# Blue Source's Greenhouse Gas Emission Reduction Protocol for SandRidge CO2 LLC's capture of Vent-Stack $CO_2$ at Pikes Peak in Combination with Enhanced Oil Recovery Operations

*Prepared by*

Blue Source

4020 WestChase Blvd., Suite 470
Raleigh, NC 27607

December 2008

# Table of Contents

**Page**

## List of Figures

**Page**



## List of Tables

**Page**

# 1.0 Introduction

Blue Source is an active supplier of emission reductions (ERs) sourced from geologic sequestration, conservation, transportation, and avoidance projects and companies. More recently, the company is actively involved in financing and developing these kinds of projects. SandRidge CO2, LLC, hereafter referred to as “SD $CO_2$” is an active gatherer, transporter and marketer of $CO_2$, and related $CO_2$ equivalents, sourced from industrial vent stacks for use in enhanced oil recovery (EOR) projects, a process which the Intergovernmental Panel on Climate Change (IPCC) has recognized as a method of sequestering $CO_2$ that would otherwise be vented to the atmosphere (IPCC 1996).

In 2004, SD $CO_2$ completed the 32-mile Sierra Madera pipeline to enable transport of $CO_2$ captured from the vent stack of the Pikes Peak gas plant for delivery at McCamey to EOR operators in the Permian basin. SD CO2 installed over 13,000 hp of compression adjacent to the gas plant, including 9,000 hp of gas engine-driven compressors and about 4,500 hp of electric drive compressors. SD CO2 also gathers vent-stack $CO_2$ from other gas plants (Grey Ranch, Terrell, and Mitchell) in the region and delivers those volumes to EOR operators at McCamey. The purchasers of SD CO2’s vent-sourced $CO_2$ can obtain underground-sourced $CO_2$ from reserves at McElmo Dome where it is compressed and transported to the oil fields through the Cortez, Central Basin, and Canyon Reef Carriers (CRC) pipelines. Therefore, the use of vent-sourced $CO_2$ will replace an equivalent volume of underground-sourced $CO_2$ and also avoid emissions that would have resulted from its compression and transport.

This protocol documents the methods used to determine the greenhouse gas ERs associated with the Pikes Peak project in accordance with International Standards Organization (ISO) 14064 guidelines (ISO 2006a, ISO 2006b). It also includes the calculated ERs from the project between October 2007 (start of Pikes Peak operations) and September 2008 time-period. During this period, approximately 635,000 metric tonnes of carbon dioxide equivalent ($CO_2e$) ERs were created by the project. Emission reductions associated with SD CO2’s operations at other facilities (i.e., Grey Ranch, Terrell, and Mitchell) are not included in this protocol.

The protocol is organized in the following sections:

- Section 2 Contact information of the project proponents;
- Section 3 Detailed project description and operation;
- Sections 4-6 Methodology used to calculate the ERs;
- Section 7 Monitoring plan;
- Section 8 Other environmental impacts;
- Section 9 Summary of the calculated ERs from the project by month;
- Section 10 Documentation of the references cited in the protocol; and
- Appendix A Tables showing the details of calculations by month.

## 2.0 Proponent Identification

The Pikes Peak gas plant is owned and operated by SandRidge Energy Inc (SD). Carbon dioxide gathering and transport to EOR operators are conducted by SandRidge $CO_2$, LLC. ("SD CO2"). Oil and gas exploration and production operations are conducted by SandRidge Tertiary, LLC. Both SandRidge $CO_2$ and SandRidge Tertiary are wholly-owned subsidiaries of SandRidge Energy, Incorporated.

The contact information for the ER project is as follows:


Proponent Contact: Mr. Mahesh Gundappa
Vice President, Engineering
Blue Source, LLC
4020 WestChase Blvd., Suite 470
Raleigh, NC 27607
Phone: (919) 827 0322
Fax: (919) 827-0479
E-mail: mgundappa@bluesource.com

Operating Contact: Mr. Greg West
President
SandRidge Tertiary, LLC
6 Desta Drive, Suite 6300
Midland, Texas 79705
Phone: (432) 687-4242
Fax: (432) 618-0767
E-mail: gwest@sdrge.com

# 3.0 Project Description

## *3.1 Site Description*

Figure 3-1 shows the location of the Pikes Peak gas processing and compression facility, The plant is located 18 miles south of the city of Ft. Stockton on Hwy. 385 in Pecos County, West Texas. The plant has been in operation since 1972.

Figure 3-2 shows some of the equipment used for gas processing and $CO_2$ compression at the plant. At the gas processing facility SD uses a Selexol gas treatment process to separate $CO_2$ from the gas stream. Prior to implementation of the $CO_2$ capture project, all of the separated $CO_2$ was discharged to the atmosphere via the $CO_2$ vent stack (Figure 3-2b).

In 2004, SD $CO_2$ completed the 32-mile Sierra Madera pipeline connecting the Pikes Peak gas plant with the Val Verde system. SD $CO_2$ installed over 13,000 hp of compression, including 9,000 hp of gas engine-driven compressors and about 4,500 hp of electric drive compressors. SD $CO_2$ began delivery of vent-source $CO_2$ to the Yates Unit in Pecos County via the Pecos connector in December 2004, and to the Mid Cross Unit in Crockett County in November 2005.

## *3.2 Pre-Project Conditions*

In the early 1970's, the highly prolific Permian Basin oil reservoirs were maturing to the point that producers became interested in pursuing enhanced recovery methods. Most commonly, EOR involves injecting fluid into the reservoirs to enhance the natural conditions affecting crude oil production. The result is increased production and the capture of a significant portion of the oil reserves not otherwise recoverable. Historically and today, EOR projects injecting $CO_2$ primarily purchased the injectant from underground pure $CO_2$ reserves sourced in the states of Colorado and New Mexico. During this period, gas-processing plants have extracted the high-value natural gas and hydrocarbon liquids for sale, while venting large volumes of essentially pure $CO_2$ to the atmosphere. Underground-sourced $CO_2$ and recycle $CO_2$ accounted for 100 percent of all injected $CO_2$ into the Permian Basin before SD $CO_2$began the capture and transport of anthropogenic $CO_2$ for EOR.

In W. Texas, SD $CO_2$ is the only operator that captures vent-source $CO_2$ and transports it for EOR. SD $CO_2$'s operations related to capture and sequestration of vent-sourced $CO_2$ are shown in Figure 3-1. Besides, the Pikes Peak operations, SD $CO_2$ leases and operates compressor stations that are located adjacent to other gas plants at Grey Ranch, Terrell, and Mitchell (Puckett is currently not operating). At those locations, SD $CO_2$ purchases and captures the waste $CO_2$ gas from the vent stacks of the natural gas processing plants and transports it to EOR operators in the Permian basin. Prior to the sale of the waste $CO_2$ to SD $CO_2$, those $CO_2$ gas streams from the gas plants were previously vented to the atmosphere.

Figure 3-3 shows a process schematic of the Pikes Peak facility. Inlet gas is dehydrated using a Glycol/Selexol dehydration unit that uses selexol as the solvent. Condensible hydrocarbons and water are removed from the gas stream. The gas stream enters the contactor of a selexol gas treatment process where $CO_2$ is absorbed by the Selexol solvent. Rich solvent from the bottom of

the contactor flows to the high pressure recycle flash drum to separate any coabsorbed product gas, which is recycled back to the contactor. Further pressure reduction in the intermediate and low pressure flash units releases the $CO_2$ offgas. The regenerated solvent is pumped back to the process and the off gas, (> 90 % CO2) is vented to the atmosphere.

### *3.3 Post-Project Conditions*

In 2004, SD $CO_2$ constructed about 32-miles of 10" $CO_2$ gathering pipeline connecting the Pikes Peak gas plant with the Val Verde system (Figure 3-1) and installed over 13,000 hp of compression at Pikes Peak to capture an additional 38 million standard cubic feet per day (MMscfd) of $CO_2$ and deliver it to EOR operators. Any remaining $CO_2$ volumes are vented to the atmosphere through the $CO_2$ vent stack (Figure 3-2b). Installed compression includes:

- Two 2,250 hp (each) electric-drive Cooper 3-stage booster compressors that compress the $CO_2$ offgas leaving the low pressure flash tank from 2 psig to 120 psig (Figure 3-2c), and

- Two 4,500 hp (each) gas-fired IC engine driven Gemini 3-stage mainline compressors that further compress the discharge from the booster compressors, which is commingled with the offgas leaving the intermediate pressure flash tank. These compressors operate at suction and discharge pressures of 120 psig and 1,800 psig, respectively (Figure 3-2d).

After compression, the $CO_2$ is transported as a high-pressure dense gas by pipeline to the McCamey pump station, where it then joins into an existing $CO_2$ distribution system in the Permian Basin of West Texas. From this custody transfer-point, the $CO_2$ is transported to various crude production fields for EOR purposes.

EOR operators can obtain underground-sourced $CO_2$ from McElmo Dome, where it is compressed using several large engine-driven compressors and transported to the EOR sites through McCamey. Additionally, SD $CO_2$ gathers anthropogenic $CO_2$ from other gas plants in the area and transports those volumes through McCamey. This protocol only includes SD $CO_2$'s portion of the $CO_2$ that originates from the Pikes Peak plant and sold to operators of EOR leases. These include:

- The South Cross, North Cross, and Mid Cross Unit leases, all located in Crockett County, Texas, and served by dedicated laterals;
- The Sharon Ridge Canyon, SACROC, and Cogdell Unit leases, all located in Scurry County, Texas, and served by the CRC pipeline; and
- The Yates Unit lease, located in Pecos County, Texas, and served by the Pecos connector.

