SME Annual Meeting
Feb. 28-Mar. 03, 2010, Phoenix, AZ

Preprint 10-090

DECREASED CARBON FOOTPRINT THROUGH EFFECTIVE COAL DEGASIFICATION

S. Keim, Virginia Tech, Blacksburg, VA
K. Luxbacher, Virginia Tech, Blacksburg, VA
M. Karmis, Virginia Tech, Blacksburg, VA

ABSTRACT

Growing concerns of climate change and its potential association with the release of greenhouse gasses to the atmosphere have prompted possible legislation which would require minimization of greenhouse gas emissions. Carbon dioxide and methane, both of which largely contribute to the greenhouse effect, have direct links to the fossil energy industry sector. Specifically, the combustion of one ton of coal produces between one and three tons of carbon dioxide, dependent upon the carbon content and heating value of the combusted coal. Additionally, coal mine methane (CMM) released through a mine's ventilation system has a radiative trapping impact approximately 20 times greater than that of an equivalent mass of carbon dioxide. The capture of coalbed methane (CBM) prior to the mining process and its utilization as an alternative energy source provides the possibility of a decreased carbon footprint. Domestically, the past 25 years have seen a significant expansion of the CBM industry. Internationally, in developing countries such as China, the need for western coal degasification technology is growing. A collaborative, international effort will be required to initiate a recognizable decrease in global greenhouse gas emissions. This paper identifies the potential decrease in equivalent carbon dioxide emissions through effective degasification at a hypothetical longwall mine located in China. Advanced, three-dimensional gas reservoir simulation software will be utilized to determine the maximum feasible CBM recovery in a low permeability, high gas content reservoir prior to the mining process.

BACKGROUND

The production and combustion of fossil fuels as an energy source release large volumes of greenhouse gasses to the atmosphere. Specifically, carbon dioxide (CO_2) and methane (CH_4), both well known greenhouse gasses, have direct ties to the coal industry. Carbon dioxide, produced from the combustion of carbon, represents the most prevalent anthropogenic greenhouse gas. The amount of CO_2 released from coal during combustion is dependent upon the heating value of the specific coal. In 2006, the United States released approximately 2,100 million metric tons of carbon dioxide from the combustion of coal (1). The EIA (Energy Information Agency) estimates that China's 2006 coal-related CO_2 emissions to be approximately 4,900 million metric tons (2). World total coal-related carbon dioxide emissions are expected to increase at rate of approximately 1.7 percent per year through 2030, with China accounting for 74 percent of the increase (2).

Methane, the main constituent of natural gas, possesses radiative trapping capabilities roughly 20 times greater than that of carbon dioxide. Inherent within the coal's structure, methane desorbs from the coal's internal surfaces during the mining process, and then moves to the atmosphere through a mine's ventilation system. Gassy coal seams are prevalent in the United States. Specifically, deep coal seams located throughout the Black Warrior and Appalachian Basins can possess gas contents greater than 300 cubic feet per ton. Comparatively, gas content's of deep coal seams located in China's Quinsui basin can exceed 500 cubic feet per ton. Additionally, these coals are thicker than those in the US, providing even greater gas content per unit area. The United States Environmental Protection Agency (EPA) compiles CO_2 equivalent emissions for coal mine methane. Carbon dioxide equivalent methane emissions for the United States and China are respectively estimated to be 72,000 and 130,000 metric tons (3).

CAPTURE OF METHANE

Throughout the past two decades, technology to capture coalbed methane has progressed rapidly. Current practices can be divided into surface and underground drilling practices.

Surface Practices

Surface drilling techniques target the coal seam ahead of the mining process. Vertical fracture wells, similar to those used in conventional gas and oil reservoirs, effectively drain methane given the proper geologic conditions. Advantages to vertical fracture wells include cost effectiveness, little concern related to mining through wells, and readily available technology. Yet, vertical wells must be spaced proximally to effectively drain ample volumes of coalbed methane.

