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COALBED METHANE EXTRA

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Methane Recovery Opportunities at Abandoned Coal Mines in the U.S.

Coal mine methane (CMM) emissions are one of the major sources of anthropogenic methane emissions in the U.S., accounting for approximately 10 percent of total emissions. Current CMM emission estimates, however, only include emissions from active, or working, mines and do not account for methane vented from abandoned mines. The U.S. Environmental Protection Agency (US EPA) has recently completed an effort to quantify abandoned underground mine methane (AMM) emissions both to improve the accuracy of the CMM emissions inventory and to assess mitigation opportunities. According to these new estimates, AMM emissions increased total U.S. coal mine methane emissions by about 13 billion cubic feet (Bcf) in 2002, or about 5% of total U.S. CMM emissions.

As understanding of abandoned mines as an emissions source has improved, the recovery and utilization of methane from abandoned coal mines has increased dramatically in recent years. Currently, about twenty recovery projects are operating at abandoned mines in the U.S., accounting for about 2,600 mmcf of emissions reductions. AMM is an excellent source of fuel for power projects, since it can often be used directly in gas-fired engines without any pretreatment. The recovery of AMM is becoming attractive because it is not only a clean burning energy source, but produces environmental benefits by reducing the amount of methane that would otherwise be vented to the atmosphere.

This article summarizes the resource potential of abandoned mine methane in the U.S. It describes the key benefits and risks of recovery projects at abandoned mines, and focuses on several ways in which project developers can mitigate risk by gathering critical information about abandoned mine emissions and characteristics. Finally, this article describes three ongoing AMM recovery projects in the U.S.

Potential Methane Resources from U.S. Abandoned Mines

US EPA estimates that nearly 400 gassy underground coal mines have been abandoned in the U.S. since 1972. In addition, at least 100 suspected gassy mines closed earlier in the 20th century. Although methane emissions data was not compiled prior to 1971 for these older mines, their size, depth, and proximity to known gassy mines make them good candidates for methane recovery projects. These abandoned mines are scattered across eleven states, with the largest concentrations found in the Central and Northern Appalachian Basins, followed by the Illinois Basin.

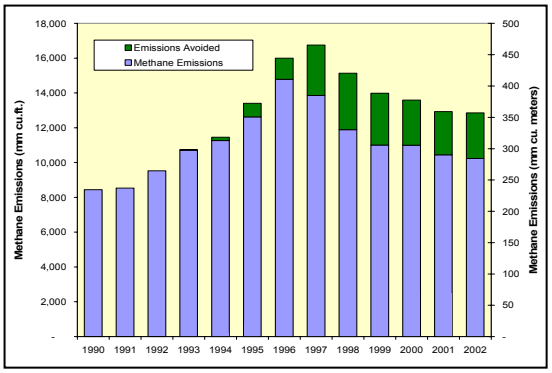

Figure 1: Abandoned Coal Mine Emissions in the U.S. from 1990-2002

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Methane Recovery Opportunities at Abandoned Coal Mines in the U.S. *(Continued From Page 1)*

As shown in **Figure 1**, estimated U.S. gross abandoned mine emissions range from 8.3 to 16.4 Bcf per annum between 1990 and 2002. Abandoned mine emissions varied as much as 2.5 Bcf from year to year. These fluctuations reflect both the number of mines closed during a given year and the magnitude of the emissions from those mines when active. Because of the large number of mine closures from 1994 to 1996 (76 mines closed during this three-year period), emissions peaked in 1996. Mine closures and abandoned mine emissions have declined or plateaued since 1996. The opportunities for AMM projects have not diminished, however, since only 20% of AMM (~2.6 Bcf) is currently being recovered.

Existing data on abandoned mine emissions over time are sparse. Therefore, to develop the abandoned mine emission inventory, US EPA developed conceptual models to predict the decline of abandoned mine emissions as a function of time, based on characteristics of several gassy U.S. coal basins. Emissions from abandoned mines peak when the mine is initially abandoned and decline relatively quickly as time passes (see **Figure 2**). Abandoned mine emissions are strongly dependent upon three key factors: the methane emissions of the mine while it was active, the time elapsed since the mine was abandoned (defined as the date when all active mine ventilation ceases), and coal permeability.

Abandoned Mine Methane Recovery in the U.S.

