United States Environmental Protection Agency
Office of Air and Radiation
6203-J
EPA-430-N-00-004
Fall 2003

COALBED METHANE EXTRA

A publication of the Coalbed Methane Outreach Program (CMOP)
www.epa.gov/coalbed

Global Market Assessment for Utilizing Coal Mine Ventilation Air Methane for Energy

A market for ventilation air methane (VAM) oxidation is emerging in many of the world's coal-producing countries. With electric power sales from ventilation air methane oxidation projects securing US$0.03 per kWh, coal mines in the US could recover over 6 million tonnes of CO_2 equivalent per year at a marginal cost of $2.00 net present value (NPV) per tonne. At a marginal cost of $3.00 NPV, reductions could exceed 25 million tonnes of CO_2 equivalent per year. Assuming reasonable power sales prices for each of the coal producing countries included in this analysis (which together are estimated to account for approximately 85 percent of global VAM emissions), globally a marginal cost of $3.00 NPV per tonne could yield more than150 million tonnes in reductions of CO_2 equivalent annually. This translates to an equipment sales market of more than US$8.4 billion.

Introduction

Methane is a heat-trapping gas second only to carbon dioxide as a contributor to global warming. One source of methane emissions is coal mine methane (CMM) emitted through mine ventilation systems. Although the exhausted ventilation air contains very low concentrations of methane (typically below 1 percent), VAM is the largest single

Assessment, continued on page 3

In this issue ...

1 *Global Market Assessment for Utilizing Coal Mine Ventilation Air Methane for Energy*
1 *Emerging Ventilation Air Methane Processing Technologies*
6 *CBM/CMM News*
7 *New Publications*
8 *Upcoming CBM/CMM Events*
8 *CMOP Moves Offices*

To obtain CMOP reports, call 1-800-STAR-YES

Access documents electronically from the "CMOP Library" pages of our World Wide Web site at **http://www.epa.gov/coalbed.**

To subscribe to *CBM Extra,* provide contact information to Clark Talkington at Talkington.clark@epa.org.

To subscribe to CBM Notes, email a subscription request to energystar@optimuscorp.com with "SUBSCRIBE" in the subject line.

Emerging Ventilation Air Methane Processing Technologies

Although containing only very low concentrations of methane, typically below 1 percent, ventilation air exhaust flows are so voluminous that they actually constitute the largest singe source of coal mine methane emissions to the atmosphere. Historically, mine ventilation systems were solely viewed as a necessary means of removing potentially explosive methane from gassy underground coal mine workings so as to maintain safe conditions underground. In recent years, however, as concern has increased over releasing this potent greenhouse gas to the atmosphere where it can contribute to global climate change, interest in finding technological means of reducing or eliminating such releases has grown.

Vendors of technologies such as thermal and catalytic flow reversal reactors, the efficacy of which has been well proven in industrial volatile organic compound emission reduction applications, have begun to target coal mine ventilation systems as possible expansion markets for deploying their equipment. Efforts are currently underway to demonstrate the ability of the systems to extract the heat generated from oxidation and use it to produce electrical power. In addition to proven oxidizer technologies, CMOP has identified a number of other technologies that are being adapted to meet the unique challenges of VAM mitigation.

Emerging Technologies, continued on page 2

Emerging Technologies, *continued from page 1*

CSIRO-LIQUATECH Hybrid Coal and Gas Turbine System – Australia's Commonwealth Scientific and Industrial Research Organisation (CSIRO) has designed and demonstrated a system that cofires VAM and waste coal in a rotary kiln. The kiln's exhaust gas heats clean air in an air-to-air heat exchanger, and the clean air powers an unfired gas turbine. Application of this technology, which can operate on a wide spectrum of VAM-to-coal ratios and VAM concentrations, is especially suitable for mines that have a substantial supply of unmarketable, off-specification coal.

