

# Characterization of Greenhouse Gas Emissions Involved in Oil and Gas Exploration and Production Operations

Review for the California Air Resources Board by Angela Zahniser

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***What greenhouse gas (GHG) emissions are associated with oil and gas extraction operations?*** The most significant sources in the oil and natural gas industries are carbon dioxide (CO<sub>2</sub>) and methane (CH<sub>4</sub>). However, nitrous oxide (N<sub>2</sub>O) and Volatile Organic Compounds (VOCs) could be an important indirect air pollutant to account for, as hydrocarbon VOCs aid in the creation of ozone and in prolonging the life of methane in the atmosphere. However, effects can be variable and depend upon air quality conditions in the local area.

***What are the different kinds of oil and gas extraction operations that produce emissions?*** GHGs are produced and emitted by various sources during the exploration, well development, production, and site abandonment phases. The American Petroleum Institute (API) categorizes the emissions sources of all oil and gas operations (including refineries) into five classifications:

- a.) Combustion Devices—includes stationary (burners, flares) and mobile (trucks, ships) sources
- b.) Point Sources—includes emissions from stacks, vents, ducts
- c.) Non-point Sources—includes fugitive emissions of methane, wastewater treatment facilities, and other sources involved in waste handling
- d.) Non-routine activities—activities associated with non-scheduled maintenance or emergency operations
- e.) Indirect emissions—emissions associated with company operations but physically occurring elsewhere, such as purchased electricity.<sup>1</sup>

During the exploration and well development phases, emissions occur from 1.) clearing the well pad and building roads; 2.) rigging up, drilling, and rigging down and 3.) well completion and testing. During the site production and abandonment phases, GHG emissions are produced by compressor engines, rigging pumps, and pipeline leaks, and will be affected by the number of well site visits and the well site facilities, which are composed of the type of disposal well, the plant and compressor station emissions, and other facilities. Emissions of CO<sub>2</sub> and CH<sub>4</sub> may also occur as a product of the biological oxygen demand (BOD) of wastewater, and as a result of abandonment procedures. The biological oxygen demand of the insects that are contained in the wastewater will determine if there are greenhouse gas emissions. Emissions will be CO<sub>2</sub> if conditions are aerobic and CH<sub>4</sub> if there are anaerobic conditions. GHG emissions will be highly dependent on the content of the wastewater, and the process through which it is handled.

Oil and Gas extraction processes and procedures are not uniform within the recovery industry and will vary according to well number and size, type of resource (oil, natural

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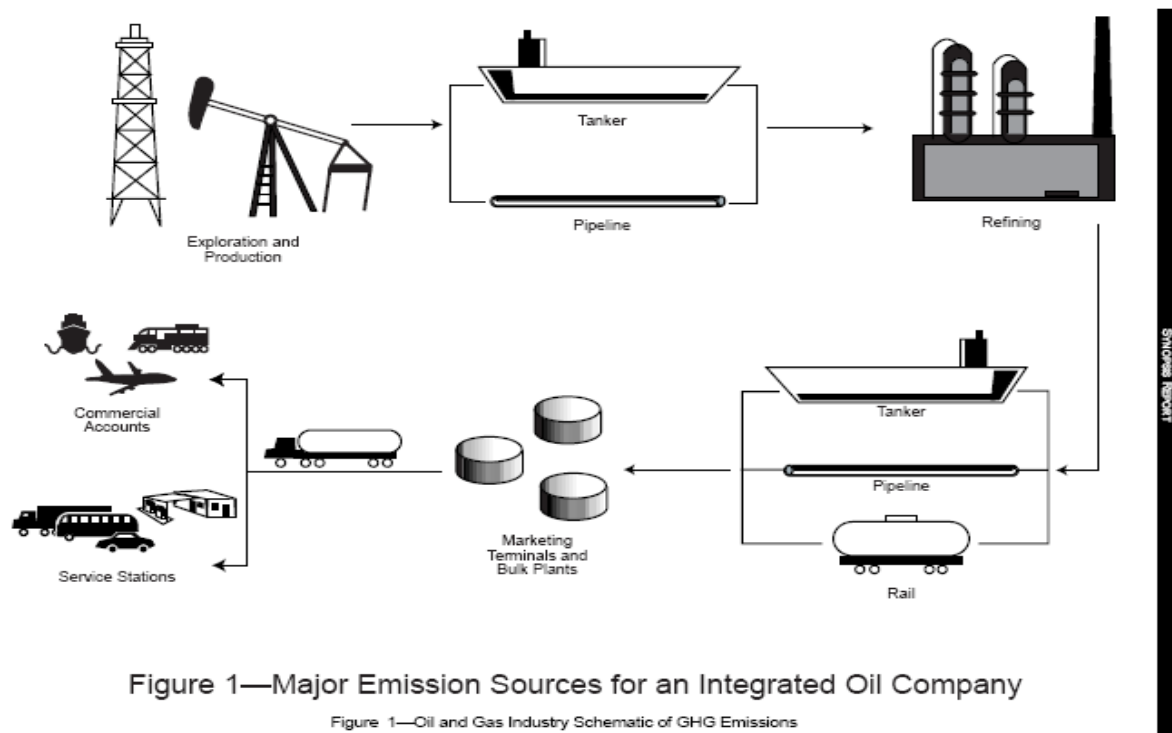
<sup>1</sup> American Petroleum Institute: Toward a Consistent Methodology for Estimating Greenhouse Gas Emissions from Oil and Natural Gas Industry Operations. Page 5.

