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Energeia

Coal Mine — Ventilation Air Methane Mitigation: Technologies to Harness an Energy and Environmental Resource

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OVERVIEW

There is much interest in the potential for methane reduction to serve as a low cost means of reducing global greenhouse gas emissions. The global coal sector is already playing a significant role in reducing its methane emissions from gas drainage systems. What remains to be addressed at a commercial-scale is the methane gas emanating from ventilation shafts, representing the single largest source of coal mine methane emissions. Because this methane is dilute, conventional methane utilization options are technically unfeasible. However, recent analyses by the U.S. Environmental Protection Agency (EPA) and others have identified and validated the technical feasibility of a number of options to oxidize ventilation air methane. This article surveys some of these options.

TECHNOLOGY	EXPECTED NICHE
VAM as Ancillary Fuel	0%-1%+CH_4, where VAM close to large gas or coal fired plant
Flow Reversal Reactor	.15%-1%+CH_4, may be used as flare or for power production
Lean Fuel Turbines	1%+CH_4 or with supplemental gas available, where power price is favorable
Hybrid VAM/Coal Rotary Kiln	0-1%+CH_4 where waste coal is available
Concentrator	.1%- 1% CH_4 with lean fuel turbines with favorable power prices, or, possibly .5% 1.5% CH_4 with rich fuel turbines
Biological VAM Removal	1%+CH_4, under assessment

Table 1. Comparison of Different Ventilation Air Methane Mitigation Technologies.

EPA has also gathered country-specific ventilation air methane emissions and mitigation costing data. These data form the basis for understanding the size of the potential mitigation market under different price signals.

INTRODUCTION

To safely produce coal, gassy underground coal mines need to circulate vast quantities of air to dilute methane concentrations. Typically, mines need to keep working areas below one percent methane concentration. Almost all of this ventilation air methane (VAM) vents to the atmosphere. EPA estimates that in the year 2000, global ventilation air methane emissions exceeded 17 billion cubic meters (600 Bcf), which is the equivalent of 237 million tons of carbon dioxide. To put this in perspective, this represents the annual CO_2 emissions of more than 50 million automobiles.

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Coal Mine Fire — Gas and Condensation Products: Collection Techniques for Laboratory Analysis

Glenn B. Stracher
East Georgia College

Wherever coal is *surface* or *deep* mined, the potential for fire exists. Coal fires associated with the abandoned workings or workings of coal mines, are reported from mining areas around the world. Surface expressions of underground coal fires observable in the field include baked rocks, patches of dead vegetation, land subsidence, and gas vents and fissures.

Coal-fire gas exhaled from vents and fissures and condensates derived from cooling gas reveal important information about the chemical composition of burning coal and the possible interaction of the gas with rock and water on its way to the surface. The chemistry of these condensates and exhaled gas reflects elements and compounds that may be released as pollutants into the atmosphere, soil, streams, or groundwater. Such pollutants may be responsible for a variety of environmental and human health problems including the destruction of floral and faunal habitats, stroke and pulmonary heart disease, and arsenosis

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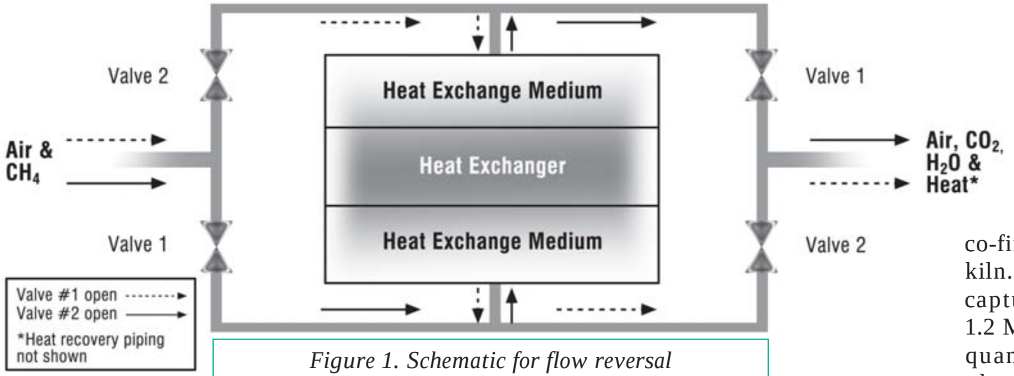

Figure 1. Schematic for flow reversal reaction technology.