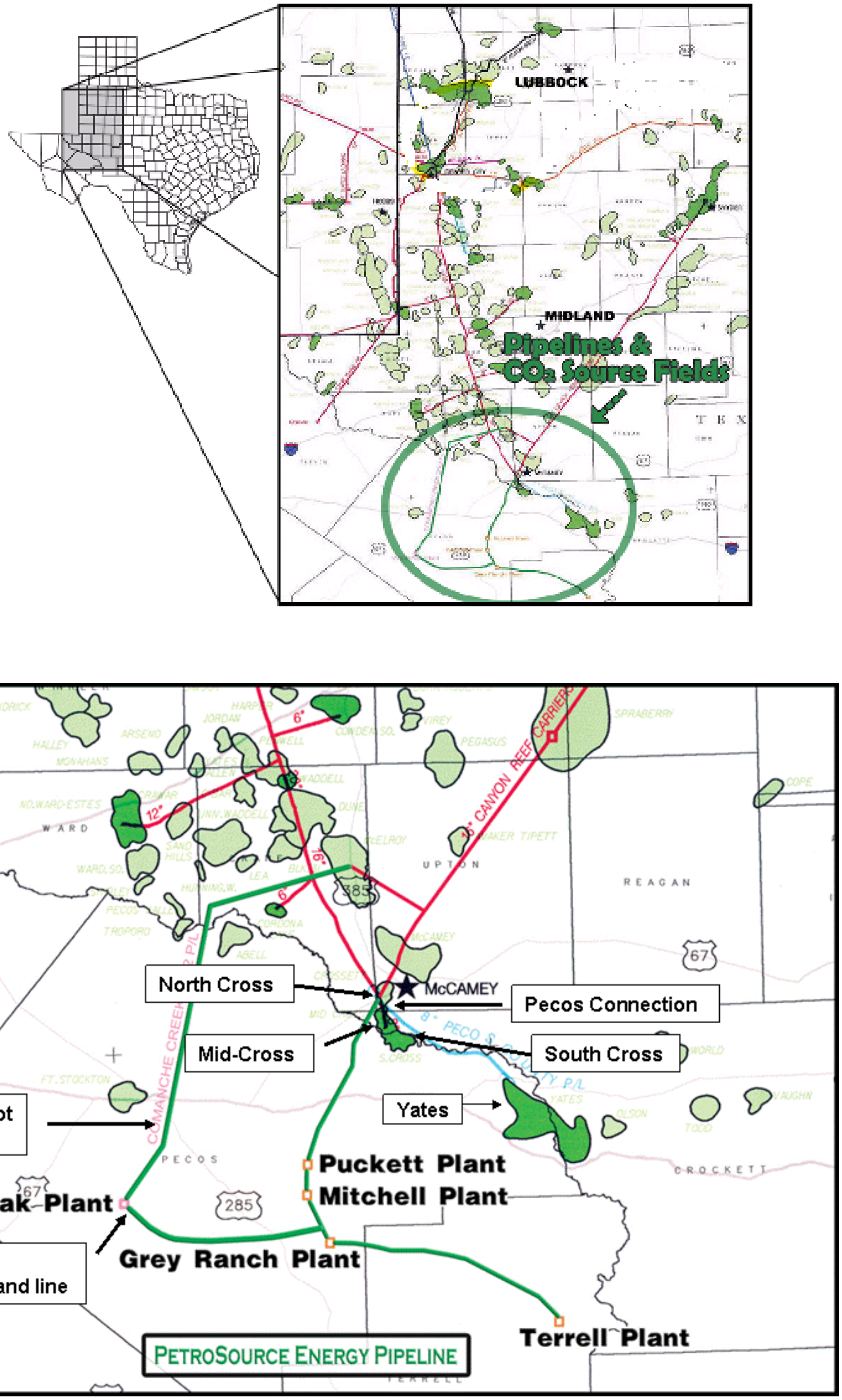


**Figure 3-1. Location of Pikes Peak Facility and $CO_2$ Pipelines**

a) Gas Processing Plant

b) $CO_2$ Vent Stack

c) $CO_2$ Booster Compressors

d) Main Line $CO_2$ Compressor Unit

**Figure 3-2. Pikes Peak Gas Processing and $CO_2$ Compression Facility**

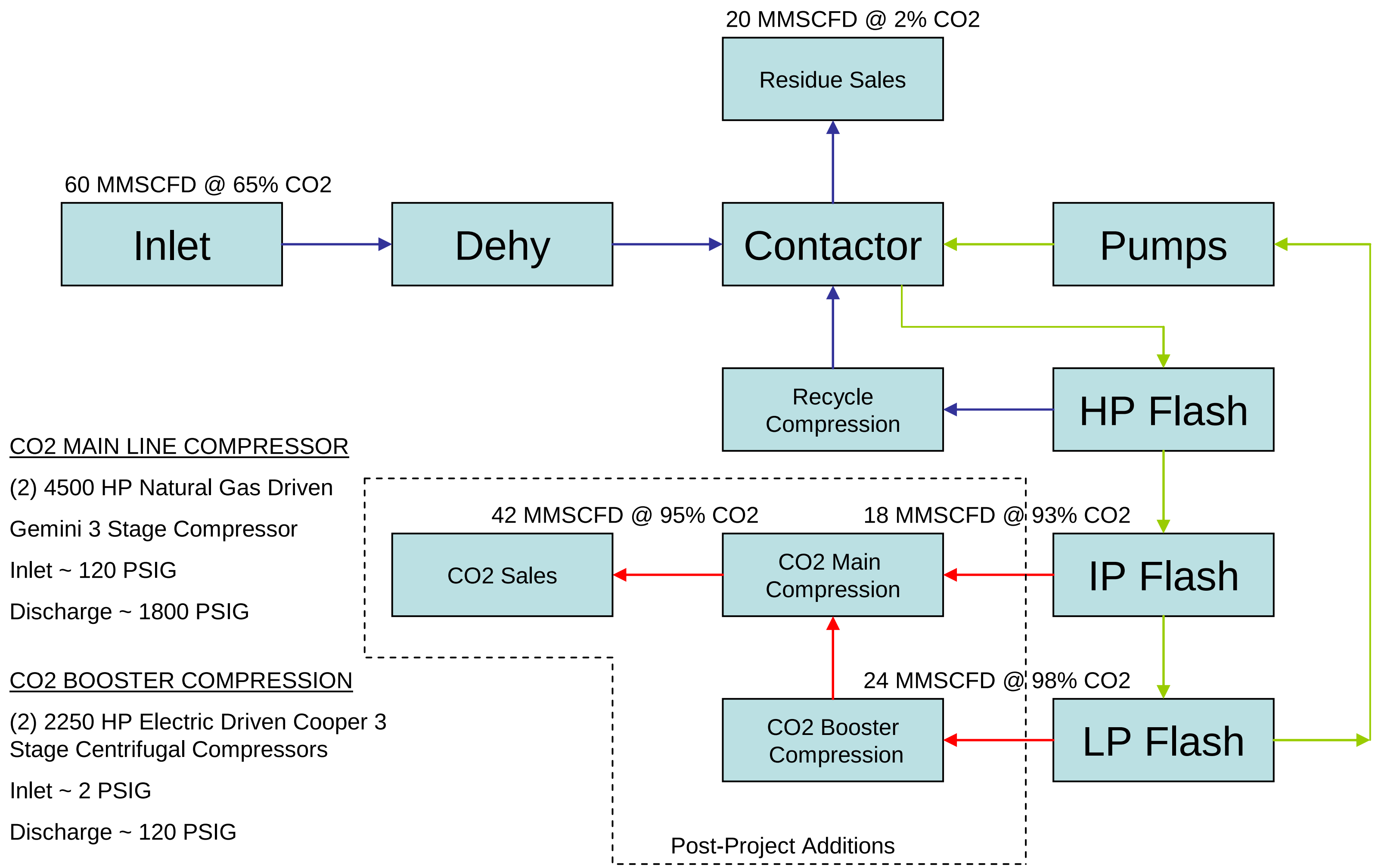


**Figure 3-3.** Process Schematic of Gas Processing and $CO_2$ Compression Facility

## 4.0 Baseline Assessment

Baseline emissions reflect emissions associated with activities that would have occurred in the absence of SD $CO_2$'s capture and transport of waste $CO_2$ from the Pikes Peak gas plant for delivery to EOR operators. Various scenarios were identified as potentially representative of the baseline and evaluated to determine the most likely scenario in the absence of the project. These include:

1. $CO_2$ from the gas plant could be processed and sold for use in another application (e.g., food processing industry);

2. $CO_2$ from the gas plant could be sequestered in a saline aquifer;

3. $CO_2$ from the gas plant could be captured and used for EOR *(project case)*, and

4. $CO_2$ from the gas plant could be vented to the atmosphere *(current operations)*.

For use in other applications such as the food processing industry, the gas stream may require further processing to increase its $CO_2$ purity. Moreover, this scenario faces additional financial risk due to the uncertainty in the market for this product. Depending on the end use application, the $CO_2$ may be ultimately vented to the atmosphere.

Storage of $CO_2$ in saline aquifers is in the early stages of development. Several US and international studies are currently underway to explore the potential of this technique as a means of geologic storage for $CO_2$ (CCP 2007, IEA 2007, USDOE 2007). To implement this technology, a detailed study of the subsurface characteristics would be required to identify suitable sites and the infrastructure would have to be developed to transport and inject the $CO_2$ from Pikes Peak to the selected storage site(s).

The project case of capture and transport of waste $CO_2$ for delivery to EOR operators requires substantial investment for compressors and a pipeline. There is financial risk because this $CO_2$ competes with underground sourced $CO_2$ which is also available to the EOR operators in the region. Although there are other gas plants operating in the area that supply anthropogenic $CO_2$ for EOR purposes, all of those capture and compression facilities together with the associated pipeline infrastructure are owned and operated by SD $CO_2$. Those facilities have benefited from the sale of carbon credits associated with their operation. As discussed in Section 5, this type of project is not common practice in the region compared with projects that have not received carbon finance and would not have been developed anyway.

