Verification of Blue Source Emission Reduction Credits Created from Denbury Resources' Geologic Sequestration Project

(October 2003 – March 2004)

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1.0 Executive Summary

Blue Source is an active supplier of emission reduction credits (ERCs) sourced from geologic sequestration, conservation, transportation, and avoidance projects and companies. Denbury Resources is the largest producer of oil and natural gas in the state of Mississippi with additional production in Louisiana and offshore in the Gulf of Mexico. Its operations include the use of carbon dioxide (CO_2) for enhanced oil recovery (EOR) operations, 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 (*Climate Change 1995*, 1996).

Denbury Resources, Incorporated began tertiary oil production in Western Mississippi with the purchase of the Little Creek field in September 1999. The company obtains CO_2 from underground reserves at Jackson Dome located near Jackson, Mississippi. The underground-sourced CO_2 is transported to the Little Creek and surrounding fields and to the West Mallalieu field for use in enhanced oil recovery (EOR) operations.

Instead of venting the CO_2 that is separated from the recovered oil to the atmosphere, Denbury Resources captures the vented CO_2 and re-compresses and re-injects (i.e., recycles) it, for EOR purposes in these oil fields. The use of vent-sourced CO_2 will displace an equivalent volume of underground-sourced CO_2 and avoid emissions that would have resulted from its compression and transport.

This verification is based on data obtained from Denbury Resources and Blue Source. Estimates of baseline emissions, actual (project) emissions, and ERCs were verified based on established emission estimation techniques, conservative estimates, accurate/reliable data sources, and documented methodologies. The use of recycled gas for EOR operations at West Mallalieu was initiated in mid-2001. The operations at this location are similar to those at Little Creek and the same ERC estimation techniques documented in the protocol are used for the West Mallalieu facility.

Verification findings indicate that all significant emission sources that materially affect the ERCs are included within the scope of the project. Both, direct emission sources that contribute to emissions within the project boundaries and indirect emission sources that contribute to emissions outside the project boundaries were included. Applicable source characteristics (e.g., gas flow rates, compressor operating parameters, electricity usage, etc.) that affect emissions were considered.

Emission reduction estimates by month are consistent over the creation period. Baseline emissions that are based on metered gas volumes are consistent month-by-month. Emission factors and methodology used to calculate actual emissions are also consistent by source type. Data consistency was also verified by comparing the Little Creek and West Mallalieu data for this creation period with the corresponding data for Oct. 2002 – Mar. 2003 creation period, which were the basis of the ERCs previously registered with CACI.

Data collection, management, and review procedures are applied at site and corporate levels. The sources of data are documented and records maintained.

This verification report documents that carbon dioxide equivalent (CO_2e) emission credits totaling 2.0 million tonnes (metric) were created during October 2003 – March 2004. The uncertainty is estimated to be within ±5.5 percent at a 95 percent confidence level.

2.0 Project Description

Denbury Resources is the largest producer of oil and natural gas in the state of Mississippi with additional production in Louisiana and offshore in the Gulf of Mexico. The company operates CO_2 compression facilities at Jackson Dome reservoir, and CO_2 gathering, compression, and injection facilities at Little Creek and surrounding fields and in West Mallalieu in southwestern Mississippi. Some of the CO_2 obtained from the Jackson Dome wells is either heated and compressed, or cooled and pumped prior to delivery through the pipeline to Little Creek and West Mallalieu.

At Little Creek, the CO_2 is heated and compressed to injection pressures required for EOR purposes. Simultaneously, the vent-sourced CO_2 obtained from Little Creek and surrounding oil fields is separated, heated, compressed, and re-injected into Little Creek and surrounding fields for EOR purposes.

In April 2003, Denbury installed a 500 hp ESP horizontal pump at the Little Creek facility in the CO_2 pipeline from Jackson Dome to improve compression efficiency and to meet their need for additional volumes of underground-sourced CO_2. Approximately 20 million standard cubic feet per day (MMscfd) of underground-sourced CO_2 is pumped in the liquid phase with the remainder heated and compressed through the existing gas compressors.

Denbury personnel indicated that the operations at the West Mallalieu compressor facility are similar to those at Little Creek in the metering of purchased and recycle gas volumes and facility electricity usage. However, at West Mallalieu, all of the underground-sourced CO_2 is pumped in the liquid phase. The recycle gas compressors are similar to those at Little Creek.

Denbury Resources has invested in the infrastructure, including recycle compressors and pipelines required to compress and re-inject the associated CO_2 back to its oil fields for EOR. This reduces the amount of underground-sourced CO_2 obtained from the Jackson Dome reservoir and avoids the discharge of waste CO_2 to the atmosphere, which could have been vented in the absence of the Denbury Resources project.

The Denbury Resources CCR, which is the subject of this verification, was prepared according to Blue Source's ERC quantification protocol that was registered with CACI during December 2002. The subject CCR includes ERCs created during the October 2003 – March 2004 time-period for Little Creek and West Mallalieu, and is being registered with CACI in conjunction with this verification report.