Vertical-to-horizontal wells, drilled vertically from the surface and turned parallel within the coal seam, have become very common in the past decade. Various horizontal drilling patterns, ranging from CDX's original Z-Pinnate (4) design to single longhole configurations, effectively degasify coal seams throughout the world. Densely spaced horizontal drilling patterns can remove methane faster with less surface disturbance than vertical fracture wells.

Underground Practices

In-mine drainage practices do not require the long waiting periods prior to the mining process for effective degasification. Often utilized in longwall mining operations, horizontal wells are bored perpendicular to longwall panels (cross panel drilling) or parallel to longwall panels (long hole drilling). Although these practices can drastically decrease gas concentrations for the longwall unit, panel development sections still exhibit gassy conditions and warrant safety concerns. In-mine drainage systems also require extensive underground piping to direct recovered methane to surface facilities.

MODELING OF DECREASED CARBON FOOTPRINT

Overview

The following section presents the methodology used to model equivalent carbon dioxide emissions through effective degasification. Pre-mining degasification modeling was completed using COMET3, a commercial unconventional gas reservoir modeling program designed specifically for coalbed methane applications. Multilateral horizontal wells, similar to current practices in China, were modeled in a reservoir with parameters typical to those found in the southern Shanxi Province.

Determination of the true decreased equivalent carbon footprint requires the examination of several scenarios:

1. *Methane Ventilated to the Atmosphere*. In this scenario, all mined coal will be used to generate electricity. Methane will not be utilized as an energy source, and will be ventilated to the atmosphere as a greenhouse gas.

2. *Methane Captured and Flared At Well.* Scenario 2 represents a typical situation where pipeline infrastructure has not been completed. Although the methane is recovered, it is burned at the well site, producing CO_2, which is released to the atmosphere. As with Scenario 1, all mined coal is used to generate electricity. Any methane not recovered is ventilated to the atmosphere.
3. *Methane Captured and Utilized as an Energy Source.* Scenario 3 represents similar parameters to Scenario 2, with all recovered methane piped to a powerplant and utilized as an energy source. Again, all mined coal is used to generate power, and unrecovered methane is emitted to the atmosphere during the mining process.

As methane is combusted in both Scenarios 2 and 3, the total equivalent carbon footprint for both scenarios will be identical. Yet, because energy is produced by Scenario 3, equivalent carbon emissions per unit of energy produced will be lower.

Degasification Modeling

A multilateral pinnate-type well was modeled to closely represent current drilling practices in the study region. The modeled well, totaling roughly 15,000 feet in length, is designed to effectively drain an area of 247 acres (roughly 1 square kilometer). Individual laterals are spaced at intervals of 600 feet. The modeled grid consists of 33 individual grid blocks in both the x and y directions, each with dimensions of 100 feet by 100 feet. This creates a grid with outside dimensions of 3,300 feet by 3,300 feet, roughly equivalent to 1 square kilometer. Figure 1 displays a plan view of the modeled grid and horizontal well.