FlexEnergy Microturbine Fueled with VAM or VAM/Gob Gas Combinations – The FlexEnergy Microturbine, a modification of the Capstone 30 kW microturbine, is expected to be capable of operating on concentrations of methane in air as low as 1.3 percent comprising any combination of VAM and supplemental fuel. The fuel/air mixture is compressed and then oxidized in a catalytic combustor, the compressor and combustor being contained within each turbine module. The hot compressed gases expand in the turbine to rotate the 30 kW electric generator. A typical VAM project would allow multiple turbines to work together (see photo).

Ingersol-Rand Microturbine – 1.0% Methane Concentration – Ingersol Rand (IR) has developed a microturbine that will run on concentrations of VAM at or above 1.0 percent, and possibly as low as 0.86 percent. It is a lean-fuel version of IR's PowerWorks Microturbine System, and the current prototype is rated at 70 kW. VAM is drawn into the PowerWorks microturbine and compressed. It then passes through a patented recuperator that captures heat from escaping exhaust gases to preheat the incoming VAM; this step significantly boosts overall efficiency of the unit. The pre-heated, compressed VAM then enters the combustion chamber where it is ignited, producing hot, rapidly expanding gases which flow through the blades of a turbine to drive the compressor, and then through a second turbine called the free power turbine. The free power turbine drives the rotating generator that produces electrical power.

EDL Carbureted Gas Turbine – Using a modified Solar Centaur turbine, Energy Developments Ltd. (EDL) has developed a Carbureted Gas Turbine (CGT) that is capable of firing a methane-in-air mixture as low as 1.6 percent. The enriched VAM at atmospheric pressure feeds into the CGT where it is compressed and combusted. The hot gases are then expanded in the turbine to produce electrical power. The gas is compressed in the standard axial compressor and then heated in an exhaust gas recuperator. Another recuperator inside the specially designed combustion chamber uses the hot combustion products to heat the air/fuel mixture to a point where ignition occurs. The hot products of combustion are returned to the turbine where they are expanded in the gas compressor turbine and the power turbine. A generator coupled to the power turbine can generate up to 2.7 MW.

CMOP is preparing technical profiles for each of the above-described technologies and plans to make them available soon on the Ventilation Air Methane portion of its Web site at **http://www.epa.gov/coalbed**. Further refinement of such technologies offers the potential to substantially expand alternatives for successful VAM mitigation project development, thereby offering additional avenues for project developers to pursue in tapping the emerging VAM processing world market (see article on page 1). ■

Assessment, *continued from page 1*

source of CMM emissions worldwide. Global VAM emissions from underground coal mining in 2000 were 230 million tonnes of CO_2 equivalent (CO_2e) and are projected to increase to just over 300 million tonnes by 2020.

VAM is a significant source of methane emissions, but also an untapped energy resource. Oxidization is the most promising technology currently available to utilize ventilation emissions. An oxidizer consists of a gravel or ceramic bed, a fan that blows ventilation air through the bed via a duct system, a heating element that initiates oxidation of the VAM during startup, and a heat exchanger that captures excess heat. If VAM concentrations are at least 0.2 percent, the unit will produce useable heat that can be captured and employed to produce electricity or to serve various thermal applications.

The US Environmental Protection Agency's (EPA) Coalbed Methane Outreach Program is now directing much of its effort toward the reduction of ventilation air methane emissions. In 2000, the program released *Technical and Economic Assessment: Mitigation of Methane Emissions from Coal Mine Ventilation Air* (EPA 430-R-001) introducing two related technologies that are capable of oxidizing VAM. Since the release of that initial VAM technology report, EPA has continued to refine project economics for oxidizers, to investigate alternative technologies that hold promise as VAM mitigation options, and to assess the potential US and worldwide markets for deploying VAM oxidation technologies. The program has now taken the next step by initiating the analysis of markets for VAM. In July of this year, EPA released an analysis of the potential VAM world market, the *Assessment of the Worldwide Market Potential for Oxidizing Coal Mine Ventilation Air Methane* (EPA 430-R-03-002). View or download both reports from **http://www.epa.gov/coalbed/clibrary/creports/vam.htm**

The VAM world market study estimates the potential for mitigating VAM emissions through 2020 using the newly available technology. Relying on public and private data sources, the assessment quantifies current and future underground coal mine production, ventilation air flow rates, and methane concentrations in major coal-producing countries worldwide. It estimates VAM abatement for a range of project costs expressed as US$ NPV per tonne of carbon dioxide equivalent (assuming country-specific power sales prices) and as US$ per kWh (assuming no revenue from carbon emission offsets). Countries included in the study are, in order of greatest VAM emissions: China, United States, Ukraine, Australia, Russia, South Africa, Poland, Kazakhstan, India, the United Kingdom, Mexico, Germany, and the Czech Republic (see Figure 1). This article reports on the study's findings.