Methane recovered from abandoned mines may have several end-use options: gas pipeline sales, industrial use, and electric power generation. The feasibility of each of these options depends on the gas quality and quantity and other mine-specific market factors. For instance, recovered methane may require gas processing to remove carbon dioxide and nitrogen to meet gas pipeline requirements, while gas pretreatment may not be required for power projects. Power generation projects may be especially attractive at abandoned mines, where project developers can optimally site and configure the methane recovery project and are not required to integrate the project with the operations of a working mine.

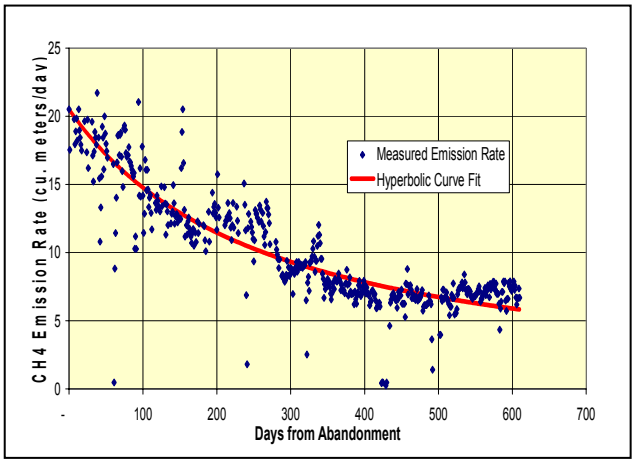

Figure 2 – Emission rate from gob well

Benefits Associated with Abandoned Mine Projects

Just as all coal mine methane recovery projects do, recovery of methane from abandoned mines provides greenhouse gas emission reductions. At the same time, abandoned mines represent a resource potential which may translate into significant economic benefits.

By its very nature, AMM differs in several respects from either active coal mine methane or conventional (virgin) coalbed methane resources. As a unique hydrocarbon resource, AMM provides several key benefits to project developers:

- Many abandoned coalmines contain accessible stocks of gas with high concentrations of methane.
- Wells needed to produce AMM are generally shallower, and therefore less expensive to drill, than most conventional gas wells.
- Individual AMM recovery wells have the ability to access large volumes of gas.
- The reservoir has already been delineated and documented.
- Documented historical methane emissions provide accurate indicators of reservoir productivity.

Risks Associated with Abandoned Mine Projects

AMM development does involve both “upstream” and “downstream” risks. Downstream risks include the often challenging negotiations with natural gas and electric power transmission companies. Market dynamics may change midway through a project, possibly resulting in a once-profitable project becoming uneconomic. In contrast, upstream risk is determined largely by the methane resource at the abandoned mine and the ability to economically produce the methane. A number of factors contribute to this upstream risk:

The mine may be partially or completely flooded, which will partially or completely shut off gas flowing into the mine.

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Methane Recovery Opportunities at Abandoned Coal Mines in the U.S. *(Continued From Page 2)*

- A well might drain a limited volume of gas due to roof collapse or in-mine seals.
- Air inflow from poorly sealed shafts or other undetected openings or fractures may dilute the methane.
- The recharge rate of methane from the remaining coal may limit the methane production rate from a well.
- "Dry holes" can occur if void areas or galleries are missed when drilling.

Successfully managing these risks can mean the difference between a successful and an unsuccessful project. A critical element of risk minimization is accurately characterizing the methane resource and other mine characteristics for a specific abandoned mine of interest.

Managing risks: Predicting emissions from specific abandoned mines

For project developers, it is especially important to develop an accurate estimate of future abandoned mine emissions. To forecast methane emissions at a given mine as a function of time elapsed since the mine was abandoned, basin-specific decline functions are used, in conjunction with mine-specific data.

Key mine-specific data for making these estimates – including the emission rate at the time of mine closure and the date of abandonment – are generally available for U.S. mines abandoned after 1972. However, a study by Mutmansky and Wang (2000) suggests that mine ventilation measurements may vary from the documented initial emission rate by as much as –10% to +30%. For mines closing before 1972, documented closure dates and emission rates are generally not available and must be estimated.

The project developer can use mine maps and production data to derive reliable estimates for other factors affecting methane liberation: the volume of the mine void, the amount of rock and coal produced, and the volume of coal in communication with the mine workings. Other parameters that must be estimated for each mine include:

- The coal's adsorption isotherm
- Methane flow capacity as expressed by permeability
- Pressure in the remaining coal at abandonment.