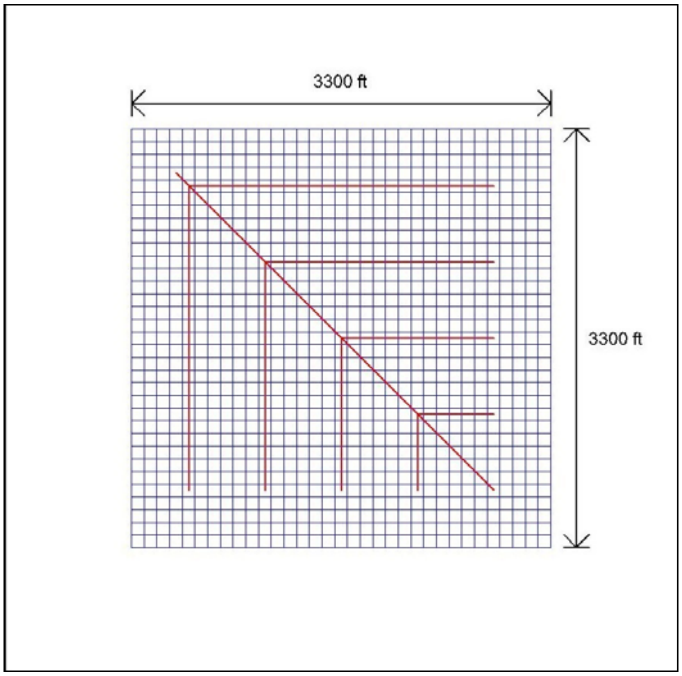

Figure 1. Modeled Grid and Pinnate Well.

Seam characteristics for the degasification model are summarized below in Table 1. All values were either measured at the study area, or estimated, based on neighboring active degasification sites.

Relative permeability curves for the study area were unavailable. Therefore, releative permeability curves from Kissell and Edward's 1975 Bureau of Mines study were assumed to accurately represent the study area's coal.

Modeling calibration parameters assume that the well produces a constant 250 barrels of water per day, until the well's bottom hole pressure reaches 14.7 psi (atmospheric pressure). Upon reaching this condition, the well's bottom hole pressure will be held constant at atmospheric pressure, and water production will be decreased accordingly.

Table 1. Modeled Seam Characteristics.

Input Parameter	Value
Seam Thickness (ft)	10
Pressure Gradient (psi per ft)	0.28
Seam Depth (ft)	2,100
Coal Cleat Water Saturation	85%
Permebility (md)	2.0
Gas Content (cubic ft per ton)	500
Coal Specific Gravity	1.4
Langmuir Pressure (psi)	290
Langmuir Volume (cubic ft per ton)	1,000

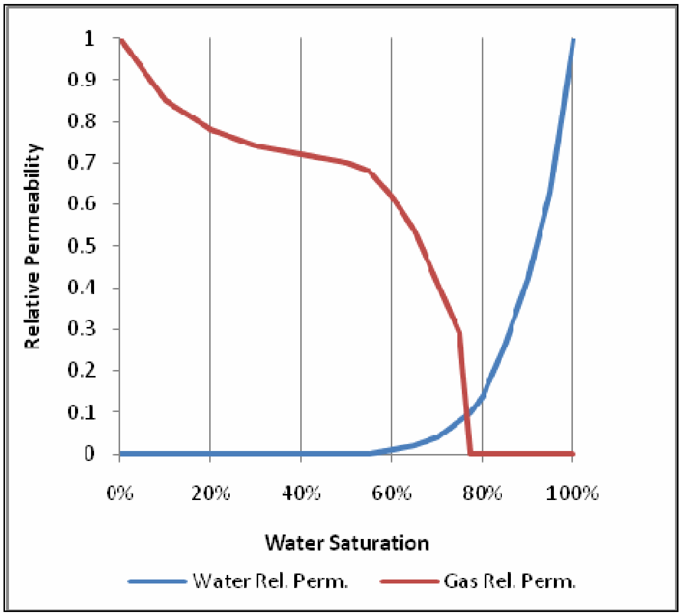

Figure 2. Relative Permeability Curves (5).

Mining Modeling Assumptions

The modeled mine is assumed to produce 4 million tons of coal on an annual basis, characteristic of similar mines in the study area. Ultimately, the carbon footprint of the mine will be analyzed according to a 20-year mine life.