3.0 Seller's Assumptions

The main assumptions used in the credit creation report to calculate the ERCs are listed below:

- Fuel usage for the natural gas-fired engine-driven compressors at Jackson Dome was based on calculations of compressor work and an assumed engine brake-specific fuel consumption (bsfc) of 8,000 Btu/hp-hr. Isothermal compression was assumed in the calculation of compressor work. This results in a conservatively lower estimate of compressor work and hence avoided emissions.
- Electricity consumption for electric-drive compressors and pumps were based on monthly electricity usage metered at each facility. "Avoided" emissions due to compression of gas from Jackson Dome were based on compressor and pump work calculated from compressor/pump suction and discharge conditions, and assumed compressor/pump and motor efficiencies of 85 and 95 percent, respectively. Isothermal compression was assumed in the calculation of compressor work.
- Compressor operating parameters (suction/discharge pressures and temperatures) used to calculate compressor work were based on the 2002 values. Plant personnel were contacted to verify that the operating conditions in 2003 and 2004 were similar to the 2002 values.
- Combustion emissions were estimated from fuel consumption rates and fuel composition. Carbon dioxide emissions were conservatively estimated by assuming all the carbon in the fuel is converted to CO_2. Methane emissions from the combustion exhaust were calculated from AP-42 emission factors that are published by the U.S. Environmental Protection Agency (EPA).
- Indirect emissions from electric drive compressors and pumps used in each project were based on state-specific emission factors for emissions of CO_2, CH_4, and N_2O from electric utilities that were compiled by the U.S. Energy Information Administration (EIA). Some differences in emission rates can be expected by the use of generator-specific emission factors (i.e., factors based on the mix of fuels and technologies used for electricity generation by the supplying utility). However, the effect of this change on calculated ERCs is insignificant. For e.g., a 50 percent change in the utility CO_2 emission factor results in <0.05 percent change in calculated ERCs.
- Fugitive emissions that occur downstream of the metering locations are not included in the project. These emissions are small (<0.0002 percent of ERC) and would have occurred anyway if Denbury Resources had secured underground-sourced CO_2 for EOR operations. Therefore, not accounting for fugitive emissions from this project is appropriate.
- A global warming potential (GWP) of 21 for CH_4 and 310 for N_2O was used in the estimation of the total CO_2 equivalent emissions. This is consistent with current guidance from the IPCC.

The effect of these assumptions and data quality on the ERC estimates was assessed in an uncertainty analysis performed in 2002 in accordance with ISO guidelines to estimate the uncertainty in the ERC estimates. The expanded uncertainty for the 2002 data was calculated to be within ±5.5 percent at the 95 percent confidence interval. Since the data sources, measurement methods, and emissions estimation techniques used for the 2003 data are similar to those used in 2002, the same level of uncertainty (i.e., ±5.5 percent) can be assumed to apply for the 2003 data. As a check, the uncertainty in the October 2003 ERCs for Little Creek was calculated as ± 13,082 tonnes which is about ±5 percent of the October 2003 ERCs of 264,250 tonnes (Table 4-1).

4.0 Real

For the Denbury Resources sequestration project, the emission reduction is real because it represents an actual and recognizable action that resulted in direct reductions of recycled CO_2 gas emissions that could be vented to the atmosphere. In the absence of the recycling project, EOR operations would have involved injecting an equivalent quantity of CO_2 obtained from Jackson Dome and venting the associated CO_2 gas produced to the atmosphere. Denbury Resources captures waste CO_2 that has been separated from recovered tertiary oil, compresses it, and re-injects it for EOR, which is a recognized sequestration technology (*Climate Change 1995, 1996*).

To estimate baseline emissions, project emissions, and the ERCs created, data obtained from Denbury Resources and Blue Source were verified. These included:

- Metered volumes of total CO_2 injection gas and purchased gas obtained from Jackson Dome. These volumes are metered at the Little Creek and West Mallalieu facilities. Monthly volumes are obtained from daily records that are maintained by Denbury Resources.
- Recycle gas composition analysis.
- Electricity usage data that included monthly billing records for Little Creek and West Mallalieu.

Calculations of baseline emissions, project emissions, and ERCs for the October 2003 – March 2004 creation time-period for Little Creek, and West Mallalieu were verified. A detailed sample calculation for October 2003 for Little Creek is included in the following sections. Monthly emissions estimates from each source that contributes to baseline and project emissions are included in Tables 4-1 — 4-3.

Table 4-1. Baseline Emissions, Actual Emissions, and ERCs by Month for Little Creek (tonnes CO_2e)

Month - Year	Baseline Emissions						Actual Emissions	Emission Reduction Credits
	Gross Volume (GV)	Avoided Emissions				TOTAL	TOTAL (IND_5)	(ERC)
		(IND_1)	(IND_2)	(IND_3)	(IND_4)			
October 2003	264,446	4	21	115	1,671	266,257	2,008	264,249
November 2003	240,763	4	19	105	1,521	242,411	1,903	240,508
December 2003	269,911	4	22	117	1,705	271,759	1,831	269,928
January 2004	271,516	4	22	118	1,716	273,375	1,856	271,519
February 2004	256,315	4	20	111	1,619	258,070	1,798	256,272
March 2004	267,721	4	21	116	1,692	269,555	1,815	267,740
Total Creation Period (Oct. 2003 – Mar. 2004)	1,570,671	23	125	683	9,924	1,581,426	11,211	**1,570,215**

Table 4-2. Baseline Emissions, Actual Emissions, and ERCs by Month for West Mallalieu (tonnes CO_2e)

Month - Year	Baseline Emissions						Leakages	Emission Reduction Credits
	Gross Volume (GV)	Avoided Emissions				TOTAL	TOTAL (IND_5)	(ERC)
		(IND_1)	(IND_2)	(IND_3)	(IND_4)			
October 2003	65,343	1	5	29	0	65,377	1,378	64,000
November 2003	68,705	1	5	30	0	68,742	1,658	67,084
December 2003	71,961	1	6	31	0	71,999	1,616	70,383
January 2004	84,709	1	7	37	0	84,754	1,998	82,756
February 2004	75,954	1	6	33	0	75,994	1,836	74,158
March 2004	84,490	1	7	37	0	84,534	2,068	82,466
Total Creation Period (Oct. 2003 – Mar. 2004)	451,161	7	36	197	0	451,401	10,553	**440,848**

