



U.S. Underground Coal Mine Ventilation Air Methane Exhaust Characterization

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Table of Contents

Introduction.....	1
Background.....	1
Characterization of U.S. Underground Coal Mine VAM Exhausts.....	2
Summary and Conclusions	5
Appendix A: VAM Characterization Summary by MSHA District 2008-2009	7
Appendix B: U.S.VAM Oxidation Projects	13
TFRR Operating Parameters.....	14
1. CONSOL Energy	15
2. Jim Walter Resources	16
Appendix C: States Comprising the MSHA Districts	17

List of Tables

Table 1. VAM Exhaust Summary by MSHA District	3
Table 2. U.S. Mines and Exhausts with Average VAM > 0.3 percent Methane (2008 – 2009)	4
Table 3. U.S. Quarterly VAM Sampling Data by MSHA District	5
Table 4. Potentially Attractive VAM Opportunities, by MSHA District	6

List of Figures

Figure 1. Schematic of Thermal Flow-Reversal Reactor.....	13
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Introduction

Methane is a powerful greenhouse gas with a global warming potential more than 20 times that of carbon dioxide. Gassy underground coal mines can emit methane into the atmosphere from a number of sources, including the ventilation system exhaust. In fact, mine ventilation systems typically are the largest source of methane emissions from underground coal mines. In 2008, U.S. coal mines released 101 billion cubic feet (Bcf) of ventilation air methane (VAM). That equated with 56 percent of total U.S. CMM emissions from coal mining (including surface mines and abandoned mines), or 80 percent of emissions from underground mining alone (including VAM, drainage emissions, and post-mining). Recognizing that VAM emissions constitute a significant proportion of overall methane emissions, the U.S. Environmental Protection Agency's Coalbed Methane Outreach Program (CMOP) strives to highlight opportunities for implementing VAM emission abatement projects. Technology capable of oxidizing VAM exhausts is commercially available, and there is an emerging carbon market that recognizes the high quality of carbon emission reductions that VAM abatement projects can offer. Therefore, a current need exists for data that can point prospective project developers to those mines where the best project implementation opportunities exist. This report provides an overview of VAM characterization data for the 2008-2009 period, with details presented in Appendix A.

Background

Methane is explosive at concentrations ranging from 5 to 15 percent in air. Therefore, to ensure ongoing worker safety, the U. S. Mine Safety and Health Administration (MSHA) requires that methane concentrations in mine workings be maintained at levels well below the lower explosive limit. To accomplish this, gassy underground mines employ large-scale ventilation systems that provide fresh air to the underground environment while also diluting and exhausting methane that is released into the mine.

Although such releases of VAM are characterized by very low methane concentrations—typically below 1.0 percent—their volumes are so great that they actually constitute the largest single source of methane emissions from underground coal mines. Because methane is a powerful greenhouse gas, its discharge makes a significant contribution to the global greenhouse gas emitted into the atmosphere.

The very low concentrations that characterize VAM also impede its mitigation, since it is unsuitable for use with conventional technologies such as internal combustion engines, flares, or even lean fuel turbines. However, one technology (the thermal flow-reversal reactor or TFRR) has been proven to operate reliably on VAM, even at concentrations as low as 0.2 percent. The TFRR also is known as a regenerative thermal oxidizer or RTO.

The efficacy of VAM oxidizers has recently been demonstrated at two domestic underground coal mines. Over a 21-month period, CONSOL Energy demonstrated a MEGTEC Systems VOCSIDIZER™ at its abandoned Windsor Mine in West Liberty, West Virginia. Additionally, Jim Walter Resources is operating a Biothermica VAMOX™ unit at an active mine in Brookwood, Alabama. These technologies both employ the principal of flow-reversal oxidation to convert methane into carbon dioxide and water (see Appendix B for a brief overview of these projects).