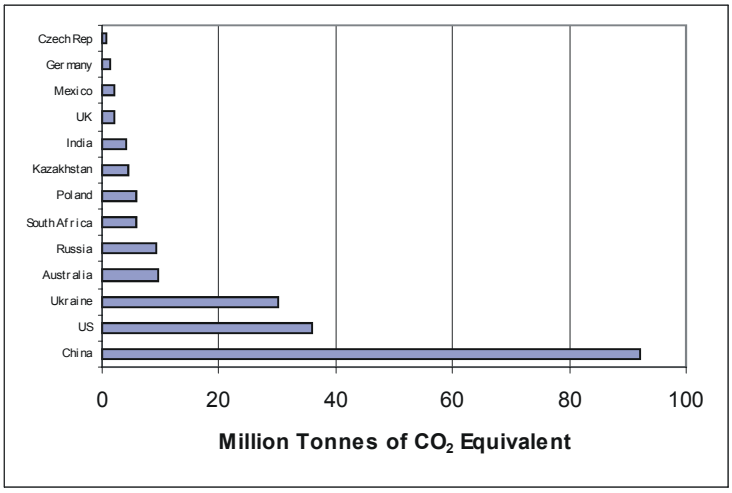

Figure 1. Total Annual VAM Emissions (2000)

Determining Mitigation Potential

To identify the international potential for VAM technology deployment, the study first estimated future VAM flows to determine the total potential methane available for recovery, and then developed marginal abatement cost (MAC) curves to evaluate the economically recoverable volumes.

Future VAM flows were estimated by developing methane emission factors for each study country correlated with estimated coal production for each country (i.e., m^3 VAM per tonne coal produced underground). These factors were developed based on known coal production and VAM emissions in recent years. Future methane emissions were then calculated applying the country-specific VAM emission factors to future coal production projections.

Country-specific MAC curves and a global MAC curve were developed by modeling oxidation projects over a range of VAM concentrations and economic assumptions to establish the break-even costs for varying quantities of VAM abated by electric power production projects. The MAC curves identify the methane mitigation potential for VAM at a given range of carbon

Assessment, continued on page 4

***Assessment,** continued from page 3*

emission reduction prices and power sales prices. The cumulative tonnage of VAM (in million tonnes of CO_2 equivalent) oxidized is plotted against each discreet incremental change in the cost of methane oxidation (expressed as NPV) and against similar changes in electric power sales price. Figures 2 and 3 present US MAC curves for electricity sales (with no carbon emission reduction revenue) and for carbon mitigation (with power sales at US$0.03 per kWh), respectively. Figures 4 and 5 present the China MAC curves—China represents the single largest country market in the world. Figure 5 reflects an estimated power sales price of US$0.035 per kWh. Figures 6 and 7 present the combined Global MAC curves based on country-specific electric power sales prices.

These figures offer a valuable frame of reference for estimating the magnitude of annual net project costs that one theoretically might expect. For example, in the U.S. (Figure 3) over 6 million tonnes of CO_2 equivalent emissions are economically recoverable at a marginal cost of US$2.00 NPV per tonne. At a marginal cost of US$3.00 NPV per tonne, the U.S. total increases to over 25 million tonnes of CO_2 equivalent per year. Similarly, the global carbon mitigation MAC (Figure 7) reveals a potential world total VAM mitigation