Table 4-3. Summary of Emission Reduction Credits by Month for the Project (tonnes CO_2e)

Month - Year	Emission Reduction Credits Little Creek	Emission Reduction Credits West Mallalieu	Emission Reduction Credits TOTAL
October 2003	264,249	64,000	328,248
November 2003	240,508	67,084	307,592
December 2003	269,928	70,383	340,311
January 2004	271,519	82,756	354,276
February 2004	256,272	74,158	330,430
March 2004	267,740	82,466	350,206
Total Creation Period (Oct.. 2003 – Mar. 2004)	**1,570,215**	**440,848**	**2,011,063**

4.1 Baseline Emissions

Baseline emissions for Denbury Resources' CO_2 recycling project are the gross volumes of recycle gas that would have been discharged (or would have had the regulatory right to be discharged) to the atmosphere in the absence of the project's activities that involve the capture, compression, and injection of the recycle gas for EOR purposes.

The gross volume of vent-sourced gas is determined as the difference between the total CO_2 injected gas volume metered prior to injection at the Little Creek and surrounding fields and the volume of CO_2 gas obtained from Jackson Dome metered at the entrance to the Little Creek compression facility. This difference represents the volume of gas that is vent sourced (recycled) and that would have been discharged to the atmosphere in the absence of the project. A similar approach is used for the West Mallalieu compression facility and associated oil fields.

To sustain the EOR operations under the baseline scenario, an equivalent volume of gas (equal to the recycle gas volumes at Little Creek and West Mallalieu) would be required from Jackson Dome. A fraction of this gas would have been either heated and compressed, or cooled and pumped, before leaving the Jackson Dome facility through the CO_2 pipeline to the point of custody transfer at Little Creek and West Mallalieu. At Little Creek, approximately 70 percent of the gas volume would have been preheated by a gas-fired heater and then further compressed to injection gas pressures prior to injection. The remaining 30 percent would have been pumped in the liquid phase. At West Mallalieu, the entire CO_2 gas volume would have pumped in the liquid phase to injection pressures. Emissions from all of these operations (except CO_2 gas heating at Jackson Dome–as explained below) are avoided in the post-project scenario but would have occurred in the absence of the project; therefore, these emissions are included in the project baseline.

Since heat from the water used to cool the engines at Jackson Dome was used to heat the CO_2 gas prior to initial compression, there are no emissions associated with this heating process that contribute to project baseline emissions. Additional fugitive emissions would have occurred during compression of additional gas volumes (equal to recycle volumes) from equipment located downstream of the gas meter at Little Creek and West Mallalieu used to meter gas from Jackson Dome. These emissions are expected to be small and are not included in the project baseline.

In April 2003, a new high efficiency horizontal ESP pump rated at 500 Hp was installed at the Little Creek facility in the CO_2 pipeline from Jackson Dome. This allowed a portion of the underground sourced CO_2 to be pumped to injection pressures in the liquid phase instead of being heated and compressed as a gas. Plant personnel indicated that soon after installation, the ESP pump was operated at maximum load and the remainder of underground-sourced CO_2 was heated and compressed through existing compressors. Based on the underground-sourced volumes metered between May – September 2003 (i.e., after installation of the pump) and pump operating conditions, on average about 30 percent of the underground sourced CO_2 was pumped.

Any additional CO_2 that was generated and released to the atmosphere as a result of the recycle operations (e.g., indirect emissions from electricity generation necessary to operate the recycle compressors) are included in the calculation of the net GHG emission reductions.

In summary, baseline emissions include:

- Gross gas volumes (i.e., the recycle gas volumes used for EOR at Little Creek and West Mallalieu -GV);
- Indirect CO_2e emissions that would have occurred from electricity usage from the chiller (IND_1) and the pump (IND_2) at Jackson Dome;
- Indirect emissions that would have occurred from fuel combustion in the compressor engines at Jackson Dome (IND_3);
- Direct emissions that would have occurred from fuel combustion in the gas heater at Little Creek used to heat the gas obtained from Jackson Dome (CMB_1); and
- Indirect emissions that would have occurred from electricity usage for the compressors and ESP pump (post May 2003) at Little Creek used to raise the pressure of underground-sourced CO_2 (equal to recycle volumes) from Jackson Dome (IND_4). At West Mallalieu, avoided emissions that would have occurred from the pumps in the CO_2 line from Jackson Dome were not included under baseline. This approach is conservative as it reduces the ERCs created from West Mallalieu.

Sample Calculation (Little Creek, October 2003)

The baseline calculations are discussed and verified using a detailed sample calculation for the month of October 2003 for the Little Creek facility. Calculations for West Mallalieu are similar based on similar operations between the two facilities.

Based on discussions with Jackson Dome plant personnel, approximately 75 percent of the CO_2 gas exits from the wells at the Dome at high pressure ~ 1,300 psig and does not require any compression before entering the pipeline. Of the remaining 25 percent, approximately two-thirds is heated and compressed by the engine-driven compressors, and one-third is cooled and pumped by the electric pump. The avoided emissions are calculated based on these ratios.

GV Calculation

The gross gas volume (converted from scf/month to tonnes/month), which represents the recycled gas volume, was calculated as the difference between the metered volumes of the total injected gas and the volume obtained from Jackson Dome. The CO_2 and CH_4 concentrations in the recycle gas were determined to be 92.955 and 3.904 percent by volume, respectively, based on typical gas composition analysis. A global warming potential (GWP) of 21 was used for methane.