Prior to the implementation of SD $CO_2$'s $CO_2$ capture and transport project, the waste $CO_2$ stream at the Pikes Peak plant was vented to the atmosphere. As discussed in Section 5, this practice is in accordance with regulations and would have continued absent the project.

Among the four candidate scenarios, candidate (1) requires additional processing costs, faces financial risks, and market uncertainty and therefore, is not likely to be undertaken in the baseline. Candidate (2) faces technological challenges and would be expensive to implement. Industry does not have enough experience with this technology to consider a large commercial scale implementation without serious financial and technological risk. Based on a lack of adequate experience and implementation costs, it is highly unlikely that the $CO_2$ from Pikes Peak

would have been injected in a saline aquifer under the baseline. The project case (3), requires substantial investment and faces financial risk of not meeting adequate returns due to competition from underground sources. This is not common practice and is not the least cost option. Therefore the capture and transport of the vent stack $CO_2$ would not have occurred in the baseline. Candidate (4) is representative of historical operations, requires no additional investment and is in accordance with regulations. Since this option has the lowest level of barriers, it is the most likely baseline scenario for the project. Therefore candidate (4) was chosen as being representative of the baseline for the project.

Figure 4-1, shows a schematic of the project and baseline operations. The captured $CO_2$ at Pikes Peak is compressed and transported along the Sierra Madera pipeline. The transported volumes are metered at the junction of the Sierra Madera and Val Verde pipelines ($GV_{PP}$). Downstream of this metering point, these volumes are commingled with SD $CO_2$'s $CO_2$ volumes captured from three other gas plants (Grey Ranch, Mitchell, and Terrell). Those volumes are compressed, metered at individual compressor stations and transported along the Val Verde pipeline to the McCamey pump station. The total $CO_2$ volumes from these three compressor stations are represented as $GV_{OCS}$ in Figure 4-1.

Baseline emissions are the actual $CO_2$e emissions that would have been discharged to the atmosphere at the Pikes Peak gas plant in the absence of the project. However, this volume is not directly quantifiable because there is no measurement of the waste $CO_2$ gas generated by the gas plant and released to the atmosphere.

In the absence of a directly measurable baseline, two approaches were evaluated for quantifying the gross volume of gas that represents the theoretical total volume of gas that would have been released to the atmosphere as waste gas from the gas plant:

1. The first approach assumes the gross volume is equivalent to the $CO_2$ gas volume metered at the junction of the Sierra Madera and Val Verde pipelines (i.e., $GV_{PP}$, representative of the $CO_2$ volumes bought by SD $CO_2$ that were previously vented to the atmosphere). This approach would require estimating the $CO_2$ emissions associated with transporting, and distributing the $CO_2$ gas to the points of sequestration (the injection wells) to calculate the creation period leakages.

2. The second approach establishes the gross volume as the $CO_2$ gas volumes metered further downstream in the pipeline at the point of sale for enhanced oil recovery (GV). The sales meter readings already account for any $CO_2$ gas losses that occur within the compressor stations, the pump station, and length of upstream pipeline. Since the sales meters also include the $CO_2$ captured from the other gas plants ($GV_{OCS}$), the volumes associated with the Pikes Peak facility ($GV_{PP,B}$) were determined as $GV_{PP,B} = (GV_{PP} /(GV_{PP} + GV_{OCS})) \times GV$.

To ensure the most accurate estimate of the net ERs created for SD $CO_2$'s operations, the second approach is used. Since the sales volumes are accurately metered and monitored, these values are more accurate and verifiable than estimates of losses associated with upstream operations.

As shown in Figure 4-1, baseline emissions also include indirect $CO_2$e emissions that would have occurred from electricity used to compress underground-sourced $CO_2$ volumes (equal to $GV_{PP,B}$ ) at McElmo Dome for transport to the oil fields in West Texas. These emissions are

avoided in the post-project scenario but would have occurred in the absence of the project, and therefore, are included in the project baseline.

Any additional $CO_2$ that was generated and released to the atmosphere as a result of the sequestration operations are included in the calculation of the net GHG emission reductions. These include:

- direct emissions released from fuel burning in the Pikes Peak compressor engines (CMB),
- indirect emissions associated with the Pikes Peak electric-drive $CO_2$ compressors ($IND_2$),
- indirect emissions associated with a portion of the electricity required to operate the McCamey pump station ($IND_{3,PP}$). To calculate $IND_{3,PP}$, the total electricity usage at McCamey was apportioned based on the fraction of Pikes Peak volumes pumped to the EOR operators at McCamey.

Fugitive emissions that occur along the pipeline between the McCamey pump station and the point of injection and emissions associated with compression of $CO_2$ that is produced with the oil and recycled during EOR are not considered. These emissions are similar to what would have occurred under the baseline, where EOR operators would obtain equivalent volumes of underground sourced $CO_2$ that would be supplied through McCamey and any produced $CO_2$ would be similarly recycled. Therefore these emissions would cancel out in the calculation of project emission reductions.

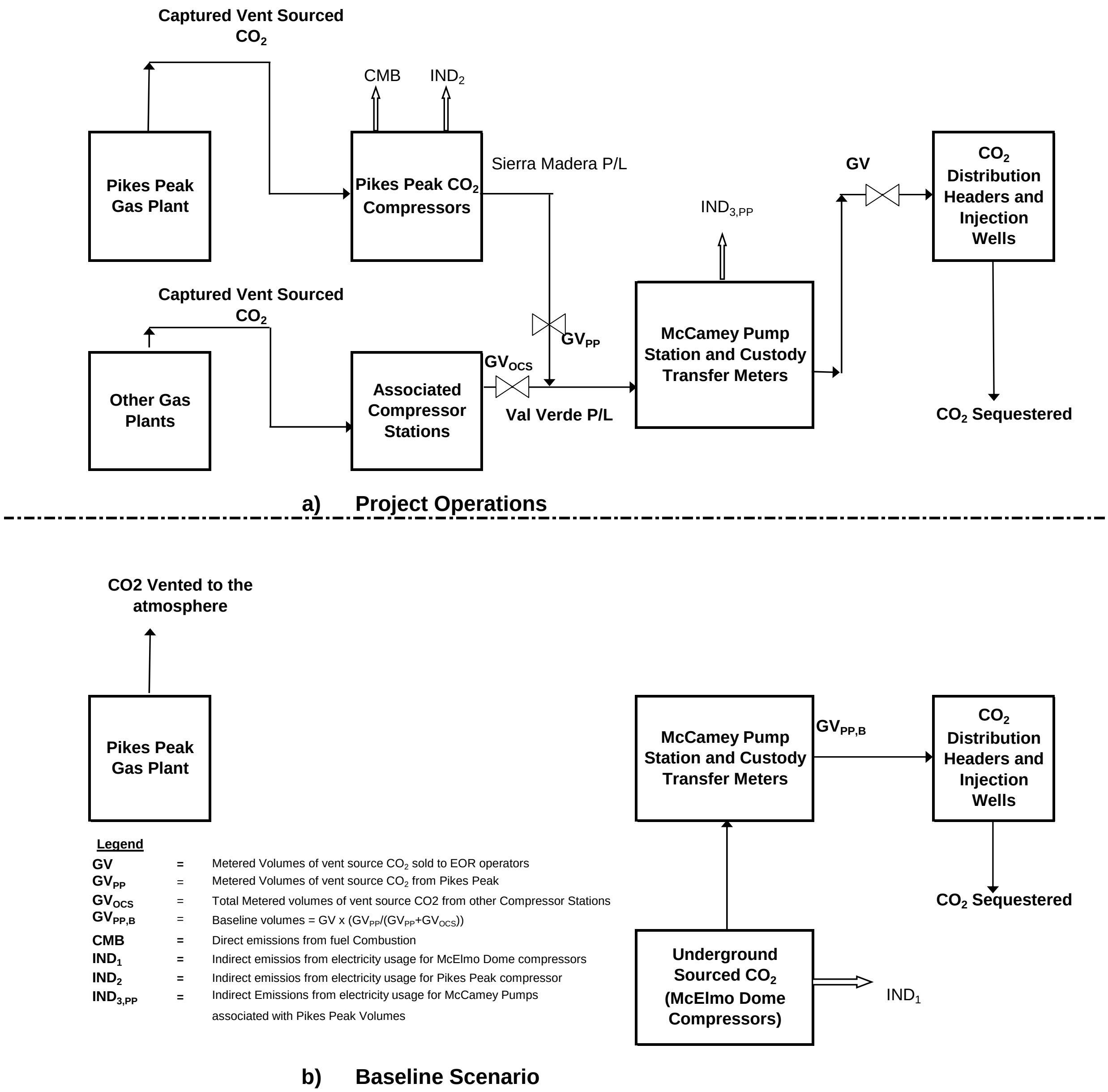


**Figure 4-1. Sources of $CO_2$e Emissions for Project Operations and Baseline**

# 5.0 Project Additionality and Permanence

The project test of additionality includes the following criteria:

- Regulatory Surplus (the project must not be mandated by law);
- Implementation Barriers (project activity faces one or more distinct barriers compared to alternatives); and
- Common Practice (project is not common practice in a sector/region).

An analysis of these criteria applied to the Pikes Peak project is discussed in the following sections. The analysis demonstrates the additional nature of the project.

Issues related to the permanence of the ERs from the project are also discussed.

## *5.1 Regulatory Surplus*

The surplus nature of these emission reductions is demonstrated by a review of applicable state and federal regulations associated with oil production operations. There are no external requirements for controlling or reducing $CO_2$ emissions. In addition, SD $CO_2$ has no voluntary obligations for reducing or controlling $CO_2$ emissions.