CO2 Emissions and Generated Power from Combusted Coal

As previously discussed, the mass of carbon dioxide emitted from combusted coal depends upon the heating value or fixed carbon content of the specific coal. Semi-anthracite in rank, the coal in the study region possesses a high heating value of 14,000 BTU per pound. Utilizing a conversion factor from BTU's to metric tons of carbon (6), in addition to stoichiometric relationships, the following Equation 1 can be derived:

Equation 1: $$Tons_{CO_2} = 1.877(10^{-4}) \cdot BTU \cdot Tons_{Coal}$$

Where $Tons_{CO2}$ represents the metric tons of carbon dioxide emitted, *BTU* represents the heating value of the coal on a per pound basis, and $Tons_{Coal}$ represents the standard tonnage of coal to be combusted. Utilizing Equation 1, the modeled coal will emit 2.62 metric tons of carbon dioxide per ton of coal burned.

Energy generated by combusted coal can be calculated by converting the BTU value to kilowatt-hours, then multiplying by power plant efficiency. Modeling assumes a power plant efficiency of 40 percent. Equation 2 represents the conversion from BTU per pound value to power creation per ton of coal.

Equation 2: $$^{KwH}/_{Ton_{coal}} = BTU \cdot 0.586 \cdot E$$

Where *BTU* represents the heating value in BTUs on a per pound basis, and *E* represents power plant efficiency. Scenarios 1, 2, and 3 utilize Equations 1 and 2 for calculations of power generated and carbon dioxide emitted from coal production and combustion. Using Equation 2, the estimated energy output per ton of coal in the study area is approximately 3,280 kilowatt hours.

CO2 Emissions and Power Generated From Combusted Methane

The mass of carbon dioxide emitted from combusted methane can be determined using a similar methodology as that of coal. Using gas composition data, the known heating value of pure methane (7), and the known mass of carbon per heating value unit of methane (7), the following relationship can be drawn:

Equation 3: $$Tons_{CO_2} = 53.1 \cdot \%_{CH_4} \cdot MMCF$$

Where $\%_{CH4}$ represents the percentage of methane in the recovered gas, $Tons_{CO2}$ represents the metric tons of carbon dioxide emitted, and *MMCF* represents millions of cubic feet of recovered gas (including impurities). Based on Equation 3, every million cubic feet of recovered gas will correspond to 47.8 metric tons of carbon dioxide emissions.

Calculation of the energy created from combusted methane is completed using gas composition data, the heating value for pure methane (7), conversion factors, and plant efficiency. Equation 4 displays the calculation for energy created from the recovered gas.

Equation 4: $$^{KwH}/_{MMCF} = 2.93 \cdot 10^{5} \cdot \%_{CH_4} \cdot E$$

In Equation 4, *KwH/MMCF* represents kilowatt hours of energy produced per million cubic feet of methane recovered. $\%_{CH4}$ represents the percentage of methane in the recovered gas, and *E* represents power plant efficiency. The study area is assumed to have a methane concentration of 90 percent, and the model assumes a power plant efficiency of 40 percent. Utilizing these parameters in conjunction with Equation 4, the energy output for the recovered gas is estimated to be 105,000 kilowatt hours per million cubic feet of recovered gas.

Equivalent CO2 Emissions from Ventilated Methane

Equivalent CO_2 emissions from ventilated methane can be calculated using the EPA's Coal Mine Outreach Program Interactive Units Converter (8). This interactive webpage assumes that the a given mass of methane is approximately 23 times as strong of a greenhouse gas as an equivalent mass of carbon dioxide. Utilizing this methodology, every million cubic feet of emitted methane has an equivalent carbon dioxide emission of 405 metric tons.

RESULTS

Figure 3 summarizes the degasification modeling output. Multilateral pinnate wells drain approximately 75 percent of the in-place gas over a period of 20 years. As evident in the graph, the majority of the gas is recovered within the first 10 years of production. The well's peak production occurs 3 months after production begins, at a rate of 2.4 million cubic feet per day.

Utilizing Equations 1, 3, and the conversion from methane emissions to equivalent carbon dioxide emissions, the net carbon footprint can be determined. Figure 4 displays the carbon footprint of Scenarios 1 through 3, as a function of degasification time. Degasification time represents production time for multilateral wells prior to the mining process.