Recycle gas volume = Total volume – volume from Jackson Dome
= 6,816,400,000 – 2,720,562,000
= 4,095,838,000 scf

$$\text{GV} = (\text{recycle gas volume}) \times [CO_2 \text{ fraction} + 21 \times (CH_4 \text{ fraction})]$$

$$= 4{,}095{,}838{,}000 \ \text{scf gas} \times \left(0.92955 \frac{\text{scf } CO_2}{\text{scf gas}} \times \frac{\text{lb mole } CO_2}{379.4 \text{ scf } CO_2} \times 44 \frac{\text{lb } CO_2}{\text{lb mole } CO_2} \times \frac{\text{tonne}}{2205 \text{ lb}} + 21 \text{ x } 0.03904 \frac{\text{scf } CH_4}{\text{scf gas}} \times \frac{\text{lb mole } CH_4}{379.4 \text{ scf } CH_4} \times 16 \frac{\text{lb } CH_4}{\text{lb mole } CH_4} \times \frac{\text{tonne}}{2205 \text{ lb}} \right)$$

$$= 264{,}446 \text{ tonnes } CO_2e$$

The mass of recycled gas is calculated from the recycled gas volume and gas molecular weight (based on typical gas analysis).

$$\text{Mass of recycle gas} = 4{,}095{,}838{,}000 \ \text{scf x } \frac{\text{lb mole}}{379.3 \text{ scf}} \text{ x } 43.1 \frac{\text{lbm}}{\text{lb mole}}$$

$$= 465.6 \text{ x } 10^6 \text{ lbm gas}$$

IND_1 Calculation

Avoided indirect emissions from electricity usage by the chiller unit (IND_1) are calculated by assuming that the fraction of total recycle gas that would have been cooled by the chiller is the same as the fraction of total Dome gas that enters the chiller. An electricity usage factor of 0.5 kW per ton of refrigeration, which is typical of electric centrifugal chillers, was assumed.

$$\text{Electricity usage} = 0.25 \text{ x } \frac{1}{3} \text{ x } 465.6 \text{ x } 10^6 \text{ lbm gas x } 0.203 \frac{\text{Btu}}{\text{lbmR}} \text{ x}$$

$$\left[(80 + 460) - (60 + 460)\right] \text{R x } \frac{\text{ton}}{12{,}000 \frac{\text{Btu}}{\text{hr}}} \text{ x } \frac{0.5 \text{ kW}}{\text{ton}} \text{ x } \frac{\text{MW} - \text{hr}}{1000 \text{ kW} - \text{hr}}$$

$$= 6.56 \text{ MW} - \text{hr}$$

$$\text{Chiller Emissions} = (\text{emission factor}) \text{ x } (\text{electrical usage})$$

$$CO_2 \text{Emissions} = (0.587) \frac{\text{tonne } CO_2}{\text{MW - hr}} \times (6.56) \text{ MW - hr}$$

$$= 3.85 \text{ tonnes } CO_2$$

$$CH_4 \text{ Emissions} = (5.99 \times 10^{-6}) \frac{\text{tonne } CH_4}{\text{MW - hr}} \times (6.56) \text{ MW - hr}$$

$$= 3.93 \text{ x } 10^{-5} \text{ tonne } CH_4$$

$$N_2O \text{ Emissions} = (0.75 \times 10^{-5}) \frac{\text{tonne } N_2O}{\text{MW - hr}} \times (6.56) \text{ MW - hr}$$

$$= 4.91 \text{ x } 10^{-5} \text{ tonne } N_2O$$

$$IND_1 (\text{Oct. } 2003)\, CO_2e = 3.54 \text{ tonnes } CO_2 + (21 \times 3.61\, x\, 10^{-5}) \text{ tonnes } CH_4$$

$$+ (310 \times 4.51\, x\, 10^{-5}) \text{ tonnes } N_2O$$

$$= 3.87 \text{ tonnes } CO_2e$$

IND_2 Calculation

Avoided CO_2e emissions from the pump (IND_2) are based on the electricity usage for the pump. Assuming a pump efficiency of 85 percent, and electric motor efficiency of 95 percent, pump work is calculated as:

$$\text{Pump work} = \left[1.51 \frac{\text{ft}^3}{\text{lb mole}} \text{ x } \frac{\text{lb mole}}{44 \text{ lbm}} \text{ x } (1{,}300 - 900) \frac{\text{lb}}{\text{in}^2} \text{ x } \right] \frac{144 \text{ in}^2}{\text{ft}^2} \text{ x } \frac{1}{0.85}$$

$$= 2{,}326 \frac{\text{ft} - \text{lb}_f}{\text{lbm}}$$

$$\text{Electricity usage} = (0.25 \text{ x } \frac{1}{3}) \text{ x } (465.6 \text{ x } 10^6) \text{ lbm x } (2{,}326) \frac{\text{ft} - \text{lb}_f}{\text{lbm}}$$

$$\text{x } \frac{\text{Btu}}{778 \text{ ft} - \text{lb}_f} \text{ x } \frac{\text{kW} - \text{hr}}{3412 \text{ Btu}} \text{ x } \frac{\text{MW} - \text{hr}}{1000 \text{ kW} - \text{hr}} \text{ x } \frac{1}{0.95}$$

$$= 35.77 \text{ MW} - \text{hr}$$

$$CO_2 \text{Emissions} = (0.587) \frac{\text{tonne } CO_2}{\text{MW - hr}} \times (35.77) \text{ MW - hr}$$

