MORE FRIENDLY MINE-MOUTH POWER FOR CHINA

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ABSTRACT
Coal extraction and use releases large volumes of greenhouse gases (principally methane and carbon dioxide) and other pollutants to the atmosphere. These emissions are the most severe in developing countries such as China which are reliant on coal for much of their energy supply. An estimated nine billion m^3 of methane is released by coal mining in China. A proportion of this gas can be captured before entering the atmosphere and used to provide clean energy for direct use, as chemical feedstock or for on-site power generation. A realistic mitigation target for China is around one third of the total methane released from underground coal mines.

Underground coal gasification has the potential to virtually eliminate methane emissions to the atmosphere from coal seams whilst allowing the energy stored in the coal to be recovered. Although not yet ready for commercialisation, progress is being made in identifying advanced technologies that could be introduced to reduce risks associated with UCG projects.

Through the UK-China Cleaner Coal Technology Transfer Programme, the UK government Department of Trade and Industry (DTI) and the government of China, has supported projects aimed at increasing the use of gases captured in working and abandoned coal mines and promoting the development of commercially feasible UCG for power generation.

1.0 INTRODUCTION

The UK DTI Cleaner Coal Technology (CCT) Transfer programme has supported a series of UK-China projects on the recovery of fuel gases from *in situ* coal seams. The aim is to promote enhanced control and use of coal mine methane (CMM), extraction and utilisation of abandoned mine methane (AMM) and the development of underground coal gasification (UCG). These projects have introduced new advanced technological concepts, effective management practices, facilitated technical exchanges, enhanced environmental awareness and furthered the understanding of commercial factors on which investment depends. The safety of coal mining operations has also been an important consideration. Although the full mitigation potential of these technologies has yet to be realised, progress towards commercialisation is being achieved.

The above technologies are capable of supplying gas for clean power generation, to displace coal-fired capacity, at the small-scale typically ranging from around $3MW_e$ up to a maximum of about $120MW_e$ depending on gas availability. However, UCG fuelled power generation systems could ultimately be scaled-up as an alternative to conventional large-scale coal-fired power plant. Chinese experts are currently considering UCG fuelled mine mouth power plants generating 200MW_e and higher, subject to successful demonstration of a combined gas turbine and steam cycle system at 10MW_e.

This paper outlines the general situation in China pertaining to the application of CMM, AMM and UCG exploitation technologies in relation to greenhouse gas mitigation. For further technical and site specific details reference should be made to the DTI reports available from Cleaner.Coal@dti.gsi.gov.uk

1.1 METHANE EMISSIONS FROM COAL MINES IN CHINA

Coal mining releases the gases naturally occurring in coal seams. The methane flow from the mine workings depends on the gas content of the coal seams, thickness and distance of adjacent coal seams from the worked seams and the method and rate of mining. Atmospheric emissions can be reduced by capturing a proportion of the gas before it enters mine airways, piping it to the surface and using it as fuel gas or as a chemical feedstock.

More than 95% of the coal mined in China comes from underground operations. Some 300 of the Key State-Owned coal mines are classified as gassy. Assuming an average specific emission of 10 m^3 of methane per tonne of coal mined, Chinese mines would liberate about 9 billion m^3 of methane annually. By 2000 there were 184 coal mines with methane drainage systems draining about 0.9 billion m^3 of gas of which only around 0.5 billion m^3 is used. Assuming on average that 30% of the gas could be captured in drainage systems, some 3 billion m^3 of gas is theoretically available and hence a methane mitigation potential of 2.5 billion m^3. The growth potential for coal mine methane (CMM) utilisation schemes is therefore large.

The coal sector in China has undergone substantial reform to improve efficiency, safety and price stability. Large numbers of small illegal and irrational mines have been closed and returns-to-scale are being achieved from larger mining units formed by merger and acquisition. Table 1 shows that CMM emissions could have increased substantially as a result of replacing small mine capacity with large longwall operations due to the greater extent of strata disturbance and hence gas release around a longwall compared with the room-and-pillar method employed in most small mines.

Table 1. Estimated CMM emissions from working coal mines in China

Year	Total coal production Mt	SOCM coal production Mt	TVCM coal production Mt	billion m^3 methane
1997	1325	705	620	7.7
2001	1106	906	200	9.3

SOCM = State-owned coal mine; TVCM = town and village coal mine

1.2 CONVENTIONAL MINE MOUTH POWER GENERATION

Congested and hazardous local road transport and costly rail transport with its limited capacity makes power generation at the mine site an attractive proposition.

