METHANE EXTRACTION AND UTILISATION FROM ABANDONED COAL MINES - CHINA/UK TECHNOLOGY TRANSFER

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by

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EXECUTIVE SUMMARY

Methane recovery in production mines has been exploited for many years. An important development is the exploitation of methane from abandoned or disused mines (AMM) in which the permeability of the gas-bearing strata has been increased greatly as a result of mining activities. AMM schemes aim to extract the methane left in remaining and unminable coal seams. Methane extraction and utilisation in abandoned coalmines can be a cost-effective means of reducing greenhouse gas emissions, whilst contributing to local and regional energy requirements.

In the UK, the exploitation of methane from abandoned coalmines is becoming an established, albeit relatively small industry and a number of successful commercial schemes have been developed to extract and utilise AMM as a source of energy for electricity generation and fuel supply to local industries by dedicated pipelines. The experience gained from these schemes may provideUK industry with opportunities to collaborate internationally in adapting and developing AMM technology for other coal producing countries.

An opportunity exists for collaboration and technology transfer with China where many mines, some deep, have been closed following a major re-structuring programme by the Chinese government to improve safety and competitiveness of the coal industry. Although the Chinese coal mining industry has some expertise in the application of methane drainage schemes in working mines, the extraction and utilisation of methane from abandoned mines is a new concept. It is anticipated that there could be potential to develop AMM schemes at some of the closed deep mines.

The overall objective of this project was therefore to bring Chinese and UK experts together to develop collaboration into the application of AMM recovery and utilisation from abandoned coal mines, and to establish market potential and address measures to promote the application of UK technologies in China, wherever appropriate. The work involved the review of technology status in both countries, field investigations in China to establish site selection principles, in-house studies into AMM resource assessment methods and investigation of utilisation options. The project involved considerable interactions between UK and Chinese researchers. These included in-house studies, fieldwork, informal communications, workshop and technical visits to the UK and China by experts from both countries.

The total cost of this project (including two extension amendments) was £330,060. It was jointly supported by the UK Department of Trade and Industry's (DTI) Cleaner Coal Technology Transfer Programme, with contributions from UK industry and the Chinese Government. The overall work was managed by the University of Nottingham in collaboration with China International Centre for Economic and Technical Exchanges (CICETE). Future Energy Solutions (FES) supervised the project on behalf of the DTI. The duration of the project was originally 18 months from January 2001 to June 2002. Two extensions (granted to 30th November 2002) allowed a UK visit by a delegation from Heilongjiang Province, a workshop in Beijing to disseminate the project results, and two additional site visits to Hegang and Jixi to gather field data for a pre-feasibility study.

This report presents the major work carried out in this project. Further details are available from the appended visit reports and technical reports prepared by China Coal Information Institute (CCII), China Coal Research Institute(CCRI) and China University of Mining and Technology (CUMT.)

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ABBREVIATIONS AND ACRONYMS

For the purposes of this report, the following acronyms have been used:

- **Coalbed methane (CBM)** - a natural gas formed during coalification in coal seams, consisting predominantly of methane. Coalbed methane is often referred to as coal seam gas or CBM, which is used as the generic name for all methane of coal seam origin.

- **Coal Mine Methane (CMM) –** gas released from the coal seams in a working mine as a result of coal mining. CMM is the subset of CBM, known as mine gas (UK), coal gas (North America).

- **Abandoned mine methane (AMM) –** mine gas produced from abandoned coal mine workings through disused mine entries and from boreholes drilled into underground roadways or former workings.

- **Virgin CBM (VCBM) –** methane rich gas recovered from unmined or virgin coal seams that have not been disturbed by mining via surface boreholes.

- **DTI**: Department of Trade and Industry
- **FES**: Future Energy Solutions
- **CCII**: China Coal Information Institute
- **CCRI**: China Coal Research Institute
- **CICETE**: China International Centre for Economic and Technical Exchange
- **CUMT**: China University of Mining Technology
- **Km**: kilometer
- **m**: metre
- **m^3** : cubic metre
- **m^3/h**: cubic metres per hour
- **MJ/kg**: Megajoule per kilogram
- **MJ/m^3**: Megajoule per cubic metre
- **Mt**: Million tones
- **MW_e**: Megawatt electrical
- **MWh**: Megawatt hours

1. PROJECT BACKGROUND AND OBJECTIVES

Until recently, the extraction and utilisation of coalbed methane in the UK has involved gas drained from working coalmines. This methane gas has been either piped to local customers for direct use or consumed in small-scale power generation schemes. These schemes were located at deep gassy coal mines practising longwall mining methods where underground methane drainage techniques were needed for mine safety.

Recently, the concept of extracting the gas from abandoned mines to provide an energy source has been developed in the UK. This is achieved by using the existing mine shafts or drifts, where these remain open, or a filled shaft by boreholes drilled from the surface into the abandoned workings. A number of commercial UK schemes have been developed to extract and utilise AMM as a source of energy for electricity generation and fuel supply to local industries.

The potential for AMM in China has been enhanced recently, by a major programme being implemented by the Chinese government to restructure the coal industry and relieve poverty in coal mining areas. The Chinese government has launched plans for reducing production capacity and closing coal mines that are resources-depleted, illegal or cannot meet safety standards. The AMM technologies developed by UK companies may have potential for application in some of these mines.

The overall objective of this project is to develop collaboration with China into the application of AMM recovery and utilisation from abandoned coal mines, and to establish market potential and address measures to promote the application of UK technologies in China. Specifically, the project aims to:

- review the status of AMM extraction and utilisation technologies and investigate the market potential for AMM technologies in China
- study mining, hydrogeological and surface conditions at selected abandoned mine sites in China in order to demonstrate site selection principles for AMM extraction and utilisation projects
- investigate application of AMM resource assessment methods and how these need to be adapted for Chinese conditions
- study AMM utilisation options and technologies, especially the experience of UK companies with pipeline and small-scale power generation schemes based on methane recovery from abandoned mines
- foster collaboration between UK and China and investigate and promote the potential of technology transfer based upon the expertise and technologies of UK companies.

This project is supported by the UK DTI and managed by the University of Nottingham (UoN) and China International Centre for Economic and Technical Exchanges (CICETE).

Project collaborators include China Coal Information Institute (CCII), China Coal Research Institute (CCRI), China University of Mining and Technology (CUMT) and Wardell Armstrong. The execution of this project has received strong support from various organisations in China and the UK. These organisations include Alkane Energy Plc, Clarke Energy, Deutz Energy UK Ltd, MAN B&W Diesel Ltd, Octagon Energy, StrataGas Plc and Warwick Energy in the UK, and Fushun Coal Mine Administration (FCMA), Tongchuan Coal Mine Administration (TCMA), Liaoning Provincial Planning and Development Commission, Jixi and Hegang Coal Mine

Administrations, the Planning and Development Commission of Heilongjiang Province (PDCH), and the Ministry of Science and Technology of China (MOST).

2. METHANE FROM ABANDONED COAL MINES

2.1 Gas Emission from Abandoned Coal Mines

Methane gas is formed during coalification and remains trapped under pressure in the coal seam, a small volume is also found in the surrounding rock strata. This trapped gas is stored within the micro porous coal matrix as a physically adsorbed layer (which usually accounts for 98% of the gas within a coal seam) and will not be released until the coal seam is fractured and pressure is reduced as a result of mining activity or reservoir stimulation such as fracing and de-watering. Once the gas pressure in the coalbed is reduced, the coal seam becomes less capable of retaining methane which then begins to desorb from the surface of the micropores and microfractures into open fractures. The rate of flow is primarily dependent on the diffusion characteristics of the gas and the permeability of the coal seam and adjacent strata.