Figure 4 displays Scenario 1 as a single dot, as no degasification takes place over time. As wells produce gas over a set period of time, the net carbon footprint of the operation decreases, represented by Scenarios 2 and 3. As shown in the chart, a 20-year multilateral well production corresponds with roughly 70-percent in place gas recovery, reducing the net carbon footprint from 226 million metric tons of carbon dioxide equivalent to 216, a reduction of 4 percent. As previously discussed, the net carbon footprint of Scenarios 2 and 3 (flaring recovered methane and utilizing recovered methane as energy source) will have the same net carbon footprint, as recovered methane is combusted in both scenarios. Yet, Scenario 3 provides a lower carbon footprint per energy unit produced, as the recovered methane is used for energy production. Figure 5 displays the total energy produced by each scenario (billion kilowatt hours) as a function of degasification time.

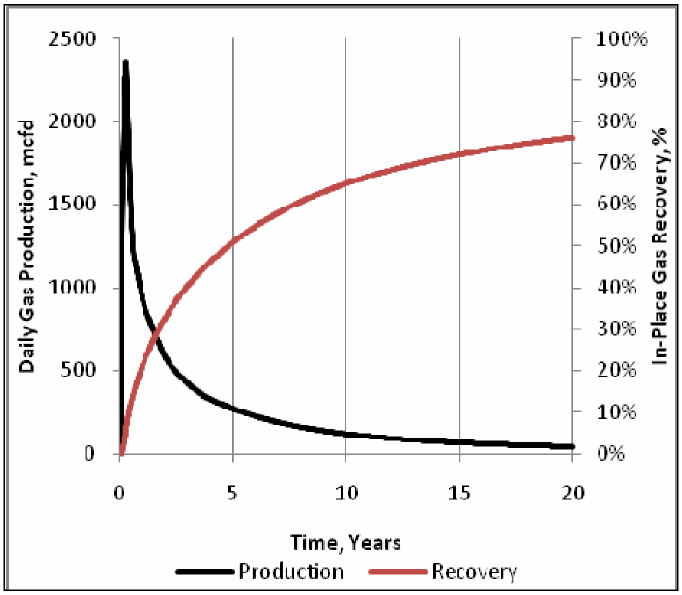

Figure 3. Degasification Model Output.

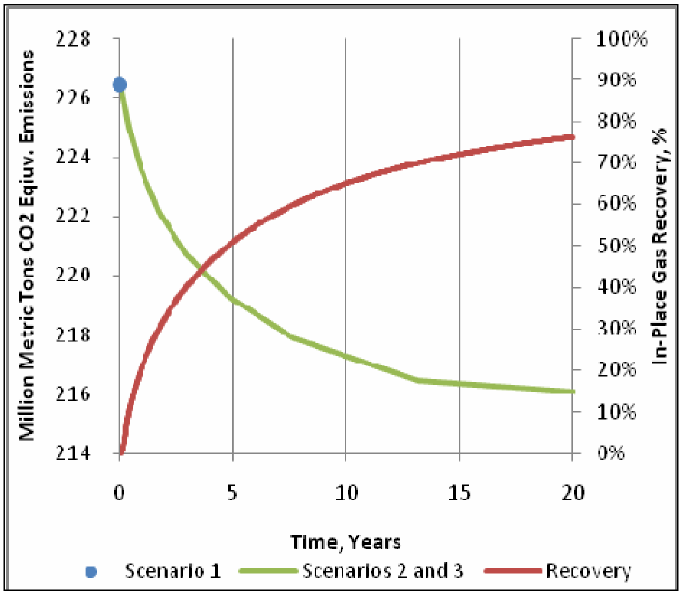

Figure 4. Net Carbon Footprint.

As evident in Figure 5, utilization of methane as an energy source provides the potential for an additional 4 billion kilowatt hours of energy, at roughly 70-percent methane recovery. The incorporation of produced energy into the carbon footprint of each scenario provides a relationship between degasification time and equivalent carbon dioxide emissions per produced energy unit, as displayed in Figure 6.