Characterization of U.S. Underground Coal Mine VAM Exhausts

MSHA conducts quarterly methane sampling at gassy underground coal mines in the United States. In that sampling program, MSHA measures and records both methane concentrations and ventilation exhaust airflows. Air sampling is conducted by MSHA inspectors using air bottles at a mine's main fans, along with a total quantity air ventilation volume reading. The sample bottles are sent to the MSHA lab for analysis, and the results are provided back to the MSHA district offices for inclusion in the inspection report. Air samples and ventilation readings are taken annually at mines with emission rates below 100,000 standard cubic feet per day (mines with such low VAM emission rates are not suitable for today's VAM mitigation technologies). According to [Section 103 \(i\) of the Federal Mine Safety & Health Act of 1977](#) (Public Law 95-164), MSHA conducts quarterly sampling at mines liberating more than 100,000 cubic feet of CH₄ per day. If emission levels are greater than 200,000 cubic feet per day, more frequent inspections are mandated (with the frequency determined by the daily CH₄ liberation rate calculated for the mine). In most cases, gassy mines with methane liberation rates in the millions of cubic feet per day are required to sample VAM on a monthly basis.

To provide an initial perspective on the subset of mines where conditions are potentially favorable for viable VAM mitigation projects, CMOP conducted a review and evaluation of recent MSHA quarterly sampling data. The results of that review are summarized in Table 1 (see Appendix A for more detailed data).

The process by which the summary was developed, as well as observations concerning the raw MSHA sampling data, is as follows:

1. Solicit and obtain from MSHA VAM sampling reports for multiple periods (preferably the last four quarters).
2. From the individual MSHA District¹ reports, record MSHA sampling results (VAM concentration, airflow) for each VAM exhaust point at each gassy mine.
3. From the multiple data points obtained from each VAM exhaust, tabulate the minimum and maximum methane concentration and airflow and calculate the average airflow and concentration.

¹ Appendix C provides a map and list of those states (or parts of states) comprising each MSHA District. Links to information on each can be found at <http://www.msha.gov/district/coalhome.htm>.

Table 1. VAM Exhaust Summary by MSHA District

MSHA District*	Parameter	<100,000 cfm	100,000-199,999 cfm	200,000-299,999 cfm	300,000-500,000 cfm	500,000-1,000,000 cfm	>1,000,000 cfm
2	# Exhausts	2	6	8	0	1	1
	CH ₄ % Range	0.30-0.35	0.31-0.40	0.43-1.09	-	0.34	0.30
3	# Exhausts	0	7	8	5	1	0
	CH ₄ % Range	-	0.43-1.26	0.36-1.25	0.30-1.23	0.33	-
4	# Exhausts	2	1	1	4	0	0
	CH ₄ % Range	0.70-0.85	0.4	0.97	0.31-0.69	-	-
5	# Exhausts	0	0	0	3	0	0
	CH ₄ % Range	-	-	-	0.44-1.06	-	-
7	# Exhausts	0	0	0	1	0	0
	CH ₄ % Range	-	-	-	0.36	-	-
8	# Exhausts	1	5	4	0	4	0
	CH ₄ % Range	0.43	0.32-0.83	0.45-0.50	-	0.21-0.37	-
9	# Exhausts	0	0	0	1	4	0
	CH ₄ % Range	-	-	-	0.35	0.39-0.55	-
10	# Exhausts	0	1	0	0	0	0
	CH ₄ % Range	-	0.31	-	-	-	-
11	# Exhausts	0	0	1	3	3	0
	CH ₄ % Range	-	-	0.41	0.31-1.11	0.35-0.93	-

**Note: No exhausts in Districts 1 or 6 were found to have VAM concentrations above the cut-off level of 0.3 percent applied in this analysis.*

Only results for exhausts with average methane concentrations of at least 0.3 percent were recorded in the summary table, although, some individual sample readings for exhausts that met the average concentration criterion may actually be below 0.3 percent. Table 2 lists the number of mines for which VAM characterization data were obtained from each MSHA District, the number of mines in each District that had average methane concentrations > 0.3 percent, and the number of individual ventilation exhausts in each District with VAM > 0.3 percent. Overall, these comprise 39 mines encompassing a total of 78 ventilation exhausts.