During coal mining, this trapped gas is removed to the atmosphere via the mine ventilation or through a drainage system. When a mine is abandoned, the remaining coal may still contain large quantities of methane gas, which, under certain conditions will desorb from the coal into adjacent voids. It has been estimated that in any sequence of coal measures, up to 80% of the in situ coal reserves may be left behind.

Barometric pressure changes have been recognised by the coal mining industry for many years as being responsible for causing, sometimes excessive, methane emissions into mine workings from abandoned and sealed off parts of a mine. The processes involved in surface gas emissions from abandoned old workings are similar to those that occur in underground mines. As the atmospheric pressure at the surface rises and falls, a pressure differential is created between the workings and the surface. If some form of migration connection exists between the two, a flow of gas between the underground voids and the surface will result; the magnitude will depend on both the pressure differential and the resistance to flow through the flow path. The highest flows to the surface will occur during rapid and sustained atmospheric pressure falls.

The dependency of gas outflow on barometric pressure can be represented as:

$$Q = C + M A (1 - e^{(-BT/A)}) \qquad [1]$$

Where

Q – the gas flow through the migration path
C - the gas make
M - the rate of barometric pressure change
A - the cavity volume; B is a constant
T - is time.

(Carter and Durst, 1956):

In practice, abandoned mine workings exist which are not tightly sealed, either because they are located in shallow seams with breaks up to the surface or because the shafts or drifts have not been effectively sealed. The limiting factors are the resistance of the flow paths, the rate of change of air pressure and the magnitude of the pressure change. A large and rapid fall in barometric pressure may result in gas being pushed quickly to the surface in high concentrations. Thus, variations in mine gas composition can occur in mine entries and underground workings as a result of

atmospheric pressure change. Whilst atmospheric pressure is rising, fresh air will enter through surface connections leading to displacement and dilution of mine gas in the vicinity of the connection, but when atmospheric pressure falls, the flow direction will reverse. During sustained barometric pressure falls, 'pure' mine gas may be expelled at the surface (Sizer et al, 1996).

Another important factor that could increase gas pressure in old workings is the hydrostatic head imposed by rising groundwater levels (Creedy, 2000). Cessation of water pumping will result in groundwater recovery and flooding, and may give rise to gas displacement, or pressurisation, as water levels rise. When the water levels are finally recovered to their original levels the problem of mine gas at the surface will be reduced considerably as most of the old workings will become flooded. This may take many years, in some instances surface emission problems can be experienced for many years, eg, Barnsley, Stoke on Trent, Cumbria.

2.2 Available AMM technologies in the UK

Presently, a number of key technologies have been successfully developed and applied by UK companies for the commercial extraction and utilisation of AMM. These include (Garner, 2002):

- **Gas resource estimation methodology and production modelling –** several AMM resources and reserve assessment methodologies have been developed for abandoned coal mines. These include in-house methods used by companies operating AMM schemes. Production modelling has also been developed to allow the production profile of gas availability to be calculated depending on the specification and performance of extraction equipment used.
- **Remote and portable monitoring equipment –** portable equipment capable of monitoring gas compositions, borehole pressures and gas flows can be used as part of any investigation. This equipment can be installed at the site and set to record information at pre-determined time intervals. The results can be accessed remotely and alarms activated if particular problems are detected.
- **Production Testing Equipment –** specialised testing units have been designed and built to provide detailed analysis for reserve potential and production characteristics of abandoned mine extraction projects. Measurements (inlet pressure, flow rate, methane content, oxygen content and external barometric pressure) are stored electronically and automatically downloaded via black box telemetry to central control systems.
- **Dry seal extraction pumps and containerised plants –** small, efficient extraction pumps which are interchangeable between sites and can be operated to match the required output of the project and gas desorption characteristics. These pumps can also be installed in containerised plants to enable the client both to exchange and rapid re-location between sites; a modularised site layout allows major capital items to be re-located when a site becomes exhausted or when production capacity is reduced as a gas reservoir becomes depleted.
- **Guided drilling technology -** has been used successfully for many years within the oil and gas industry. The use of this technology has proven to be critical for the success of an AMM scheme where no mine entry is available and a gas extraction borehole is required. This technology has the ability to form an effective connection between the surface and a selected position in underground mine workings.
- **Casing while drilling –** investigation boreholes to determine water levels and gas compositions will often pass through old worked areas (goafs) which can cause instability. Drilling techniques, allowing the borehole casing to follow directly behind the drill bit, can be used to minimise these problems.

- **Control system and remote telemetry technology** – using monitoring sensors installed at strategic points within the surface gas extraction and treatment installation. This innovative system enables remote interrogation of data and system performance. Where necessary, the performance of the system can be adjusted as required with pumps stopped and started, and control valves regulated. This telemetry allows engineers to monitor the performance of a plant in real time from remote locations.
- **Lean burn spark ignition engines and advance fuel management systems** –units within the range of 1-3.5MW_e can be incorporated within self-contained transportable units to allow rapid installation and re-location of equipment. Such an approach means that the unit can be transferred to other sites if gas availability or market conditions change. The engines can operate on a gas containing as little as 40% methane.

2.3 Key Issues in AMM schemes

Successful AMM schemes at abandoned mine sites will require both adequate methane quality and quantity and an identified gas market. The following aspects are identified as key issues that need to be addressed in any AMM scheme.

2.3.1 AMM Reservoir

The primary sources of methane in an abandoned mine originate from coal or coal seams and goafs in the vicinity of worked out areas. The methane found in old goafs (worked-out longwall panels), roadways and shafts will also have originated from primary coal seam sources. The precise origin of AMM will be indeterminate and therefore the whole mine and its associated fracture systems can be considered to form a boundary to the reservoir.

The gas reservoir comprises all the coal seams in strata disturbed by mining which is likely to emit significant quantities of gas into the workings. Research in the UK has indicated that coal seams up to 150m to 200m above a longwall coalface and 40m to 70m below may be de-stressed (Creedy et al, 2001). The reduction in stress results in the creation and relaxation of fractures, and thus increases the permeability of the coal bearing strata (including the coal seams) surrounding the extracted seams. The amount of gas remaining in the unworked coal seams above longwall goafs depends on the initial gas content of the coal and the distance from the worked seam and the number of worked seams that interact with the coal seam. Any seams present where the de-stressed zones of workings in two different seams overlap will have degassed twice and have a reduced residual gas content. The greater the distance a seam is above (or below) the workings, the less gas it will have lost, however, not all of this residual gas will be available to an abandoned mine gas extraction scheme.

Underground roadways provide the means of linking suction pressure from the surface pumps to the primary gas reservoirs. Suction is needed to overcome the pathway resistance and generate pressure gradients to allow the release of gas from the coal. The gas production process will therefore largely rely on gas desorbing from primary sources (coal seams) entering void space and gas extraction pumps linking these voids through roadways and stoppings; only small leakage from a large number of stoppings may be needed to maintain a production flow.

Information can then be used to produce a ‘footprint’ for the mine – which is the extent of disturbance by the underground workings in the various seams that were mined. Knowledge of the

footprint area will help the calculations of the potential gas resources in the underground workings (Oldham, 2002; 2001).

Many of the abandoned workings in the UK have been subject to an initial desk study review to identify those areas where more detailed site investigation, gas resource calculations and water studies are required. Although advances in the understanding of AMM reservoirs have been made, more work is required to reduce the uncertainties, in particular the rate and effects of water recovery within the abandoned workings and in the ability to recover gas from the mines at commercial flow rates over the longer term.