gas, coalbed natural gas, or oil), amount of reserve, and geographical distribution (e.g. onshore or offshore) of the resource.

Carbon dioxide emissions are mostly the result of combustion emissions (vehicles, stationary engines, etc.), but could also be fugitive because CO<sub>2</sub> is also a component of natural gas. In estimating CO<sub>2</sub> emissions from combustion devices, it is important to determine the amount of fuel consumed, but categorizing it by the type of combustion device is unnecessary because the emission factors for CO<sub>2</sub> are relatively uniform across type of combustion devices.

The majority of CH<sub>4</sub> emissions are fugitive emissions from equipment such as separators, dehydrators, pipelines, wells, gas-powered devices, and miscellaneous other equipment. Methane is also emitted in the exhaust of natural gas combustion engines and turbines, and from operator and control devices. Accidental release can also be a source of methane emissions. Emission factors for methane do vary according to the type of combustion device, and could contribute as much as 17% of greenhouse gas fuel-use emissions.<sup>2</sup> N<sub>2</sub>O emissions from fuel combustion are a much less important contributor to overall fuel-use GHGs.

While this report focuses on emissions in the oil and gas exploration and production side, the diagram below depicts the operations and emissions sources for the lifecycle of oil and gas industry operations:



Source: American Petroleum Institute: *Toward a Consistent Methodology for Estimating Greenhouse Gas Emissions from Oil and Natural Gas Industry Operations*. Page 4.

<sup>2</sup> Canadian Association of Petroleum Producers, Technical Report on A National Inventory of Greenhouse Gas, Criteria Air Contaminant, and Hydrogen Sulphide Emissions by the Upstream Oil and Gas Industry, Volume 4. Page 16. <http://www.capp.ca/raw.asp?x=1&dt=NTV&e=PDF&dn=86224>

The following is a more detailed outline of the process of oil and gas exploration and production, and the possible sources of greenhouse gas emissions associated with them:

## 1. Exploration Phase:

**A.** Seismic waves are generated in an area to determine if there is a reasonable chance that a sufficient amount of hydrocarbons (oil and/or gas) is present and will be discovered if an exploratory well is drilled. These waves can be generated by a variety of sources including the detonation of explosives in holes below the earth's surface; marine airguns (commonly used in offshore exploration); and vibroseis, (specialized trucks that place vibrating pads on hard surfaces such as paved roads in order to create seismic waves). In California, vibroseis is the most common exploration method, and explosive devices are rarely used.

*GHG Emissions:* Depending on method used, CO<sub>2</sub> emissions from truck motors used in vibroseis or the use of explosive devices.

## 2. Well Development Phase:

Natural gas taken from the process is usually the principal type of fuel used for stationary combustion devices. Liquid fuels such as diesel or gasoline are generally used for mobile sources such as trucks and construction equipment. Compressors, pumpjack engines, and portable heaters and torches also sometimes use propane.

**A. *Clearing Area for the Well Pad:*** Large diesel powered trucks are often used to clear an area where the well pad is located. In more recent years, smaller amounts of acreage have been disturbed for the actual well pad. Increased use multi-rig pads can also reduce amount of surface acre disturbance, therefore decreasing number of trucks and truck trips needed for well pad clearance. Additionally, depending on the size of the well, the location, and the number of well pads being cleared, disturbing vegetation could have the effect of eliminating an already established carbon sink through destruction of vegetation and through disturbing organic carbon stored in soil.