The capture of waste $CO_2$ at the Pikes Peak facility is not mandated by law. The facility operates under Texas Commission on Environmental Quality (TCEQ) permit No. 1374A (TCEQ 2005) authorized under Title 30 Texas Administrative Code § 116.116 (30 TAC § 116.116). A review of the permit indicates that the facility is subject to specific limits for emission of criteria pollutants; however, there are no limits on $CO_2$, $CH_4$, or $N_2O$ emissions. The facility is not subject to any external requirements or voluntary obligations for controlling or reducing $CO_2$, $CH_4$, or $N_2O$ emissions.

Since the project is not mandated by law and is not required to control GHG emissions, the project is purely voluntary and associated ERs generated by the project are deemed to be surplus in nature.

## *5.2 Implementation Barriers*

The Pikes Peak project faced substantial investment risk during the planning and execution phases. EOR operators in the Permian basin can procure large volumes of $CO_2$ from underground sources through the same transportation networks that SD $CO_2$ uses to supply anthropogenic sourced $CO_2$. As shown by the pipeline network (in red) in Figure 3-1, significantly larger volumes of underground sourced $CO_2$ can be supplied from McElmo Dome, Sheep Mountain, and Bravo Domes through the Central Basin pipeline to McCamey . This pipeline varies in diameter from 26 inches at Denver City down to 16 inches near McCamey, Texas. The present capacity of the line is 1000 MMscfd, but if power were added, the capacity could be increased to 1,200 MMscfd (Kinder Morgan 2007). These volumes are significantly larger than the 38 MMscfd capacity of SD $CO_2$'s Sierra Madera pipeline from Pikes Peak or the 110 MMscfd Val Verde pipeline that aggregates all of SD $CO_2$'s anthropogenic $CO_2$ for delivery at McCamey.

Since the large pipeline infrastructure used to transport underground sourced $CO_2$ has been operational for the last 20-30 years, capital costs associated with those projects have been recovered. Although underground sourced $CO_2$ has to travel greater distances to be supplied to EOR operators in the Permian basin, compression cost ($/MMscf of compressed gas) are low because operating well pressures are significantly higher than the near atmospheric pressures of the separated anthropogenic $CO_2$, which requires more compression to raise its pressure to pipeline pressures. Other operating costs for underground sourced $CO_2$ (e.g., pipeline maintenance costs) also benefit due to economies of scale.

Due to severe pricing competition from underground sourced $CO_2$ suppliers who have the ability to deliver significantly large volumes at a competitive price, SD $CO_2$ faces substantial risk of not meeting an adequate return on investment. For the Pikes Peak project, SD $CO_2$ invested about $20 million (current dollars) towards pipeline and compressor costs. Without carbon finance, the IRR for the Pikes Peak project was calculated as 9 percent. This is substantially lower than the minimum IRR values of about 20 percent expected by the Company. The inclusion of the potential revenue stream from the sale of the carbon credits improves the IRR for the project to about 18 percent.

### *5.3 Common Practice*

The use of anthropogenic $CO_2$ for EOR purposes is not common practice. There are about 73 EOR projects in the US injecting a total of approximately 30 million metric tonnes of $CO_2$ for EOR. However, only about 3 Mt $CO_2$ (~10 percent) are from anthropogenic sources with the remaining being supplied from natural underground sources of $CO_2$ (IPCC 2005). In the Permian basin, SD $CO_2$ is the only supplier of anthropogenic $CO_2$ to EOR operators. All of SD $CO_2$ projects have benefited from carbon finance. Therefore, there are currently no EOR projects using anthropogenic sourced $CO_2$ in the Permian basin that operate without the benefit of carbon finance.

### *5.4 Permanence*

As long as there is continued supply of waste $CO_2$ from the vent stacks of the gas processing plants and demand remains for the use of $CO_2$ in EOR operations, the project's $CO_2$e emissions reductions are expected to continue over its complete economic life.

Geologic structural and stratigraphic traps have demonstrated the ability of reservoirs to seal and store hydrocarbons over millions of years. The mechanisms that initially trapped these hydrocarbons remain intact as fluids are extracted from or injected into these reservoirs. The proven ability for hydrocarbon reservoirs to successfully trap and store fluids for up to several million years make storage of $CO_2$ in depleted hydrocarbon reservoirs "the best currently available option for long term sequestration." (Bachu, 2000). Per the UNFCCC special report on carbon capture and storage, the fraction of injected $CO_2$ that is retained in appropriately selected and managed geological reservoirs is very likely to exceed 99% over 100 years and is likely to exceed 99% over 1,000 years (IPCC 2005).

For a geologic trap to be considered a suitable mechanism for long term storage, the tectonic structure and setting need to be stable and understood. The Permian Basin is a convergent basin on stable continental platforms that are not prone to significant tectonic activity, earthquakes or proximity to volcanism, which would pose the potential for accidental rapid escape of stored $CO_2$ back to atmosphere. The Permian Basin, through extensive exploration and production, has geology and hydrogeology that is well understood and documented. These properties make storage of $CO_2$ in hydrocarbon reservoirs in the Permian Basin a viable long-term option and mitigate the possibility of leakage as a result of natural occurrences.

Notwithstanding the geophysical argument for permanence, as long as recycled $CO_2$ competes with $CO_2$ sourced from underground reserves (McElmo Dome), potential geologic leakage, which is the core of permanence in geological sequestration, does not represent a negative impact on the SD $CO_2$ vent-stack $CO_2$ project. In the absence of this project, the project's baseline EOR operations would have occurred anyway with additional underground sourced $CO_2$, and its associated increased vented $CO_2$ emissions, as well as potential geologic leakage. This project baseline leakage offsets any leakage that would occur with vent-stack sourced $CO_2$ from the SD $CO_2$ project. Because these quantities are very small and essentially equivalent, they offset each other, and potential leakage in this project is not a negative impact on the definition of permanence, or on the volume of ERs estimated.

## 6.0 Calculation and Reporting of Emission Reductions

The net emission reductions by month are calculated using the following equation:

$$ERs = \text{Baseline Emissions} - \text{Project Emissions}$$

$$= (BE) - (PE) \qquad \text{(Equation 6-1)}$$

where:

ER = Net emission reduction (expressed as tonnes $CO_2e$ per month);
BE = Baseline Emissions (tonnes $CO_2e$ per month); and
PE = Project emissions (tonnes $CO_2e$ per month).

Using the schematic shown in Figure 4-1, baseline emissions are calculated as,

$$BE = (GV_{PP,B} + IND_1) \qquad \text{(Equation 6-2)}$$

where:

$GV_{PP,B}$ = Gross volume of gas for the Pikes Peak baseline (calculated from equations 6-2 and 6-3 below, tonnes $CO_2e$); and
$IND_1$ = Indirect emissions that would have occurred from electricity usage to compress underground-sourced $CO_2$ volume (equal to $GV_{PP,B}$)for transport from McElmo Dome to the oil fields (expressed as tonnes $CO_2e$);

The baseline volumes are calculated using equations 6-3 and 6-4,

$$GV_{PP,B} = PP_{frac} \times GV \qquad \text{(Equation 6-3)}$$

and

$$PP_{frac} = GV_{PP} / (GV_{PP} + GV_{OCS}) \qquad \text{(Equation 6-4)}$$

where,

$PP_{frac}$ = Ratio of Pikes Peak volumes to total volumes supplied to McCamey;

GV = Total volumes metered at sales meters at McCamey and sold for EOR (based on monthly metered volumes and converted to tonnes $CO_2e$);
$GV_{PP}$ = Gross volume of gas supplied by the Pikes Peak plant (based on monthly metered volumes); and
$GV_{OCS}$ = Total volume of gas supplied by other compressor stations (i.e., Mitchell, Terrell, and Grey Ranch, based on monthly metered volumes).

The approach for estimating PE takes into account losses and emissions associated with SD $CO_2$'s operations to capture, compress, and transport $CO_2$ to the injection wells, as defined below:

$$PE = CMB + IND_2 + IND_{3,PP} \qquad \text{(Equation 6-5)}$$

where:

CMB = Combustion emissions associated with compression of $CO_2$, tonnes $CO_2e$; and
$IND_2$ = Indirect emissions associated with electricity usage for Pike's Peak compressors, tonnes $CO_2e$;
$IND_{3,PP}$.= Indirect emissions associated with electricity usage at McCamey that is associated with Pikes Peak volumes, tonnes $CO_2e$.

The emissions associated with combustion of natural gas to compress the $CO_2$ for transport is estimated based on a mass balance approach, assuming all carbon in the fuel is converted to $CO_2$. Methane and $N_2O$ emissions from the combustion exhaust were based on EPA AP-42 emission factors (USEPA 2000). Calculated emissions were converted to a $CO_2$ equivalent ($CO_2e$) basis, using a Global Warming Potential (GWP) of 21 for methane and 310 for $N_2O$.

This approach is conservative as it assumes all carbon in the fuel is converted to $CO_2$ while simultaneously accounting for methane emissions in the exhaust, leading to double counting the carbon that remains in the exhaust as unburned methane.

**Sample Calculation**

The calculation procedures and algorithms are discussed using a detailed sample calculation for the baseline volume ($GV_{PP}$), avoided emissions ($IND_1$), project emissions (PE), and the net ERs for the month of October 2007. Calculation results on a monthly basis for the entire creation period are shown in Table A-1. Supporting data are included in Tables A – 2 to A – 6. (Appendix A).

Baseline Emissions

The volumes supplied from the other compressor stations ($GV_{OCS}$) is calculated as

$$GV_{OCS} = 791{,}300 + 835{,}650 + 200{,}090$$

$$= 1{,}827{,}040 \text{ mscf}$$

Using Equation 6-4, the fraction of Pikes Peak volume is calculated as,

$$PP_{frac} = (432{,}670)/(432{,}670 + 1{,}827{,}040)$$

$$= 0.191$$

The total gas volumes metered at the custody transfer meters at McCamey (GV) were calculated as the sum of the $CO_2e$ sales metered to South Cross, North Cross, Mid Cross, Yates (Pecos Connection), and the production leases served by the CRC pipeline. The $CO_2$ and $CH_4$ concentrations in the gas were based on measured values for each month. A GWP of 21 was used for methane.

