

# **COAL MINE METHANE DEVELOPMENT PROJECT** The First Large-Scale Capture and Use of Coal Mine Methane for Power Generation in Asia

Sihe Methane Power Generation Plant

- The expansion of coal production and consumption in the People's Republic of China (PRC), fueled by fast-paced economic growth, has increased environmental, health, and safety hazards at coal mines.
- Coal mines emit 6 billion cubic meters of methane per year, causing widespread pollution and acid rain in about a third of the country. In 2002, more than 6,000 miners died in methane-related explosions.
- In 2004, the Asian Development Bank and the PRC established the Coal Mine Methane Development Project to develop new technologies that will demonstrate efficient and effective coal mine methane capture, production, and utilization in power generation and also improve the environment.
- When completed in 2010, the project had significantly contributed to reduced mine-related deaths, improved local air quality and living conditions, and reduced greenhouse gas emissions, while providing reliable energy supply to thousands of households.

## CONTEXT

he People's Republic of China (PRC) is the world's largest producer and consumer of coal. Rapid economic growth and an increasing demand for energy has expanded annual coal production, from about 1.3 billion tons in 2002 to 1.7 billion tons in 2003 (22%).<sup>1</sup> Coal fuels about 64% of the PRC's primary commercial energy and generates 75% of all electricity.

As household incomes rise and economic growth continues, so do energy demand and coal production and consumption. Projections suggest that coal consumption will increase to 4.8 billion tons per year by 2020.<sup>2</sup> However, the PRC can no longer use its usual coal production practices because many of its small- and large-scale mines were reaching the end of their lifetime in the early 2000s. In addition, connecting new mining sites to consumers would require new transport infrastructure.

Coal mining is very dangerous because it releases methane, a highly explosive gas produced during coal formation. When coal is mined, methane is released from the coal seams and the surrounding disturbed rock strata.<sup>3</sup> Workers must drain the methane to maintain safe working conditions and avoid explosions. In the early 2000s, as many as 7,000 miners in the PRC died every year in underground accidents, mainly due to methane explosions. By 2013, tightened safety standards reduced the number of deaths to 1,049 (footnote 1).

### **PROJECT SNAPSHOT**

LOAN APPROVAL DATE: December 2004

LOAN AMOUNT:

\$117.4 million

BORROWER: People's Republic of China

**EXECUTING AGENCY:** 

Shanxi Provincial Government

GEOGRAPHICAL LOCATION: Jincheng, Shanxi

TYPE OF ENERGY PROJECT: Conventional energy generation

PROJECT COMPLETION DATE: 2011

Methane is also lethal to the environment because it effectively absorbs and traps heat in the atmosphere. Every year, PRC coal mines release more than 6 billion cubic meters ( $m^3$ ) of methane, which is 21 times more potent than carbon dioxide ( $CO_2$ ). Methane contributes to global warming and accounts for 20% of the enhanced greenhouse effect.<sup>4</sup> Coal bed methane (CBM) and coal mine methane (CMM) need to be captured in the PRC's mining sites so that instead of becoming an environmental and health hazard, they can be used to generate power. However, the technologies for capturing methane were new in the 2000s and not used in the PRC.

<sup>&</sup>lt;sup>1</sup> Asian Development Bank. 2004. Report and Recommendation of the President to the Board of Directors: Proposed Loan to the People's Republic of China for the Coal Mine Methane Development Project. Manila.

<sup>&</sup>lt;sup>2</sup> The PRC is working to reduce coal in its overall energy mix and has vowed to cap total production capacity at 4.1 billion tons per year by 2015. However, analysts expect total annual production capacity to exceed that level.

<sup>&</sup>lt;sup>3</sup> World Coal Association. Coal. http://www.worldcoal.org/coal/ (accessed 19 December 2014).

<sup>&</sup>lt;sup>4</sup> Environmental Defense Fund. Methane: The Other Important Greenhouse Gas. http://www.edf.org/climate/methane (accessed 19 December 2014).

The Asian Development Bank (ADB) assisted the PRC in exploring possible approaches to cleaner and more efficient coal mining as early as 1996. From 1996 to 2002, ADB provided two technical assistance packages to study the feasibility of a demonstration project to introduce new methane-capture technologies. ADB initiated the Coal Mine Methane Development Project (CMMDP) in 2004. CMMDP curbed methane emissions and helped ensure mine safety, improved the local environment, and helped close the projected energy deficit with new technologies that effectively and efficiently captured methane from coal mining operations and transformed it into energy for power generation.