2.3.2 AMM Resource and Reserve Estimation

The development of an AMM project requires a reliable estimation of the gas volume and production potential of the AMM reservoir. In the UK, several AMM resources and reserve assessment methodologies have been developed for abandoned coal mines. These methods differ in detail, however, all credible models only consider coal that has been de-stressed.

The key factors are:

- the volume of coal in which the permeability has been enhanced by mining and which is connected to the extraction point
- the remaining seam gas content of the coal
- the volume of this gas that can be desorbed from the coal at a given suction pressure
- groundwater recovery
- when considering reserves then air ingress is a major factor as is resistance of connections

The void volume in the worked-out seams also needs to be estimated, although the magnitude of the void volume is irrelevant to the quantification of the gas resource. The void space is important as a conduit for collecting gas, for transmission of suction pressure and also as a receptor for water inflow, which will progressively reduce the magnitude of the accessible reservoir.

It is apparent that not all closed mines contain significant quantities of methane. Some mines which have worked coals with low gas contents emit mixtures of de-oxygenated air and carbon dioxide (blackdamp). Where there are few seams in the strata above the workings, the AMM reservoir may be too small to support a commercial scheme (Creedy et al, 2001). Even abandoned workings that have a high initial gas content can have a limited gas resource if multiple seam workings have taken place in close proximity

The effect of minewater recovery is critical. Gas cannot be extracted in commercial quantities from waterlogged workings. Account must, therefore, be taken of minewater flows in estimating potentially recoverable gas. One approach to recoverable reserve estimation is to take account of this effect by reducing recoverable gas in proportion to the calculated volume of void filled by water each year.

It is clear that a detailed and reliable resource and reserve assessment would require a study of local geology, mine plans and the likely scenario of mine water rebound. In practice, gas reserve assessment is usually combined with the monitoring of gas emission from access points to the abandoned workings to give an indication of potential flow levels. Most pump tests are not

designed to indicate flow potential. Production tests at pitheads are normally used to assess the effect of gas flow on reservoir pressure and the dynamic behaviour of the system.

2.3.3 Ground Water

While in operation, many coalmines have to pump water to maintain suitable working conditions underground. After mine closure, if water pumping operations in the mine cease, there will be flooding (the rate will vary) of the underground mine workings up to certain level, depending on the rate of recharge, underground void volume, and connections with adjacent workings and the surface. Once waterlogged, the associated gas sources will no longer release gas into the voids. The rate of water recovery and level of water in an abandoned mine is therefore likely to be a very important constraint on the potentially recoverable methane resources. This may also mean that there is a limited 'window of opportunity' to extract methane from these mines before they become flooded.

Preferred AMM sites are those where mine water recovery rates are very slow, or where de-watering is being continued. It is therefore crucial to determine whether underground workings are flooded or dry.

Mine water pumping records prior to closure provide an indication of likely water inflow but the sealing of mine entries and removal of surface water connections may reduce this value. Groundwater studies can arrive at an apparently correct water level scenario by a fortuitous combination of void volume and water inflow rate although the magnitudes of both values could be too high.

In mines that have been abandoned for some years prior to installation of a gas extraction system, mine water may have accumulated in some goaf areas and displaced methane into roadways and shallower seam workings. The displaced gas may be accessible for production and, if pressurised, may initially enable high flow rates to be obtained. However, the total volume of available gas may be too small to support a commercial AMM scheme.

Groundwater rebound is a major limiting factor for AMM scheme. To de-water a mine solely to facilitate testing with no certainty of commercial gas production would be considered high risk and too costly an option to pursue at most sites. This means that there is a limited 'window of opportunity' to exploit AMM from many mines, before they become flooded. However, de-watering may be continued at recently closed mines to prevent the abandoned mine gas reservoir flooding in the first instance provided the AMM scheme can support the pumping costs.

2.3.4 Production Testing

Estimates of production rates are required to allow the operator to have the right equipment. Pump selection, in part, is a function of final suction pressure to be exerted on the mine to achieve recoverable reserves and pipeline capacity for the capture and distribution of the methane gas produced. The production rates of methane from an abandoned mine is likely to decrease over time and it is beneficial for the operator to know how much they can recover within a reasonable project lifetime.

To help obtain the above understanding, production (active/pump) testing is required at the final exploration stage through vents installed in sealed shafts or using boreholes drilled into the

workings. The tests utilise extraction fans with variable speed drives that can create shaft and inlet pressures simulating the actual mine extraction process. Gas composition and system pressure are measured for a range of flow rates. An increase of oxygen as flow rate increases indicates fresh air is being drawn into the system and a need for surface remedial measures. A rapid increase in suction pressure applied to the workings may indicate a "tight" connection to the reservoir or a depleted reservoir. The production tests would also provide further information for reserve potential and production characteristics of abandoned mine extraction projects.

Figure 1. shows a typical layout of a production test at a former colliery.

2.3.5 <u>Air Ingress and Seal Design</u>

Air leakage into the gas extraction system is a major concern during the entire production period. In most cases the effectiveness of gas extraction could be compromised where there are fresh air leakages into the mine workings through imperfectly sealed surface entries. These problems should be identified at an early stage of the project. The cost and practicality of remedying such problems must be considered when assessing the feasibility of an AMM scheme. To improve the effectiveness of gas extraction, consideration should be given to the depth of the rockhead, and wherever possible, the seal must be built into the rockhead to avoid air leakage.

Active test trials can be used to assess the degree of air leakage and hence the need for remedial sealing work. It is important that remedial work is undertaken where it is judged that it will have the most effect and that access for the works is practical.

Table 1 summarises a number of practical problems that have been experienced in the UK. Most of these are a direct result of inappropriate design and supervision during the mine closure, and in many cases were preventable. Valuable lessons can be learnt from these projects for future schemes.

It has been noted during the field visits to China that there have been some misinterpretations in terms of the design criteria and the importance of an effective seal to the closed mine entry. One of the issues is understanding what we mean by a closed mine in UK, it has a different meaning in China. A mine can be closed but other mines still use part of the mine infrastructure. The current stopping design practice in China is primarily for safety reasons (to prevent accidental entry) and is inadequate for AMM extraction.

Experience in the UK demonstrates the importance of identifying and undertaking engineering works on closure to minimise the potential for air ingress, water accumulation and isolation of workings. Not only must the treatment be suitably designed but also the level of supervision is critical (Garner, 2002).

2.3.6 <u>Gas Production Rate and Project Life</u>

Over time, as gas is produced, reservoir pressure will decline necessitating more pumping effort to maintain flow. Eventually, the pumps will no longer be able to maintain the required gas flow rate and consequently a commercial decision will have to be taken.

Project life therefore depends on the total available gas volume, the projected annual gas production and the volume of gas made inaccessible by flooding each year. The volume of gas that cannot be

recovered due to rising water is obtained by reducing the volume of available methane in proportion to the inflow of water. Account must be taken of uncertainty and estimates discounted accordingly.

2.3.7 <u>Market Conditions and Cost Factors</u>

AMM schemes must be competitive in the energy market. In the UK it is necessary for mine gas to be offered at an attractive price compared with other fuels such as natural gas to win a market share. There are many factors that influence the commercial viability of an AMM project including local and national energy prices (Table 2), gas and electrical supply arrangements and grid connections, existing infrastructure, regulation, planning, environmental and land access. AMM schemes can be commercially attractive due to their rapid payback and high return potential compared with other types of CBM projects.