GV= (Sales to South Cross + Sales to North Cross + Sales to Mid Cross
+ Sales to Yates + Sales to CRC[1])

= (Sales volume) × [$CO_2$ fraction +21 x $CH_4$ fraction]

$$= (1{,}063{,}310 + 429{,}920 + 62{,}740 + 320{,}545 + 375{,}130) \times 10^3 \text{scf gas} \times$$
$$\left( \begin{array}{l} 0.96869 \dfrac{\text{scf } CO_2}{\text{scf gas}} \times \dfrac{\text{lb mole } CO_2}{379.3 \text{ scf } CO_2} \times 44 \dfrac{\text{lb } CO_2}{\text{lb mole } CO_2} \times \dfrac{\text{tonne}}{2205 \text{ lb}} + 21 \text{ x} \\ 0.02445 \dfrac{\text{scf } CH_4}{\text{scf gas}} \times \dfrac{\text{lb mole } CH_4}{379.3 \text{ scf } CH_4} \times 16 \dfrac{\text{lb } CH_4}{\text{lb mole } CH_4} \times \dfrac{\text{tonne}}{2205 \text{ lb}} \end{array} \right)$$
$$= 136{,}865 \text{ tonnes } CO_2e$$

Sequestered volumes associated with the Pikes Peak baseline ($GV_{PP,B}$) were calculated using Equation 6-3,

$GV_{PP,B}$ = 0.1915 × 136,865

= 26,206 tonnes $CO_2$e

Baseline Emissions that would have occurred if underground-sourced $CO_2$ were purchased from McElmo Dome rather than vent-sourced $CO_2$, were calculated based on the electricity required to drive the McElmo Dome compressors. Fresh $CO_2$ from McElmo Dome would have to be compressed to approximately 2,300 psig and transported to the EOR sites. Electric-drive compressors for these operations would require about 800 kW-hr/MMscf based on discussions with McElmo Dome operations personnel and would generate indirect emissions ($IND_1$) at the power supplier's facility.

Indirect CO2 emissions were based on the most recent data on average grid factor (lb $CO_2$/MWh generation) for the State of Colorado, which was obtained from EPA eGRID2006 Version 2.1 published in April 2007 (USEPA 2007). The factor is based on the mix of fuels and operating hours of generating capacity during 2004. Emission factors compiled by the U.S. Energy Information Administration (EIA) (USDOE, 2002) for the State of Colorado were used to calculate indirect $CH_4$, and $N_2O$. The total $CO_2$e emissions were calculated using a GWP of 21 for $CH_4$, and 310 for $N_2O$. Calculated values of $IND_1$ by month are included in Table A-2.

$$IND_1 \text{ (energy)} = 0.1915 \times (320.545 + 375.130 + 429.920 + 1{,}063.310 + 62.74) \text{ MMscf gas}$$
$$\times \frac{800 \text{ kW - hr}}{\text{MMscf gas}} \times \frac{\text{MW}}{1000 \text{ kW}}$$
$$= 345 \text{ MW - hrs}$$

[1] Includes sales to Sharon Ridge, Oxy Cogdell, and SACROC.

$$CO_2 \text{ emissions} = 1{,}986 \ \frac{\text{lb}}{\text{MW - hr}} \times \frac{\text{tonne}}{2205 \text{ lb}} \times 345 \text{ MW - hrs } = 311 \text{ tonnes}$$

$$CH_4 \text{ emissions} = 0.0127 \frac{\text{lb}}{\text{MW - hr}} \times 345 \text{ MW - hr} \times \frac{\text{tonne}}{2205 \text{ lb}} = 0.002 \text{ tonne}$$

$$N_2O \text{ emissions} = 0.0289 \frac{\text{lb}}{\text{MW - hr}} \times 345 \text{ MW - hr} \times \frac{\text{tonne}}{2205 \text{ lb}} = 0.005 \text{ tonnes}$$

$$\begin{aligned} IND_1 \text{ (Oct. 2007) } CO_2e &= 311 \text{ tonnes} + \left(21 \times 0.002 \text{ tonnes } CH_4\right) \\ &+ \left(310 \times 0.005 \text{ tonnes } N_2O\right) \\ &= 312 \text{ tonnes } CO_2e \end{aligned}$$

Total baseline emissions were calculated using Equation 6-2,

$$\begin{aligned} BE &= 26{,}206 + 312 \\ &= 26{,}518 \text{ tonnes } CO_2e \end{aligned}$$

Project Emissions

Combustion emissions (CMB) due to fuel usage in the engine compressors were calculated from the measured fuel consumption rates and fuel analysis data. These data are included in Table A - 3. The fuel analysis provided information on fuel composition (i.e., percentage of methane, ethane) of the fuel and fuel properties (i.e., density, heating value). The $CO_2$ emissions from fuel combustion were conservatively estimated by assuming that all the carbon in the fuel is converted to $CO_2$ during the combustion process and discharged to the atmosphere.

Based on the monthly fuel analysis data, the moles of $CO_2$ emitted from the combustion of a mole of fuel was calculated for each month. An example calculation is shown in Table A - 6 for the Oct. 2007 data.

The $CO_2$ emissions for October 2007 were then calculated as shown below:

CMB = (Fuel usage) × (heating value) × ($CO_2$ emitted based on the carbon balance, assuming complete combustion)

$$= \left[ \begin{array}{l} (13{,}193)\ \text{MMBtu} \times \dfrac{10^6\ \text{Btu}}{\text{MMBtu}} \times \dfrac{\text{scf fuel}}{963\ \text{Btu}} \times \dfrac{\text{lb mole fuel}}{379.3\ \text{scf fuel}} \\ \times\, 0.986\ \dfrac{\text{lb mole } CO_2}{\text{lb mole fuel}} \times 44\ \dfrac{\text{lb } CO_2}{\text{lb mole } CO_2} \times \dfrac{\text{tonne}}{2205\ \text{lb}} \end{array} \right]$$

$$= 711\ \text{tonnes } CO_2$$

The $CH_4$ emissions were calculated from U.S. Environmental Protection Agency (EPA) AP-42 emission factors for gas-fired engines (USEPA, 2000).

For example, the $CH_4$ emissions from the combustion sources for Oct. 2007 are calculated as:

$$\begin{aligned} CH_4\ \text{Emissions} &= (\text{emission factor}) \times (\text{fuel usage}) \\ &= \left[ (1.45)\ \frac{\text{lb}}{\text{MMBtu}} \times (13{,}193)\ \text{MMBtu} \times \frac{\text{tonne}}{2205\ \text{lb}} \right] \\ &= 8.676\ \text{tonnes } CH_4 \end{aligned}$$

Finally, the $CO_2$ equivalent ($CO_2e$) emissions for combustion sources were calculated using a GWP of 21 for methane.

$$\begin{aligned} \text{CMB (Oct. 2007) } CO_2e &= CO_2 + (21 \times CH_4) \\ &= 711 + (21 \times 8.676) \\ &= 893\ \text{tonnes } CO_2e \end{aligned}$$

Indirect $CO_2$ emissions were based on the most recent data on average grid factor (lb $CO_2$/MWh generation) for the State of Texas, which was obtained from EPA eGRID2006 Version 2.1 published in April 2007. Emission factors compiled by the U.S. Energy Information Administration (EIA) (USDOE 2002) for the State of Texas were used to calculate indirect $CH_4$, and $N_2O$. The total $CO_2e$ emissions were calculated using a GWP of 21 for $CH_4$, and 310 for $N_2O$. The indirect emissions represent the emissions due to the generation of electricity required to operate the Pikes Peak compressor station ($IND_2$) and a portion of the electricity usage at the McCamey pump station ($IND_{3,PP}$). These emissions were calculated from actual electricity usage data as reflected in the electric utility bills for each station

Emissions = (emission factor) × (electrical usage)

Electricity usage = Electricity usage at Pikes Peak + Portion of McCamey station's electricity used for Pikes Peak volumes
=1,261,582 + 0.1915 × 228,097

$$=1{,}305{,}256 \text{ kWh}$$

$$CO_2 \text{ emissions} = 1{,}472 \ \frac{\text{lb}}{\text{MWh}} \times (1{,}305{,}256) \text{ kWh} \times \frac{\text{tonne}}{2{,}205 \text{ lb}} \times \frac{\text{MW}}{1{,}000 \text{ kW}} = 871 \text{ tonnes}$$

$$CH_4 \text{ emissions} = 0.0077 \ \frac{\text{lbs}}{\text{MWh}} \times (1{,}305{,}256) \text{ kWh} \times \frac{\text{tonne}}{2205 \text{ lbs}} \times \frac{\text{MW}}{1{,}000 \text{ kW}} = 0.0046 \text{ tonne}$$

$$N_2O \text{ emissions} = 0.0146 \ \frac{\text{lbs}}{\text{MWh}} \times (1{,}305{,}256) \text{ kWh} \times \frac{\text{tonne}}{2205 \text{ lbs}} \times \frac{\text{MW}}{1{,}000 \text{ kW}} = 0.0086 \text{ tonne}$$

$$\begin{aligned} IND_2 + IND_{PP} \text{ (Oct. 2007)} &= 871 \text{ tonnes } CO_2 + \left(21 \times 0.0046 \text{ tonnes } CH_4\right) \\ &+ \left(310 \times 0.0086 \text{ tonnes } N_2O\right) \\ &= 874 \text{ tonnes } CO_2e \end{aligned}$$

Project Emissions during Oct. 2007 were calculated using Equation 6-5,

| | |
|---|---|
| PE (Oct. 2007) | = CMB + $IND_2$ + $IND_{3,PP}$ |
| | = 893+874 |
| | = 1,767 tonnes $CO_2e$ |

The net ER created during Oct. 2007 were calculated using Equation 6-1,

| | |
|---|---|
| Net ER (Oct. 2007) | = BE - PE |
| | = 26,518 – 1,767 |
| | = 24,751 tonnes $CO_2e$ |

The net emission reduction is summed over each month of operation during the creation period, October. 2007 through September 2008.