Emissions calculations for abandoned mines are much more sensitive to coal permeability values and the initial emission rate than to either initial pressure or adsorption isotherm values. To account for the variability in the highly sensitive parameters, the dimensionless decline curves used in US EPA's inventory calculations incorporate low, mid and high values for permeability and initial emission rate. For the less sensitive parameters (initial pressure and the average basin isotherm), the decline curves utilize only mid-case estimated values.

Managing Risks: Using Models to Characterize Abandoned Mines

In addition to predicting methane production from abandoned mines, models can provide a great deal of critical information to project developers that will help to mitigate the upstream project risk. Models ranging from the simple to the very complex can be used at various stages of project development.

Simple models can be used to select the best candidates from a large number of mines for further evaluation. They can provide a great deal of information depending on the quality of data available. Based on a conceptual mine configuration, these models use volumetric and material balance calculations. The basic data needed to construct a simple model include the following:

- The volume of the mine workings
- The amount of coal and rock produced from the mine workings
- An estimate of the volume of coal in communication with the mine workings through a flow conduit
- The adsorption isotherm of methane on the coal
- The gas pressure within the old workings
- The permeability of the coal
- The sorption time (related to diffusion rate)
- Time since abandonment

More complex models can be used to investigate the effects of geologic structure, the configuration of mine workings, and the extent of flooding on the amount of recoverable gas. Based on the actual configuration of the mine workings and the mine's geologic setting, these models are useful for a more detailed understanding of the current and future performance of wells drilled into a mine for AMM recovery. These models incorporate all of the data necessary for the simple model but also require mine maps and information on geologic structure and stratigraphy.

In addition, models may be used to integrate both geological and financial information. For instance, numerical mine models can simulate the flow of mine gas

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Methane Recovery Opportunities at Abandoned Coal Mines in the U.S. *(Continued From Page 3)*

in the mined-out void and the remaining coal in contact with the void. These models can minimize the financial and operational risk of CMM development through improved decision-making.

Operational AMM Recovery Projects in the U.S.

Currently in the U.S., there are approximately 20 abandoned mine methane projects recovering gas from over 30 coal mines. **Figure 1** shows the annual emissions reductions due to recovery projects. Below are three examples of ongoing abandoned mine methane recovery projects.

One of the longest-running AMM projects in the U.S. is Northwest Fuel Development's CMM power system built in 1994 at the Nelms #1 Mine in Ohio (photo courtesy of Northwest Fuel Development). It uses approximately 300

thousand cubic feet per day (mcfd) of coal bed gas with a 70% methane content to operate twelve internal combustion engines that together generate nearly 1MW of electricity. The project employs continuous pressure swing adsorption to upgrade the quality of the gas. In addition, 300-400 mcfd of methane is enriched and sold to a local pipeline. In August 2003, FuelCell Energy began participating in a demonstration project at the site with its patented carbonate fuel cell technology. FuelCell Energy is using a 250 kW lithium and potassium carbonate fuel cell to generate electricity, primarily from AMM. The demonstration project is expected to run for six months.

Grayson Hill Farms operates an innovative project, located in southern Illinois, that generates 1.7 MW of electricity using two rebuilt CAT 3512 model gensets. A portion of the electricity is used to run a greenhouse operation which grows tomatoes and cucumbers, while the remaining electricity is sold to a local utility. During the colder months, waste heat from the combustion units is used to heat water for the greenhouses' in-floor radiant heat system.

Another AMM project in southern Illinois that began operating in August 2003 uses the Engelhard molecular gate process to remove two common contaminants found in coal mine gas, nitrogen and carbon dioxide (photo courtesy of Engelhard). This process applies a pressure swing adsorption system which adsorbs the N_2 from the feed gas. Pore size optimization and adsorbent properties are also used to

remove CO_2. The abandoned coal mine project produces 700 mcfd of methane which is sold to a pipeline. Engelhard has plans to operate a second facility at an abandoned coal mine in southwestern Pennsylvania by early 2004.

Conclusions

The success of these AMM recovery projects suggests that U.S. abandoned mine methane projects are technically and financially viable projects. They should have a bright future, especially if natural gas prices remain favorable. As interest in methane recovery from abandoned coal mines grows, several other projects are under development in the U.S. With the increased cost-effectiveness of small-scale gas processing and electric power generation, project developers will continue to evaluate the potential of abandoned mines as a gas resource. Through modeling and testing, project developers can minimize risk and maximize project benefits.