Approximately 88 percent of all VAM emissions are found in only twelve countries. China alone is responsible for over one third of all emissions, followed by the U.S., Ukraine, Russia and Australia. Methane concentrations vary from ventilation shaft to ventilation shaft, and from country to country. Concentrations in only a few cases exceed 1 percent, but in most countries studied a large portion of emissions are greater than .5 percent.

TECHNOLOGIES TO HARNESS VENTILATION AIR METHANE

There are several technologies **(Table 1)** that may be applied for the oxidation of ventilation air methane. EPA is assessing their optimal niches over the range of VAM air flows, markets, and concentrations.

One of the more robust technologies, flow reversal reactors can use up to 100 percent of the methane from ventilation shafts, and the byproduct – heat — may be used to produce power or to satisfy local heating needs.

These technologies employ the principle of regenerative heat exchange between a gas and a solid bed of heat exchange medium **(Figure 1)**. VAM flows into and through the reactor in one direction and the temperature is increased until the methane is oxidized. The hot products of oxidation then lose heat as they continue towards the far side of the bed, until the flow is automatically reversed. Through the use of heat exchange technologies, excess heat may be transferred for local heating needs, or for the production of power in steam or gas turbines. Based on laboratory and field experience, flow reversal reactors may sustain operation with ventilation air with methane concentrations as low as .1 percent. Several demonstrations of flow reversal reactor technologies are making this approach ready for commercial deployment.

Ventilation air methane may also be used as combustion air for power projects. This approach is technically straightforward and commercially proven, but the greenhouse gas reduction potential is limited since it requires the siting of large, capital intensive power projects close to ventilation shafts. The Appin Colliery in Australia used approximately 10 percent of its VAM as combustion air for a series of internal combustion engines. Another ancillary fuel use is soon to be undertaken at a large coal-fired boiler in Australia. Because of the size of the project, most of a mine's VAM will be used. This approach is dependent, however, on the siting of large boilers near ventilation shafts.

Several companies have or are developing technologies to employ VAM in gas turbines as a significant or even the primary fuel source **(Figure 2)**. Some of the technologies employ catalysts for the VAM combustion, while others take place in an external combustor without catalysts but at a lower temperature than with normal turbines. To date, the technology vendors claim that they can use VAM (or a mixture of VAM and higher concentration gas) down to concentrations of between 1 and 1.6 percent, but several are researching means of lowering the required concentration to .8 percent or below. Depending on the VAM concentration, these turbines may use VAM for over 80 percent of all fuel if methane concentrations are high, or less than 20 percent with low VAM concentrations.

One novel approach that has been developed is a plant that co-fires waste coal and VAM in a rotary kiln. For the demonstration, the captured heat shall be used to power a 1.2 MW gas turbine. Depending on the quantities of coal versus VAM used, this plant is either a VAM ancillary or a VAM primary technology. Unlike the lean fuel turbine approaches, it doesn't require supplemental gas to increase the methane concentration of VAM to sustain operations.

Concentrators are traditionally used to control volatile organic compounds and may be another possible economical option for supporting VAM use technologies. Conceivably, a concentrator might increase the methane concentration of VAM twenty fold. Depending on the output concentration, this might be useful in blending with lower concentration VAM for use in lean fuel turbines, or it might even increase concentrations for use in rich gas applications. EPA has worked with a concentrator vendor to test the efficiency of this technology on .1 — 1.0 percent methane concentrations with limited success so far. However, the vendor is testing different options to make a concentrator effective on VAM.

Ventilation air methane might be a good feedstock for the production of single celled, methane consuming proteins, called methanotrophs. Single celled proteins are used as a supplement to animal feed. There are a number of approaches that have been proposed to produce these proteins from VAM.