The MSHA VAM data tabulation and analysis was complicated by a number of factors. First, different MSHA districts report the results of their sampling efforts in different formats. For example, while some provide the overall airflow and methane concentration for each ventilation exhaust, others report on each entry to an exhaust. In the latter case, the individual readings must be summed to obtain the overall value for the exhaust point.

Table 2. U.S. Mines and Exhausts with Average VAM > 0.3 percent Methane (2008 – 2009)

MSHA District	Number of Mines Reported	Number of Mines with Average VAM > 0.3%	Number of Exhausts with Average VAM > 0.3%
1	5	0	0
2	42	6	18
3	30	8	21
4	147	6	8
5	4	2	3
6	8	0	0
7	9	1	1
8	16	6	14
9	24	5	5
10	12	1	1
11	7	4	7
Total	304	39	78

Second, the nomenclature used for individual sampling points does not appear to be uniform over time. Therefore, sampling at the same exhaust may have different names in different quarters. These differences are minor in some cases and more significant in others. Thus, misinterpreting the exhaust naming could lead to erroneous totaling of readings for a given point.

Third, the number of quarters for which sample data were provided varied by district as indicated in Table 3. The number of quarters for which sampling results were provided also varies by exhaust in some cases. Thus, the discrete number of samples upon which the “averages” were reported in Appendix A varies across the sample set.

Review of the data in Appendix A reveals that, in some cases, minimum methane concentrations fall below the self-sustaining limit of ~0.2 percent, thus necessitating supplemental fuel to maintain oxidizer operation during the low-concentration periods.

Table 3. U.S. Quarterly VAM Sampling Data by MSHA District

MSHA District	Number of Quarters Reported	Quarters Reported
1	4	4 th of '08 – 3 rd of '09
2	1	2 nd of '09
3	4	4 th of '08 – 3 rd of '09*
4	4	3 rd of '08 – 2 nd of '09
5	2	4 th of '08 – 1 st of '09
6	4	4 th of '08 – 3 rd of '09
7**	2	3 rd of '08 – 2 nd of '09
8	4	1/08 - 4/08
9	4	2/08 - 1/09
10	4	4/07 - 3/08
11	2	4/08 - 1/09

**Only July readings were reported for the 3rd quarter of '09.*

***Different time periods were reported for different mines.*

Summary and Conclusions

As reflected in Table 1, 39 mines in the United States have average methane concentrations equal to or greater than 0.3 percent. Table 4 reveals that 24 exhausts at 16 of those mines appear to constitute the best opportunities for VAM mitigation project development because those exhausts have average VAM concentrations above 0.8 percent. At such concentrations, project economics should be attractive given a vibrant domestic carbon market. However, even some of these “high-concentration” exhausts may require supplemental fuel to support a project over time, as the sampling data reflect a significant degree of variation in concentration. For example, one exhaust with an average concentration of 0.93 percent also reported a minimum value of 0.48 percent. Exhausts with average VAM concentrations below 0.8 percent may still prove to be good project hosts, especially if the mine has supplemental drained methane available to raise the effective VAM concentration entering the oxidizer

It should be noted that the data contained herein provide perspective on the U.S. VAM mitigation opportunities, but are not adequate to support site-specific project assessment and planning. Much more detailed VAM sampling will be needed to provide insight into the actual degree of variability in VAM flow and concentration over time (and under changing mining conditions underground) needed to fully evaluate project feasibility.

