thiocyanate sodium	540-72-7	1
Thioglycolic acid	68-11-1	6
Thiourea	62-56-6	9
Thiourea polymer	68527-49-1	3
Titanium complex	*	1
Titanium oxide	13463-67-7	19
Titanium, isopropoxy (triethanolaminate)	74665-17-1	2
Toluene	108-88-3	29
Treated ammonium chloride (with anti-caking agent a or b)	12125-02-9	1
Tributyl tetradecyl phosphonium chloride	81741-28-8	5
Tri-calcium silicate	12168-85-3	1
Tridecyl alcohol	112-70-9	1
Triethanolamine (2,2,2-nitrilotriethanol)	102-71-6	21
Triethanolamine polyphosphate ester	68131-71-5	3
Triethanolamine titanate	36673-16-2	1
Triethanolamine zirconate	101033-44-7	6
Triethanolamine zirconium chelate	*	1
Triethyl citrate	77-93-0	1
Triethyl phosphate	78-40-0	1
Triethylene glycol	112-27-6	3
Triisopropanolamine	122-20-3	5
Trimethylammonium chloride	593-81-7	1
Trimethylbenzene	25551-13-7	5
Trimethyloctadecylammonium (1-octadecanaminium, N,N,N-trimethyl-, chloride)	112-03-8	6
Tris(hydroxymethyl)aminomethane	77-86-1	1
Trisodium ethylenediaminetetraacetate	150-38-9	1
Trisodium ethylenediaminetriacetate	19019-43-3	1
Trisodium nitrilotriacetate	18662-53-8	8
Trisodium nitrilotriacetate (Nitrilotriacetic acid, trisodium salt monohydrate)	5064-31-3	9
Trisodium ortho phosphate	7601-54-9	1
Trisodium phosphate dodecahydrate	10101-89-0	1
Ulexite	1319-33-1	1

Chemical Component	Chemical Abstract Service Number	No. of Products Containing Chemical
Urea	57-13-6	3
Wall material	*	1
Walnut hulls	*	2
White mineral oil	8042-47-5	8
Xanthan gum	11138-66-2	6
Xylene	1330-20-7	44
Zinc chloride	7646-85-7	1
Zinc oxide	1314-13-2	2
Zirconium complex	*	10
Zirconium dichloride oxide	7699-43-6	1
Zirconium oxide sulfate	62010-10-0	2
Zirconium sodium hydroxy lactate complex (Sodium zirconium lactate)	113184-20-6	2

** Components marked with an asterisk appeared on at least one MSDS without an identifying CAS number. The MSDSs in these cases marked the CAS as proprietary, noted that the CAS was not available, or left the CAS field blank. Components marked with an asterisk may be duplicative of other components on this list, but Committee staff have no way of identifying such duplicates without the identifying CAS number.*

END OF REPORT