Table 6-1 presents the annual and total GHG emission reductions (expressed as $CO_2$e) associated with the Pike's Peak project over the creation period. Detailed calculation results on a monthly basis are summarized in Section 9.0.

**Table 6-1. Annual Net Emission Reduction Summary (tonnes $CO_2$e)**

| | 2007 (Oct. – Dec.) | 2008 (Jan. – Sep.) | TOTAL (Oct. 07 – Sep. 08) |
|---|---|---|---|
| **$GV_{PP,B}$** | 130,693 | 529,676 | 660,368 |
| **$IND_1$** | 1,518 | 6,013 | 7,532 |
| **Total Baseline** | 132,211 | 535,689 | 667,900 |
| **CMB** | 4,259 | 16,773 | 21,033 |
| **$IND_2$ + $IND_{3,PP}$** | 2,447 | 9,083 | 11,530 |
| **Total Project** | 6,706 | 25,856 | 32,562 |
| **Net ER** | **125,505** | **509,833** | **635,338** |

## 7.0 Monitoring Plan

This section describes the monitoring of data used to calculate baseline and project emissions. It includes a description of the parameters monitored, measuring equipment, frequency of measurement, and data archiving methods.

Baseline emissions are based on baseline volumes associated with Pikes Peak and avoided indirect emissions. Baseline volumes at Pikes Peak are calculated from the total sales gas meters readings at McCamey and the individual compressor station meter readings.

The gross volume of $CO_2$ gas that is sold by SD $CO_2$ is metered at the custody transfer point at McCamey station. Five separate metering systems each measure the vent sourced $CO_2$ gas supplied to the CRC pipeline (Sharon Ridge, Sacroc, and Cogdell fields), the North Cross fields, the South Cross fields, the Mid Cross fields, and the Yates fields. The metering systems include calibrated orifice plates and Rosemount static and differential pressure transducers, and temperature sensors. Data are recorded using an Omni flow computer. Daily sales volumes measured by the five sales meters at McCamey are compiled each month to provide a monthly total of sales gas volumes sold by SD $CO_2$. The meters are calibrated monthly to within ±2 percent by an independent company.

The total metered volumes at the five sales meters include commingled volumes of the total vent sourced gas compressed at the four compressor stations (Pikes Peak, Grey Ranch, Mitchell, and Terrell). Flow meters that measure the compressed $CO_2$ gas throughput are also located at each of these compressor stations. These meters are similar to the sales meters at McCamey and are calibrated monthly. Besides serving as an independent check to the total sales volumes, these meter readings are also used in this project to apportion the total sales volumes between Pikes Peak and the other compressor stations as described in the previous sections.

Avoided indirect emissions associated with the compression of equivalent underground sourced volumes (from McElmo Dome) are based on typical energy consumption rates (kWh/MMscf) at McElmo Dome.

Project emissions include direct (fuel combustion) and indirect (electricity usage) emissions associated with SD $CO_2$'s operations. Fuel gas used to operate the engines at Pikes Peak is metered using calibrated orifice meters. The fuel flow meters are calibrated to within ±2 percent on a quarterly basis. Electricity consumption rates at Pikes Peak and at McCamey are measured using electric meters that are calibrated and maintained by the electric power company.

The $CO_2$ gas and fuel gas compositions are analyzed once per month to quantify the mass fraction of organic species. These analytical procedures are performed in accordance with standard established procedures (e.g., Gas Processor's Association (GPA) Methods 2261 and 2286).

Emission factors used to calculate indirect emissions are based on the state-averaged emission factors as published in the most recent version of the USEPA eGRID database (or other equivalent data as may become available). Currently data in eGRID 2006 Version 2.1 is being used. Baseline $CH_4$ and $N_2O$ emissions are based on EIA data (USDOE 2002). Fuel gas $CH_4$ and $N_2O$ emissions are based on USEPA AP-42 (USEPA 2000) emission factors and fuel flow rates.

Table 7-1 shows the activity data used to calculate baseline and project emissions. The measurement and recording frequency for each parameter are also included in the table. Parameters to be monitored include:

- sales gas volumes at McCamey,
- gas volumes supplied from each compressor station (Pikes Peak, Grey Ranch, Mitchell, and Terrell),
- fuel gas flow rate at Pikes Peak,
- electricity consumption rates for $CO_2$ compressors at Pikes Peak and pumps at McCamey, and
- fuel gas composition and heating value at Pikes Peak.

**Table 7-1. Monitoring and Data Management Plan**

| Data Variable | Data Unit | Measured Calculated Estimated | Measurement Frequency | Recording Frequency (Archiving Method)[1] |
|---|---|---|---|---|
| Sales gas volumes at McCamey | Scf/month | Measured | Continuous | Monthly (P) |
| $CO_2$ volumes at individual compressor stations | Scf/month | Measured | Continuous | Monthly (P) |
| Fuel gas flow rate at Pikes Peak | Scf/month | Measured | Continuous | Monthly (P) |
| Electricity usage | kWh | Measured | Continuous | Monthly (P) |
| Fuel gas composition | Mole % | Measured | Monthly | Monthly(P) |
| Fuel gas heating value | Btu/scf | Measured | Monthly | Monthly (P) |

[1] E=Electronic, P=Paper

# 8.0 Other Impacts

## *8.1 Internal Impacts*

SD $CO_2$'s operations involve the compression of $CO_2$ for gathering and transport to downstream oil reservoirs. The compression operation requires the combustion of natural gas, which results in $NO_x$, CO, and VOC emissions associated with combustion. Estimates of $NO_x$, CO, and VOC emissions were calculated from the fuel usage rates measured for the Pikes Peak compressor engines and appropriate emission factors based on AP-42 (USEPA, 2000). These emissions are small, compared to the volume of $CO_2$ sequestered as a direct result of the project.

## *8.2 External Impacts*

The use of electricity to operate the compressors results in air emissions of $NO_{x,}$ $SO_2$ and mercury (Hg) associated with the fossil fuel combustion required for electricity generation at the electric power supplier's facility. However, these emissions are offset by the avoided emissions due to reduced electricity usage at McElmo Dome under the baseline.

## 9.0 Summary of Emission Reductions

A summary of the calculated baseline emissions, project emissions, and emission reductions by month is shown in Table 9-1. Emission reductions totaled 635,447 tonnes of $CO_2$e between October 2007and September 2008.

**Table 9-1. Summary of Baseline Emissions, Project Emissions, and Emission Reductions by Month (tonnes $CO_2$e)**

| Month-Yr | Baseline Emissions | Project Emissions | Emission Reductions |
|---|---|---|---|
| **October-07** | 26,518 | 1,767 | **24,751** |
| **November-07** | 46,169 | 2,169 | **44,000** |
| **December-07** | 59,524 | 2,769 | **56,755** |
| **January-08** | 53,513 | 2,840 | **50,674** |
| **February-08** | 58,724 | 2,746 | **55,978** |
| **March-08** | 62,090 | 2,979 | **59,111** |
| **April-08** | 58,862 | 3,434 | **55,429** |
| **May-08** | 64,184 | 2,725 | **61,459** |
| **June-08** | 56,856 | 2,166 | **54,690** |
| **July-08** | 64,392 | 2,951 | **61,441** |
| **August-08** | 65,444 | 3,168 | **62,276** |
| **September-08** | 51,624 | 2,849 | **48,775** |
| **TOTAL (Oct. - Dec. 2007)** | **132,211** | **6,706** | **125,505** |
| **TOTAL (Jan. - Sep. 2008)** | **535,689** | **25,747** | **509,833** |
| **TOTAL (Oct. 07 – Sep. 08)** | **667,900** | **32,453** | **635,338** |

# 10.0 References

(Bachu 2000): Bachu, S., Sequestration of $CO_2$ in geologic media: criteria and approach for site selection in response to climate change, Energy Conversion & Management, 41:954, (2000).

(CCP 2007): $CO_2$ Capture Project, www.co2captureproject.org

(IEA 2007): International Energy Agency (IEA), Greenhouse Gas R&D programme, http://www.ieagreen.org.uk/ also http://www.co2captureandstorage.info/co2db.php.

(IPCC 1996): Climate Change 1995. Impacts, Adaptations and Mitigation of Climate Change: Scientific-Technical Analyses. Contribution of Working Group II to the Second Assessment Report of the Intergovernmental Panel on Climate Change, Section 19.2.3.3, Cambridge University Press, 1996.

(IPCC 2005): IPCC Special Report on Carbon Dioxide Capture and Storage. Prepared by Working Group III of the Intergovernmental Panel on Climate Change [Metz, B., O. Davidson, H. C. de Coninck, M. Loos, and L. A. Meyer (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA, 442 pp.

(ISO 2006a): International Standards Organization, 14064-2, Greenhouse gases —Part 2: Specification with guidance at the project level for quantification, monitoring and reporting of greenhouse gas emission reductions or removal enhancements, First Edition, March 2006.

(ISO 2006b): International Standards Organization, 14064-3,Greenhouse gases —Part 3: Specification with guidance for the validation and verification of greenhouse gas assertions, First Edition, March 2006.

(Kinder Morgan 2007): KM $CO_2$ Company-$CO_2$ Transportation Central Basin Pipeline, http://www.kindermorgan.com/business/co2/transport_central_basin.cfm

(SPE 2006): Benson, S.M., Monitoring Carbon Dioxide Sequestration in Deep Geological Formations for Inventory Verification and Carbon Credits, SPE 102833, presented at 2006 Annual Technical Conference and Exhibition, San Antonio, September 2006.