Table 4. Potentially Attractive VAM Opportunities, by MSHA District

MSHA District	Mine	Exhaust	Average CH₄ Concentration
1	None	---	---
2	Cumberland	#5 Bleeder	1.09
	Emerald	#7 Bleeder	0.89
	Bailey	6-H Bleeder	0.85
		9-I Bleeder	0.97
	Enlow Fork	E-15 Bleeder	0.96
		F-14 Bleeder	0.89
3	Federal No. 2	Daybrook	0.93
	Blacksville No. 2	22M Bleeder	1.26
		16 W Shaft	0.81
	Robinson Run No. 95	10A	1.06
	Loveridge No. 22	11 D	1.09
		Campbell's Run	1.06
	Century	15 East Bleeder	1.25
	McElroy	4 North Bleeder	1.25
		5 South Bleeder	1.18
		B Bleeder	1.02
		5 North Bleeder	1.23
4	Beckley Crystal	Surface Bleeder	0.85
	Mountaineer II	Bend Branch Fan	0.97
5	Buchanan Mine #1	Fan #12	1.08
6	None	---	---
7	None	---	---
8	Galatia	#16 Bleeder	0.83
9	None	---	---
10	None	---	---
11	JWR No. 7	7-1	0.93
		7-7	1.11
	JWR No. 4	4-9	0.93
Total	16	24	

Appendix A: VAM Characterization Summary by MSHA District*

2008-2009

**States in each MSHA District are listed in Appendix C*

		Airflow (cfm)			CH ₄ Concentration (%)		
Mine	Exhaust Point	Min.	Max.	Average	Min.	Max.	Average
District 1							
None*							
District 2							
No. 84	Lang Bleeder	166,300	166,300	166,300	0.31	0.31	0.31
	2-D Bleeder	264,200	264,200	264,200	0.43	0.43	0.43
Cumberland	#5 Bleeder	241,936	241,936	241,936	1.09	1.09	1.09
	#4 Bleeder	262,839	262,839	262,839	0.59	0.59	0.59
	#6 Return	807,300	807,300	807,300	0.34	0.34	0.34
Emerald	#5 Bleeder	176,025	176,025	176,025	0.32	0.32	0.32
	#7 Bleeder	203,467	203,467	203,467	0.89	0.89	0.89
Bailey	6-H Bleeder	208,759	208,759	208,759	0.85	0.85	0.85
	1-E Bleeder	197,522	197,522	197,522	0.38	0.38	0.38
	9-I Bleeder	258,000	258,000	258,000	0.97	0.97	0.97
	12-A Bleeder	165,400	165,400	165,400	0.40	0.40	0.40
Enlow Fork	E-15 Bleeder	212,151	212,151	212,151	0.96	0.96	0.96
	A-11 Bleeder	80,884	80,884	80,884	0.35	0.35	0.35
	E-9 Bleeder	172,500	172,500	172,500	0.37	0.37	0.37
	3 North	1,014,720	1,014,720	1,014,720	0.30	0.30	0.30
	F-7 Bleeder	120,240	120,240	120,240	0.37	0.37	0.37
	F-14 Bleeder	253,990	253,990	253,990	0.89	0.89	0.89
Clementine	Main Fan	85,880	85,880	85,880	0.30	0.30	0.30

**No mines in this District were reported to have VAM concentrations in excess of 0.3 percent.*

Mine	Exhaust Point	Airflow (cfm)			CH ₄ Concentration (%)		
		Min.	Max.	Average	Min.	Max.	Average
District 3							
Federal No. 2	Daybrook	149,448	150,280	149,734	0.48	1.18	0.93
	1 Left Bleeder	319,272	1,561,305	755,491	0.14	0.43	0.33
Blacksville No. 2	22M Bleeder	124,910	215,088	178,641	0.54	1.73	1.26
	7 North Shaft	216,325	266,493	247,347	0.48	0.73	0.62
	16 W Shaft	152,420	152,420	152,420	0.81	0.81	0.81
Robinson Run No. 95	2A Bleeder	205,430	214,456	209,943	0.32	0.41	0.36
	Camp Run	385,368	392,160	388,764	0.35	0.35	0.35
	10A	264,000	314,848	283,616	0.82	1.43	1.06
Loveridge No. 22	11 D	199,204	223,710	210,435	0.74	1.55	1.09
	Campbell's Run	236,326	236,326	236,326	1.06	1.06	1.06
	2 D	244,630	307,518	276,074	0.48	0.62	0.55
	9 South	33,640	810,752	422,196	0.26	0.34	0.30
Sentinel	Return Shaft	466,819	466,819	466,819	0.38	0.38	0.38
	Main Return	271,330	485,700	406,939	0.37	0.50	0.42
Century	15 East Bleeder	128,097	202,707	160,065	1.22	1.26	1.25
Powhatan No. 6	2 West	145,861	173,659	159,760	0.32	0.53	0.43
	Cool Hill Bleeder	228,550	228,550	228,550	0.62	0.62	0.62
McElroy	4 North Bleeder	133,592	406,170	258,475	1.16	1.37	1.25
	5 South Bleeder	116,763	116,763	116,763	1.18	1.18	1.18
	B Bleeder	193,410	193,410	193,410	1.02	1.02	1.02
	5 North Bleeder	397,422	397,422	397,422	1.23	1.23	1.23