As shown in Figure 6, the total metric tons of carbon dioxide emissions per million kilowatt hours of energy produced decrease from 862 (Scenario 1) to 824 (Scenario 2 at 70-percent recovery). When utilizing methane as an energy source, this value decreases to 816 (Scenario 3 at 70-percent recovery). This corresponds with a 5-percent reduction in equivalent carbon dioxide emissions, normalized by energy produced. Figure 7 displays the percentage reductions of

CO$_2$ emissions and CO$_2$ emissions per energy unit produced for Scenarios 2 and 3 from Scenario 1.

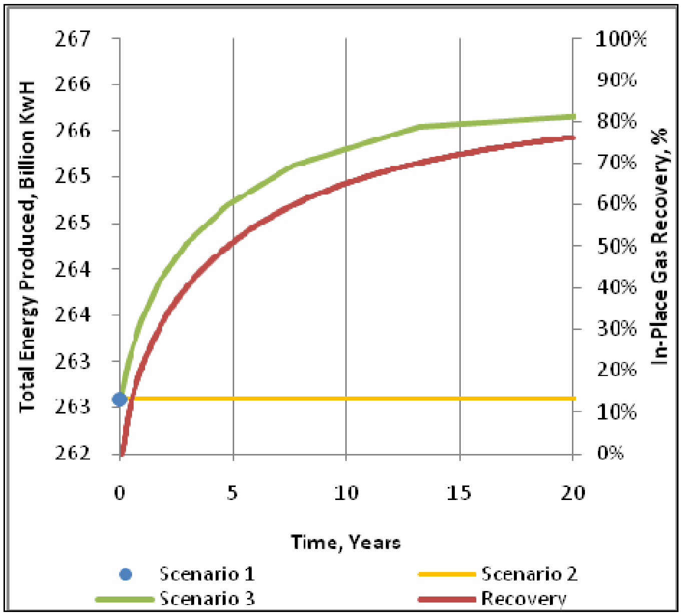

Figure 5. Total Energy Produced.

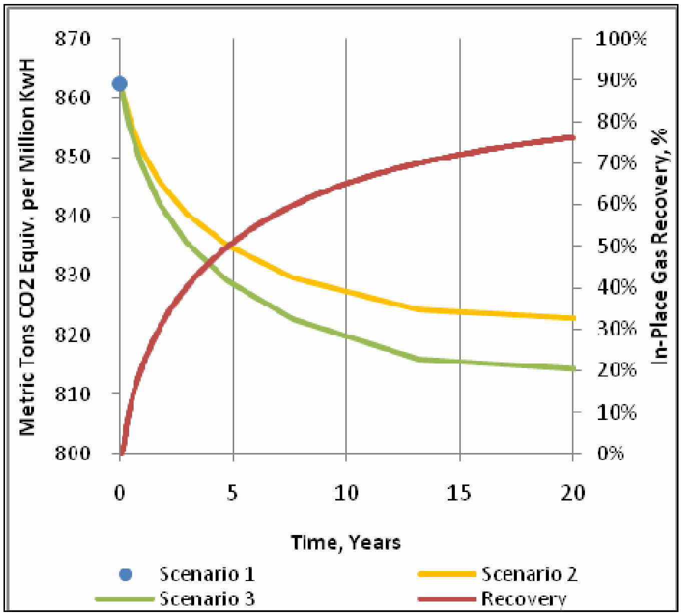

Figure 6. Net Carbon Footprint per Energy Unit Produced.

CONCLUSIONS

The use of multilateral pinnate-style wells in this case study increases methane recoveries in relatively low permeability, high gas content coal seams. Although the duration of recovering the majority of the gas is somewhat long (10 to 20 years), this technology can be implemented in conjunction with detailed mine planning. Effective coal degasification can decrease the carbon footprint from the fossil energy industry sector. Additionally, captured methane can provide a significant energy source while simultaneously improving mining safety. Internationally, the need for western degasification technology is crucial to significantly reduce world greenhouse gas emissions.