*GHG Emissions:* CO<sub>2</sub> combustion emissions from fuel used in trucks. Additionally, one-time and potentially long-term effects could include lost carbon sinks due to surface and vegetation disturbance.

**B. *Constructing Roads:*** Constructing Roads for oil and gas extraction is also a source of GHG emissions, mainly due to fossil fuel combustion emissions from vehicles used to build roads to the wells and rigs. In addition, surfactants are often used on roads for dust prevention. Depending on the type of surfactant used, there could be greenhouse gas emissions associated with the manufacture and application of these surfactants. Generally, there are two types of roads:

1. Access Roads –shorter roads that lead the resource road to the individual well pad
2. Resource Roads--longer, wider, more arterial roads that feed into the access roads

*GHG Emissions:* Combustion emissions, CO<sub>2</sub>, from fuel used in trucks. Additionally, one-time effects could include lost carbon sinks due to surface and vegetation disturbance (see Section 2A).

**C. Rigging Up and Drilling:** The process of setting up a drill rig and performing the actual drilling is a source of GHG emissions from fossil fuel combustion. "Rig" is a general term that refers to the complex set of equipment that is used to drill through the surface of the earth to sample and extract resources. In addition to the actual drill, equipment could include de-sanders, de-silters, vacuum degassers, diesel engines, the derrick, etc. Several factors may influence the type and amount of GHG emissions. First, drill rigs are used for both exploration and production, i.e. they are used to identify reservoirs as well as extract resources from those reservoirs over the longer term. A pumping rig is sometimes called a derrick—it is generally the centerpiece of the rig. Rigs and derricks can either be mobile or stationary, small and portable (e.g. rigs used in exploration drilling), or very large and capable of drilling through thousands of feet. Factors influencing the size and type of rig are: whether or not directional drilling is being performed, the size of the operation, anticipated length and intensity of the operation, and the depth and range of the well. Rigs often have a lot of equipment, such as de-sanders and de-silters, and vacuum degassers, which remove gases. Drilling rigs could have fugitive emissions from leaks in equipment (i.e. pipe fittings), and combustion emissions from operation of the engines and heaters used by the rigs. Combustion emissions should be assessed based on fuel consumption, including the type of fuel consumed by engines and boilers.

*GHG Emissions:* CO<sub>2</sub> combustion emissions from fuel used by rigs. Many rigs are powered with electricity. Therefore, indirect CO<sub>2</sub> emissions could occur from the fuel input used in the electrical generating unit.

**D. Drilling Fluids:** Drilling fluids are used to cool and lubricate the drill bit and to remove rock fragments, and to balance formation pressures. Drilling fluids may be gas, foam, or liquid-based fluids (such as water-based muds). Water-based muds are the most common. There are two potential causes for GHG emissions from drilling fluids: entrainment of solution natural gas and volatilization of drilling fluids. Generally, the net emissions from entrainment are considered to be insignificant when compared to GHG emissions from other sources at the drill site. Usually, invert fluids are composed of about 80% diesel 20% water vapor. The Canadian Association of Petroleum Producers estimate emissions from use of invert fluids by calculating the evaporation rate in the mud

tanks, and applying the result to the total number of operating hours accumulated in the reference year.<sup>3</sup>

*GHG Emissions:* Possible CO<sub>2</sub> and CH<sub>4</sub> from flaring or venting of the vapors associated with the drilling fluids

**E. Casing:** To stabilize the well hole and prevent caving, well casing is placed in the well. The casing is important because it prevents natural gas, oil, and brine from leaking into nearby aquifers.

*GHG Emissions:* Although likely to be insignificant, possible CH<sub>4</sub> fugitive emissions leaks.

**F. Well Completion and Testing (drilling is complete):** When drilling to the reservoir is complete, the well is tested to ensure whether there are enough hydrocarbons to justify well completion and production. Possible tests that may be performed are coring, wireline logging, and drill stem testing. CO<sub>2</sub> and CH<sub>4</sub> may be emitted during the process, depending on which method is used. Fugitive emissions of methane from initial rock fracturing, from flaring, and from compressor stations may occur during this stage.

1. **Fracturing:** Fracturing may also occur during well completion and is a process that involves injecting a substance (usually water) under high pressure down into the rock to blow it open and open up pore space in the rocks, which releases the oil or gas. It occurs after the well is drilled and when it has been determined that the oil or gas doesn't easily come to the surface. Some operations will use produced water from other wells.