		Airflow (cfm)			CH ₄ Concentration (%)		
Mine	Exhaust Point	Min.	Max.	Average	Min.	Max.	Average
District 4							
Beckley Pocahontas	Return	347,780	527,878	421,770	0.31	0.41	0.35
Beckley Crystal	Surface Bleeder	7,399	55,264	31,332	0.54	1.15	0.85
	No. 5 Drift	181,282	187,425	184,233	0.33	0.51	0.40
American Eagle	Coal Fork #3 Bleeder	314,720	457,600	352,350	0.15	0.40	0.31
Pinnacle	Trail Fork Fan	305,553	456,876	397,457	0.57	0.85	0.69
Justice #1	EP #1	7,394	11,159	9,277	0.54	0.89	0.70
	Lavian Fan	344,635	344,635	344,635	0.48	0.48	0.48
Mountaineer II	Bend Branch Fan	283,768	325,330	292,709	0.79	1.23	0.97
District 5							
Buchanan Mine #1	Fan #12	283,067	343,900	313,484	0.59	1.56	1.08
Deep Mine #26	No. 1 Return	338,555	341,687	340,121	0.42	0.49	0.46
	No. 2 Return	342,684	367,308	354,996	0.42	0.46	0.44
District 6							
None*							
District 7							
E3-1	Main fan	335,062	396,752	365,907	0.35	0.38	0.36
District 8							
Galatia	#1 Main #5 Seam	470,652	715,780	623,283	0.06	0.38	0.21
	#1A Main #6 Seam	370,480	737,400	590,384	0.18	0.31	0.23
	Flanningan East	206,830	206,830	206,830	0.45	0.45	0.45

*No mines in this District were reported to have VAM concentrations in excess of 0.3 percent.

		Airflow (cfm)			CH ₄ Concentration (%)		
Mine	Exhaust Point	Min.	Max.	Average	Min.	Max.	Average
District 8 (cont'd.)							
Galatia (cont'd.)	Graben	202,164	202,164	202,164	0.50	0.50	0.50
	New Future	167,570	167,570	167,570	0.32	0.32	0.32
	1st-8th North	176,055	176,055	176,055	0.43	0.43	0.43
	2nd West	297,155	297,155	297,155	0.48	0.48	0.48
	#16 Bleeder	151,340	151,340	151,340	0.83	0.83	0.83
	#17 Bleeder	260,314	260,314	260,314	0.49	0.49	0.49
Pattiki	Return Upcast	459,472	584,460	515,716	0.27	0.44	0.37
Mach #1	Bleeder	89,166	216,596	173,284	0.06	0.48	0.35
Gibson	Main Return	496,746	1,016,304	695,921	0.26	0.31	0.30
Freelandville	Main Return	42,204	51,230	47,050	0.35	0.50	0.43
Carlisle	Return Upcast	122,598	175,826	138,061	0.41	0.67	0.59
District 9							
San Juan South	Not specified	659,100	972,485	871,294	0.31	0.48	0.39
Bowie No. 2	Not specified	740,744	813,008	767,784	0.31	0.60	0.51
Elk Creek	Not specified	639,524	794,101	721,680	0.31	0.56	0.46
South Central	Not specified	317,680	409,586	353,419	0.30	0.39	0.35
West Ridge	Not specified	692,685	766,463	729,093	0.32	0.94	0.55
District 10							
Paradise	Return	37,860	511,691	173,023	0.08	1.21	0.31