$$= 21.0 \text{ tonnes } CO_2$$

$$CH_4 \text{ Emissions} = (5.99 \times 10^{-6}) \frac{\text{tonne } CH_4}{\text{MW - hr}} \times (35.77) \text{ MW - hr}$$

$$= 2.14 \text{ x } 10^{-4} \text{ tonne } CH_4$$

$$N_2O \text{ Emissions} = (0.75 \times 10^{-5}) \frac{\text{tonne } N_2O}{\text{MW - hr}} \times (35.77) \text{ MW - hr}$$

$$= 2.68 \text{ x } 10^{-4} \text{ tonne } N_2O$$

$$IND_2 \text{(Oct. 2003) } CO_2e = 21.0 \text{ tonnes } CO_2 + \left(21 \times 2.14 \text{ x } 10^{-4} \text{ tonnes } CH_4\right)$$

$$+ \left(310 \times 2.68 \text{ x } 10^{-4} \text{ tonnes } N_2O\right)$$

$$= 21.1 \text{ tonnes } CO_2e$$

IND_3 Calculation

Avoided emissions from the compressors at Jackson Dome (IND_3) are based on the fuel consumed by the compressor engines. Fuel usage was based on calculated values of compressor work and an engine-brake-specific fuel consumption of 8,000 Btu/hp-hr. Isothermal compression was assumed in the calculation of compressor work.[1]

$$\text{Compressor work} = (10.73) \frac{\text{psia ft}^3}{\text{lb mole R}} \text{ x } (95 + 460)\text{R x}$$

$$\ln\left(\frac{1300 + 14.7}{900 + 14.7}\right) \text{ x } \frac{\text{lb mole}}{44 \text{ lb}} \text{ x } \frac{144 \text{ in}^2}{\text{ft}^2}$$

$$= 7{,}070 \frac{\text{ft lb}_f}{\text{lbm}}$$

[1] Estimates of compressor work under isothermal conditions are lower than actual work between the same suction and discharge pressures. Using this approach for the avoided emissions, the calculated electricity usage and avoided emissions estimates are conservatively lower.

$$\text{Compressor engine fuel usage} = 0.25 \text{ x } \frac{2}{3} \text{ x } 465.6 \text{ x } 10^6 \text{ lbm x } 7{,}070 \frac{\text{ft} - \text{lb}_f}{\text{lbm}}$$

$$\text{x } \frac{\text{hp s}}{550 \text{ ft lb}_f} \text{ x } \frac{\text{hr}}{3600 \text{ s}} \text{ x } (8{,}000) \frac{\text{Btu}}{\text{hp hr}}$$

$$\text{x } \frac{\text{scf}}{1050 \text{ Btu}} \text{ x } \frac{\text{MMscf}}{10^6 \text{ scf}}$$

$$= 2.11 \text{ MMscf}$$

$$CO_2 \text{Emissions} = 120{,}000 \frac{\text{lb}}{\text{MMscf}} \times 2.11 \text{ (MMscf) x } \frac{\text{tonne}}{2205 \text{ lb}}$$

$$= 115 \text{ tonnes}$$

$$CH_4 \text{ Emissions} = 2.3 \frac{\text{lb}}{\text{MMscf}} \times 2.11 \text{ (MMscf) x } \frac{\text{tonne}}{2205 \text{ lb}}$$

$$= 2.20 \text{ x } 10^{-3} \text{ tonne}$$

$$IND_3 \text{ (Oct. 2003) } CO_2 = 115 + 21 \text{ x } 2.20 \text{ x } 10^{-3}$$

$$= 115 \text{ tonnes } CO_2e$$

IND_4 Calculation

Avoided emissions for the compressors at Little Creek used to further compress the gas from Jackson Dome to well injection pressures (IND_4) are calculated from an estimate of compression work required to compress the recycle gas volumes. In April 2003, new ESP pumps were installed in the pipeline bringing CO_2 from Jackson Dome. The calculation of avoided emissions was based on approximately 30 percent of recycle gas volumes being pumped and the remainder being compressed. This assumption was verified based on pump hp rating and operating suction and discharge pressures.

The isothermal compressor work was calculated from:

$$\text{Compresor Work} = (10.73) \frac{\text{psia ft}^3}{\text{lb mole R}} \text{ x } (460 + 72) \text{ R x ln} \left(\frac{2{,}950 + 14.7}{1{,}150 + 14.7} \right)$$

$$\text{x } \frac{\text{1b mole}}{44 \text{ lbm}} \text{ x } 144 \frac{\text{in}^2}{\text{ft}^2}$$

$$= 17{,}455 \frac{\text{ft . lb}_f}{\text{lbm}}$$

Assuming 70 percent of recycled gas is compressed,

$$\text{Compressor Energy Usage} = 0.7 \times 465.6 \times 10^6 \text{ lbm} \times (17{,}455)\,\frac{\text{ft} - \text{lb}_f}{\text{lbm}}$$
$$\times \frac{\text{Btu}}{778 \text{ ft} - \text{lb}_f} \times \frac{\text{kW} - \text{hr}}{3412 \text{ Btu}} \times \frac{\text{MW} - \text{hr}}{1000 \text{ kW} - \text{hr}} \times \frac{1}{0.95}$$
$$= 2{,}255 \text{ MW} - \text{hr}$$

The remaining 30 percent of the recycled gas is pumped through the new pumps.