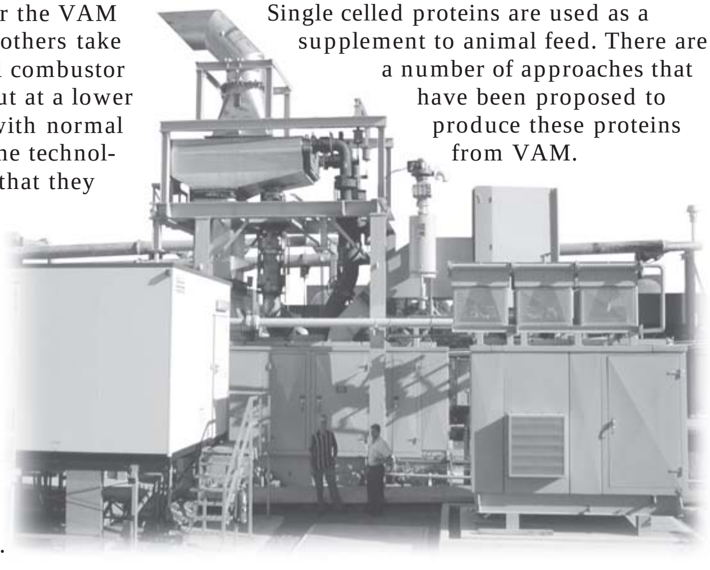

Figure 2. Carburated lean fuel gas turbine (courtesy Energy Developments Ltd.).

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Coal Mine, (cont.)

The above technologies require further assessment before knowing precisely which to employ in different circumstances. As discussed in the technical descriptions, the application and viability of the different options depends on the methane concentrations in the ventilation air and other site-specific situations. Clearly, however, if there is a sufficient revenue stream available for the energy or greenhouse gas reductions produced from the oxidation of ventilation air methane, then these projects make economic sense.

COST ANALYSES AND MARKET CONSIDERATIONS

EPA published a report in July, 2003 that evaluates the global VAM market. The *Assessment of the World-wide Market Potential for Oxidizing Coal Mine Ventilation Air Methane* (available on EPA's website at www.epa.gov/coalbed) estimates VAM emissions for the major underground coal-producing countries and the methane concentrations of these emissions (the most critical factor in technology choice and cost). It uses these data and cost estimates for the most universally applicable technology, flow reversal reaction, and prevailing country-level power prices to determine the size of the market, based on varying price signals for power and CO_2 equivalent emission reductions.

The report finds that of the total of 237 million metric tons of CO_2e VAM emissions (16.6 billion cubic meters of methane), with a net project cost of $3.00 per ton of CO_2e and with average industrial power prices, approximately 172 million tons of CO_2e could be oxidized. The analysis shows that the quantity of emissions that may be mitigated at lower costs is much less: at $2.00 per ton approximately 60 million tons of CO_2e could be mitigated.

Translating these costs to market size, at $3.00 per ton CO_2e nearly 3,000 MW of net electric capacity could be developed, and annual revenue could approach $900 million. **Table 2** also shows that the largest VAM emitters are also the largest markets for VAM projects. China has the potential to reduce nearly 5.5 billion cubic meters per year of VAM for less than $3.00 per ton CO_2e, which may lead to $3.8 billion worth of equipment sales and $430 million in annual revenues. The U.S. is the second largest market, with nearly $1.5 billion in equipment sales potential and $150 million in annual revenue at $3.00 per ton of CO_2e. While these two countries represent more than half of the global market, there are significant market potentials in most of the important underground coal mining nations.

COUNTRY	TOTAL 2002 VAM EMISSIONS (Bm^3)	TOTAL 2002 VAM EMISSIONS <$3.00 TON CO_2e (Bm^3/y)	NET ELECTRIC CAPACITY (MW)	EQUIPMENT SALES (US$000,000)	ANNUAL REVENUE (US$000)
China	6.7	5.48	1,367	3,811	431,321
U.S.	2.6	2.17	549	1455	148,412
Ukraine	2.2	1.13	263	910	71,383
Russia	0.7	0.61	141	498	56,002
Australia	0.7	0.37	96	243	17,310
Poland	0.4	0.26	52	258	22,364
Kazakhstan	0.3	0.04	11	29	1,726
Czech Republic	0.1	0.06	13	47	5,579
U.K.	0.2	0.14	33	104	8,986
Mexico	0.1	0.10	27	62	11,480
Germany	0.1	0.07	16	63	9,178
Study Country Totals	14.8	10.43	2,568	7,480	783,742
Other Countries	2.5	1.5	377	1,098	115,045
World Totals	**17.3**	**12.0**	**2,945**	**8,578**	**898,787**

Table 2. Potential Worldwide Market for VAM Projects (@ under $3.00/ton CO_2e).