The critical path elements in starting new schemes are identification of a customer t and contract agreement for gas sales and completion of either the utilisation facility or the delivery pipeline. Investment costs can be minimised by modularising equipment to allow 'just-in-time' installation and easy transfer of existing equipment from exhausted sites to new sites. The major capital costs could include improving surface sealing of shafts and drifts, gas extraction and cleaning equipment, preparation of access to the mine, gas transport to remote consumers, power generation equipment and grid connections.

As introduced previously, AMM in the UK is exploited in two different ways; electrical power generation for supply to the grid or supply via pipeline to local industry for direct use. To date, AMM use has been predominantly for electrical power generation using spark ignition engines. Although the use of gas turbines is an option, particularly where fuel quality deteriorates with time, or where only low quality fuel is available, the electrical efficiency and modular approach of spark ignition engines is considered to provide a more flexible approach. Ultimately, the end use of the gas and technology selected, is a commercial decision based on capital and operating costs of equipment, cost of alternative fuels and revenue from gas or electricity sales.

A review of the design, management and operation of AMM schemes operating in the UK suggests contractual arrangements need to be flexible to meet local market conditions. Most contracts fall into one of the following two categories:

- gas is sold to a third party joint venture partner
- gas is used to generate electrical power with the electricity generated sold by the gas supplier.

When considering AMM schemes presently operating in the UK only one project is generating electricity that is then sold by the AMM operator. All the other schemes are operated as joint ventures in which the gas is sold to a third party either for power generation or direct use. Most AMM companies prefer to sell gas rather than electricity.

2.3.8 <u>Environmental factors</u>

Although AMM schemes benefit the environment by providing clean energy from a waste product of mining and by reducing greenhouse gas emissions, the development of some sites can be complicated by planning issues in the UK. Environmental issues, including the exterior colour and appearance of the buildings, as well as water disposal, noise and other emissions from the site have to be minimised. Judicious choice of site, detailed consultation with local authorities and residents,

action groups attention to local sensitivity and the relatively small scale of operations tend to remove most, if not all, concerns raised by local authorities.

The condition of AMM sites usually mean that substantial improvements are required to accommodate the production equipment and to raise the quality of mine entry seals. The landowner benefits from these environmental improvements and is therefore unlikely to present any obstacles on termination of gas extraction.

2.3.9 Site Selection Principles – a Summary

The results achieved in the UK have indicated the potential for AMM schemes elsewhere in the world. Such schemes should be considered whenever mine closures are planned. However, some of the technical points to be considered when assessing such schemes in the future include:

- **potential gas resource in the abandoned workings**. What will be the gas yield after mine closure? Valuable information can be obtained from investigations undertaken while the mine is operational
- **ground water inflow**. Would underground water rebound critically affect a successful extraction?
- **interconnections of underground workings**. What spatial relationship exists between underground workings, surface entries and adjacent mines?
- **gas extraction seal**. Where is the best position in the shaft/drift for the installation of a stopping?
- **gas market**. Is gas market available for all the extracted gas? If not, how much of the availability can be used? Can the scheme be incorporated with other methane drainage schemes such as those in adjacent operational mines?

Prior knowledge of forthcoming mine closures is necessary so that plans, reports and estimates can be prepared for consideration of such a scheme, and the work of 'sealing-off' shafts should be organised well before mine closure.

Table 3 summarises the positive and negative factors when selecting an AMM project site.

2.3.10 Major Benefits of AMM Schemes

Gas from abandoned deep coal mines typically comprises methane, carbon dioxide, and oxygen-deficient air (predominantly nitrogen). There are over 900 deep coalmines in the UK from which it is estimated that between 200,000-300,000 tonnes of methane (equivalent to 4.2 to 6.3 million tonnes of carbon dioxide) are emitting into the atmosphere each year (ACMMO, 2001; Sage, 2001, IMCL, 1997). Methane is estimated by the Intergovernmental Panel on Climate Change (IPCC) to have a global warming effect almost 21 times that of carbon dioxide. The recovery of mine gas from abandoned mine workings therefore provides opportunities to convert a waste product with significant global warming potential to productive use, either on-site or locally. Such schemes have the potential for appeal in environmental, economic and community terms. Major benefits include:

- reducing global emissions of greenhouse gases through the capture and utilisation of methane from abandoned coalmines
- minimising potential surface health and safety hazard to individuals and property

- the potential to provide clean energy and electricity availability to local users, especially in cases where former colliery sites are developed for industry and commerce
- encouraging local/regional economic growth by providing local industry stimulus
- inward investment into coalfield community areas with developed technology creating jobs
- stimulating the development of new and innovative technologies necessary to harness this new source of energy.

2.4 Status of AMM in the UK

The exploitation of AMM is not a new concept. In Europe, in the past, gas from closed mines has been used to supply a single industrial customer or fed into a mine gas grid. In addition to environmental and social benefits, the exploitation of methane from abandoned coalmines has recently become a strong commercial interest in the UK, France, Germany (IMM, 2000) and the USA (Hupp et al, 1999).

Gas from abandoned mines was first used in the 1950's when gas from the Old Boston Colliery was used in boilers to heat water for the pit head baths used by workmen from a neighbouring colliery (Bromilow, 1959). Avon Colliery provided a particular example of AMM use from a closed coalmine (Morgan, 1974). Mine gas, with purity ranging from 62% in the early stages of the project rising to an average of 77% was extracted and transmitted to the South Wales Methane Grid during August 1971. The benefits from this gas extraction scheme were recognized as providing significantly improved financial returns to the South Wales Area as well as preventing pollution to the atmosphere.

The climate for the commercial development of AMM projects in the UK has changed significantly in recent years. The introduction of the Coal Act in 1994, which clarified the gas ownership issue, combined with de-regulation of the electricity supply and distribution industries, has removed the principal regulatory barriers to AMM development in the UK. In addition, environmental considerations, in particular concerns about greenhouse gases, have also provided an impetus for capturing coalmine methane that might otherwise be vented.

In the UK, some abandoned mines were capped and fitted with vent pipes to prevent the build-up of underground pressure and protect against methane seeping from old workings into surface. Other deep mine shafts were infilled for stability and to prevent this hazardous gas from migrating to the surface. Methane is extracted from these abandoned mine workings via either:

- disused/unfilled mine shaft/drift, or
- boreholes drilled into old workings or de-stressed gob areas using guided drilling technologies.

Figure 2 illustrates the concept of AMM extraction methods from abandoned coal mines. To date, a small number of AMM schemes exist in the UK, providing electrical power generation and alternative fuel supply to local industry for direct use. Table 4 provides a summary of the present AMM activities in the UK.

AMM projects in the UK typically involve schemes of up to 10 MW_e equivalent with a potential project life in excess of 10 years at some sites. The gas extracted from these abandoned mine sites is sold either direct to industrial users or to electricity generators, with the latter being the larger market. Electricity generators normally build a small-distributed power station on site to supply

their customers via the local distribution grid. Presently, several UK companies are active in the commercial extraction and utilisation of AMM, these include:

Alkane Energy Plc: The company, which was floated on the stock exchange in December 2000, is one of the largest holders of DTI onshore oil and gas licences with 4,302 km^2 in its portfolio. Alkane Energy extracts methane from abandoned coal mines for direct supply to local consumers or for use on site for power generation. These extraction plants are all designed as remotely monitored automatic, unmanned systems. The company currently has 5 Green Energy Parks in full production and is reported to be planning more plants across the UK. The company has recently developed modularised extraction plants allowing rapid re-location when a site becomes exhausted. Figure 3 shows the Shirebook Green Energy Park operated by Alkane Energy.