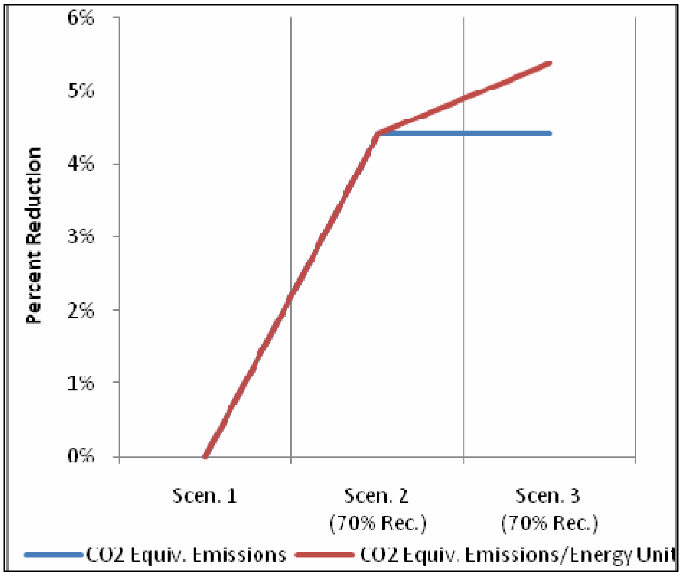

Figure 7. Percentage reductions of CO$_2$ emissions.

REFERENCES

1. "Emissions of Greenhouse Gases Report." *Energy Information Administration: Official Energy Statistics from the U.S. Government*. 2008. Energy Information Administration, Web. 14 Oct 2009. <http://www.eia.doe.gov/oiaf/1605/ggrpt/carbon.html>.

2. "International Energy Outlook 2009." *Energy Information Administration: Official Energy Statistics from the U.S. Government*. 2009. Energy Information Administration, Web. 27 Oct 2009. <http://www.eia.doe.gov/oiaf/ieo/emissions.html>.

3. United States. *Global Anthropogenic Non-CO2 Greenhouse Gas Emissions: 1990-2020*. , 2006. Web. 20 Sept 2009.

4. Zupanick, Joseph A. Drainage Pattern With Intersecting Wells Drilled From Surface. CDX Gas, LLC, assignee. Patent 6,357,523. 19 Mar. 2002. Print.

5. Kissell, Fred N., & Edwards, J. (1975). Two-Phase Flow in Coal Beds. *Report of Investigations - United States, Bureau of Mines. 8066.*

6. United States. *Emissions of Greenhouse Gasses in the United States*. , 1996. Web. 17 Oct 2009. http://tonto.eia.doe.gov/FTPROOT/environment/057395.pdf .

7. "Approximate Heating Values of Common Fuels." Michigan State University, Web. 14 Oct 2009. http://www.hrt.msu.edu/Energy/pdf/Heating%20Value%20of%20Common%20Fuels.pdf

8. "Interactive Units Converter." *Coalbed Methane Outreach Program*. 28 Jan 2008. U.S. Environmental Protection Agency, Web. 23 Oct 2009. http://www.epa.gov/cmop/resources/converter.html

ACKNOWLEDGEMENTS

This research was supported in part Agreement No. XA-833963-01 by the U.S. Environmental Protection Agency. This paper has not been reviewed by EPA. The views expressed in this document are solely those of the authors and EPA does not endorse any products or commercial services mentioned in this publication.

The authors would like to thank Scott Keim, Mike Miller, and Matt Conrad, all of Marshall Miller and Associates, for technical advice and insight.

Additionally, the authors would like to thank George Koperna and Karine Schepers of Advanced Resources International for technical advice of the COMET program.