(TCEQ 2005): Texas Commission on Environmental Quality, Standard Permit Number 1374A, Pikes Peak Plant Gas Production Facility, Fort Stockton, Pecos County, October 2005.

(USDOE 2002): Energy Information Administration (EIA). *Updated State- and Regional-level Greenhouse Gas Emission Factors for Electricity* (March 2002). http://eia.doe.gov/pub/oiaf/1605/dcrom/pdf/e-supdoc.pdf.

(USDOE 2006): US Department of Energy (DOE) Office of Fossil Energy, Office of Oil and Natural Gas, Basin Oriented Strategies for $CO_2$ Enhanced Oil Recovery: Permian Basin, February 2006.

(USDOE 2007), US Department of Energy (DOE) National Energy Technology Laboratory (NETL), Carbon Sequestration Technologies, http://www.netl.doe.gov/technologies/carbon_seq/index.html

(USEPA 2000): U.S. Environmental Protection Agency (EPA). *Compilation of Air Pollutant Emission Factors, Volume I: Stationary Point and Area Sources*, AP-42, U.S. EPA Office of Air Quality Planning and Standards, Fifth Edition, Supplement F, Table 3.2-1, August 2000,-- http://www.epa.gov/ttn/chief/ap42/ch03/index.html.

(USEPA 2007): U.S. Environmental Protection Agency (EPA) The Emissions & Generation Resource Integrated Database for 2006 (eGRID2006), Version 2.1, April 2007. http://www.epa.gov/cleanenergy/egrid/index.htm

# Appendix A

## Data Tables for Oct. 2007 – Sep. 2008 Time Period

**Table A-1. Summary of Baseline Emissions, Project Emissions, and Emissions Reductions by Month (tonnes $CO_2e$)**

| Month-Year | Baseline Emissions | | | Project Emissions | | | Emission Reductions (ER) |
|---|---|---|---|---|---|---|---|
| | Metered Volumes ($GV_{PP,B}$) | Avoided Emissions ($IND_1$) | Total (BE) | Combustion (CMB) | Indirects ($IND_2$ + $IND_{3,PP}$) | Total (PE) | |
| **October-07** | 26,206 | 312 | 26,518 | 893 | 874 | 1,767 | **24,751** |
| **November-07** | 45,612 | 558 | 46,169 | 1,590 | 580 | 2,169 | **44,000** |
| **December-07** | 58,875 | 649 | 59,524 | 1,776 | 993 | 2,769 | **56,755** |
| **January-08** | 52,919 | 594 | 53,513 | 1,858 | 982 | 2,840 | **50,674** |
| **February-08** | 58,083 | 640 | 58,724 | 1,867 | 878 | 2,746 | **55,978** |
| **March-08** | 61,405 | 685 | 62,090 | 1,983 | 996 | 2,979 | **59,111** |
| **April-08** | 58,164 | 698 | 58,862 | 2,110 | 1,323 | 3,434 | **55,429** |
| **May-08** | 63,477 | 707 | 64,184 | 1,703 | 1,023 | 2,725 | **61,459** |
| **June-08** | 56,230 | 626 | 56,856 | 1,291 | 874 | 2,166 | **54,690** |
| **July-08** | 63,675 | 717 | 64,392 | 2,029 | 922 | 2,951 | **61,441** |
| **August-08** | 64,710 | 733 | 65,444 | 2,140 | 1,028 | 3,168 | **62,276** |
| **September-08** | 51,012 | 612 | 51,624 | 1,792 | 1,056 | 2,849 | **48,775** |
| **TOTAL (Oct. - Dec. 2007)** | 130,693 | 1,518 | 132,211 | 4,259 | 2,447 | 6,706 | **125,505** |
| **TOTAL (Jan. - Sep. 2008)** | 529,676 | 6,013 | 535,689 | 16,773 | 9,083 | 25,856 | **509,833** |
| **TOTAL (Oct. 07 - Sep. 08)** | 660,368 | 7,532 | 667,900 | 21,033 | 11,530 | 32,562 | **635,338** |

# Table A-2. Metered Sales Gas Volumes, Gas Composition, and Avoided Emissions ($IND_1$) by Month

| Month-Year | Sales Meter Volumes | | | | | | CO2 volume measured at Pikes Peak ($GV_{PP}$, Mscf) | PP fraction of CO2 supplied ($PP_{frac}$) | Sales Gas Comp. | | PP Baseline ($GV_{PP,B}$) | | | Avoided Indirect Emissions | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Pecos | CRC | North Cross | South Cross | Mid Cross | Total (GV) | | | $CO_2$ | $CH_4$ | $CO_2$ (A) | $CH_4$ (B) | Total CO2e ($GV_{PP,B}$= A+21xB) | Avoided Energy Usage | $CO_2$ | $CH_4$ | $N_2O$ | Total $CO_2e$ ($IND_1$) |
| | (Mscf) | | | | | | | | (% mole) | | (tonnes) | | | (MW-hr) | (tonnes) | | | |
| October-07 | 320,545 | 375,130 | 429,920 | 1,063,310 | 62,740 | 2,251,645 | 432,670 | 0.19 | 96.869 | 2.445 | 21,971 | 202 | **26,206** | 345 | 311 | 0.002 | 0.005 | **312** |
| November-07 | 330,450 | 531,410 | 548,680 | 1,186,510 | 70,680 | 2,667,730 | 778,920 | 0.29 | 97.369 | 1.987 | 39,462 | 293 | **45,612** | 616 | 555 | 0.004 | 0.008 | **558** |
| December-07 | 349,730 | 445,320 | 592,940 | 1,238,520 | 122,650 | 2,749,160 | 930,850 | 0.33 | 95.359 | 3.866 | 44,957 | 663 | **58,875** | 717 | 646 | 0.004 | 0.009 | **649** |
| January-08 | 356,000 | 350,330 | 579,880 | 1,200,670 | 144,460 | 2,631,340 | 827,410 | 0.31 | 95.634 | 3.528 | 41,288 | 554 | **52,919** | 657 | 591 | 0.004 | 0.009 | **594** |
| February-08 | 329,320 | 475,980 | 521,860 | 1,208,240 | 119,660 | 2,655,060 | 912,890 | 0.33 | 95.094 | 3.892 | 44,253 | 659 | **58,083** | 708 | 637 | 0.004 | 0.009 | **640** |
| March-08 | 352,440 | 603,500 | 531,530 | 1,241,140 | 152,370 | 2,880,980 | 972,500 | 0.33 | 95.552 | 3.632 | 47,591 | 658 | **61,405** | 757 | 682 | 0.004 | 0.010 | **685** |
| April-08 | 308,647 | 459,880 | 504,070 | 1,228,160 | 144,970 | 2,645,727 | 992,720 | 0.36 | 97.117 | 2.289 | 49,292 | 422 | **58,164** | 772 | 695 | 0.004 | 0.010 | **698** |
| May-08 | 313,555 | 492,170 | 507,110 | 1,244,800 | 130,880 | 2,688,515 | 998,200 | 0.36 | 95.528 | 3.665 | 49,094 | 685 | **63,477** | 781 | 704 | 0.005 | 0.010 | **707** |
| June-08 | 288,573 | 443,160 | 463,630 | 1,136,050 | 124,820 | 2,456,233 | 868,560 | 0.35 | 95.376 | 3.693 | 43,398 | 611 | **56,230** | 692 | 623 | 0.004 | 0.009 | **626** |
| July-08 | 266,653 | 434,020 | 522,420 | 1,287,920 | 53,450 | 2,564,463 | 970,520 | 0.39 | 95.401 | 3.500 | 49,740 | 664 | **63,675** | 793 | 714 | 0.005 | 0.010 | **717** |
| August-08 | 264,947 | 395,420 | 613,940 | 1,291,030 | 61,260 | 2,626,597 | 991,220 | 0.39 | 95.685 | 3.372 | 50,989 | 653 | **64,710** | 810 | 730 | 0.005 | 0.011 | **733** |
| September-08 | 255,486 | 359,640 | 540,790 | 1,085,730 | 147,040 | 2,388,686 | 834,010 | 0.35 | 96.078 | 2.449 | 42,701 | 396 | **51,012** | 676 | 609 | 0.004 | 0.009 | **612** |
| TOTAL (Oct. - Dec. 2007) | 1,000,725 | 1,351,860 | 1,571,540 | 3,488,340 | 256,070 | 7,668,535 | 2,142,440 | | | | 106,390 | 1,157 | **130,693** | 1,678 | 1,511 | 0.010 | 0.022 | **1,518** |
| TOTAL (Jan. - Sep. 2008) | 2,735,621 | 4,014,100 | 4,785,230 | 10,923,740 | 1,078,910 | 23,537,601 | 8,368,030 | | | | 418,345 | 5,301 | **529,676** | 6,646 | 5,986 | 0.038 | 0.087 | **6,013** |