Octagon Energy: The company owns and operates a production, distribution and storage system in the Stoke-on Trent area where the methane is used by a nearby industrial customer and a 9.5 MW_e power station in Holditch near Newcastle-under-Lyme. Methane is presently extracted from the former Silverdale Colliery and pumped into the gas grid. The company has also started electricity generation at its Hickleton site near Barnsley, South Yorkshire. The 5.5 MW_e plant is the first in a series of power generation developments being undertaken by the company. Figure 4 shows the gas extraction house at the former Silverdale Colliery.

2.5 Status of AMM in China

The potential of AMM as a source of clean energy in China had not been recognised until the launch of a UK-China CBM Technology Transfer project during which AMM schemes in the UK were introduced to Chinese engineers (Creedy and Garner, 2001). To date no AMM project has yet been developed in China.

Strong interest has been observed throughout this project during field studies and workshops. The Ministry of Since and Technology (MOST) of China is supporting CCRI Xian Branch under the '10^{th} Five-Year Plan' to undertake a technological study of the development and utilisation of AMM in China. Statistical studies by CCII suggest that over 30 billion tonnes of coal reserves may be left in closed mines and in gob areas of working coal mines, with an estimated AMM resource over several hundred billion m^3. Although this project has yet to identify a promising commercial AMM site, given the size of the Chinese coal mining industry further exploration and investigation should be continued, particularly at the sites identified by this project. Pre-feasibility studies would be required to provide a basic geological and mining review of the closed coalmines to ensure that any AMM project is both technically and financially feasible.

The likely option for an AMM scheme in China would be for direct gas use on-site or for subsidising gas supplies from an existing methane drainage system. About 70% of the abandoned coalmines investigated by CCII are classified as highly gassy mines. AMM schemes in these areas will be seen not only as a means of clean energy recovery, but also as safety measures against hazardous gas emission to the environment as well as employment opportunities after mine closure.

3. TECHNOLOGY TRANSFER ACTIVITIES

Technical transfer activities were primarily conducted by means of field visits to China and the UK, technical presentations and workshops at various locations. In addition, extensive informal discussions and communications have taken place concurrently between project team members and local experts on various issues on AMM schemes.

Three field visits were made to China by the UK team and two visits to the UK by the Chinese during the project. The first visit to China was part of the original proposal, the following two visits were made possible by additional support from the DTI to allow further information to be collected from Jixi and Hegang in Heilongjiang Province for a pre-feasibility study. Figure 5 shows the locations of the field visits in China.

3.1 China Visit 1 – Tongchuan and Fushun

This visit took place between 19th August and 2nd September 2001. The UK delegation consisted of representatives from the University of Nottingham, Wardell Armstrong and Alkane Energy Plc.

Further details on this visit are given in Appendix 1.

3.1.1 Field Visit to Wangjiahe Mine, Tongchuan

The team began the visit at CCRI Xian Branch, where a presentation was given by the Chinese team on Tongchuan Mining Administration (TCMA) and the abandoned Wangjiahe Coal Mine which was selected for fieldwork by CCRI. The UK team also made technical presentations covering a number of specific topics on AMM technologies. Practical procedures and advice, including the development of a methodology capable of assessing gas reserves from an abandoned mine, were presented to CCRI. Suggestions were provided in developing a strategy to evaluate further the proposed abandoned mine site including testing procedures, drilling investigation options and the specification of any extraction scheme.

TCMA lies in the western part of the Weibei Coalfield, some 90km in the south of Xian, the Capital City of Shaanxi Province. It operates in two major mining areas: Tongchuan and Jiaoping, with a total area of ~387km^2. TCMA presently has 10 production mines, producing 9.1Mt. per year. There are five abandoned mines: Wangjiahe, Lijiata, Shijiahe, Qianwei and Dongbeita but only Wangjiahe mine is a gassy mine. Figure 6 shows the location of TCMA and Wangjiahe mine.

Figure 7 shows the stratigraphy of the coal-bearing strata in Wangjiahe mine. This mine started production in 1958 with a design capacity of 0.21Mt/year. In this mine seams are numbered 2 to 10 with No.10 being the main extractable seam, average thickness 1.0~1.5 m, relative gas emission rate 2.33 ~ 47.9 m^3/t.day. Mining depth was about 570-690 m and a total of 3.8 Mt. of coal was extracted from the mine. Coal seams were accessed via two shafts and a drift in a single level using longwall panels. The mine has an area of 25.5km^2, with an estimated goaf area of 4.06 km^2. The Taiyuan formation is the main coal-bearing stratum, containing seams No.5 to No.10. Table 5 shows the some of the characteristics of the coal seams in Wangjiahe Mine.

The two shafts have been filled and the site is presently used as a cement plant owned by TCMA. The drift, located about 1km north of the shafts, was chosen by CCRI to carry out gas emission

monitoring work. The drift, about 730m long with a slope angle of 23 degrees, was driven into the coal measure rocks from the foot of a hill. The drift entry is surrounded by farmlands. At the time of the visit, the stopping in the drift near the surface had been opened by TCMA. Another stopping had been constructed at the bottom of the drift and was found to have an accumulation of water in front it, which was believed to have prevented gas emission from the mine. By examining the hydrogeology of the drift, CCRI believed that the water might have come from an aquifer near surface. To confirm the hydrological conditions in the mine, preparation work was undertaken to drill a large diameter borehole from the drift into the main roadway. Ventilation facilities have been installed to provide fresh air to the drilling site near the bottom of the drift. Figure 8 shows the entry to the abandoned drift.

The limited available information and observations from the site visit indicated that the gas reservoir at Wangjiahe mine would be too small to support a large-scale commercial project. This site, which was chosen by CCRI for carrying out some fundamental studies, could be developed for a small technical demonstration project to obtain essential operational experience and development principles for other schemes in China.

Fieldwork carried out by CCRI Xian branch is summarised in section 4.3.

3.1.2 <u>Field Visit to Shengli Mine, Fushun</u>

Fushun lies in the east of Shenyang, the provincial capital of Liaoning Province, about 30km from the gas pipeline network of Shenyang. Fushun Coalfield has an area of 40km^2 with an average coal seam thickness of over 40m and depth of 600-850m. There has been extensive coal mining activity over the past 100 years in Fushun, and to protect the city from mining induced surface subsidence, two deep coal mines, Shengli and Longfeng, were closed respectively in 1975 and 1999. The visit in Fushun concentrated on a site visit to assess the potential and practical options for the development of an AMM project at the closed Shengli Mine.

Shengli Coal Mine started production in 1901 with a production of 1.8Mt/year. This mine has a complex system with a combination of drifts (at shallow depth) and shaft extensions at depth to 7 mining levels linked to longwall panels. There are at least 7 entries to this mine, all of which are believed to be intact and presently used either for ventilation or for de-watering purposes. Currently, this mine is still partly ventilated and used for pumping water from the nearby West Openpit.

Site visits were made to the entrance of two abandoned drifts to Shengli Mine. Figure 9 shows surface entrance conditions of one of the drifts.

In the Fushun Mining area, methane is currently extracted from nearby Laohutai Mine using underground drainage. This gas is then purchased by Shunyang CBM Co. Ltd., and mixed with liquid petroleum gas and transported to Shenyang City via a 32km long, 37 mm diameter pipeline. There are excellent surface storage and transport facilities, including gas pipelines and a mixing and pressurisation station, all managed by Shunyang CBM Limited. A visit was made to this company and its facilities while in Fushun. Figure 10 shows the gas mixing station and the gas holder in Fushun.