EPA's analyses demonstrate that there is a large global supply of ventilation air methane, which can become a valuable energy and environmental resource. In order to develop this market, however, a number of coordinated steps must be undertaken including demonstration of the technologies at commercial scale, provision of sufficient financial incentives to commercialize the projects, and information on the technologies and markets must be made readily available. EPA already has a web site (www.epa.gov/coalbed, visit the "ventilation air methane" section) that provides a significant amount of technical and market data, and EPA will continue its efforts to develop and provide unbiased information to industry and to partner with other organizations worldwide.

Karl Schultz has recently formed a consulting/project development company, Climate Mitigation Works, Limited. He can be reached at: climateschultz@yahoo.co.uk or telephone +44 (0) 207 354 3595."

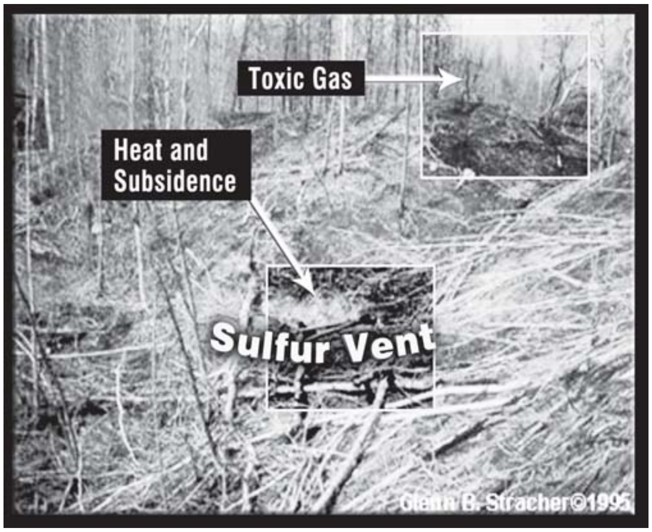

Figure 1. Hazards of collecting coal fire condensates (sulfur in this case) and gas observed at the southern end of Centralia, PA. Note subsidence around the sulfur vent, extending into the smoke filled valley in the upper right corner of the photo. Field of view is approximately 35 meters.

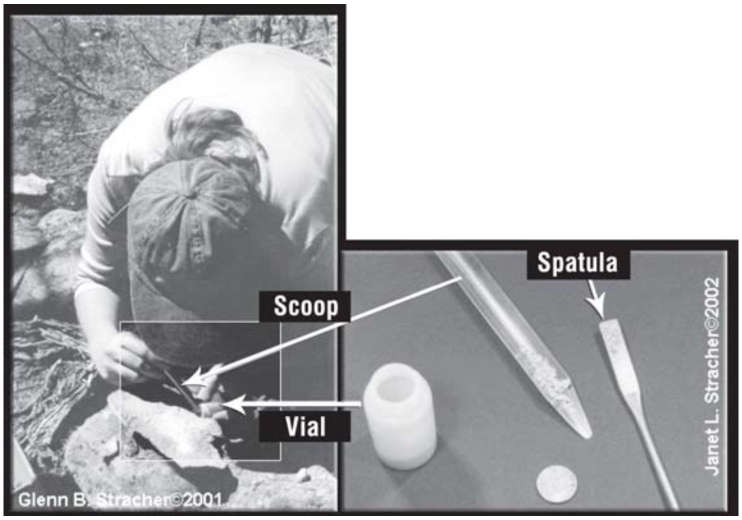

Figure 3. Collecting Gas Condensates. Tammy Taylor from the Chemical Division of Los Alamos National Lab using a spatula and scoop to scrape condensate off rock and soil into a plastic vial, while using caution to minimize contamination from these substrates. The sample was identified by X-ray diffraction as orthorhombic sulfur-8. It was collected from the Southern Ute Indian Reservation near Durango, Colorado, where an underground coal fire is thought to have been ignited by a forest fire.

and fluorosis. Consequently, the study of coal-fire gas and associated condensates can be critically useful in understanding environmental pollution caused by coal-mine fires.