The government of China has formulated an ambitious strategy to generate electricity in areas with large coal and hydroelectricity resources and distribute the power across China to meet the high energy demands of eastern China while assisting the economic development of the western provinces. Competition has also been introduced into the power sector to stimulate increased efficiency and reduced costs. In December 2002, five power generation companies, two power grid companies and four ancillary companies were formed out of the China State Power Corporation separating generation from distribution. Power producers are therefore now expected to seek more competitive and reliable coal supplies so as to reduce the electricity generation costs by investing in coal mines near their plant. This could open up new opportunities in remote coal mining areas for investment in combined mine and mine-mouth power schemes. A particular attraction will be the saving of rail transport costs which can increase coal costs by 30-50% or more depending on transport distance.

There are environmental benefits from reduced transportation and materials handling in terms of dust emissions and energy savings together with increased efficiencies in new power plant. Some of the energy benefits will be lost through power transmission losses. Nevertheless, the coal mining process will still impact on land stability, land use, surface water and underground aquifers. These environmental impacts will be increasingly felt in the more environmentally sensitive western provinces if the coal-by-wire strategy proves successful.

Increased CMM emissions in the western provinces could be mitigated by implementing CMM power generation schemes at new gassy mines to supply all or part of the mine's electricity needs. Such an approach has been successfully demonstrated in the UK at Tower colliery which generates $8MW_e$ from drained gas. Although gas drainage may be installed for safety reasons, a CMM utilisation plant is not generally considered an essential part of initial mine construction and may not be developed until the mine has been operating for a few years. This enables actual gas flows to be measured and reduces investment risk but means that substantial volumes of methane are vented to the atmosphere. Flaring of the drained gas could be introduced as an intermediate step but there is no precedence for this practice in China and no incentive unless CDM financing could be used.

CMM drainage technologies only capture a proportion of the gas released into mine workings. Captures achieved in individual mining panels can typically range from 30% to 80% depending on the drainage technology used, the geology and the mining conditions. Technologies also exist for removing the diluted methane from mine ventilation air but these are not yet commercially viable. The potentially drainable CMM resource in China achievable using tried and tested technology is currently so large that treatment of mine ventilation air is not yet warranted. Gas capture and use could be enhanced significantly through improvements in the management of existing technologies and control practices.

1.3 CBM FOR MINE POWER GENERATION

CBM is the generic name for all methane of coal seam origin. CBM is a clean fuel with similar properties to natural gas when not diluted by air or other non-combustible mine gases. It can be recovered from virgin coal, using surface or underground boreholes, and from coal seams disturbed by mining, using various drilling or other techniques (Creedy et al, 1997). The characteristics of virgin CBM, CMM and AMM sources differ in terms of reservoir definition, production technology and gas composition. Gas utilisation schemes at working and abandoned coal mines can generally be implemented at lower cost, and are less dependent on natural coal permeability conditions than VCBM projects. They have a direct benefit on the environment by reducing greenhouse gas emissions to the atmosphere. VCBM projects which drain gas ahead of mining benefit the environment by reducing gas emissions when, or if, the coal is finally extracted as well as by displacing some coal burn. Projects of this type have been proposed in China but none have yet come to fruition.

2.0 USE OF COAL MINE METHANE

Most of the CMM used in China is distributed via pipelines to mining communities and neighbouring cities for domestic use, mainly cooking. Some CMM is used in colliery boilers and for small-scale power generation. The demand from domestic consumers varies widely both daily and seasonally, gas often being vented in summer. In comparison, a power generation scheme can consume gas at a steady base load rate, all year round, offering higher returns on investment and greater reductions in greenhouse gas emissions. There are few CMM power generation schemes in China because local authorities and mining enterprises for social reasons often consider domestic consumers as a priority. Achieving an electrical grid connection is problematic and financing is difficult as many mines have poor credit ratings. However, there is potential to develop more CMM schemes to supply power to mines as they have a predictable base electrical load and offer a number of advantages as a customer for generated power.

There is also considerable scope for increasing the availability and quality of gas drained from coal mines for utilisation but investment is needed in modern underground drilling equipment, computerised monitoring and control systems and management practices.