### SOLUTIONS

**Selecting a pilot site.** ADB's technical assistance packages helped the PRC explore possible sites for demonstration projects. The PRC eventually selected the coal mining area around Jincheng municipality in the PRC's Shanxi province as a pilot site, focusing particularly on the Sihe mine in Jincheng, which is owned and operated by the Jincheng Anthracite Mining Group. The Sihe mine has an estimated coal reserve of 3.5 billion tons, producing about 435,000 m<sup>3</sup> of CMM per day and releasing about 304,000 m<sup>3</sup> into the atmosphere (footnote 1).

The pilot site was identified as a good project demonstration area because Shanxi was among the most polluted and largest coal-producing provinces in 2002. The population of Jincheng municipality, in southern Shanxi, was 2.11 million people, including about 221,500 rural and 97,000 urban poor. The municipality used about 850,000 tons of coal per year; annual emissions of sulfur dioxide (SO<sub>2</sub>) and particulate matter totaled about 120,000 tons. In 2001, the municipality qualified for Class II<sup>5</sup> designation for ambient air quality for only 28 days.

**Efficient and effective drainage of coal bed and coal mine methane.** Methane drainage captures gas and prevents it from entering a mine's airways.<sup>6</sup> To capture CMM at the pilot site, CMMDP used 1,000-meter drilling rigs for advanced directional drilling of long inseam boreholes in the underground coal mine, extending the reach of the gas drainage. Next, workers drilled 1,620 kilometers (km) into the underground coal seams and installed a corresponding length of drainage pipes. To prevent air from entering the drainage system and leaking into the mine, workers used high-density polyethylene (piping with fused seals).<sup>7</sup> This type of pipe is more expensive, but it is safer. The underground infrastructure of gas pipelines yielded a drained CMM recovery rate of 80%, a 100% increase in drainage efficiency over the preproject level.<sup>8</sup>

Drainage systems capture CBM through a series of vertical or horizontal wells drilled directly into the coal seam. Water is first drawn out from the coal seam to reduce pressure and release the methane from its adsorbed state on coal and rock surfaces. Once pressure has been reduced, the released methane can escape more easily to the surface through the wells (footnote 3). Initially, CMMDP planned to build 20 vertical wells and 1 horizontal well. Despite geological and technical challenges it ultimately constructed 100 vertical wells and 80 horizontal wells,

<sup>&</sup>lt;sup>5</sup> Class II standard includes residential mixed-use areas and sets emission limits for SO<sub>2</sub>, particulate matter less than 10 microns (PM<sub>10</sub>), and nitrogen dioxide (NO<sub>2</sub>).

<sup>&</sup>lt;sup>6</sup> United Nations. 2010. Best Practice Guidance for Effective Methane Drainage and Use in Coal Mines. ECE Energy Series No. 31. New York and Geneva. http://www.unece.org/fileadmin/DAM/energy/se/pdfs/cmm/pub/BestPractGuide\_MethDrain\_es31.pdf

<sup>&</sup>lt;sup>7</sup> World Bank. 2004. Jincheng Clean Development Mechanism Project Design Document Form. https://wbcarbonfinance.org/Router .cfm?Page=Projport&ProjID=9603

<sup>&</sup>lt;sup>8</sup> ADB. 2012. Completion Report: Coal Mine Methane Development Project in the People's Republic of China. Manila.



thereby significantly increasing output. CBM from the 100 vertical wells reached 200,000 m<sup>3</sup> per day, with a gas concentration of 99%.

**Building a Clean Development Mechanism-registered power plant.** In 2008, CMMDP completed construction of a methane-fired power plant on the border of Qinzhuang village, Jiafeng, Shanxi. This 120-megawatt (MW) plant processes about 182.4 million m<sup>3</sup> of CMM and CBM from the Sihe mine per year using internal combustion gas engines (1.5–3.5 MW per engine), waste heat boilers, and steam turbines to convert methane into energy. Based on a meticulous and conservative assessment of expected methane production at the Sihe mine, the plant design is flexible enough to accommodate any variation in methane supply. If the Sihe mine cannot produce enough methane, mines within a few kilometers can supply additional methane to close the deficit.

Registration under the Clean Development Mechanism (CDM) of the Kyoto Protocol (April 2009) (footnote 8) allowed the plant to earn saleable certified emission reduction (CER) credits, each equivalent to 1 ton of  $CO_2$ .<sup>9</sup> From April 2009 to the third quarter 2011, verified emission reductions totaled 9.06 million tons of  $CO_2$  equivalent (CO<sub>2</sub>e). When the PRC signed the first ever greenhouse gas emission reductions purchase agreement

<sup>&</sup>lt;sup>9</sup> United Nations Framework Convention on Climate Change. Clean Development Mechanism. http://unfccc.int/kyoto\_protocol/

mechanisms/clean\_development\_mechanism/items/2718.php (accessed 20 December 2014).

for a coal mine methane project,<sup>10</sup> estimated CDM revenues of \$100 million offset about three-fourths of the total power plant cost of \$132 million (footnote 8).