$$\text{Pump work} = \left[1.51\,\frac{\text{ft}^3}{\text{lb mole}} \text{ x } \frac{\text{lb mole}}{44 \text{ lbm}} \text{ x } (2{,}950 - 1{,}150)\,\frac{\text{lb}}{\text{in}^2} \text{ x }\right]\frac{144 \text{ in}^2}{\text{ft}^2} \text{ x } \frac{1}{0.85}$$
$$= 10{,}465\,\frac{\text{ft} - \text{lb}_f}{\text{lbm}}$$

$$\text{Pump Energy Usage} = 0.3 \times 465.6 \times 10^6 \text{ lbm} \times (10{,}465)\,\frac{\text{ft} - \text{lb}_f}{\text{lbm}}$$
$$\times \frac{\text{Btu}}{778 \text{ ft} - \text{lb}_f} \times \frac{\text{kW} - \text{hr}}{3412 \text{ Btu}} \times \frac{\text{MW} - \text{hr}}{1000 \text{ kW} - \text{hr}} \times \frac{1}{0.95}$$
$$= 579.6 \text{ MW} - \text{hr}$$

Total Energy Usage = 2,255 + 579.6
= 2,834.6 MW-hr

$$CO_2 \text{Emissions} = (0.587)\,\frac{\text{tonne } CO_2}{\text{MW - hr}} \times (2{,}834.6) \text{ MW - hr}$$
$$= 1{,}664 \text{ tonnes } CO_2$$

$$CH_4 \text{ Emissions} = (5.99 \times 10^{-6})\,\frac{\text{tonne } CH_4}{\text{MW - hr}} \times (2{,}834.6) \text{ MW - hr}$$
$$= 0.017 \text{ tonne } CH_4$$

$$N_2O \text{ Emissions} = (0.75 \times 10^{-5})\,\frac{\text{tonne } N_2O}{\text{MW - hr}} \times (2{,}834.6) \text{ MW - hr}$$
$$= 0.021 \text{ tonne } N_2O$$

$$IND_4 \text{ (Oct 2003) } CO_2e = 1{,}664 \text{ tonnes } CO_2 + (21 \times 0.017 \text{ tonnes } CH_4)$$
$$+ (310 \times 0.021 \text{ tonnes } N_2O)$$
$$= 1{,}671 \text{ tonnes } CO_2e$$

CMB_1 Calculation

Gas-fired heaters are used to heat the purchased gas from Jackson Dome and the recycled gas through the same temperature differential. Therefore, the direct emissions CMB_1 that would have occurred in the baseline scenario, where CO_2 gas volumes equal to recycle gas volumes are heated, are equal to direct emissions from the recycle gas heater in the post-project scenario (CMB_2). In the estimation of project ERCs, these emissions offset each other exactly and, therefore, are not estimated.

Total Baseline Calculation

The baseline total includes the gross volumes of recycled gas plus the avoided emissions. Therefore,

Baseline Emissions (Little Creek, Oct 2003) = $(GV + IND_1 + IND_2 + IND_3 + IND_4)$
= (264,446 + 4 + 21 + 115+ 1,671)
= 266,257 tonnes CO_2e

4.2 Actual Emissions

Actual (Project) emissions include direct CO_2e emissions resulting from the heater used to heat the recycle gas prior to compression (CMB_2), and indirect emissions due to electricity usage by the recycle gas compressors (IND_5). As discussed in the previous section, project emissions CMB_2 are equal to avoided emissions CMB_1 and, offset each other in the calculation of net ERCs. Therefore, CMB_2 emissions are not estimated. A sample calculation for actual emissions from the recycle gas compressors for October 2003 is shown.

IND_5 calculation (Oct 2003)

Post-project indirect emissions from the recycle gas compressors at Little Creek (IND_5) were estimated based on the difference between the station total electricity usage (E_{TOTAL}), as measured by the utility company electricity usage meter, and the estimate of electricity used by the electric-drive compressors used for final compression of gas from Jackson Dome (E_{JDG}). Beginning in May 2003, about 30 percent of the gas from Jackson Dome was assumed to be pumped using the ESP pump installed in April 2003. The remaining 70 percent was assumed to be compressed through the compressors. This assumption was verified based on pump hp rating and operating suction and discharge pressures.

At West Mallalieu, the electricity usage for the pumps operating on the CO_2 line from Jackson Dome was neglected and the station total electricity usage and hence actual emissions was attributed to the recycle compressors. This is a conservative approach as the ERCs calculated would be lower based on higher indirect emissions from the recycle gas compresssors.

For Little Creek, the electricity used to compress recycle gas, E_{RG}, is calculated from:

$$E_{RG} = E_{TOTAL} - E_{JDG}$$

E_{JDG} was estimated from calculation of compressor work assuming isothermal compression and an electric motor efficiency of 95 percent. The work per lbm gas is similar to that calculated for IND_4.

Gas obtained from the Dome (assuming ~100% CO_2) is calculated from:

$$\text{Mass of gas from dome} = (2{,}720.6) \times 10^6 \text{ scf x } \frac{\text{lb mole}}{379.4 \text{ scf}} \text{ x } 44 \frac{\text{lb}}{\text{lb mole}}$$
$$= 315.6 \times 10^6 \text{ lbm}$$

Assuming 70 percent of purchase gas is compressed,

$$\text{Compressor Energy Usage} = 0.7 \times 315.6 \times 10^6 \text{ lbm} \times (17{,}455) \frac{\text{ft} - \text{lb}_f}{\text{lbm}}$$
$$\times \frac{\text{Btu}}{778 \text{ ft} - \text{lb}_f} \times \frac{\text{kW} - \text{hr}}{3412 \text{ Btu}} \times \frac{\text{MW} - \text{hr}}{1000 \text{ kW} - \text{hr}} \times \frac{1}{0.95}$$
$$= 1{,}529 \text{ MW} - \text{hr}$$