In this article, two useful procedures for collecting condensates and a technique for collecting coal-fire gas for laboratory analysis are presented after discussing hazards associated with the collection process.

Figure 2. Hazards associated with collecting coal fire condensates and gas. Glenn Stracher is holding his breath to avoid inhaling toxic fumes. Note the lined leather glove used to protect his right hand during insertion of a thermocouple temperature probe into a coal fire vent: adjacent to a closed section of Route 61 on the eastern end of Centralia, PA. The white Teflon tube near the bottom of the photo was used to extract gas out of the vent with a hand pump). Gas temperature was 126.2 °C. CO and CO_2, measured with Drager tubes, were highly toxic at 1000 ppm and 2200 ppm respectively. Condensation products associated with this vent have yet to be identified.

Safety precautions are essential in the field when collecting coal-fire condensates or gas. The most dangerous impediments when sampling from active vents and fissures are toxic vapors, heat, and subsidence. **Figure 1** illustrates all three of these at the southern end of Centralia, Pennsylvania. The Centralia Mine Fire began in and has been burning since 1962, when an abandoned strip mining cut was ignited to reduce its volume and control rodents. The Buck Mountain anthracite seam in the landfill ignited and the fire spread to abandoned underground coal-mine tunnels. For safety, it is best to never collect alone. In addition, a walking stick used to test the ground ahead of oneself while heading toward a vent or fissure is a wise precaution against subsidence. One should never venture, even with a field assistant and gas mask, into an area completely engulfed in smoke like the valley in the upper right hand corner of **Figure 1**. The consequence of becoming disoriented could prove fatal. Once a vent or fissure is found with material worthy of collection, gloves may be necessary to avoid getting burned when working at or near the collection site (**Figure 2**). Extreme caution is necessary to avoid breathing as much coal gas as possible, and a gas mask should be worn where fresh air is not immediately nearby or when sampling requires an extended period surrounded by toxic vapors. I have recorded temperatures and collected gas and condensates from vents and fissure by holding my breath (**Figure 2**) and then "coming up for air" after moving to a location several meters away with adequate ventilation. For safety sake, someone was always standing nearby to watch my activities.

The most difficult part of collecting a gas condensate for identification and chemical analysis is to avoid contaminating the condensate with soil or rock upon which the gas has condensed. X-ray diffraction and electron probe analysis of the condensate are then easier to interpret. One method for collecting delicate or small amounts of condensate is to scrape the material off of the underlying substrate into a vial using a metal spatula and laboratory scoop (**Figure 3**). Some separation of the condensate from contaminants may still be necessary, and it is absolutely essential for wet chemical analysis. On one occasion, I was sent several beautiful condensate samples from coal fires in East Kalimantan, Indonesia. Numerous coal fires in Indonesia started when fire was used to clear forested areas for

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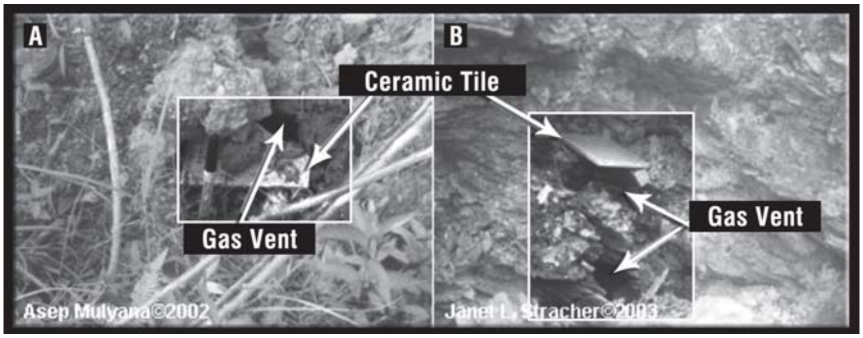