**Connecting the power plant to the power grid.** The power plant was connected to the Shanxi power grid in March 2008. After trial runs, the power plant and its connection to the power grid fulfilled the requirements of the Shanxi Power Company (October 2008) and national and provincial agencies for environmental, safety, fire protection, and other licensing requirements (December 2008). Commercial operations began in July 2009, and the plant has operated continuously since then.

**Energy transmission and distribution.** CMMDP also established three collection and three transmission stations. The main station at Gaozhuang includes a 2 x 30,000 m<sup>3</sup> gas storage tank. The stations at Chengzhuang and Duanshi have been operational since April 2009 and July 2010, respectively. The transmission stations are in Zhanglin, the Yangcheng Industrial Zone, and Yangcheng county. The first two are operational; pipelines have been installed at Yangcheng, but construction remains incomplete. For distribution, CMMDP installed a network of pipelines comprising 81.95 km medium-pressure and 29.87 km low-pressure gas pipes. The transmission and distribution facilities supply about 100,000 households and nearly 500 businesses with clean, reliable gas. Connection to poor households was free, and they pay a lower monthly rate for gas. CMMDP has prevented the release of over 3 million tons of CO<sub>2</sub>e into the atmosphere per year.<sup>11</sup>

**Distribution safety measures.** To ensure safety, CMMDP installed a gas leakage monitoring system in the transmission and distribution pipeline. This automated system monitors methane and hydrogen sulfide ( $H_2S$ ) and triggers an alarm if methane concentrations reach explosive limits and  $H_2S$  exceeds designated workplace safety limits (footnote 1).

### RESULTS

**Enhanced mining safety.** Because the efficient capture of CMM and CBM reduced methane in the mine, accidents and deaths declined significantly. Methane capture also reduced mining-associated mortality per million tons of coal production in 2009, from 0.33 to 0.11. By reducing the number of inefficient coal-fired boilers and stoves, CMMDP also contributed to the reduction of health risks associated with coal combustion (e.g., respiratory, cardiovascular, and nervous system disorders).

**Reliable gas supply and electricity.** CMMDP provides a reliable supply of gas to 70,000 households, 128 boilers, 400 commercial organization, and 2 industries in Jincheng city. In Gaoping, 3,000 households receive gas from CMMDP and about 10,000 more have applied for connection and supply. In Quinshi, 7,000 of 8,000 receive gas from CMMDP. The methane-powered plant also provides reliable electricity, generating 890 gigawatt-hours (GWh; 106% of desired output) in 2011.

<sup>&</sup>lt;sup>10</sup> World Bank. 2004. China to Reduce Greenhouse Gas Emissions from Coalmine Methane through "First of" Initiative. http://web. worldbank.org/WBSITE/EXTERNAL/COUNTRIES/EASTASIAPACIFICEXT/EXTEAPREGTOPENERGY/0,,contentMDK:2028825 8~menuPK:574057~pagePK:34004173~piPK:34003707~theSitePK:574015,00.html

<sup>&</sup>lt;sup>11</sup> ADB. 2014. Methane Turned into Clean Energy in China. *World Coal.* 21 May. http://www.worldcoal.com/news/cbm/articles/ Methane\_turned\_to\_clean\_energy\_in\_China\_CBM41.aspx#.VGWvbzSUcVA



Zhangling Gas Distribution Station, one of the major outputs of the project

**Improving the environment.** CMMDP provided many environmental benefits. In 2009, a total of 182.92 million metric tons of CMM was used to produce 773 GWh of electricity, and 30.31 million m<sup>3</sup> of CMM and CBM was used for heating and cooking fuel. CMM and CBM utilization increased gradually, reaching 288.66 million m<sup>3</sup> in 2011. The 120-MW CMM-fired power plant consumed around 226.22 million m<sup>3</sup> of this total to produce 890 GWh of electricity; the rest was used for heating and cooking in 2 industries, about 102,400 households, and 2 commercial establishments.

The power plant has contributed to the reduction of 9.1 million tons of CO<sub>2</sub>e, and the plant will achieve an additional 40 million tons of CO<sub>2</sub> reduction during its life cycle (footnote 8). In 2011, CMMDP avoided the emissions of about 288.7 million m<sup>3</sup> of CMM and CBM. By displacing 465,097 tons of standard coal, it reduced carbon emissions by 4.77 million tons CO<sub>2</sub>e in 2011. CMMDP also helped clear Shanxi's air, reducing particulate matter (PM<sub>10</sub>) by 8,313 tons, SO<sub>2</sub> by 5,594 tons, and NO<sub>x</sub> by 2,185 tons. In 2011, Jincheng city achieved Class II standard ambient air quality for 354 days, compared with only 28 days in 2001.