Mine	Exhaust Point	Airflow (cfm)			CH ₄ Concentration (%)		
		Min.	Max.	Average	Min.	Max.	Average
District 11							
North River	Tyro Creek	214,143	261,039	237,591	0.25	0.58	0.41
Oak Grove	No. 5	305,397	429,730	367,564	0.28	0.34	0.31
	Split Shaft	466,662	732,376	599,519	0.34	0.36	0.35
JWR No. 7	7-1	902,939	961,760	932,350	0.87	0.98	0.93
	7-7	316,930	366,773	341,852	1.02	1.20	1.11
	7-9	727,617	1,059,079	893,348	0.60	0.63	0.62
JWR No. 4	4-9	438,575	460,785	449,680	0.84	1.02	0.93

Appendix B: U.S.VAM Oxidation Projects

TFRR Operating Parameters

If the concentration of methane entering flow-reversal reactors is high enough (i.e. ≥ 0.2 percent), the proper amount of heat will be released into the oxidizer bed to support ongoing auto-oxidation of incoming VAM without the need for any supplemental fuel. Higher concentrations of methane can release excess heat (over and above that required to sustain the oxidation reaction) that can be captured and beneficially used (e.g., for electricity generation, space/water heating). However, if inflow methane concentrations are too high, so much heat will be released per unit time that the physical integrity of the oxidizer and its ceramic bed may be compromised. Therefore, there exists a methane concentration window that successful VAM oxidation projects can safely and reliably operate within: 0.2 percent to approximately 1 percent methane. Projects that can operate at the ~ 1 percent upper operational limit will offer the highest return on investment because they will generate the highest revenues from energy and carbon credit revenues. If VAM concentrations exiting mines exceed 1 percent, they can be diluted with ambient air to lower the concentration entering the oxidizer to the preferred 1 percent level. Conversely, if VAM concentrations exiting the mine are low, they can be raised with supplemental drained coal mine methane (e.g., gob gas), if available, to approach or reach the ~ 1 percent upper boundary. Following are descriptions of two VAM projects in the U.S.