Figure 4. Collecting gas condensates from unglazed ceramic tiles placed over coal-fire gas vents: (A) East Kalimantan, Indonesia and (B) Centralia, PA. Condensation products identified by X-ray diffraction on the bottom of the Indonesian tile (not visible in the photo) are gypsum and sulfur. The tile in Centralia was recently placed and will be checked every two weeks.

rubber, oil palm plantations, pulpwood, and farming. The specimens I received were never separated from the soil they condensed on. By the time they reached my lab, each condensate was completely pulverized and mixed with the soil, rendering separation and identification impossible.

Another useful method for collecting condensates is to "force" the gas to condense onto a substrate placed partially over a vent or fissure. Unglazed ceramic tiles were successfully used in East Kalimantan for this purpose (**Figure 4A**), and condensates appeared within two weeks. Several tiles were sent to my lab, where the condensates were removed and identified by X-ray diffraction as gypsum and orthorhombic sulfur-8. Several tiles were recently emplaced over gas vents associated with the Centralia fire (**Figure 4B**) and will be checked every two weeks for condensation products.

A cost effective and efficient way of collecting gas from coal-fire vents and fissures is to use a hand-operated pump with Teflon inlet and exhaust tubes. The gas is then pumped into an inert and impermeable container for storage and transported to the lab for analysis. Although glass storage vials are available, I prefer to use Tedlar bags, made of Teflon because they are compact and won't break. The bags have a swage lock used to seal the gas inside. A circular disk 3 mm in diameter on the side of the bag is used to insert a hypodermic needle and extract the gas for analysis. A LaMotte pump connected to Teflon lines and a Tedlar collection bag are illustrated in **Figure 5**. This pump delivers 50 ml per stroke and the bags used here hold 600 ml, so twelve strokes fill a bag. If a vent is hot enough to melt the Teflon tubing, gas may still be obtained by working quickly. If the tube starts to melt, I extract it from the vent after getting as much gas as possible, let it cool down, and then proceed with the extraction process.

Figure 5. Collecting coal-fire gas, Centralia PA. Glenn Stracher (right) pumping coal fire gas from a vent through a Teflon exhaust line into a Tedlar gas collection bag held by Joe Nolter (left). The intake line in Stracher's left hand (leather glove) extends several cm down into the gas vent. Vent temperature measured with a thermocouple was 363 ^{o}C.

The collection procedures described above for obtaining coal-fire gas and condensates were successfully field tested and a number of analyses obtained for fires in SW Colorado, Indonesia, and the Wuda coal field in the Inner Mongolia autonomous region of northern China. Work on samples from Centralia will soon begin. All results will be published in forthcoming articles along with pressure-temperature stability diagrams. One such diagram was derived for the condensation of orthorhombic sulfur from anthracite gas by considering polymophic transformations in the sulfur during cooling. The diagram illustrates gas-orthorhombic sulfur stability fields below approximately 600 K.

Interestingly, few articles have been published about coal-mine fire condensates and their associated gases. The author would enjoy hearing from anyone interested in such research.

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Glenn B. Stracher received his Ph.D. in geology and engineering mechanics from the University of Nebraska-Lincoln. He is an Associate Professor of Geology and Physics at East Georgia College. He may be reached at: stracher@ega.edu.

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Petra David, General Secretary ICCP; Alan Cook, President ICCP;
Dr. Jim Hower receiving the Reinhardt Thiessen Medal (August 2003).

Jim Hower Wins Thiessen Award

Dr. Jim Hower, 25 year veteran of the University of Kentucky Center for Applied Energy Research, has won a prestigious international award. In 1956 the International Committee for Coal and Organic Petrology (ICCP) created the Reinhardt Thiessen Medal. It is awarded annually to one outstanding petrologist who has made significant contributions in the field. Dr. Hower is the 27th recipient and only the 5th American to receive the award. This award was presented to him during the 2003 ICCP conference held in Utrecht, The Netherlands in August.

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