U.S. CMM Update

West Elk Mine Uses CMM to Heat Mine Ventilation Air

West Elk Mine in Western Colorado, operated by Mountain Coal Company (a subsidiary of Arch Coal), is now using gob gas recovered from sealed areas through in-mine horizontal wells to heat mine ventilation air. The gas is collected underground and pumped to the surface with centrifugal blowers. The gas is then transferred approximately 1/2 mile to the heater facility by pipeline and distributed to four combustors using a 50 hp positive displacement blower for each combustor. Designed by Northwest Fuel Development (photo courtesy of Raven Ridge Resources), the combustors consume approximately 900 cfm (~1,037 mcfd of methane) of the ~5,100 cfm collected from the in-mine boreholes. The concentration of the gob gas is currently approximately 80% methane. Currently, the flares increase the temperature of the mine ventilation air at the bottom of the intake shaft by approximately 65 degrees Fahrenheit. This benefit allows for much more favorable working conditions in the mine, as well as a reduction in labor required to start cold equipment underground.

The project is scheduled to operate through the Spring of 2004, and resume again in the fall when cold temperatures return to the Rocky Mountains. Mountain Coal had no plans to design a mine air heating project using propane, diesel, or any other fuel, but initiated the project with the goal of reducing a portion of their methane emissions to the atmosphere. Mine management is also evaluating other opportunities for use of the recovered gas at the West Elk Mine.

U.S. EPA Welcomes New Administrator, Mike Leavitt

Michael O. Leavitt was sworn in as the 10th Administrator of the United States Environmental Protection Agency on November 6, 2003. Prior to leading the agency, Leavitt served as Utah's 14th governor and was a national leader on homeland security, welfare reform and environmental management.

Governor Leavitt led his state during the 2002 Olympic Winter Games, the most environmentally-sensitive games ever. Organizers achieved net zero air emissions, zero waste and full compliance with all safety and environmental regulations. One-hundred-thousand trees were planted as a lasting legacy of the environmental accomplishments.

Born February 11, 1951, in Cedar City, Utah, Governor Leavitt graduated with a bachelor's degree in economics and business from Southern Utah University. After earning his degree, he eventually became president and chief executive officer of a regional insurance firm, establishing it as one of the top insurance brokers in America. He is married to Jacalyn S. Leavitt; they are the parents of five children.

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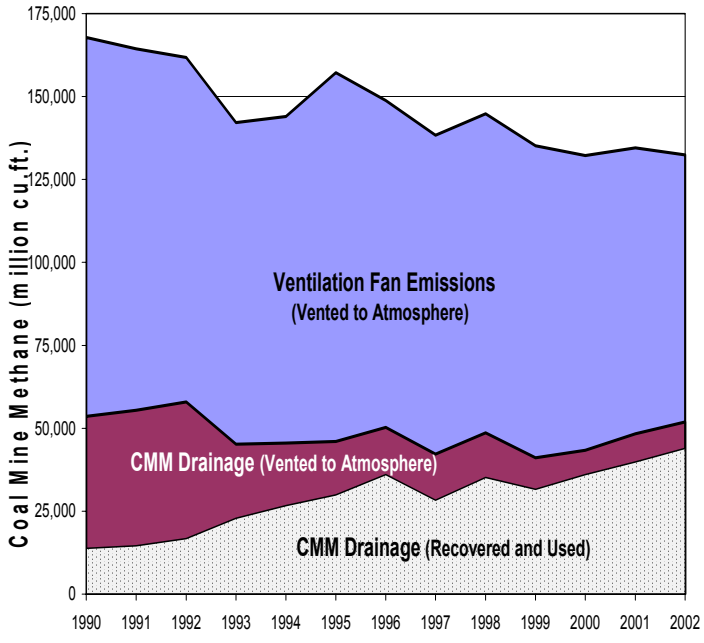
U.S. CMM Update continued

Summary of Recent Trends in U.S. CMM Recovery

The recovery of coal mine methane from active U.S. coal mines has been on the rise each year since 1999 with over 80% of the drained CMM being recovered and used. This increase in recovery has kept pace with a 26% increase in CMM drainage through various degasification efforts during the same time period (see graph). As a result, very little of the additional drainage gas from coal mines is being vented to the atmosphere. Ventilation fan emissions, on the other hand, have decreased by 17% since 1999. Consequently, net coal mine methane emissions have decreased by 16% between 1999 and 2002.