Assessment, continued on page 5

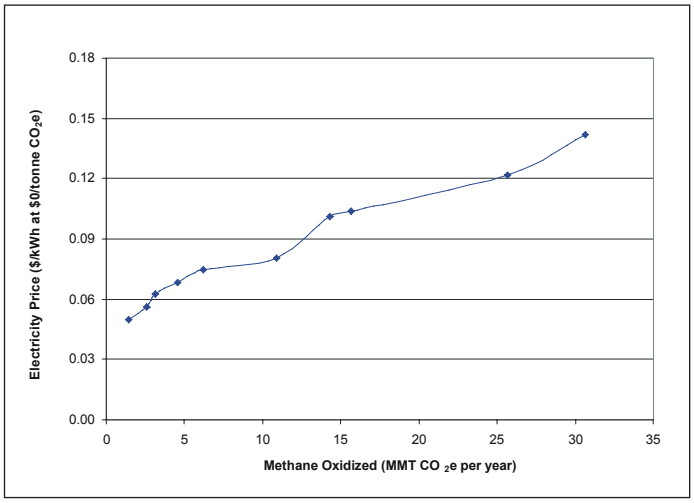

Figure 2. MAC Analysis for the United States—Power Production

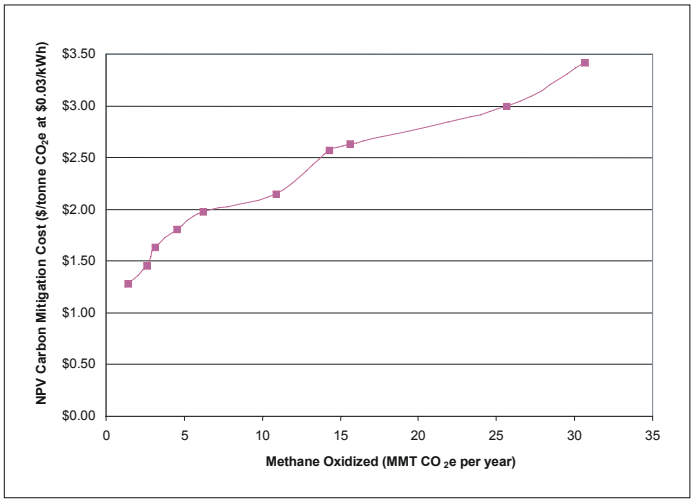

Figure 3. MAC Analysis for the United States—Carbon Mitigation

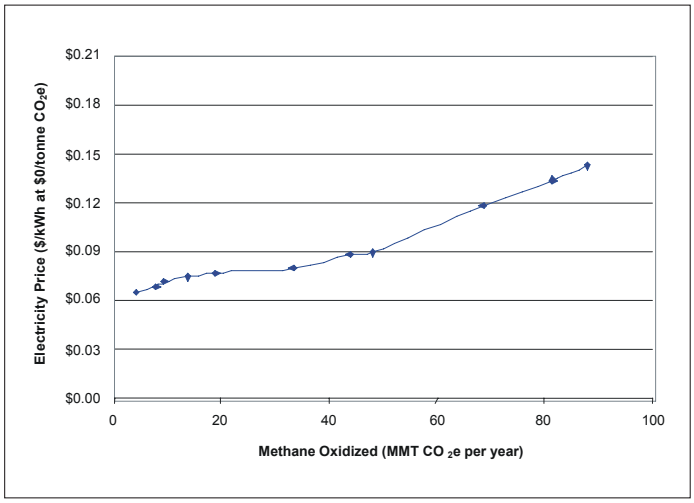

Figure 4. MAC Analysis for China—Power Production

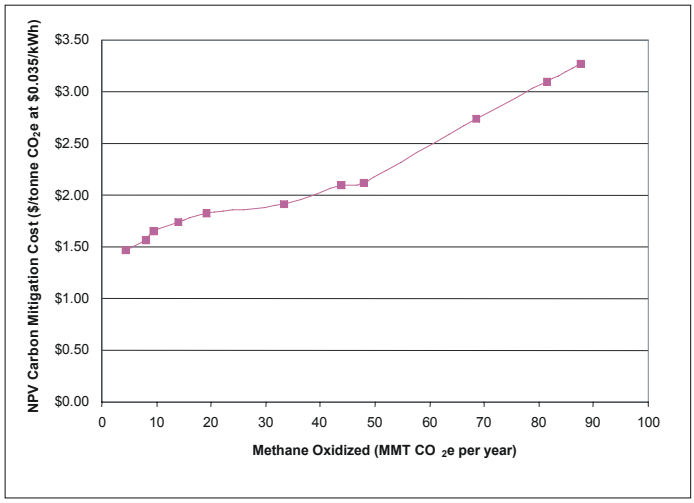

Figure 5. MAC Analysis for China—Carbon Mitigation

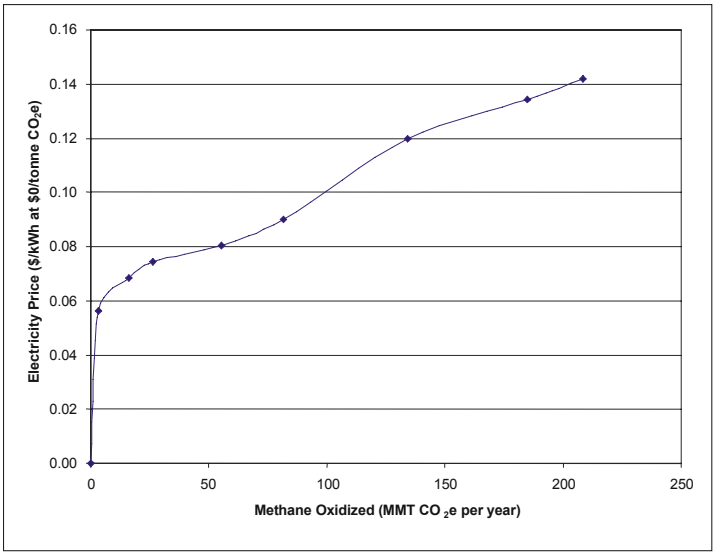

Figure 6. Global MAC Analysis—Power Production

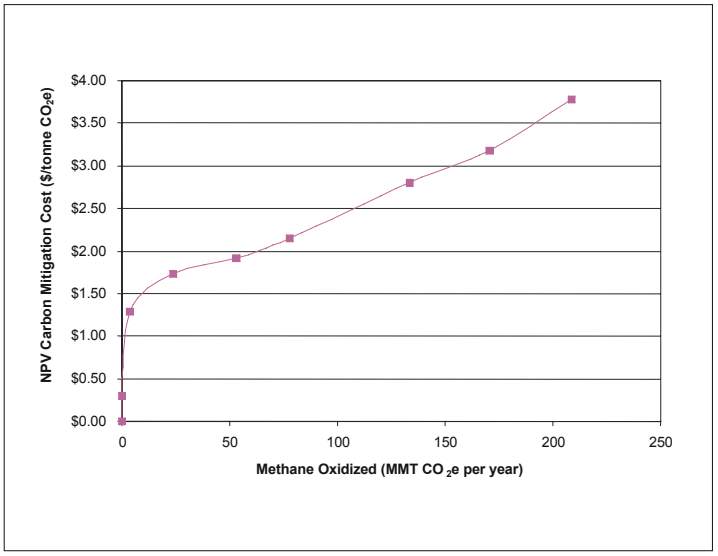

Figure 7. Global MAC Analysis—Carbon Mitigation

Assessment, *continued from page 4*

potential of about 60 million tonnes at a marginal cost of US$2.00 NPV per tonne and over 150 million tonnes at a cost of US$3.00 NPV per tonne.

Beyond estimating avoided emissions, the global market assessment also estimates the electric power-generating capacity that potentially could be supported by VAM projects, the equipment sales associated with that capacity, and the annual power revenues that would result. Table 1 on page 6 presents those data.

The MAC curves described in this article should offer encouragement to the countries, firms, and individuals who hope to address the largest source of CMM emissions, ventilation air methane. Large-scale VAM use is, or soon could be, affordable in most of the countries considered in the analysis.

In the US, with power sales at US$0.03 per kWh and a CO_2 equivalent emission marginal abatement cost of $3.00 NPV per tonne, a potential equipment sales market of US$1.2 billion exists to support development of more than 450 MW of new power generation capacity and US$124 million in annual power sales revenue. This provides an optimistic outlook for US-based oxidizer projects.