While in Fushun, the project team had discussions with mine personnel and identified a number of key issues that have to be addressed to assess the AMM potential in Shengli mine, including:

- collation of factual information on the layout of the coal mine
- detailed geology, hydrogeology and mining records
- confirmation of details of the current water pumping scheme
- consideration for future engineering measures to allow water and gas extraction
- market considerations and options for gas use.

During the visit, only limited data was made available to the team regarding the abandoned Shengli Mine. All the entries to the mine are likely to be left open (or with simple stoppings) for some time in the near future and used for either de-watering or ventilation purposes. Fushun has excellent infrastructure for gas storage and transport as well as a market, but the complexity of the mining operations and surface features would make the extraction of methane from the abandoned mine difficult, if not impossible.

A one-day workshop was held in Shenyang to introduce AMM schemes and key technologies developed by UK organisations. The workshop was well attended by engineers from Fushun, Tiefa, Shenyang and Fuxin in Liaoning Province and representatives from Heilongjiang Province.

The visit was concluded with a meeting in Beijing attended by the UK team and all the Chinese partners and representatives from Liaoning, Heilongjiang, and CICETE.

It was observed from this visit that the concept and the potential of AMM schemes have attracted the attention of research organisations, coal mine administrations, CBM companies as well as government bodies such as the Ministry of Science and Technology of China. Valuable knowledge has been gained by the China team in aspects such as site investigation, gas monitoring and testing, gas reserve assessment procedures and engineering methods for mine closure to assist subsequent AMM exploitation.

3.2 UK Visit by China Project Team

The Chinese team visited the UK between 25th November and 2nd December 2001. The principal objective of this visit was to gain a first-hand understanding of the UK technologies and assess their suitability and commercial technology transfer potential to China. The Chinese delegation consisted of six key staff from CCRI, CCII, FCMA and TCMA.

The visit focused on the following aspects:

- innovative gas capture and utilisation technologies developed by UK companies
- power generating facilities
- advanced techniques for AMM resource assessment and extraction.

The team visited the following locations:

- the former Hem Heath Colliery site, where site emission monitoring was taking place
- the gas extraction scheme in Silverdale operated by Octagon Energy
- the StrataGas AMM site at the former Bentinck Colliery
- markham and Shirebook projects operated by Alkane Energy
- University of Nottingham, where a presentation was given by MAN B&W Diesel Ltd on gas burning reciprocating engines for power generation.

The UK activity was concluded by a visit to Future Energy Solutions (FES) the managing body of the UK DTI's Cleaner Coal Technology Transfer Programme.

This visit provided the Chinese team with an opportunity to see the operation of commercial AMM schemes in the UK. The team gained improved knowledge on the many technical issues relating to AMM projects, ranging from site identification, resource and reserve assessment, gas extraction methods, modern control and monitoring systems, and options for gas utilisation to the dynamics of the gas market. The team's attention was also drawn to the valuable lessons that UK companies have learnt from AMM projects.

Further details on this visit are given in Appendix 2.

3.3 UK Visit by a delegation from Heilongjiang Province

As part of the project extension, a Chinese delegation from Heilongjiang Province of China visited the UK between the 21st - 28th April 2002. The principal objective of this visit was to examine the development of AMM schemes in the UK. The delegation was particularly interested in the key technologies, government policies and their suitability and commercial transfer potential to Heilongjiang Province.

The Chinese delegation was headed by a Deputy Director of Heilongjiang Provincial Planning and Development Commission, and consisted of staff from Hegang Coal Mining Administration, Heilongjiang Provincial Geology Bureau.

Visits were made to the Octagon Energy AMM project in North Staffordshire, the external facilities of the 9.5MW power station located at the former Holditch Colliery, the former Hem Heath Colliery site (where a production test simulating the actual mine extraction process was undertaken), and the Alkane Energy Shirebrook Green Energy Park. The visit was concluded by meeting the project management team at FES in Oxford.

The visit provided the Chinese delegation with the opportunity to obtain a deep understanding of UK technologies and assess their suitability to the mining and market conditions in Heilongjiang. Specifically, this visit enabled the team to examine technology status, market development and associated policies/incentives that could help promote such schemes in China.

A report on this visit is given in Appendix 3.

3.4 China visit 2 - Field Visit to Hegang and Jixi

Following the visits to Tongchuan and Fushun, a request was received from the planning and development commission of Heilongjiang province to carry out an additional site study at Jixi and Hegang to assess AMM potential in some of their coal mines. The Commission made the necessary arrangements, in collaboration with the Provincial Geological Bureau, for Wardell Armstrong and CCII to carry out a brief field study at these mines. This work was then followed by a project extension, allowing the project team to visit Hegang and Jixi in Heilongjiang Province between 12th and 20th May 2002. The specific objectives of this visit were to gather data, view the closure mine sites, explain the technology, discuss engineering aspects and examine gas market conditions in this province. Sites visits were made to Nanshan Mine and the closed Xinyi mine in Hegang, and a surface methane extraction plant at the closed Mulin mine in Jixi. The visit was co-ordinated by the

provincial development and planning commission and supported by the Provincial Geology Bureau, Local Governments and Coal Mining Administrations. Figure 11 shows the location map of Jixi and Hegang in Heilongjiang Province.

A report on this visit is given in Appendix 4.

3.4.1 Visit to Hegang Coal Mining Administration

Hegang Coalfield lies about 572km from Harbin in the north east of Heilongjiang Province. Coal has been mined in this area for over 85 years. There are 8 production coalmines with a total production of 12Mt per year. Financial constraints are forcing a series of mine closures. One mine has ceased production, two have been closed and the closure of three more is planned. The closed Xinyi coalmine was the focus of this field visit. Figure 12 illustrates the locations of major coalmines in Hegang.

Coal seams in Hegang Coalfield are late Jurassic in age, consisting of 41 seams, of which 36 are workable. The total coal thickness in the succession varies from 38.5m to 85.8m and the total area of the Hegang Coalfield is $252km^2$. Table 6 summarises the major coal seams and their gas parameters.

Visit to Xinyi Coalmine:
Xinyi Mine started production in September 1955 with a designed capacity of 0.9Mt per year, lately increased to 1.8Mt per year. It ceased production in June 1999 and was officially closed in November 2000.

Following a presentation by Hegang Coal Mine Administration, a site visit was made to the abandoned Xinyi Mine. Figure 13 shows the surface features of a shaft at Xinyi mine.

The total mine 'take' is 6.5km x 2.88km, with a total area of $18.73km^2$. There are 30 coal seams with a total thickness of 85.8m, and a geological reserve of 581.47Mt. The mine has produced 55Mt of raw coal with 467 Mt of reserves remaining. The average overburden thickness is 30m—550m. There are 16 entrances to the mine - 5 shafts and 11 drifts - and 4 production levels at depths of 140m, 340m, 540m and 740m respectively. Mining methods employed are primarily longwall retreat with total roof caving. Within the 'take' of Xinyi mine, there are 30 small mines, of which 21 are in production and 9 have been closed. Most of these mines are believed to be connected with Xinyi mine by cracks or fractures as a result of mining activity, as summarised in Table 7. Total water inflow is estimated at about $1000m^3hr^{-1}$ ($100m^3hr^{-1}$ for level 1 and $500m^3hr^{-1}$ hour for levels 2 and 3 respectively). The sources of mine water are from the strata, coal seams and rainfall.

The total goaf area is estimated by the Mining Bureau as $10.2km^2$ but a significant proportion of the mine is flooded. According to available data and observations, Xinyi mine is flooded below 340m from the surface.

