

Sino-U.S. New Energy Sci-Tech Forum
and Conference on Coalmine Methane Recovery and Utilization
Jincheng, Shanxi Province, China
February 24-27, 2009

Summary Report

Introduction. On February 24-27, 2009, a group of 25 international experts met in Jincheng, China, at the invitation of the Municipal Government of Jincheng and the Shanxi Foreign Affairs Office with local officials and enterprise managers to discuss development of the city's coalmine and coalbed methane resources. The experts group was organized by the Jackson Hole Center for Global Affairs (JHCGA), based in Jackson Hole, Wyoming. The visit was organized with funding provided by a grant from the U.S. Environmental Protection Agency (EPA) (cooperative agreement XA-83396201).

The purpose of the February 24-27 meeting was to share information and experience relating to future cooperation in the areas of recovery and utilization of coalmine methane (CMM). CMM is a combustible gas which must be extracted for safety reasons from coal mines prior to and during mining operations. As an alternative to simply releasing it into the atmosphere, where it has over 20 times the heat-trapping capacity of carbon dioxide, it can be deployed as a clean-burning fuel source equivalent in chemical composition and energy content to conventional natural gas.

Wang Maoshe, Mayor of Jincheng, and Jia Xuefeng, Deputy Director-General of the Shanxi Foreign Affairs Office, served as co-hosts on the Chinese side. The group also met with Jincheng Party Secretary Zhang Maocai. Jack Wen, President of GE/Energy (China region), co-chaired the discussions on behalf of the group of experts. David Wendt, President of JHCGA, assembled the group as director of the JHCGA project and wrote this report. Pamela Franklin represented EPA as Director of EPA's Coalbed Methane Outreach Program and U.S. Co-Chair of the Coal Subcommittee of the Methane to Markets Partnership. Other experts in the group are listed in Appendix B.

Other senior Jincheng government officials participating in the discussions included Vice Mayors Guo Changqing and Wang Shuxin; Li Guoji, Director, Jincheng Municipal Development and Reform Commission; Li Chengtai, Director, Jincheng Environmental Protection Bureau; Wang Renqing, Director, Jincheng Science and Technology Bureau; and Zhao Wanchou, Director, Jincheng Coal Industry Bureau. Mr. He Tiancai made a presentation behalf of the Jincheng Coal Mining Group (JCMG), of which he serves as Chief Engineer.

Worldwide development of CMM. The experts' presentations covered a range of issues having to do with the planning, design, implementation, and financing of CMM recovery and utilization projects. Pamela Franklin of the U.S. Environmental Protection Agency explained the Methane-to-Markets Partnership, a global methane emissions reduction effort which brings together public and private sector partners in 28 countries with the aim of achieving annual reductions of 180 million metric tons of carbon dioxide

equivalent by the year 2015. These reductions will be achieved in four sectors – coal mining, oil and gas systems, landfills, and agriculture – through technical assistance programs (e.g., support for project development through feasibility and pre-feasibility studies), training and capacity-building, and other activities.

Jim Marshall of Raven Ridge Resources reviewed trends in CMM recovery and utilization in the U.S. Based on the 2007 US emissions inventory:

- 1) Total methane emissions from U.S. coal mines amount to 4.4 billion cubic meters (62.2 MMTCO₂E*).
- 2) About 24 active underground US mines have drainage systems to remove the methane in advance, during, or after mining. About 14 of these mines recover and use some of their drained gas (mostly for natural gas pipelines), resulting in a **total of 900 million cubic meters of methane emissions avoided (12.9 MMTCO₂e)**. The portion of drained gas recovered and used represents about 87% of all drained gas. Methane emitted from drainage systems (e.g., methane that was not captured and used) totaled about 130 million cubic meters (1.9 MMTCO₂e).
- 3) Underground mine ventilation systems emitted about 2.3 billion cubic meters (32.5 MMTCO₂e). One demonstration project has recently been installed at an active underground coal mine, but no emissions reductions have yet been reported from mine ventilation systems.
- 4) There are thousands of abandoned mines in the US; EPA has developed a database of some 400 abandoned mines that are considered “gassy” and potentially viable projects. The estimated national emissions from all abandoned mines is about 400 million cubic meters annually (5.7 MMTCO₂e). EPA estimates that there are about 20 different projects that capture and utilize methane from abandoned mines (often pooling several different mines into a single project). These abandoned mine projects recover and utilize about 220 million cubic meters of methane, or 3.2 MMTCO₂e of emissions avoided.
- 5) 22% of total U.S. methane emissions are produced from surface mines. Currently, there is only one project known to be recovering and utilizing methane from pre-mine drainage at a US surface mine, but details about the amount of methane emissions avoided from this project are unavailable at this time.