The opportunities for additional CMM recovery are great, as 80 Bcf of ventilation air methane (VAM) and 8 Bcf of drained gas were vented to the atmosphere in 2002 (draft *Inventory of U.S. Greenhouse Gas Emissions & Sinks: 1990-2002)*. New technologies for utilizing VAM are currently being investigated in the U.S. and Australia. Also, new technologies for treating medium-quality drained gas (gob gas) are being used at several abandoned coal mines in the U.S. The successful demonstration of these and other gas-use technologies will help CMM reach its full development potential in the near future in the U.S.



U.S. Coalbed Methane Production Increases 3%

The U.S. Energy Information Administration reports a 3% increase in U.S. coalbed methane production in the latest *Annual Report on U.S. Crude Oil, Natural Gas, and Natural Gas Liquids Reserves* In 2002, CBM production grew from 1,562 billion cubic feet (44.2 Bm3) to 1,614 Bcf (45.7 Bm3). Almost all of the growth remains in the Western US, although Alabama production grew by 6 Bcf. CBM Reserves grew to 18,491 Bcf (524 Bm3) from 17,531 Bcf (496 Bm3) in 2001. For more information, please visit http://www.eia.doe.gov/pub/oil_gas/natural_gas/data_publications/crude_oil_natural_gas_reserves/current/pdf/arr.pdf.

New CMOP Program Manager, Pamela Franklin

CMOP welcomes our new Program Manager, Pamela Franklin. Most recently, Pamela spent a year on Capitol Hill working as a Congressional Science Fellow, sponsored by the American Association for the Advancement of Science, as a legislative assistant in the office of Rep. Adam Schiff. Pamela earned a Ph.D. from the Energy and Resources Group at the University of California at Berkeley. Her research focused on combustion byproducts of gasoline oxygenates (such as MTBE and ethanol) and the use of scientific evidence in regulatory decision-making. Prior to graduate school, she spent several years working as an environmental consultant, working primarily on air quality emissions inventories, engineering evaluations, and regulatory support for industrial clients. Her background is in chemical engineering (B.S.E., Princeton University) and environmental engineering (M.S., Stanford University). In her free time, Pamela is an avid swimmer, runner, and hiker.

New Publications

Conference papers from The Australian Journal of Mining Coal Seam and Mine Methane Development Conference held December 3-4, 2003, Brisbane Australia. Purchase papers at: http://www.theajmonline.com

Proceedings from Third International Methane and Nitrous Oxide Mitigation Conference, held November 17-21, 2003, in Beijing, China. Available in hard-bound version for US$100 from the China Coal Information Institute. Contact Ms. Liu Xin at cbmc@public.bta.net.cn. Expected to be available electronically and on CD March 1, 2004. Visit www.epa.gov/coalbed for more information beginning March 1.

International Coal Mine Methane Updates

Chinese Government to Enhance Safety of Coal Mines

According to *China Daily*, the Chinese government plans on spending 2.2 billion Yuan (US$265 million) this year to enhance safety at the country's coal mines, an increase from 2 billion Yuan (US$240 million) last year. The focus of the fund will be the improvement of the methane drainage systems at the mines. Estimated China coal mining-related methane emissions range from 10 to 12 billion cubic meters annually. Of these emissions, 1.1 billion cubic meters is drained, accounting for a little over nine percent of total emissions.

The Chinese Government considers coalbed methane to be under-utilized and insufficiently recognized. Current legislation provides five-year income tax exemptions for projects that drain and use methane.

UNDP/GEF Project Update: "Russian Federation –Removing Barriers to Coal Mine Methane Recovery & Utilization"

In October of last year a workshop was held in Kemerovo, Russia, devoted to the launch of the UNDP/GEF-sponsored project "Removing Barriers to Coal Mine Methane Recovery & Utilization in the Russian Federation." The workshop was attended by representatives from the Ecological Department of Russian Federation Ministry of Energy, the Kemerovo Regional Administration, the UNDP office in Moscow, as well as many local coal mining industry representatives. Also in attendance were representatives of the Russian National Pollution Abatement Fund (NPAF) and Uglemetan.

The purpose of the workshop was to address the goals, objectives, structure, technical tools and financial arrangements of project implementation. Also, discussions were held regarding the potential for including the project in NPAF operating projects, as well as attraction of additional funds under the framework of Kyoto Protocol mechanisms.

Work scheduled for 2004 includes the formation and capitalization of Coal Mine Methane Recovery and Utilization Company (CMMRUC). In addition, 2004 plans call for final selection of the methane utilization technology, as well as mine site selection within the Kuznetsk Basin, located in Western Siberia.