Gas drainage in gassy working mines is an important safety measure as well as a source of clean fuel. These two aspects are intimately linked and both have a high profile in China due to an unacceptably high number of gas explosions, a shortage of clean energy and an urgent need to reduce greenhouse gas emission from coal mines.

Development of gas drainage and utilisation schemes are technically constrained due to use of inappropriate gas drainage technologies in some instances, inadequate monitoring and control of gas drainage systems and obsolete drilling equipment. On the positive side there is generally strong local government support for CMM schemes at mines and technical competence amongst Chinese engineers at the mines.

3.0 ABANDONED COAL MINE METHANE

Methane continues to be emitted from coal mines after closure. Mitigation can be achieved by extracting and using the gas or allowing the mine to flood rapidly to prevent further emissions. The UK is among the world leaders in the production and exploitation of AMM with an installed capacity $60MW_e$ of electricity generation equivalent. A UK DTI sponsored technology transfer project has been undertaken to transfer the UK's knowledge and expertise on the recovery and use of methane from abandoned coal mines. Practical methods for AMM resource and reserve estimation, reservoir evaluation and engineering design together with the production technologies developed by UK companies were taught to Chinese counterparts. A site appraisal methodology was introduced to ensure that only suitable sites are considered for development and that limited financial resources are used effectively.

AMM offers major production advantages over VCBM in that the permeability of gas-bearing strata has been greatly increased as a result of extensive mining activities. This allows methane to migrate from coal seams disturbed by mining into the abandoned mine roadways. The gas is extracted via a shaft or borehole to the surface. Important to the success of AMM schemes is the ability to prevent air ingress and predict water recovery within the former workings.

China is undertaking a major rationalisation and re-structuring of the coal mining sector. Since 1999, some 30,000 small coal mines have been closed and more than 120 State-owned coal mines (SOCMs) with depleted resources and no commercial future will be closed. Initial research indicates that some suitable sites could exist for AMM exploitation. The best AMM project prospects are likely to be large SOCMs that will close soon but are still accessible. Thus, the necessary underground engineering works can be undertaken to ensure an effective gas extraction scheme can be developed. Of the mines currently identified for closure, not all will be gassy or necessary suitable for AMM extraction. AMM projects may need to be linked with coal mine methane schemes at working mines to achieve commercial scale.

Successful AMM schemes could help to alleviate the adverse effects of mine closures by continuing to provide employment together with a clean energy source to stimulate industrial re-development. In conjunction with a CMM scheme they can provide gas to help meet peak demand as well as provide gas storage.

4.0 UNDERGROUND COAL GASIFICATION

UCG based energy production should have a lower environmental impact than the combination of coal mining and surface combustion of coal. It is also potentially safer and intuitively more efficient. It is perhaps the ultimate CCT but it has yet to be established as a commercial technology. Whether UCG is eligible for Clean Development Mechanism (CDM) assistance in developing countries also needs clarification. UCG technology in the UK envisages high efficiency, combined cycle power generation as the prime end-use. Uses for UCG in China also include domestic fuel gas and chemical feedstock. In comparison with conventional coal mining and modern steam power plant, UCG with combined cycle power generation offers the overall environmental advantages of:

- Lower particulate emissions, noise and visual impact on the surface
- Less water used (this is important in many of the mining areas in China)
- Lower risk of surface water pollution
- Reduced methane emissions from coal mining
- No dirt handling and disposal at mine sites
- No coal washing and fines disposal at mine sites
- No ash handling and disposal at power station sites
- Less SO_2 and NO_x
- Lower energy consumption as less materials and product transport
- Less heavy surface transport
- Smaller land area occupied
- Fewer liabilities after mine abandonment.

Additional benefits of the UCG power generation approach are:

- Lower occupational health and safety risks (fewer miners underground)
- Lower capital and operating costs compared with conventional systems
- Flexibility of access to mineral
- Larger coal resource exploitable.

The CO_2 emissions from the “best” recent international UCG trials are compared with emissions from conventional fossil fuel power stations in Table 2. The tabulated emissions exclude consideration of any gases emitted during mining. For an average methane emission of $10m^3/t$ of coal mined, approximately 0.05 tons of CO_2 equivalent is attributable to coal mine emissions per MWh of electricity generated. Assuming typical specific emissions (volumes of gas released per tonne of coal mined), methane emissions could be reduced by say $5m^3/t$ in shallow seams and $20m^3/t$ to $75m^3/t$ in deep seams, reducing greenhouse gas emissions from around 0.02t/MWh in shallow coal seams up to 0.4t/MWh in deep gassy seams (carbon dioxide equivalent per unit electricity generated).