Ron Collings of Ruby Canyon Engineering shared his company’s experience in estimating methane reserves and designing drainage operations at a series of 11 abandoned mines in the state of Illinois, with an average mined coal seam thickness of 2.5 meters. Utilizing a Computational Fluid Dynamics simulation model, total reserves in the 11 mines have been estimated at 429 million cubic meters. The drainage strategy

*MMTCO₂E stands for million metric tons of carbon dioxide *equivalent* (1 ton of methane = same heat-trapping capacity as 21 tons of carbon dioxide)

was designed to take into account the following performance risks: flooding in the mines, low pressure through leakage in seals and historical venting; roof collapse and drilling into pillars; and air inflow, compromising gas quality.

Gas extraction rates (74% methane) at project inception in October 2002 reached 384,800 cubic meters/day, for total cumulative drainage for the 5-year period through September 2007 (exclusive of 1-year period April 2004-May 2005, when operations were idle) of 232 million cubic meters. *Lessons learned* from this experience include the following: 1) need for adequate resource evaluation to avoid over-sizing of facilities; 2) need for continuous monitoring of production volumes, wellhead pressures, and gas composition to refine model for reserves analysis; and 3) need to take into account performance risks based on flooding and/or compartmentalization.

Dustin Bleizeffer of the Casper Star-Tribune explained the evolution of the CBM industry in Wyoming, the U.S.'s largest coal-producing state with 462.4 million tons of production in 2008. The first CBM wells were introduced in the 1970s in Wyoming's Powder River Basin – its largest coal mining area – as a means of releasing water from coal seams in advance of surface mining operations, not to recover methane. The methane was simply released into the atmosphere. CBM drilling for methane recovery began in earnest in the late 1990s, and CBM production grew rapidly to 30,000 CBM wells in 2008, with total cumulative production of 82 billion cubic meters. Water discharge remains an issue.

Recovery and utilization of CMM in Jincheng and China. Jincheng leads China in the development of coalmine methane resources, with total extracted volume in 2008 of 1.65 billion cubic meters. This leadership is especially pronounced in the area of surface wells. Of total surface well drainage capacity of 2.2 million cubic meters, 650 million cubic meters was actually drained in 2008. A total of 2621 surface wells have been drilled, more than half of which (1453, including two horizontal wells) have been drilled by the Jincheng Coal Mining Group (JCMG).

Working in cooperation with Qinshui Blue Flame Methane Ltd. and universities and other research organizations throughout China, JCMG has acquired intellectual property rights to a range of surface drilling technologies, including an innovative fracturing system, a software system for CBM digital management, and other systems especially suitable to drainage of Jincheng's abundant reserves of anthracite coal. These technologies enabled JCMG to extract 376 million cubic meters of methane from its surface wells in 2008.

As explained by He Tiancai, Chief Engineer at JCMG, two principles have guided JCMG's approach to CMM recovery in Jincheng. The first is the principle of integrated coal mining and gas recovery, referring to three aspects: 1) optimal *sequencing* of gas recovery operations prior to, during, and after mining operations; 2) optimal *spacial allocation* of surface wells with respect to planned mining operations; and 3) *multiple functionality* of wells with respect to estimation of resources as well as amounts extracted before, during, and after mining.

Criteria guiding surface well development include maximization of advance drainage time and equal distribution of gas drained from seams, so as to avoid leaving high concentrations in any one area. Other safety factors taken into account include avoidance of underground mining roadway and shaft chamber, maximization of draining from working face; and other aspects of multiple functionality.

The other principle guiding JCMG's approach to CMM recovery has been the principle of "three-phase gas treatment." This principle applies as follows: 1) for areas of concentration greater than 16 cubic meters per ton of coal, pre-drainage operations to be undertaken 5-8 years in advance; 2) for areas of concentration of 8-16 cubic meters per ton of coal, pre-drainage operations to be undertaken 3-5 years in advance; and 3) for areas of concentration below 8 cubic meters per ton of coal, construction of roadways not less than 30 meters from the area being mined, and advance layout of roadways for succeeding areas.

Jincheng also leads China in the utilization of coalmine methane, with a utilization rate in 2008 of 60% of drained methane. Again, JCMG has led the way with combined CBM/CMM utilization in 2008 of 317 million cubic meters, accounting for 20% of China's total utilization. City officials including Mayor Wang explained how the municipality had achieved significant reductions of methane emissions from coalmines through high rates of CMM utilization in various areas. These included 40% for residential use (80,000 households), 30% for transportation (5 filling stations and 2,000 vehicles), 20% for power generation (200 MW, including world's largest CMM-fired power at 120 MW), and 10% for industrial use. Distribution capabilities include 950,000 cubic meters liquefaction capacity per day and a total of 6 pipelines, including two completed, two under construction, and two more planned.