The global outlook is similarly optimistic for worldwide VAM emission reductions. Accounting for country-specific differences in power sales prices, with CO_2 equivalent emission abatement marginal costs at $3.00 NPV per tonne, one might expect countries with underground mining to oxidize more than 150 million tonnes of CO_2 equivalent annually to support more than 2,870 MW of new electric generation capacity and US$880 million in annual power sales revenues. Of that amount, China, Ukraine, and Russia have a combined equipment sales potential of US$5.2 billion, equating with 1,770 MW of new generation capacity and US$558 million in annual power sales.

Looking to the Future

With the great potential that exists worldwide, several manufacturers are targeting mine ventilation air as a viable market. To date, VAM oxidizers have been developed by two groups, MEGTEC Systems and CANMET (with licensees Neil & Gunter, Ltd., and Lefebvre Freres, Ltd.) and other technology vendors are investigating application of their technologies to the potentially large world market. If cost effective, implementation of the new technologies could reduce abatement costs and result in additional VAM emission reductions.

EPA will continue directing much of its coal mine methane mitigation effort toward VAM recovery. Possible future projects include:

- Continued analysis of oxidation technologies and other new and innovative technologies;

Assessment, continued on page 6

Table 1. Potential Worldwide Market for VAM Projects (at under $3.00/tonne CO_2e)

Country*	Total 2002 VAM Emissions (Bm^3)	2002 VAM Emissions <$3.00 Tonne CO_2e (Bm^3)	Net Electric Capacity (MW)	Equipment Sales (US$000,000)	Annual Revenue (US$000,000)
China	6.7	5.47	1,365	3,802	431
United States	2.6	1.81	457	1,213	124
Ukraine	2.2	1.13	264	912	71
Russia	0.7	0.61	141	498	56
Australia	0.7	0.37	96	243	17
Poland	0.4	0.26	52	258	22
Kazakhstan	0.3	0.04	11	29	2
United Kingdom	0.2	0.13	31	96	8
Mexico	0.1	0.10	27	62	11
Germany	0.08	0.07	16	63	9
Czech Republic	0.06	0.04	5	54	2
*Study Totals***	*14.8*	*10.04*	*2,464*	*7,229*	*754*
Other Countries	2.5	1.7	409	1,199	125
World Totals	**17.3**	**11.7**	**2,873**	**8,428**	**880**

* In order of 2002 VAM emissions
** Numbers may not equal totals due to rounding.

Assessment, *continued from page 5*

- Additional characterization of coal mine ventilation techniques and practices and assessment of how they will impact VAM flows and concentrations;
- Development of monitoring and verification procedures for the reduction of methane emissions from commercial-scale VAM oxidation technologies; and
- Further evaluation of bleeder shafts (which exhibit higher methane concentrations than do traditional ventilation shafts) as particularly attractive VAM sources. ■

For more information on VAM, readers are encouraged to visit: **http://www.epa.gov/coalbed/vam/index.htm.**

CBM/CMM News

Africa: **CBM Clean Energy Project in Botswana** – Recognizing methane's value as a clean-burning fuel and its potency as a greenhouse gas, in June 2003 the US Trade and Development Agency (TDA) signed a Memorandum of Understanding with the Botswana Development Corporation as a first formal step toward funding a feasibility study for beneficial development of coalbed methane (CBM) in eastern Botswana. Potential CBM uses in Botswana include power generation, transportation (fuel), petrochemical feedstock, and residential heating and cooking. In addition, water of a sufficiently high quality that is co-produced with CBM also may find industrial or public use in the country. TDA estimates that if the project proves feasible and is implemented it could result in the export of US$357 million in US technology. The feasibility study will be carried out by Advanced Resources International. **http://www.tda.gov**

European Union: **CMM-Derived Electricity to be Exempt from the Climate Change Levy** – EU state aid clearance has been granted for CMM-derived electricity to be exempt from the Climate Change Levy (CCL). Effective November 2003, this move will address an inconsistency wherein CMM that is used directly was exempt but electricity derived from CMM was not. In economic terms, this change may mean as much as a 15 percent increase in revenues for CMM-based power projects in the EU. Meanwhile, industry continues lobbying the UK government to have CMM-derived electricity included in that country's renewables obligation, which would dramatically increase the economic feasibility of CMM power generation projects there (see related story below).