Other problems were identified in the continuing small-scale shallow mining operations which use part of the Xinyi mine to access the coal and for ventilation. This would require further consideration if the mine were to be sealed while still allowing access.

Also, the water pumping regime would need to be assessed in detail. Although the mine had been closed, the surface infrastructure is still in place and so any AMM scheme would have to consider both the costs and practical engineering problems of removing these structures.

The UK team suggested that further consideration should be given to the evaluation of pumping costs and the engineering works required to allow the continued shallow small-scale mining operation to continue. Information was requested on the area of workings not flooded to allow further assessment of gas potential.

The team also visited the nearby Nanshan coalmine to examine the methane drainage facilities and technical capability which could be used to facilitate the development of an AMM project. This mine has a well-established local pipeline network for methane extraction, storage and supply. There are also four gas-holders in this area, with a total capacity of 45,000m^3. Nanshan mine is producing 21.3m^3min^{-1} pure methane from its pre-drainage system. Presently, the gas is used by 20,000 households, with an average consumption of 25,000-30,000m^3 per day. Additional residential and industrial customers (600 boilers in Hegang) are present and consideration is being given to explore this market for gas use.

3.4.2 <u>Visit to Jixi Coal Mining Administration</u>

Jixi mining area is located in the eastern part of Heilongjiang province, covering an area of 3078km^2. Jixi has 82 years of mining history, with 10 production mines and a capacity of 10 Mt pr year. At the end of 2000, Jixi had 6 abandoned mines - Mulin No.2, No.3, and No.6, Hengshan Drift, Xiaohengshan, and Datonggou Mine. Total production capacity of these mines is 2.4 Mt per year, with 360Mt of coal unmined. Further mine closure is planned for Didao and Erdaohezhi. Figure 14 shows the mine locations in Jixi.

Visit to Mulin Mine

Mulin mine was started in 1957 with production commencing in 1958 with modest production of 60,000 tonnes per year. Total coal production from the mine was some 10million tonnes. Longwall caving methods had been used at the mine. Water ingress was reported to be about 50m^3hr^{-1} (1200 m^3 per day). The mine was relatively gassy having a specific emission of 10 m^3t^{-1}.

Mulin mine had a total of 5 mine entries into the underground workings, three of which had been treated (infilled). Figure 15 shows two drift entries to Mulin Mine and the surface conditions. The drifts were kept open to allow access to the mine for salvage work.

The UK team was concerned with the manner in which the mine would be sealed. The method proposed by the local Chinese team would involve building a brick wall about 100m down the drift and then back-filling to the surface with colliery spoil. Another wall would then be build at the surface. The walls will not be keyed back into the natural strata and no roadway support will be removed. As used in shaft infilling, spoil will be end-tipped down the open shaft and a cap will be possibly placed at the surface, although in most cases this is not done to allow top-up of the fill. The UK team commented on the proposed sealing method and explained that, in the UK, problems had been experienced using such techniques with air ingress back into the mine when suction was applied. The UK team provided details on a number of options for improving the performance of mine seals and which involved little extra cost.

The limited available information indicated that Mulin mine would not be a suitable AMM site as little de-stressed coal was left above the worked seams. Water inflow was also high and would result in a rapid recovery of water levels within a small area of the abandoned workings. However, the Bureau believes there is a great potential in the area for the development of CBM, AMM and CMM projects. A large market exists in Jixi City which is planning to submit an application to the state government for assistance in developing CBM extraction and use. This will require a large investment in both surface and underground infrastructure, purchase of equipment and management and design costs.

It is understood that other larger mines (Didao and Erdaohezhi) are planned to close in the next one to two years, although little information was available at the time of this visit.

3.4.3 A Brief Visit Summary

On returning to Harbin, the UK team was welcomed by the Planning and Development Commission. Initial findings were presented to the Heilongjiang Planning Commission. In summary:

- Hegang Mining Bureau had collated and presented the required quality of base data to allow an initial appraisal to be undertaken of the closed Xinyi mine. They had clearly demonstrated that they understood what information was required to undertake a pre-feasibility study for a potential AMM project.
- Xinyi mine had all the required characteristics for an AMM project in terms of the volume of de-stressed coal and gas contents but the level to which water had recovered would reduce the available gas. A number of issues needed further consideration, in particular the impact of small-scale shallow mines, water pumping costs and the cost of removing existing surface infrastructure and forming effective gas tight seals at the surface.
- Mulin mine had no potential for an AMM project as there was little de-stressed coal in the mine, i.e. no gas resource. The UK team introduced their experience from the UK and raised concerns that the proposed method of sealing the mine entries would allow air ingress. Design options based on UK experiences were also presented to the Chinese team.
- Other mines in Jixi that were planned to close in the next 2 years, in particular Erdaohezhi and Didao mines, may, subject to a review of information, be suitable for AMM development.

The UK team suggested that if Heilongjiang Planning Commission intends to support the development of this type of technology they needed to undertake a pre-feasibility study of all the mines in the Province so that the best sites could be identified.

3.5 AMM Workshop in Beijing

To disseminate the findings from the project, a one-day workshop entitled 'Exploitation of Methane from Abandoned Mines–Resources, Technologies and Commercialisation' was held in the Landmark Hotel, Beijing, on 21st May 2002.

The workshop was organised by CCII and attended by over 40 delegates from some six Provinces, including eight Government organisations and consultancies, an EU-Chinese body, and 15 coal companies and Bureaux. Mr J R Buckley, DTI Trade Promoter, attended the workshop on behalf of the UK DTI's Cleaner Coal Technology Transfer Programme.

The workshop included a formal opening session, two technical sessions (morning and afternoon, each having 5 presentations), and a session for discussion and questions. Papers presented in the workshop were published in the workshop proceedings which are available from CCII.

Further detail on the workshop is given in Appendix 4.

3.6 China Visit 3 - Field Investigation in Hegang and Jixi

Following the visit to Hegang and Jixi and the workshop in Beijing, a proposal was submitted to the UK DTI Cleaner Coal technology Transfer Programme, which was subsequently approved, to support another extension to allow a further field investigation to Hegang and Jixi, with the aim of taking the present project to a pre-commercial stage.

With the assistance of PDCH and Hegang and Jixi Mining Administrations, a field study was undertaken by UoN between 17th – 21st October 2002 to Hegang and Jixi. Further information was collected for Xinyi and Dalu in Hegang, and Datonggou and Erdaohezhi in Jixi. Assisted by CCII, this information was then interpreted by Wardell Armstrong and a report prepared covering:

- an appraisal of the potential AMM sites short-listed by the local coal mining administrations and UoN
- a specific project site study proposal and outline schedule
- a suggested project structure and roles for consultants and contractors.

This report is given in Appendix 5. The report will be presented to the Heilongjiang Planning Commission following completion of translation into Chinese and arrangements for continuing liaison and feedback from the project will be made.

4. IN-HOUSE AND FIELD STUDIES

4.1 University of Nottingham (UoN) and Wardell Armstrong (WA)

In-house studies in the UK have focused on the techniques and methodologies that are presently used by UK AMM operators of abandoned mines to assess the potential of AMM resources/reserves. The study also concentrated on UK experience in the location, selection, extraction and commercial development of AMM from abandoned coalmines. Practical procedures and advice, including the development of a methodology capable of assessing gas reserves from an abandoned mine, were introduced to Chinese partners. Comparisons have been made between the geological and mining settings in China and the UK and some general site selection principles have been established (as shown in Table 4) for favorable AMM projects.