## Table A-3. Fuel Usage, Project Combustion Emissions (CMB), and Fuel Properties by Month for Pikes Peak $CO_2$ Compressors

| Month-Year | Station Fuel Usage | | Emissions | | | Fuel Composition (mole %) | | | | | | | | | | | Mole $CO_2$/mole fuel | Fuel HHV (Btu/scf) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | (MMBtu) | (scf) | $CO_2$ (tonnes) | $CH_4$ (tonnes) | $CO_2$e (tonnes) | Nitrogen | $CO_2$ | methane | ethane | propane | n-butane | iso-butane | n-pentane | iso-pentane | hexanes + | Total | | |
| October-07 | 13,193 | 13,699,896 | 711 | 9 | 893 | 1.425 | 3.195 | 95.315 | 0.056 | 0.009 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 100.000 | 0.986 | 963 |
| November-07 | 23,547 | 24,375,776 | 1,264 | 15 | 1,590 | 1.445 | 2.6 | 95.909 | 0.046 | 0 | 0 | 0 | 0.000 | 0.000 | 0.000 | 100.000 | 0.986 | 966 |
| December-07 | 26,350 | 27,221,074 | 1,413 | 17 | 1,776 | 1.397 | 2.497 | 96.076 | 0.031 | 0 | 0 | 0 | 0.000 | 0.000 | 0.000 | 100.001 | 0.986 | 968 |
| January-08 | 27,532 | 28,471,562 | 1,478 | 18 | 1,858 | 1.421 | 2.549 | 95.959 | 0.071 | 0 | 0 | 0 | 0.000 | 0.000 | 0.000 | 100.000 | 0.987 | 967 |
| February-08 | 27,683 | 28,627,715 | 1,485 | 18 | 1,867 | 1.437 | 2.534 | 95.988 | 0.041 | 0 | 0 | 0 | 0.000 | 0.000 | 0.000 | 100.000 | 0.986 | 967 |
| March-08 | 29,416 | 30,388,430 | 1,577 | 19 | 1,983 | 1.455 | 2.461 | 96.016 | 0.068 | 0 | 0 | 0 | 0.000 | 0.000 | 0.000 | 100.000 | 0.986 | 968 |
| April-08 | 31,273 | 32,373,706 | 1,678 | 21 | 2,110 | 1.483 | 2.561 | 95.922 | 0.033 | 0 | 0 | 0 | 0.000 | 0.000 | 0.000 | 99.999 | 0.985 | 966 |
| May-08 | 25,256 | 26,117,890 | 1,354 | 17 | 1,703 | 1.542 | 2.485 | 95.908 | 0.066 | 0 | 0 | 0 | 0.000 | 0.000 | 0.000 | 100.001 | 0.985 | 967 |
| June-08 | 19,130 | 19,803,313 | 1,027 | 13 | 1,291 | 1.515 | 2.617 | 95.769 | 0.098 | 0 | 0 | 0 | 0.000 | 0.000 | 0.000 | 99.999 | 0.986 | 966 |
| July-08 | 30,068 | 31,061,983 | 1,614 | 20 | 2,029 | 1.492 | 2.538 | 95.738 | 0.22 | 0.012 | 0 | 0 | 0.000 | 0.000 | 0.000 | 100.000 | 0.988 | 968 |
| August-08 | 31,744 | 32,827,301 | 1,701 | 21 | 2,140 | 1.601 | 2.412 | 95.865 | 0.122 | 0 | 0 | 0 | 0.000 | 0.000 | 0.000 | 100.000 | 0.985 | 967 |
| September-08 | 26,521 | 27,482,902 | 1,426 | 17 | 1,792 | 1.589 | 2.733 | 95.461 | 0.204 | 0.013 | 0 | 0 | 0.000 | 0.000 | 0.000 | 100.000 | 0.986 | 965 |
| TOTAL (Oct. - Dec 2007) | 63,090 | 65,296,747 | 3,388 | 41 | **4,259** | | | | | | | | | | | | | |
| TOTAL (Jan. - Sep. 2008) | 248,623 | 257,154,801 | 13,340 | 163 | **16,773** | | | | | | | | | | | | | |

**Note:**
For highlited months, fuel composition data were based on previous month's values

**Table A - 4. Project Electricity Usage and Indirect Emissions ($IND_2$, + $IND_{3,PP}$) by Month**

| Month-Year | Electricty Usage (kWh) | | | | Indirect Emissions (tonnes) | | | |
|---|---|---|---|---|---|---|---|---|
| | Pikes Peak (PP) (A) | McCamey (B) | PP's fractional share of McCamey electricity ( C) | TOTAL A+BxC | $CO_2$ | $CH_4$ | $N_2O$ | Total $CO_2e$ ($IND_2$ + $IND_{3,PP}$) |
| **October-07** | 1,261,582 | 228,097 | 0.19 | 1,305,256 | 871 | 0.0046 | 0.0086 | **874** |
| **November-07** | 776,977 | 307,030 | 0.29 | 865,639 | 578 | 0.0030 | 0.0057 | **580** |
| **December-07** | 1,392,177 | 276,522 | 0.33 | 1,482,314 | 990 | 0.0052 | 0.0098 | **993** |
| **January-08** | 1,387,549 | 251,013 | 0.31 | 1,465,832 | 979 | 0.0051 | 0.0097 | **982** |
| **February-08** | 1,223,771 | 262,862 | 0.33 | 1,311,345 | 875 | 0.0046 | 0.0087 | **878** |
| **March-08** | 1,393,332 | 287,518 | 0.33 | 1,487,814 | 993 | 0.0052 | 0.0099 | **996** |
| **April-08** | 1,862,888 | 310,821 | 0.36 | 1,976,229 | 1,319 | 0.0069 | 0.0131 | **1,323** |
| **May-08** | 1,414,288 | 309,719 | 0.36 | 1,526,823 | 1,019 | 0.0053 | 0.0101 | **1,023** |
| **June-08** | 1,219,631 | 244,637 | 0.35 | 1,305,774 | 872 | 0.0046 | 0.0086 | **874** |
| **July-08** | 1,256,797 | 311,806 | 0.39 | 1,377,295 | 919 | 0.0048 | 0.0091 | **922** |
| **August-08** | 1,419,524 | 298,569 | 0.39 | 1,534,663 | 1,025 | 0.0054 | 0.0102 | **1,028** |
| **September-08** | 1,487,795 | 252,910 | 0.35 | 1,577,240 | 1,053 | 0.0055 | 0.0104 | **1,056** |
| **TOTAL (Oct. - Dec. 2007)** | 3,430,736 | 811,649 | 0.27 | 3,653,209 | 2,439 | 0.0128 | 0.0242 | **2,447** |
| **TOTAL (Jan. - Sep 2008)** | 12,665,575 | 2,529,855 | 0.35 | 13,563,015 | 9,054 | 0.0474 | 0.0898 | **9,083** |

## Table A - 5. Pikes Peak Volume Fraction ($PP_{frac}$) by Month

| Month-Year | CO2 Supply Volumes Metered at Compressor Stations (Mscf) | | | | | Pikes Peak fraction ($PP_{frac}$) = A/B) | Other Compressor Stations fraction $V_{frac}$ = (1- A/B) |
|---|---|---|---|---|---|---|---|
| | Terrell | Grey Ranch | Mitchell | Pikes Peak (A) | Total (B) | | |
| October-07 | 791,300 | 835,650 | 200,090 | 432,670 | 2,259,710 | 0.19 | 0.81 |
| November-07 | 770,400 | 640,890 | 507,130 | 778,920 | 2,697,340 | 0.29 | 0.71 |
| December-07 | 755,210 | 508,670 | 660,930 | 930,850 | 2,855,660 | 0.33 | 0.67 |
| January-08 | 479,080 | 658,380 | 688,200 | 827,410 | 2,653,070 | 0.31 | 0.69 |
| February-08 | 799,510 | 389,010 | 638,700 | 912,890 | 2,740,110 | 0.33 | 0.67 |
| March-08 | 815,840 | 423,770 | 747,310 | 972,500 | 2,959,420 | 0.33 | 0.67 |
| April-08 | 752,630 | 321,641 | 655,400 | 992,720 | 2,722,391 | 0.36 | 0.64 |
| May-08 | 785,100 | 284,671 | 679,270 | 998,200 | 2,747,241 | 0.36 | 0.64 |
| June-08 | 656,260 | 374,880 | 566,910 | 868,560 | 2,466,610 | 0.35 | 0.65 |
| July-08 | 798,340 | 0 | 742,510 | 970,520 | 2,511,370 | 0.39 | 0.61 |
| August-08 | 776,790 | 0 | 802,350 | 991,220 | 2,570,360 | 0.39 | 0.61 |
| September-08 | 701,560 | 0 | 822,630 | 834,010 | 2,358,200 | 0.35 | 0.65 |
| TOTAL (Oct. - Dec. 2007) | 2,316,910 | 1,985,210 | 1,368,150 | 2,142,440 | 7,812,710 | 0.27 | 0.73 |
| TOTAL (Jan. - Sep. 2008) | 6,565,110 | 2,452,352 | 6,343,280 | 8,368,030 | 23,728,772 | 0.35 | 0.65 |

**Table A-6. Calculation of $CO_2$ in Exhaust Due to Fuel Combustion (Oct. 2007)**

| Specie | mole percent (m.p.) | mole fraction (m.f.)=(m.p)/100 | moles of $CO_2$ in flue gas per mole fuel specie (c.c.) | moles of $CO_2$ in flue gas (c.c. x m.f.) |
|---|---|---|---|---|
| **nitrogen** | 1.425 | 0.01425 | 0.00 | 0.0000 |
| **carbon dioxide** | 3.195 | 0.03195 | 1.00 | 0.0320 |
| **methane** | 95.315 | 0.95315 | 1.00 | 0.9532 |
| **ethane** | 0.056 | 0.00056 | 2.00 | 0.0011 |
| **propane** | 0.009 | 0.00009 | 3.00 | 0.0003 |
| **i-butane** | 0.000 | 0.00000 | 4.00 | 0.0000 |
| **n-butane** | 0.000 | 0.00000 | 4.00 | 0.0000 |
| **i-pentane** | 0.000 | 0.00000 | 5.00 | 0.0000 |
| **n-pentane** | 0.000 | 0.00000 | 5.00 | 0.0000 |
| **hexane** | 0.000 | 0.00000 | 6.00 | 0.0000 |
| **heptane+** | 0.000 | 0.00000 | 7.00 | 0.0000 |
| **TOTAL** | **100.000** | **1.00000** | | **0.9865** |