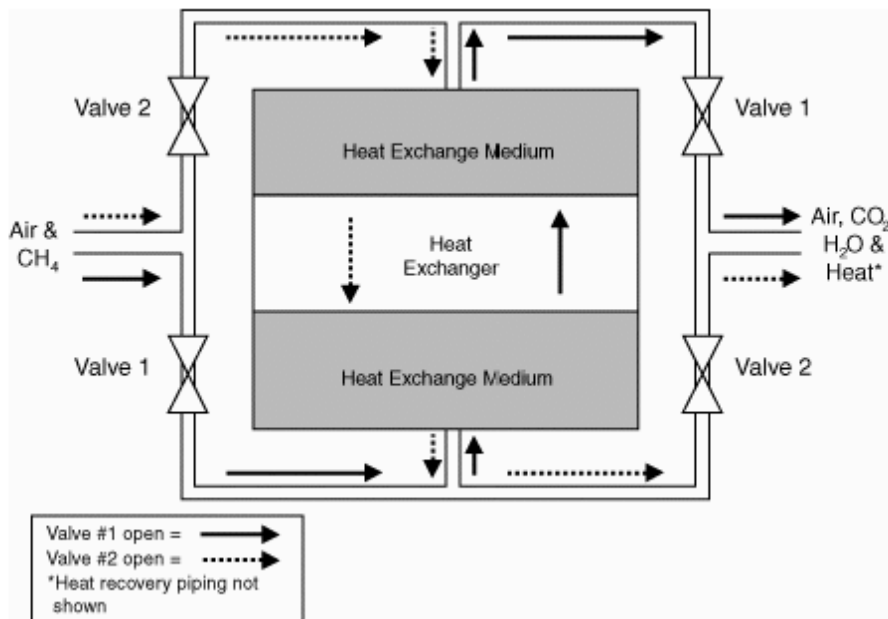


Figure 1. Schematic of Thermal Flow-Reversal Reactor

1. CONSOL Energy

CONSOL Energy conducted a field demonstration of a MEGTEC Systems' ventilation air methane (VAM) TFRR—called the VOCSIDIZER™—at their abandoned Windsor Mine in West Liberty, West Virginia. In the VOCSIDIZER™, the ventilation exhaust stream exiting the mine is conveyed via ducting to the oxidizer, where valves and dampers direct its flow into, across, and out of the heat-exchange bed. Prior to introduction of VAM, the preheating system brings the bed's temperature to or above methane's oxidation point (1,000°C), following which VAM inflow is initiated and the preheating system is turned off. When the methane reaches the preheated bed, it undergoes flameless oxidation, releasing heat. That heat is transferred to the oxidizer bed. If enough heat is released, the oxidizer bed's temperature will be maintained at or above the temperature necessary to support auto-thermal operation. Therefore, following the initial bed preheating, if the concentration of inflow methane is maintained at a high enough level, the oxidizer will require no auxiliary fuel to continue operation.



Windsor Mine VAM Oxidation Demonstration Project
(Photo courtesy: CONSOL Energy)

The U.S. Department of Energy and the U.S. Environmental Protection Agency funded that first U.S. field demonstration of VAM oxidation. Because it was sited at an abandoned mine, the Windsor project simulated a typical VAM flow by diluting methane drained from the closed mining area. The project operated from February 2007 through October 2008, employing a single VOCSIDIZER™ unit to process 30,000 cubic feet per minute (cfm) of simulated VAM at a concentration of 0.6 percent methane. This project provided hands-on experience in operating a VAM oxidizer and verified (1) VAM destruction efficiency, (2) system operational safety, and (3) reliable operation of the system under U.S. field conditions. It provided a) proof of the system's ability to convert the low concentration methane typical of underground coal mine exhausts to carbon dioxide and water, b) insight into the cost of deploying this technology at U.S. coal mines, and c) a basis for estimating the amount of useful energy that TFRRs can produce.

2. Jim Walter Resources

Canadian firm Biothermica Technologies, Inc. teamed with Jim Walter Resources (JWR) to design and install the second North American VAM demonstration project at JWR's Mine No. 7 in Brookwood, Alabama. Their VAMOX™ design differs slightly from that employed by MEGTEC in that a double, side-by-side reactor bed is employed. Mine ventilation exhaust enters the oxidizer and travels through one bed into a plenum (oxidation chamber), which is located at the top of and communicating with both beds; the exhaust then travels into and then out through the second bed. Flow reversal in this configuration occurs when the incoming ventilation airflow periodically is redirected so that it enters the second bed, travels through the plenum and into the first bed, and then exits from the first bed.



Jim Walter Resources VAM Oxidation Project

(Photo courtesy: Biothermica Inc.)

The ongoing demonstration at JWR employs a single VAMOX™ unit that oxidizes 850 m³ per minute of 0.9 percent VAM. This project, which began in January 2009, is the first to operate at an active mine in the Americas. It also is the first VAM oxidation installation to receive approval from the U.S. Mine Safety and Health Administration. The project plans to secure revenues from the sale of ~35,000 tonnes of carbon dioxide equivalent per year during its planned four-year operational lifetime.

Appendix C: States Comprising the MSHA Districts

MSHA District	States
1	Pennsylvania (anthracite region)
2	Pennsylvania (bituminous regions)
3	Maryland, Ohio, and Northern West Virginia
4	Southern West Virginia
5	Virginia
6	Eastern Kentucky
7	Central Kentucky, North Carolina, South Carolina, and Tennessee
8	Illinois, Indiana, Iowa, Michigan, Minnesota, Northern Missouri and Wisconsin
9	All States west of the Mississippi River, except for Minnesota, Iowa, and Northern Missouri
10	Western Kentucky
11	Alabama, Georgia, Florida, Mississippi, Puerto Rico, and the Virgin Islands