For China as a whole, Dr. Huang Shengchu of the China Coal Information Institute and Dr. Hu Yuhong of the State Administration of Work Safety explained that in 2007, 1.45 billion cubic meters were utilized of a total extracted amount of 4.7 billion cubic meters; in 2008, the utilized amount was 1.72 billion cubic meters of a total extracted amount of 5.67 billion cubic meters. In both cases, these utilization rates met the target of 30% set by the national government in the 11th 5-year plan. However, 50-60% of total CMM extracted in 2007 was of less than 30% concentration, the threshold for mandatory use under current central Chinese government policy. Mr. Huang explained current efforts to revise this policy, and stated his view that the threshold for utilization could be reduced all the way to 20% concentration without incurring increased safety risks.

More broadly, it is estimated that ventilation air methane (VAM) of less than 1% concentration accounted in 2007 for 65-75% of total CMM emitted that year from coal mines in China, or 182-210 MMTCO₂E of the total 280 MMTCO₂E emitted, using Dr. Huang's figures. As pointed out by Richard Mattus, Managing Director of MEGTEC, in the presentation of his company's VAM oxidation technology, annual VAM emissions from just one average size coal mine produce 50,000 tons of methane per year, or 1

MMTCO₂E. This equals the amount of carbon dioxide emitted annually from one mid-size (300 MW) coal-fired power plant.

Constraints in financing and price structure affecting CMM development. The other constraint standing in the way of more effective utilization of VAM, as explained by both David Creedy of Sindicatum Carbon Capital and Cliff Mallett of Carbon Energy, is that even with price subsidies it is not capable of generating as much revenue as more concentrated CMM. The problem, as explained by both Mr. Mallett and Mr. Mattus, is not the technology, of which there are several which have been successfully demonstrated. It is the lack of a process for adequately valuing VAM through the Clean Development Mechanism (CDM) of the Kyoto process.

More specifically, as pointed out by Mr. Creedy, the current system of carbon financing is constrained by a number of factors which render investments in otherwise marginal economic projects problematical. These constraints include the uncertainties of CDM in a post-Kyoto world, the recent collapse in the price of Certified Emissions Reductions (CER) credits, the increasing complexity of the CDM process (including strengthening of the rules of additionality), and the lack of a methodology to calculate credits for either abandoned mine methane (AMM) or use of CBM for synthesis of dimethyl ether (DME). As long as these constraints in the system of carbon financing persist, it is unlikely under current conditions of worldwide capital scarcity that investors will be attracted to anything but the “best, least risky” projects.

Indeed, as explained by Mr. He of JCMG, even utilization of CMM at more concentrated levels for power production is currently only a break-even proposition for JCGM, notwithstanding the fact that subsidies for CMM are now partially in place and that JCMG can use its own CMM without having to purchase it from another supplier. As for pure CBM, it must compete with conventional natural gas sold at government-controlled price levels, and can therefore be utilized for power production and other purposes only for “reasons other than profit,” such as substitution for coal. Clearly, major revisions in the price structure will be needed to correct these market distortions and place development of VAM, CMM, and CBM on a more sustainable economic basis.

Merlita Pajarillo of the Asian Development Bank (ADB) discussed loans for CMM/CBM projects provided by ADB to China. These included the \$117 two-phase loan provided to Jincheng for CMM-fired power production (120 MW Sihe Mine Plant) and CMM transmission and distribution infrastructure. Social and environmental benefits included increased coal mine safety, coal substitution (291,000 tons/year for 1st phase, 138,000 tons/year for 2nd stage), and methane emissions reduction (3 million metric tons of carbon dioxide equivalent for 1st phase, and 2.5 million metric tons of carbon dioxide equivalent for 2nd phase). ADB also provided a \$102 million infrastructure loan for CMM recovery, storage, and distribution in three cities elsewhere in Shanxi province. Ms. Pajarillo reviewed the portfolio of carbon financing mechanisms provided by ADB, including funds providing upfront financing for project construction as well as funding on a pay-on-delivery basis.