**Recognition and replication.** The 120 MW plant is the largest CMM-based power plant in the world. Its gas supply and distribution components have won national and international awards, including the China Habitat Environment Prize from the Ministry of Housing and Construction (2009) and the Dubai International Award for Best Practices to Improve the Living Environment (2010). CMM and CBM development has expanded rapidly in Shanxi and the PRC.



CMMDP demonstrated the importance of tapping new technology. Its innovative mining operations changed the way Shanxi province handles a major environmental, safety, and health hazard.

**Considerable benefits from new clean energy technologies.** New technologies for installing a CMM drainage system were cost-effective for the project. CMMDP transformed methane from threat to useful energy. Before CMMDP, the Sihe mine vented 70% of its methane into the air, warming the earth. Since project completion, captured methane has been firing a 120 MW power plant, as well as residential and commercial boilers, stoves, and vehicles. In addition, ventilation costs decreased because the mine needs less air to maintain underground safety.

The PRC has started to adopt and increase CMM recovery and is fast becoming the global leader in CMM recovery and use. In 1994, only 130 coal mines in the PRC used CMM drainage and recovery activities. By 2007, this number had more than doubled. In that year, there were about 40 CMM projects in the PRC, a fifth of the world's total.<sup>12</sup>

**Project structure.** The clear assignment and distribution of roles was a key factor in the success of CMMDP. As executing agency, the Shanxi provincial government established a project management office to coordinate and oversee the complex operation of the project, which has three implementing agencies: the Jincheng Anthracite Mining Group Company operates the power plant, the Shanxi Energy CBM Company Limited (SECC) implements and operates CMM transmission, and the Jincheng CMM Comprehensive Utilization Company Limited (JCCUC), wholly owned by the Jincheng Municipal Government, implements and operates CMM distribution (footnote 1). Figure 2.1.1 illustrates this project structure.



### Figure 2.1.1: Coal Mine Methane Development Project: Project Structure

CBM = coal bed methane, CMM = coal mine methane, JCCUC = Jincheng CMM Comprehensive Utilization Company Limited, JMC = Jincheng Anthracite Mining Group Company Limited, PMO = project management office, SECC = Shanxi Energy CBM Company Limited, SPG = Shanxi provincial government, VAT = valueadded tax. Source: ADB.

<sup>2</sup> International Energy Agency. 2009. Coal Mine Methane in China: A Budding Asset with the Potential to Bloom. Paris. http://www.iea.org/ publications/freepublications/publication/china\_cmm\_report.pdf

**Construction of a large-scale, clean energy power plant as a least-cost alternative.** The power plant is massive, the largest methane-fueled power plant in the world. Its capacity was designed to handle the methane output of the Sihe mine. However, this large-scale plant was a least-cost alternative for CMMDP. Previously, the mine was operated by electricity; thus, construction of the methane-powered 120 MW power plant provided long-term savings. The huge capacity of the plant has rendered the construction of captive coal-based power plants unnecessary.

**Use of high-quality pipes for safety.** In underground mining, safety should be the foremost concern. High-density polyethylene pipes ensure that air will not enter the drainage system and methane will not seep into the underground mines. The pipes also ensured the safety of miners and significantly reduced mining-related deaths.

**Offsetting investment by registering with the Clean Development Mechanism.** CMMDP was among the first CMM projects in the world to register with the Kyoto Protocol's CDM. Registration allowed access to a market-based financing instrument that provides additional revenue through the sale of CERs. From April 2009 to the third quarter of 2011, the project's total verified emission reductions reached over 9 million tons of CO<sub>2</sub>e and yielded an estimated \$100 million in CDM revenues. Thus, CDM sales could recover about 75% (\$100 million) of the total power plant cost (\$132 million) in less than 3 years.

### Keywords

Coal mine methane, methane, mining, energy, People's Republic of China, power plant, methane power plant, Clean Development Mechanism, emissions, climate change, coal

#### For further reading

- http://www.adb.org/projects/documents/coal-mine-methane-development-project-pcr
- http://www.adb.org/projects/documents/coal-mine-methane-development-project-rrp

#### For further information

- Ashok Bhargava, director, East Asia Department Energy Division (abhargava@adb.org)
- Aiming Zhou, senior energy specialist, Sector Advisory Service Division, Sustainable Development and Climate Change Department (azhou@adb.org)
- Dongxiang Li, advisor, Economic Research and Regional Cooperation Department (dongxiangli@adb.org)