Third International Methane and Nitrous Oxide Mitigation Conference

Nearly 300 participants from 29 countries attended the Third International Methane and Nitrous Oxide Mitigation Conference, held November 17-21, 2003, in Beijing, China. Jointly organized by the China Coal Information Institute and U.S. EPA, the conference was co-sponsored by numerous private and governmental organizations including the IEA Greenhouse Gas R&D Programme, the United National Development Programme, the Asian Development Bank, China National Coal Association, China Association of Urban Environmental Sanitation, China Academy of Agricultural Sciences, the US Department of Energy, the UK Department of Trade & Industry and the Commonwealth Scientific & Industrial Research Organization of Australia.

The conference featured detailed discussions on important sources of methane and nitrous oxide, including coal mining, landfills and sewage management, natural gas and oil systems, and agriculture.

During the coal mining source-specific technical sessions, 28 participants gave informative oral presentations. Another 10 coal mining papers were delivered through poster presentations. Presenters covered a range of topics, including global trends in CMM recovery, evolution of CMM markets, country-specific project updates, new technology developments, and methods of quantifying methane emissions. In addition, Mr. Fan Weitang, Chairman of the China National Coal Association, gave a very informative overview of China's coal mine methane industry in the opening plenary session.

An emerging theme at the conference in Beijing was the greater effort toward bilateral and multi-lateral cooperation among both governmental and not-for profit organizations. Numerous organizations exist to promote coalbed methane throughout the world. These organizations have significant technical and, in some cases, financial resources to encourage project development. By bringing together so many parties from the international community, the Beijing conference highlighted the possibilities for these organizations to work together to create additional opportunities for project development and greenhouse gas emission reductions.

Upcoming Events

GTI Coalbed Methane Reservoir Engineering Short Course
Morgantown, WV USA 23025 February 2004
West Virginia University
Tel: +1 (304) 293-7682
Fax: +1 (304) 293-5708
Shahab@wvu.edu

The Clearwater Conference: 29th International Technical Conference On Coal Utilization And Fuel Systems
Clearwater, FL, USA, 18-22 Apr 2004
Barbara Sakkestad, Coal Technology Association, 601 Suffield Drive, Gaithersburg, MD 20878, USA
Tel: +1 (301) 294 6080
Fax: +1 (301) 294 7480
Email: barbarasak@aol.com
Internet: www.coaltechnologies.com

2004 International Coalbed Methane Symposium
Tuscaloosa, AL, USA, 3-7 May 2004
Eddie Martin, 2004 International CBM Symposium, College of Continuing Studies, The University of Alabama, Box 870388, Tuscaloosa, AL, 35487-0388, USA
Tel: +1 (205) 348 7192
Fax: +1 (205) 348 9276
Email: emartin@ccs.ua.edu
Internet: www.bama.ua.edu/~coalbed

10th U.S. Mine Ventilation Symposium
Anchorage, Alaska, USA, 16-19 May 2004
Dr. Sukumar Bandopadhyay, School of Mineral Engineering, University of Alaska Fairbanks, PO Box 755800, Fairbanks, AK 99775, USA
Tel: +1 (907) 474 7730
Fax: +1 (907) 474 6994
Email: ffs0b@uaf.edu

GHGT-7: 7th International Conference On Greenhouse Gas Control Technologies
Vancouver, BC, Canada, 5-9 Sep 2004
Ted Morris, GHGT-7 conference Secretariat, Prairie Adaptation Research Collaborative, Suite 300, 6 Research Drive, Regina, SK S4S 7J7, Canada
Tel: +1 (306) 337 2290
Fax: +1 (306) 337 2301
Email: Ted.Morris@uregina.ca

21st Annual International Pittsburgh Coal Conference
Osaka, Japan, 13-17 Sep 2004
University of Pittsburgh, School of Engineering, Dominion Center for Environment and Energy
1249 Benedum Hall, Pittsburgh, PA 15261, USA
Tel: +1 (412) 624 7440
Fax: +1 (412) 624 1480
Email: pcc@engr.pitt.edu
Internet: www.engr.pitt.edu/pcc

Strategic Research Institute 5th Annual Coalbed & Coal Mine Methane Conference
Denver, Colorado, May 24 - 25, 2004
Location to be announced
For more information contact Christine Tse at
+1 (212) 967-0095, ex. 256, or
Email: ctse@srinstitute.com
Internet: www.srinstitute.com

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