New technologies. One promising opportunity identified by Mr. Creedy and Dr. Hua Guo of the Commonwealth Scientific and Industrial Research Organization (CSIRO) was the availability of new technologies for maximizing methane content in drained gas. In CSIRO's case, this is done through the use of a computational model to gauge gas concentrations under various conditions, locations, stages of the mining process. The model calculates goaf gas flow behind the face as the face advances, and takes into account such factors as oxygen ingress into the longwall goaf and decreases in concentrations resulting from even small seal leakages. The strategy for drainage is then designed to correct for these factors, resulting in an increase in methane concentrations from 30 percent to 40 to 50 percent.

Options for processing ventilation air methane (VAM) of 1% or lower concentrations include mitigation/abatement and utilization for production of thermal energy or electric power. Richard Mattus of MEGTEC explained how his company's VOCSIDIZER technology utilizes a thermal oxidation process which can produce all three outcomes. One of these units was first installed in China in Zhengzhou in 2008. Cliff Mallett of Carbon Energy explained a range of other combustion processes, including catalytic oxidation, through which the energy content of VAM can be captured. All of these options need to be adapted to the particular characteristics of the mine site and integrated with the development of the site so as to be co-located with the ventilation air shaft. Most of them, as explained previously, are in the demonstration stage and cannot be commercialized without changes in the economics of energy pricing and carbon financing.

Professor Yang Kejian of the Beijing Guoneng Energy Technology Company explained his company's cryogenic separation technology for the purification and liquefaction of coal methane. As explained by Prof. Yang, this process takes advantage of the differential temperatures at which oxygen, nitrogen, and methane become liquid to first remove the former two ingredients and then liquefy the remaining methane at very high levels of concentration. According to Prof. Yang's economic analysis, the higher sales price commanded by the resulting product yields a profit of some 40%, in comparison with the near-zero profitability of other processes for coalmine methane utilization (e.g., power production), as discussed above.

Jason Liu and Joe Zhou reviewed CBM/CMM power generation capabilities of GE and Caterpillar, respectively. Mr. Liu summarized some of the cost advantages provided by GE's CMM gensets, manufactured by Jenbacher, as a result of their superior power density (the size of the units vs. their power generating capacity) and the fact that they are designed to operate without gas holders; the latter feature also confers a safety advantage. Mr. Zhou called attention to the three power plants utilizing Caterpillar gensets already installed in Jincheng, including not only the Sihe Mine Power plant @ 120 MW (60x1.8 MW gensets plus 12 MW cogen), but also the Chengzhuang Mine @ 10x1.8 MW and the Meiganshi Power Plant @ 12x1.8 MW. These units supply most of Jincheng's currently installed capacity of 200 MW generated from CMM/CBM.

Conclusions and next steps. Priorities for cooperation identified in summary discussions included drainage of methane from subsided coal seams (e.g., abandoned coal mines) and technologies for purification and liquefaction of methane drained from mines. With regard to the former, He Hui, Director of JCMG's CBM Industry Development Bureau explored with Ron Collings the possibility of a visit to abandoned coal mine sites in the U.S. to learn more about these technologies. Mr. Collings responded enthusiastically to this idea and indicated preliminary information needed to select an appropriate site (e.g., nature of the subsided areas to be explored, how these were related to mining activities already underway, and size of the longwall panels under which subsidence is taking place).

In both the presentations and summary discussion, representatives of the Municipal Development and Reform Commission indicated considerable interest in the purification and liquefaction technologies explained by Mr. Yang and others. Dr. Franklin referenced the EPA document, *Methane Technologies for Mitigation and Utilization* (http://www.methanetomarkets.org/resources/coalmines/docs/cmm_tech_database.pdf), which explains the cryogenic process, and Han Jiaye of the China Coalbed Methane Clearinghouse mentioned in particular the company BCCK, referenced in that document. JHCGA will enlist the cooperation of EPA, Raven Ridge Resources, and the China Coalbed Methane Clearinghouse in helping to bring BCCK, Beijing Guoneng Energy Technology Company (Dr. Yang's company) and other companies to Jincheng to explain more about their technologies in this area.

The ultimate aim of both of these activities will be to facilitate efforts to supply methane to rural areas to replace coal as a fuel for home heating and cooking. Both efforts will be brought together within a single framework by the Municipality of Jincheng to support this goal. In addition, it is anticipated that EPA will extend an invitation to Mayor Wang Maoshe to visit the U.S. later in 2009, at which time he will gather further information to support this and other joint efforts. JHCGA will serve as host for this visit.

The meeting concluded with signature of the "Jincheng Declaration," pledging the commitment of both sides to the principles of resource conservation and emissions reductions. The Declaration was signed by Mayor Wang Maoshe on behalf of the Municipality of Jincheng and by Deputy Director-General Jia Xuefeng on behalf of the Shanxi Foreign Affairs Office; signatories on the U.S. side included David Wendt on behalf of JHCGA and Jack Wen on behalf of GE. The Declaration will serve as a platform from which the partners can project leadership in future joint clean energy efforts, including the efforts outlined above.