Germany and the UK: **Alkane Energy Transfers Project Focus to Germany** – The United Kingdom's largest coal mine methane (CMM) producer, Alkane Energy, is transferring the focus of its project development energies to Germany where

News, continued on page 7

News, continued from page 6

preferential energy pricing makes producing electricity from coal mine methane economically attractive. Their first German project will be a 2.7 MW generation plant to be developed in the Nordrhein-Westfalen region of the country. Through its Renewable Energy Law (Erneuerbare Energien Gesetz), which guarantees a sale price of 64.84 Euros (US$76.60) per MWh generated from CMM, Germany offers an attractive investment environment for CMM-based projects. **http://www.alkane.co.uk**

***Poland:* Studies Show Power Project at Brzeszcze May Be Profitable** – Under a contract from the US Trade Development Agency (TDA), MEGTEC Systems and its subcontractor, International Resources Group (IRG), are preparing a feasibility study, project document, and an implementation plan for an 11 MW power project that would be fueled with ventilation air methane (VAM) blended with coal mine methane (CMM). If implemented, the proposed project would be located at the Brzeszcze Mine in Poland's Upper Silesian Basin. This mine produces about 2.4 million tonnes per year of gassy coal (about 40 m^3 of methane per tonne of coal mined).

Describing the project, MEGTEC, a US manufacturer of flow-reversal oxidation equipment, revealed that an array of oxidizers would capture virtually all (about 600,000 m^3/h) of the ventilation airflow from one of the Brzeszcze Mine's exhaust shafts. VAM content of 0.5 percent methane would be supplemented with drained CMM to bring the mixture to about 1.0 percent methane. Heat of oxidation would be converted to about 11 MW of electric power using a steam cycle configuration, and the power would be sold to the grid as well as to the mine.

MEGTEC and IRG are weighing financing options, which include Polish environmental lending agencies, carbon offset buyers, and conventional sources. The study, to be completed by the end of this year, will be available from TDA.
http://www.tda.gov
http://www.megtec.com
http://www.irgltd.com

***United States:* Fuel Cell Energy, Inc., Dedicates World's First CMM-based Fuel Cell** – On October 22, 2003, FuelCell Energy Inc., dedicated the world's first fuel cell project designed to operate on coal mine methane. Located at the American Electric Power Company's (AEP) Ohio Coal LLC Rose Valley Site in Hopedale, Ohio, USA, the project is co-funded by the U.S. Department of Energy's National Energy Technology Laboratory. This demonstration project consists of a 200-kW Direct Fuel Cell power plant that will use approximately 55,000–80,000 cubic feet of CMM per day (42–47% methane), primarily from abandoned mines. Northwest Fuel Development, Inc., operates the plant. AEP will purchase the electricity generated at the site under a power purchase agreement between Northwest Fuel Development, Inc., and AEP.

According to a study by FuelCell Energy, 1,000 megawatts of fuel cell power could be generated worldwide using coal mine methane from active and abandoned mines.

For more information, contact Steve Eschbach, FuelCell Energy, 203-825-6000, seschbach@fce.com or Peet Soot at Northwest Fuel Development, at northwestfueldev@qwest.net.

***China:* International Workshop on China CBM/CMM Development** – On September 10–11, 2003, the Asian Development Bank (ADB), China Coal Information Institute, US Environmental

News, continued on page 8

New Publications

Assessment of the Worldwide Market Potential for Oxidizing Coal Mine Ventilation Air Methane (EPA 430-R-03-002; July 2003)
Available in hard copy or compact disc by calling 1-888-STAR-YES. The CD also contains *Technical and Economic Assessment: Mitigation of Methane Emissions from Coal Mine Ventilation Air* (EPA 430-R-001) and other VAM-related materials. The report can also be downloaded electronically from CMOP's Web site at **http://www.epa.gov/coalbed**.