The remaining 30 percent of the recycled gas is pumped through the new pumps.

$$\text{Pump Energy Usage} = 0.3 \times 315.6 \times 10^6 \text{ lbm} \times (10{,}465) \frac{\text{ft} - \text{lb}_f}{\text{lbm}}$$
$$\times \frac{\text{Btu}}{778 \text{ ft} - \text{lb}_f} \times \frac{\text{kW} - \text{hr}}{3412 \text{ Btu}} \times \frac{\text{MW} - \text{hr}}{1000 \text{ kW} - \text{hr}} \times \frac{1}{0.95}$$
$$= 392.9 \text{ MW} - \text{hr}$$

Energy for recycled gas compressors is calculated from:

$$E_{RG} = 5{,}328 - 1{,}529 - 392.9$$
$$= 3{,}406 \text{ MW} - \text{hr}$$

Finally, indirect emissions from the recycle compressors are calculated as:

$$CO_2\text{Emissions} = (0.587)\ \frac{\text{tonne } CO_2}{\text{MW - hr}} \times (3{,}406)\ \text{MW - hr}$$
$$= 2{,}000 \text{ tonnes } CO_2$$

$$CH_4\ \text{Emissions} = (5.99 \times 10^{-6})\ \frac{\text{tonne } CH_4}{\text{MW - hr}} \times (3{,}406)\ \text{MW - hr}$$
$$= 0.020 \text{ tonne } CH_4$$

$$N_2O\ \text{Emissions} = (0.75 \times 10^{-5})\ \frac{\text{tonne } N_2O}{\text{MW - hr}} \times (3{,}406)\ \text{MW - hr}$$
$$= 0.026 \text{ tonne } N_2O$$

$$IND_5\ (\text{Oct 2003})\ CO_2e = 2{,}000 \text{ tonnes } CO_2 + (21 \times 0.020 \text{ tonnes } CH_4) + (310 \times 0.026 \text{ tonnes } N_2O) = 2{,}008 \text{ tonnes } CO_2e$$

Actual Emissions (Little Creek, Oct. 2003) = IND_5 (Oct. 2003) = 2,008 tonnes CO_2e

4.3 ERCs Created

Emission reduction credits are calculated as the difference between baseline emissions and actual emissions.

The net ERC created for October 2003 is calculated from:

Net ERC = Baseline Emissions – Actual Emissions
= 266,257 – 2,008
= 264,249 tonnes CO_2e

4.4 Summary of Findings

The methodology used in the CCR is appropriate. The calculations are correct and contain no major errors. All sources that materially affect emissions were included.

A consistency check of the data was performed by comparing the Oct. 2003 – Mar. 2004 data with the Oct. 2002 – Mar. 2003 data that were the basis of the ERCs registered y with CACI in December 2003. This comparison for Little Creek is shown in Table 4-4. Emissions from each source are expressed as a percentage of GV to check for consistency in relative magnitudes from each emission source.

Total ERCs created during each 6-month time period were approximately the same at 1.57 million tonnes. Recycled gas volumes during the Oct. 2003-Mar. 2004 time-period were about 6 percent greater than volumes recycled during Oct. 2002-Mar. 2003. However, because of differences in recycle gas composition, the recycle volumes expressed as tonnes of CO_2e (GV), are slightly lower for the Oct. 2003-Mar. 2004 time-period. Increases in avoided emissions (IND_1 – IND_3) during the Oct. 2003-Mar 2004 time-period are consistent with the increase in recycle gas volumes. The decrease in avoided emissions, IND_4, reflects the reduced electricity usage that would have been required following the installation (in April 2003) of the more efficient ESP pumps used to pump the CO_2 obtained from Jackson Dome.

Although recycle gas volumes increased in 2003-04, actual emissions decreased slightly, and reflects variability in electricity usage data. However, the effect of this difference on ERCs is insignificant. For e.g., a 50 percent error in electricity usage results in a 0.5 percent change in ERCs which is well within the uncertainty level of $\pm$ 5.5 percent.

Table 4-4. Data Consistency Check for Little Creek

	(Oct. 2002 – Mar. 2003)		(Oct. 2003 – Mar. 2004)	
	Tonnes CO_2e	% of GV	Tonnes CO_2e	% of GV
GV	1,572,939	100.00	1,570,671	100.00
IND_1	21	0.00	23	0.00
IND_2	116	0.01	125	0.01
IND_3	635	0.04	683	0.04
IND_4	10,490	0.67	9,924	0.63
Baseline Emissions	1,584,202	100.72	1,581,426	100.68
Actual Emissions	11,509	0.73	11,211	0.71
Net ERCs	1,572,694	99.98	1,570,215	99.97

A comparison of the Oct. 2002 – Mar. 2003 and the Oct 2003 – Mar. 2004 data for West Mallalieu is shown in Table 4-5. Total ERCs for West Mallalieu increased from 261,000 tonnes CO_2e in 2002-03 to 441,000 tonnes during the same 6-month period in 2003-04, a 69 percent increase. This is consistent with a similar increase in recycle volumes during the same period.

Plant personnel indicated that increases in both recycle and underground-sourced volumes over time reflect a trend of increased production at the West Mallalieu fields. The Plant has installed additional pump capacity in 2003 (two 500 hp ESP pumps) to handle current and future needs for underground sourced CO_2. A review of the recycle and underground-sourced volumes used at West Mallalieu indicates that the recycle gas volumes injected during Oct. 2003 – Mar. 2004 were almost two times greater than the recycle volumes injected during the Oct. 2002 – Mar. 2003. At the same time, underground-sourced CO_2 volumes injected in Oct. 2003 – Mar. 2004 were more than four times greater than the Oct. 2002 – Mar. 2003 volumes.