Appendix A: Follow-up meeting with Shanxi Vice Governor Niu Renliang in Taiyuan. In a subsequent discussion in Taiyuan, the provincial capital of Shanxi, Vice Governor Niu Renliang emphasized his interest in the issue of methane drainage from abandoned coal mines. He asked a number of questions in this area, including the amount of methane drained from abandoned coal mines in the U.S. (roughly 100 million

cubic meters, according to the above presentation by Jim Marshall of Raven Ridge Resources) and the profitability of drainage operations. **He specifically requested further information on the latter point with reference not only to the U.S., but also to Russia and the European Union.**

Vice Gov. Niu expressed his strong and continued support on behalf of the Shanxi Provincial Government for JHCGA's and EPA's CMM initiative with Jincheng. **He went further to suggest that this initiative be elevated to the level of the Provincial Development and Reform Commission, over which he has supervision.** He noted in this regard that the Provincial Development and Reform Commission is currently formulating new policies relating to coalmine methane utilization and recovery, and that the work of our U.S.-Jincheng initiative could provide valuable guidance in this regard.

Vice Gov. Niu also expressed his continued interest in common interests shared between Shanxi province and Wyoming, as the two largest coal-producers in their respective countries. I updated him on recent production figures in our state (462 million tons of coal in 2008) and on recent steps taken by the state legislature to establish a policy and regulatory framework for carbon sequestration. I mentioned also the fact that we had brought with us to Jincheng the chief energy correspondent of Wyoming's largest newspaper, and that his articles would help to drive home to people in Wyoming the enormous challenges China faces in cleaning up its coal production and consumption, as well as its progress in meeting these challenges.

Vice Gov Niu, an academic economist by training, inquired as to the current economic crisis in the U.S. I went over the Obama Administration's recent initiatives in fiscal policy, including the emphasis in the recently proposed 10-year budget on clean energy, health, and education. Jokingly, I leaned over and stressed that the success of this package would depend upon our continued ability to borrow the money from China. Vice Gov. Niu assured me that this would continue to be the case, not only for reasons of U.S.-China friendship, but also because of the inevitable interdependence of the two economies (the U.S. on China in the area of finance and China on the U.S. in the area of technology).

I took the liberty in this regard of sharing with him my recent policy paper, *Clean Coal: U.S.-China Cooperation in Energy Security*, published (in English and Chinese) by the East-West Institute and the China Institute of International Relations. The policy paper makes the same point that the future of clean coal development in both China and the U.S. hinges on the possibility of future U.S.-China cooperation in this area.

Appendix B: Experts Participating in February 24-27 meeting in Jincheng

Jack Wen, President, GE/Energy (China Region) – U.S. Co-chair
David Wendt, President, JHCGA – project director
Pamela Franklin, Coalbed Methane Outreach Program Manager, U.S. Environmental Protection Agency

Dustin Bleizeffer, Chief Energy Correspondent, Casper Star-Tribune
Ronald C. Collings, President, Senior Engineer, Ruby Canyon Engineering

David Creedy, CMM Director, Sindicatum Carbon Capital
Han Jiaye, Engineer, China Coalbed Methane Clearinghouse
Hu Yuhong, Deputy Director-General, State Administration of Work Safety, China National Coal Association
Hua Guo, Research Leader, Sustainable Mining Systems, CSIRO
Huang Lan, Associate Researcher, China Coal Information Institute, China Coalbed Methane Clearinghouse
Huang Shengchu, President, China Coal Information Institute
Liu Weiguo, Sales Manager, GE Jensbacher (China)
Molly Loomis, Middlebury College
Lu Tao, Ruby Canyon Engineering
Cliff Mallett, Executive General Manager, Carbon Energy
Jim Marshall, Executive Vice President, Raven Ridge Resources
Richard Mattus, Managing Director, Megtec Systems
Olivia Meigs, Director of Communications, JHCGA
Merlita Pajarillo, Energy Specialist (Finance), Asian Development Bank
Luke Pryor, Staff Accountant, First Data, Inc.
Zoey Wang, Market Development Consultant, Caterpillar
Martin Weil, Raven Ridge
Jeremy Wendt, Data Services Associate, Prima Capital
Yang Kejian, President, Beijing Guoneng Energy Technology Co.
Joe Zhou, Gas Consultant, Caterpillar
Steve X. Zou, President, Asian American Gas, Inc.