*GHG Emissions:* Fugitive CH<sub>4</sub> emissions, CO<sub>2</sub> from fuel used in injection machinery. Diesel trucks are often used.

2. **Flaring:** Flaring, or burning off of excess or waste gas or flammable gas, is sometimes performed when the gas has become over-pressurized. It is also sometimes done prior to initial resource extraction to burn off initial waste gas for one or two days, and then intermittently as needed throughout the extraction process.

*GHG Emissions:* CO<sub>2</sub> and CH<sub>4</sub> However, in California, flaring is allowed only in specific circumstances and it is on a case by case basis. The company must apply for a permit to flare, which is issued by the county or local air board.

3. **Venting:** Venting is the direct release of gas into the atmosphere. It occurs at a number of points in both the oil and gas development process, including well completion, well maintenance, pipeline maintenance, and tank maintenance. Large quantities may be vented to the atmosphere.

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<sup>3</sup> Canadian Association of Petroleum Producers, Technical Report on A National Inventory of Greenhouse Gas, Criteria Air Contaminant, and Hydrogen Sulphide Emissions by the Upstream Oil and Gas Industry, Volume 4. Page 66. <http://www.capp.ca/raw.asp?x=1&dt=NTV&e=PDF&dn=86224>

The alternative to venting is flaring (see F.2.). This raw natural gas may also contain carbon dioxide.

*GHG Emissions:* Because venting in California is not allowed, CO<sub>2</sub> or CH<sub>4</sub> from fugitive emissions could occur. All tanks are covered tanks, and often, a unit will have a vapor recovery system attached. Also important to note is that compliance with venting procedures could be a critical factor in the estimation of GHG emissions.

**4. Compressor Engines:** Compressor engines pressurize the gas in the pipe so that it can more easily move throughout the reservoir. They may be located on the ground next to the well head; however, if the gas is under high natural pressure, compressor engines are unnecessary. Smaller compressor engines have less overall emissions, though they have higher emission rates. Compressor units generally operate with either a reciprocating engine or a turbine engine. Reciprocating engines that operate on natural gas range in size from about 30 to 3500 kW, and operate at speeds of 800 to 1800 rpm. Gas turbine engines generally range from 1 to 25 megawatts. Gas turbines generally emit less exhaust than reciprocating engines, where methane emissions are an order of a magnitude lower than in reciprocator engines.<sup>4</sup>

*GHG Emissions:* CO<sub>2</sub> associated with combustion of fuel input (diesel or natural gas) into the compressor engine.

**5. Tubing Installation:** Tubing to carry liquids and gas to the surface is usually installed after testing has warranted well production capability. Equipment and installation could include pump separation equipment, and a pipeline connector or storage tank.

*GHG Emissions:* Fugitive CH<sub>4</sub> emissions and CO<sub>2</sub> emissions from fuel combustion associated with installation of equipment.

### 3. Primary and Secondary Production Phases:

**A. Compressor Equipment:** As in the well completion and testing phase, equipment used to increase the reservoir pressure is often used. Equipment may include compressor engines, stations, pumps, or gas lift valves. They are used throughout the production phase in order to continue to pressurize the gas in the pipeline(s) so that it can more easily move throughout the reservoir. They may be located on the ground next to the well head; however, if the gas is under high natural pressure, compressor equipment may be unnecessary. Smaller compressor engines have less overall emissions, though they have higher emission rates. In multi-pad operations, there may also be centrally located compressor stations, which provide energy to the smaller wellside stations in the

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<sup>4</sup> Canadian Association of Petroleum Producer, Technical Report on A National Inventory of Greenhouse Gas, Criteria Air Contaminant, and Hydrogen Sulphide Emissions by the Upstream Oil and Gas Industry, Volume 4. Page 21. <http://www.capp.ca/raw.asp?x=1&dt=NTV&e=PDF&dn=86224>

area. They are usually large buildings and can be fueled by diesel or natural gas. Compressor units generally operate with either a reciprocating engine or a turbine engine. Reciprocating engines that operate on natural gas range in size from about 30 to 3500 kW, and operate at speeds of 800 to 1800 rpm. Gas turbine engines generally range from 1 to 25 megawatts. Gas turbines generally emit less exhaust than reciprocating engines, where methane emissions are an order of a magnitude lower than in reciprocator engines.