Table 2. Comparisons of CO_2 emissions (adapted from Green 1999)

Fuel	**Utilisation process**	**Efficiency %**	**CO_2 t/MWh**
UCG gas	Modern steam plant	38	1.00 to 1.14
UCG gas	**Combined cycle**	46	0.83 to 0.94
UCG gas CO_2 removal	Combined cycle	46	0.44
Natural gas	IGCC	46	0.43
Coal (pulverised fuel)	Modern steam plant	38	0.93

4.1 ATMOSPHERIC AND GROUNDWATER POLLUTION

The detrimental environmental impacts of the UCG process are considered to be fairly low as the main product of the process is gas and any by-products are either left in the ground, or they can be removed by conventional processes or even re-injected back into the coal seam. However, there are some environmental issues which still remain, particularly the possible effects of the process on surface and subsurface environments. These include leaching of organic compounds and heavy metals from the residues in the gasifier, increased concentrations of inorganic salts near the gasification zone and dissolving of hazardous gases in groundwater.

The main groundwater pollution concern is phenol residues but these can be flushed out due to their relatively high water solubility, and the water treated. No serious groundwater pollution problems have been detected in any trials. However, groundwater quality should be monitored as part of any UCG scheme as a precautionary measure.

The UCG product gas will need to be cleaned to remove pollutants to minimise environmental emissions and to prevent corrosion and damage to utilisation plant. More research is needed to develop cost-effective gas cleaning systems. CO_2 in the product gas could be absorbed using waste alkaline solution and fixed into a high calcium coal ash for filling into the UCG cavity thus reducing the greenhouse emission impact and raising the heating value of the product gas per unit volume.

4.2 SUBSIDENCE

Cavity formation and subsidence will depend on the mechanical properties of the rocks, geological and thermal stresses. In general, as extraction depth increases, surface subsidence decreases. Waste residue and caved rock after gasification are left underground, thus eliminating the accumulation of waste on the surface and reducing the cavity space formed underground compared with longwall mining techniques. Surface subsidence per unit of energy produced may therefore be less with UCG compared with conventional coal mining.

4.3 UCG IN CHINA

There are two distinct UCG approaches being developed in China, both of which differ from the remote access, surface to in-seam directional drilling method being pursued in the UK. These are the *Undersurface gasification* (UG) method and the *Long tunnel, large section, two-stage* method.

UG is an extension of mining in which gasifiers replace working faces and are controlled independently from underground to ensure optimum performance. Underground access is maintained at all stages of the operation.

The long tunnel, large section gasifier is constructed using mining methods and the connections to the surface for injection and production of gases are drilled. The system is monitored and operated remotely from the surface. The two-stage process involves oxidation in an air-blown first stage to raise the temperature of the reactor then injection of steam which is decomposed on contact with the heated coal to form hydrogen and carbon monoxide. This method can produce gas with heat values in the range 12 to 14 MJ/m^3 and a hydrogen content of around 60% but can be more difficult to control than the UG arrangement.

Performance, safety, environmental, process control, gas cleaning, market and financial issues will require further attention in China before commercialisation can become a reality. The deep UCG method envisaged for application in the UK would avoid many of the problems which limit the technologies used in China.

If UCG is to achieve credibility as an environmentally acceptable technology, a high standard of environmental protection should be demonstrated at all field trials in China and elsewhere.

5.0 CONCLUSIONS

There is an urgent need to increase the number of CMM utilisation schemes in China to mitigate the large greenhouse gas emissions associated with coal mining. On-site power generation is likely to be the most commercially attractive application at most mines unless there is a large industrial consumer nearby.

A radical approach to mine mouth power generation is provided by UCG which enables the energy in coal to be released without need to extract, process, transport and combust it. UCG virtually eliminates greenhouse gas emissions associated with coal extraction. Hitherto, the potential net greenhouse gas emission mitigation benefits of UCG power generation compared with conventional coal extraction and coal-fired power plant have received little attention. Whether CDM can be used to finance UCG to encourage energy saving and methane emission reductions deserves consideration.

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