Proceedings from Oberhausener Grubengas—Tage 2003 (i.e., German Coal Methane Conference)
The publication is now available through the Institute's Web site at **http://www.umsicht.fhg.de/publikationen/44_umsicht_ggt_cmm.php** or by contacting Ms. Sandra Dall de Cepeda at Sandra.Dall-de-Cepeda@umsicht.fhg.de. The volume contains 21 papers covering a range of technical, market, and policy issues. The papers are in English or German. Cost: 39 Euros.

***News,** continued from page 7*

Protection Agency, and the Shanxi Energy Industries Group, Ltd., sponsored a workshop in Wutaishan, China, on a variety of technical and finance topics related to coalbed methane (CBM) and coal mine methane (CMM) project development. Financing projects through portfolios combining traditional financing options and greenhouse gas financing stimulated much discussion. The ADB discussed its program to finance environmentally sound projects, including coal mine methane projects. The technical program centered on the production and use of methane drainage, including upgrading gob gas and power generation. USEPA and International Resources Group also introduced methods to capture and use ventilation air methane (VAM) in anticipation of further work in China on this source of CMM emissions.

In a discussion that involved all participants, it was concluded that, barriers to implementation notwithstanding, interest in CBM/CMM development in China remains high, with continued growth in emissions reductions and project development. Although there could be future opportunities for VAM capture and use, many opportunities to recover drained gas still remain.

http://www.adb.org
http://www.coalinfo.net.cn
http://www.epa.gov/coalbed ■

CMOP Moves Offices

The Coalbed Methane Outreach Program moved offices effective October 6th. While our mailing address remains the same (our mail is routed through EPA's main mail room), our phone/fax numbers and delivery location have changed, as shown below:

Mail: Coalbed Methane Outreach Program
US Environmental Protection Agency
6202J
1200 Pennsylvania Ave., NW
Washington, DC 20460

Phone: 202-343-9484
Fax: 202-343-2208

Email: talkington.clark@epa.gov

Delivery: 1310 L Street, NW
Washington, DC 20005

Upcoming CBM/CMM Events

2003

Third International Methane and Nitrous Oxide Mitigation Conference, *November 17–21*

Coordinated by the China Coal Information Institute and held in Beijing, China, the conference will describe the mitigation activities of various Chinese and U.S. governmental entities, the Asian Development Bank, the United Nations Development Programme, and other organizations and will cover the agricultural, coal, landfill, and natural gas sectors. In addition, coal, landfill, and agricultural sector field trips are being offered.

Details: China Coal Information Network,
http://www.coalinfo.net.cn/coalbed/meeting/2203/2203e.htm

AJM's Coal Seam and Coal Mine Methane Development Conference, *December 3–4*

The conference, to be held in Brisbane, Australia, will address the current state of CBM and CMM in Australia.

Details: **http://www.ibcoz.com.au**

Third Applied Research Conference, *December 10–11*

Held at Ohio University in Athens, the first day of the conference will be dedicated to Coalbed Methane, a current topic of interest to coal producers as well as oil and gas producers in Ohio.

Details: **http://www.dnr.state.oh.us/mineral/arc/arc03overview.htm**

2004

2004 International Coalbed Methane Symposium, *May 3–7*

Hosted by the University of Alabama (Tuscaloosa, Alabama, USA) at its Bryant Conference Center, the symposium will address a range of topics relating to basic as well as innovative technologies for exploiting coalbed methane, tight gas sands and Devonian shales.

Details: **http://www.bama.ua.edu/~coalbed**

Tenth U.S./North American Mine Ventilation Symposium, *May 16–19*

Held by the University of Alaska Fairbanks (School of Mineral Engineering) and the Society for Mining, Metallurgy, and Exploration, Inc., in Fairbanks, Alaska, the symposium will bring together a range of experts involved in various aspects of and issues related to mine ventilation including ventilation technology and ventilation system design, gas and dust management, fire and explosion control, heat and humidity, and face ventilation.

Details: **http://www.faculty.uaf.edu/ffrg/vent**