*GHG Emissions:* CO<sub>2</sub> and CH<sub>4</sub> associated with combustion of fuel input (diesel, natural gas) by the compressor equipment.

**B. Secondary and Tertiary Recovery:** Because primary recovery of oil and gas only extracts a fraction (about 25%) of the available resource, secondary and tertiary recovery methods are often employed. Water is often re-injected. Gas could also be injected to enhance gas cap drive. Substances, such as steam, carbon dioxide, surfactants, and microbes, can also often be injected to help mobilize the resource. This process is often energy intensive.

*GHG Emissions:* Fugitive CH<sub>4</sub> if gas is reinjected; CO<sub>2</sub> from combustion emissions of injection equipment. Fugitive emissions of CO<sub>2</sub> if used as an injectable fluid.

**E. Wellsite Visits:** During production, there will generally be routine wellsite visit schedule. Frequency of visits will vary among operations, but fossil fuel emissions associated with truck trips can be significant. Documentation of frequency and distance traveled is important.

*GHG Emissions:* CO<sub>2</sub> from fuel combustion during truck visits

**F. Wellsite facilities:** Two pieces of important equipment at the well site are the separator and the dehydrator. With these two pieces of equipment, there are sometimes smaller flares to prevent pressure buildup. There are also sometimes disposal wells or evaporation ponds installed next to the well pad.

1. **Separator**—the piece of equipment separates the resource from any other organic liquids. The liquid that is taken off (separated) is called condensate. The gas is fed into the pipeline, and the condensate remains.

**Crude Oil Separation (oil recovery only):** After the oil is extracted, gaseous components and other solids must be separated and removed before it is transported to a refinery.

*GHG Emissions:* Fugitive CH<sub>4</sub> emissions and CO<sub>2</sub> emissions associated with separation equipment.

**Natural Gas Conditioning (natural gas recovery only):** After extraction, natural gas is conditioned to remove impurities from the stream so that it can be transported through pipelines. However, it is not always required if the natural gas is pure enough. Impurities may

include hydrogen sulfide and nitrogen. Conditioning is performed either through dehydration or sweetening. Sweetening removes H<sub>2</sub>S and CO<sub>2</sub> from the gas stream, usually by amine treatment. The sulfur may be disposed of by flaring or sending it to a sulfur-recovery unit for sale.

*GHG Emissions:* CO<sub>2</sub> emissions that may be vented after separated from the gas stream

2. **Dehydrator**—the dehydrator removes the water from the resource. The most common type is called a glycol dehydrator. The emissions associated with these are volatile organic compounds (which indirectly adds to the lower atmosphere ozone load), and methane leaks associated with the hooking up of pipes.

*GHG Emissions:* CO<sub>2</sub> or CH<sub>4</sub>

3. **Wastewater Disposal:** After the condensate is separated from the resource, the disposal method by which the condensate is dealt with varies among operations. Sometimes, trucks will transport it away. Other times, a pipe system is constructed and the condensate is piped out to a central facility for treatment or disposal. Generally, condensate is only piped out when a large operation is ongoing. Still other times, this water is used for fracturing or is reinjected into a well for disposal. Other times, evaporation ponds are created to dispose of the contaminated wastewater. Contaminants in the wastewater are highly variable depending on the geology of the area. Most of it is inorganic, and includes salts, sodium chloride, sulfates, bicarbonates and other salts and minerals. There may also be some VOC's mixed in with the resource, including benzene. The concentrations of these contaminants varies widely. Areas on the western side of California generally contain a higher salt content than those on the east side of the valley.

California water quality regulations require that, prior to wastewater discharge to evaporation ponds, the operator must inform the Water Quality Board. The Water Quality board will then determine if a permit is required. If the wastewater is being re-inject or otherwise recycled back into the earth, the operator must go through the California Division of Oil, Gas, and Geothermal Resources to determine proper procedures.

Because of the contaminants in the wastewater, the biological oxygen demand (BOD or Chemical Oxygen demand, COD) may result in CO<sub>2</sub>, CH<sub>4</sub>, or N<sub>2</sub>O emissions, especially if the disposal unit is an evaporation pond. These emissions are the result of aerobic respiration and anaerobic fermentation. Earthen pits that are exposed to the air are often used to store or evaporate the wastewater from the dehydration and/or separation equipment, and also to store the wastes from the drilling fluids and fracturing fluids. Natural gas, VOCs, and chemical

emissions from surfactants, solvents, and lubricants may be emitted. Some of the lighter or more volatile chemicals and compounds will evaporate from the ponds into the atmosphere. To determine emissions from the wastewater in terms of methane per BOD, one should look at the type of treatment system that is used to manage the waste. Larger, centralized treatment facilities can control anaerobic environments, and are more likely to capture and re-use methane while smaller decentralized methods have less control over the anaerobic environment and are unlikely to capture methane emissions for re-use.