In Table 4-5, the check for consistency in relative magnitudes from each baseline emission source expressed as a percent of GV indicates that these values are consistent between the two time periods. Actual emissions are a higher percentage of GV compared to Little Creek (1.7 and 2.3 vs. 0.7 percent) because of the conservative assumption used for West Mallalieu that the station's total electricity usage is attributed to the recycle compressors (i.e., the electricity usage from underground-sourced CO_2 compressors and pumps is not subtracted from the total station electricity usage). The higher relative value of 2.3 percent for the Oct. 2003 – Mar. 2004 time-period is due to significantly more electricity required to handle a disproportionately larger fraction of underground-sourced CO_2 that was not subtracted from the station total energy usage.

Table 4-5. Data Consistency Check for West Mallalieu

	(Oct. 2002 – Mar. 2003)		(Oct. 2003 – Mar. 2004)	
	Tonnes CO_2e	% of GV	Tonnes CO_2e	% of GV
GV	265,016	100.00	451,161	100.00
IND_1	4	0.00	7	0.00
IND_2	21	0.01	36	0.01
IND_3	116	0.04	197	0.04
IND_4	0	0.00	0	0.00
Baseline Emissions	265,158	100.05	451,401	100.05
Actual Emissions	4,465	1.68	10,553	2.34
Net ERCs	260,693	98.37	440,848	97.71

5.0 Surplus

The surplus nature of these emission reduction credits is demonstrated by a review of applicable state and federal regulations associated with oil production operations. As summarized in Table 5-1, there are no external requirements for controlling or reducing CO_2 or methane emissions. In addition, Denbury Resources has no voluntary obligations for reducing or controlling CO_2 emissions.

The compressors used for recycling CO_2 at Little Creek and West Mallalieu are driven by electric motors. The facilities in this study are not subject to any federal or local regulations that require CO_2 or methane emission reductions. Although Denbury Resources' facilities are potentially subject to the regulations referenced in Table 5-1, none of these regulations apply to CO_2 or other greenhouse gas emissions (e.g., methane).

Table 5-1. Regulations Potentially Requiring CO_2 Emission Reductions for Denbury Resources Facilities

Agency	Rule/Citation	Applicability to Denbury Resources Facilities
Mississippi Commission on Environmental Quality (Mississippi Department of Environmental Quality – Office of Pollution Control) (MDEQ)	APC-S-1. Section 3. Specific Criteria for Sources of Particulate Matter.	This regulation does not apply to carbon dioxide or methane emissions.
MDEQ	APC-S-1. Section 4. Specific Criteria for Sources of Sulfur Compounds.	This regulation does not apply to carbon dioxide or methane emissions.
MDEQ	APC-S-1. Section 6. New Sources.	This regulation does not apply to carbon dioxide or methane emissions.
MDEQ	APC-S-1. Section 8. Hazardous Air Pollutants.	This regulation does not apply to carbon dioxide or methane emissions.
MDEQ	APC-S-5. Emergency Episodes.	This regulation does not apply to carbon dioxide or methane emissions.
MDEQ	APC-S-6. Title V Operating Permit Regulations	The facilities being reviewed are not currently subject to this regulation because of their total emissions of regulated pollutants. Also, this regulation does not apply to carbon dioxide or methane emissions.
MDEQ	APC-S-8. Air Toxic Regulations.	This regulation does not apply to carbon dioxide or methane emissions.
EPA	40 CFR 60 New Source Performance Standards (NSPS)	According to information provided by Denbury Resources, the facilities being reviewed are not subject to any NSPS subpart. Also, this regulation does not apply to carbon dioxide emissions.
EPA	40 CFR 61 National Emission Standards for Hazardous Air Pollutants (NESHAP)	According to information provided by Denbury Resources, the facilities being reviewed are not subject to any NESHAP subpart. Also, this regulation does not apply to carbon dioxide or methane emissions.
EPA	40 CFR 63 National Emission Standards for Hazardous Air Pollutants for Source Categories (NESHAPS for Source Categories)	According to information provided by Denbury Resources, the facilities being reviewed are not subject to any subpart of NESHAP for Source Category. Also, this regulation does not apply to carbon dioxide or methane emissions.

6.0 Unique

Emission Reduction credits from Denbury Resources' sequestration activities at Little Creek and from West Mallalieu during the creation period of October 2003 through March 2004, have not previously been registered or claimed.

7.0 Conclusions

A summary of the verifiable ERCs created from the project is shown in Table 7-1. CO_2e emission credits totaling 2,011,063 tonnes were created from the project. This estimate is consistent with the claims in the CCR.

Table 7-1. Summary of Baseline Emissions, Actual Emissions, and Net ERCs (tonnes CO_2e)

Calendar Year	**(Oct. 2003 – Mar. 2004)**
Little Creek	
Baseline	1,581,426
Actual	11,211
Net ERCs	1,570,215
West Mallalieu	
Baseline	451,401
Actual	10,553
Net ERCs	440,848
TOTAL	
Project Net ERC	**2,011,063**

8.0 Verification

I hereby warrant that this report was prepared by me based on my examination of information and records provided by Denbury Resources and Blue Source. The findings indicate that the ERCs created from the project meet the criteria as discussed in Sections 4.0 to 7.0 of this verification report.

Mahesh Gundappa, P.E. ______________________________