*GHG Emissions:* CO<sub>2</sub>, CH<sub>4</sub>, and VOCs

4. **Other Facilities:** There may be other plants or facilities used to meet industry needs, which may result in other types of emissions sources (e.g. amine plants, evaporation ponds, land farming operations).

*GHG Emissions:* CO<sub>2</sub>, CH<sub>4</sub>, others.

**G. Leaks:** Throughout the lifetime of the well (exploration, development, and production), fugitive emissions from leaks will occur. This could include leaks in the casing and tubing, valves, tanks, open pits, or leaks that occur from routine maintenance and replacing of motors and other equipment. The primary types of equipment that leak are: reciprocating compressor packing systems, centrifugal compressor seals, valves, pump seals, connectors, pressure regulator diaphragms, pressure-relief devices, and open-ended valves and lines. Almost all equipment is expected to leak some amount, yet most of it doesn't leak sufficiently from one particular source to warrant a repair. Generally, if excessive leaks are under 2% of the potential leak sources, the operations are considered normal.<sup>5</sup>

*GHG Emissions:* CH<sub>4</sub>, CO<sub>2</sub>, and other VOCs

**H. Accidental Acute Release:** Though rare due to installed control measures, an oil or gas well will occasionally have a blowout. They can occur at any phase of the operational process, and happens when a drill encounters a zone of unexpected or non-uniform pressure. Formation fluid and drilling fluid can rise to the surface, and can ignite an engine spark. Blowouts can take from several days to several months to control.

*GHG Emissions:* CH<sub>4</sub>, CO<sub>2</sub> that is a natural part of the gas

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<sup>5</sup> Canadian Association of Petroleum Producer, Technical Report on A National Inventory of Greenhouse Gas, Criteria Air Contaminant, and Hydrogen Sulphide Emissions by the Upstream Oil and Gas Industry, Volume 4. Page 51. <http://www.capp.ca/raw.asp?x=1&dt=NTV&e=PDF&dn=86224>

#### 4. Site Abandonment:

A. When the well is finished producing, plugging and abandoning the well can take various forms. Each state has specific requirements that govern well abandonment. In California, regulations require that heavy drilling mud and several cement plugs be placed at specific intervals.<sup>6</sup> These plugs are strategically placed to prevent migration of residual oil and gas to other zones, aquifers, or to the surface. Sometimes, when CO<sub>2</sub> has been used for enhanced secondary or tertiary recovery, part of the abandonment procedure involves blowing down the well to release any existing pressure. If this is done, large amounts of CO<sub>2</sub> could be released into the atmosphere.

*GHG Emissions:* CO<sub>2</sub> and CH<sub>4</sub> from venting

#### **Information Sources:**

American Petroleum Institute: Toward a Consistent Methodology for Estimating Greenhouse Gas Emissions from Oil and Natural Gas Industry Operations  
[http://www.climatevision.gov/sectors/oil\\_gas/pdfs/ghg\\_synopsis.pdf](http://www.climatevision.gov/sectors/oil_gas/pdfs/ghg_synopsis.pdf)

U.S. Environmental Protection Agency, Office of Compliance Sector Notebook: Project Profile of the Oil and Gas Extraction Industry, October 2000.  
<http://www.epa.gov/compliance/resources/publications/assistance/sectors/notebooks/oilgaspt1.pdf>

2007 Draft U.S. Greenhouse Gas Inventory Report Draft Inventory Of U.S. Greenhouse Gas Emissions And Sinks: 1990-2005, February 2007. <http://epa.gov/climatechange/emissions/usinventoryreport07.html>

Canadian Association of Petroleum Producer, Technical Report on A National Inventory of Greenhouse Gas, Criteria Air Contaminant, and Hydrogen Sulphide Emissions by the Upstream Oil and Gas Industry, Volume 4. <http://www.capp.ca/raw.asp?x=1&dt=NTV&e=PDF&dn=86224>

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<sup>6</sup> <http://web.ead.anl.gov/dwm/regs/state/california/index.cfm>