In addition, studies have also been carried out in collaboration with the Chinese team, on the available data collected from China field visits to Wangjiahe Coalmine in Tongchuan, Xinyi and Dalu Mine in Hegang, and Datonggou and Erdaohezhi in Jixi.

4.2 China Coal Information Institute (CCII)

The main project task for CCII was to focus on the study of coal mine methane utilisation options, the evaluation of AMM potential at selected coal mines and market assessment in general. Appendix 6 provides an executive project summary by CCII.

Information and data acquisition was achieved by:

- **Literature survey:** extensive literature has been studied using in-house facilities and databases. Additional information and data has been collected from conference proceedings, research papers, monographs and articles from periodicals.

- **Site visits:** visits have been made to China Coal Research Institute (CCRI), Fushun Branch; Fushun Coal Mining Administration, Tiefa CMA, CCRI Xian Branch; Tongchuan CMA, Jixi CMA, Hegang CMA and Yangquan CMA and other CMAs.

- **Questionnaires:** to investigate coal mine closures and methane emissions in China, a set of questionnaires was specifically designed and sent to all major Coal Mining Administrations. Questionnaires were received from 82 state-owned key coal mining administrations, of which 69% have abandoned coal mines. Over 30% of these Administrations expressed their strong interest in the extraction of utilisation of methane from abandoned coal mines. Appendix 7 lists the questionnaire prepared by CCII for this study.

On the basis of the above information, CCII has undertaken the following in-house studies:

- **Status of CBM/CMM recovery and Utilisation in China's Coal Mining Areas**: Since the 1950s, in-mine methane drainage has been carried out in China. Up to 1999, coal mine methane recovery activities had been carried out in 151 coal mines with annual methane recovery up to 789 million m^3. China's coalbed methane resources are up to 30-35 trillion m^3. At present, 35 coal mining areas started or are implementing CBM exploration drilling or trial production drilling.

- **Coal Mine Closure Conditions in China:** Since 1997 China has been implementing a mine closure programme targeted towards small mines and state-owned mines with depleted resources, poor safety and environmental protection records. Most of these coal mines are high gassy coal mines. Up to 1998, China has closed 459 state owned key coal mines and over 47,000 small coal mines. Abandoned coal mines are mainly distributed in areas with long history of mining, especially Northeast China and Southwest China such as Jixi, Hegang, Liaoyuan, Beipiao, Shuicheng, Yongrong, Tianfu. Many of these abandoned coal mines had serious gas outburst problems before they were closed.

- **AMM Resources Estimation Methods:** Conventional methods for methane resource calculation in operating coal mines were studied and a method for calculating gas reserves in abandoned mines proposed.

The following method was used by CCII for its calculations:

Proven AMM reserves = in-situ gas resources – gas emitted by ventilation – gas recovered by drainage
= coal reserves _ in-situ gas content - gas emitted by ventilation – gas recovered by drainage

- **Abandoned Coalmine Information Database:** This information database contains information and data concerning abandoned coal mines in more than 80 coal mining administrations around China. This database has the following functions: (1) information and data storage; (2) retrieving relevant information and/or data on the basis of a certain known fact; (3) making statistics and analysis according to certain information and data.

- **AMM Potential:** Based on the questionnaires and feedback information, analysis and assessment have been made for the development potential of the abandoned coal mines and AMM resources in China's state-owned coal mines. It is estimated that coal reserves remaining in abandoned mines and in gob areas of operating coal mines are over 30 billion tonnes. The proven mine methane reserves are estimated up to several hundred billion m^3.

- **Preliminary Estimate on AMM Resources in Selected Key Coal Mining Areas:** Of the 82 key coal mining administrations investigated, CCII has made preliminary estimates on AMM resources in coal mines that are identified as promising sites. These areas include Tongchuan, Fushun, Shuicheng, Yongrong, Tianfu, Nantong, Yangquan, Fengcheng, Hegang and Jixi. Table 8 shows the AMM reserves estimated by CCII in some of these identified coal mines.

- **AMM Extraction and Utilisation Prospect - Case Studies**: Using an in-house developed economic evaluation model, two case studies have been conducted for the abandoned coal mine gas drainage and utilisation projects in Fushun and Tongchuan.

The study and information collection by CCII provided a useful database from which further investigations can be conducted by interested parties to identify favorable AMM sites in China. The study also raised the awareness and attractiveness of commercial AMM schemes in China, an area that has been ignored to date.

4.3 China Coal Research Institute (CCRI)

CCRI Xian Branch has focused their effort on site-related technical issues with abandoned coal mines. The abandoned Wangjiahe coalmine in Tongchuan Coal Mining Administration has been selected for fieldwork and fundamental parameter studies. Appendix 8 provides an executive project summary by CCRI Xian Branch.

CCRI has conducted extensive work in the following aspects in Wangjiahe Coalmine.

- **Geological conditions**
  Detailed studies were undertaken on the following:
  Stratigraphy: Geological settings of the strata in the coal mine were mapped out. The strata in ascending order are shown in Figure 16.
  Structure: Major geological structures such as folds and faults were identified and described. Figure 17 shows the geological structures within the mine boundary.
  Coal-bearing property: All the coal-bearing strata in the Wangjiahe mine field were identified and are given in Figure 7 as well as the basic characteristics of all coal seams.
  Hydrogeology: The aquifers and aquifuges in this area (as shown in Figure 16) are identified as the Quaternary bottom alluvial aquifer (water discharge is $0.006 m^3 s^{-1}$) and the Shiqianfeng Formation sandstone fracture aquifer (water discharge is $0.053 m^3 s^{-1}$). The production level (550m) in Wangjiahe mine is higher than the water level of the Ordovician water. The mine water flows to the depth from the main roadways located in the limestone and the fracture and karst located in other limestone layers along the dip. The karst and fracture in the Ordovician limestone are the main drainage sites for the mine water.
  Geological features of methane: Wangjiahe mine is the only gassy mine, the relative gas emission range from 2.3 to 47.9 m^3 per tonne, averaging $22.59 m^3$ per tonne, a magnitude of 10-20 times greater when compared with other mines. The measured gas pressure on the working faces in Wangjiahe mine ranges from 6.5 to 10.2 atmosphere.

- **Characteristics of AMM reservoir**
  Thickness of coal seams: Coal seams within the mine take are unstable and thickness varies largely, and the total thickness of coal seams ranges in 0.1-4.5m, as shown in Figure 18. A seam thickness contour map was also prepared for the No.10 seam and the mine goaf area clearly marked. The elevation of coal seam is from 830 to 400m, but generally between 700 to 450m. The elevation of the abandoned mining area ranges from 700 to 550m, as shown in Figure 19.
  Gas Content*:* Gas content measurement were not made. Based on the data provided by the Wangjiahe mine, it is calculated that in the range of 375-530m of the buried depth of coal, the gas content is in the range: $1.9\text{-}6.4 m^3 t^{-1}$. Gas content of No.5 seam in other mines in Tongchuan mining area was measured at $4.76\text{-}8.13 m^3 t^{-1}$. As Wangjiahe mine is a highly gassy mine, a gas content of $6 m^3 t^{-1}$ as the average value in Wangjiahe is adopted.

  In addition, studies were also carried out on adsorption isotherms, coal petrological fracture characteristics, strata permeability and gas reservoir pressures. Adsorption isotherm curves, based upon tests on No.10 seam from Tiaoyuan mine (which is less than 5km from Wangjiahe Mine), are shown in Figure 20, which were used for calculating the residual gas resource.

- **Goaf area and coal reserve estimation**
  The location of the abandoned coal mine of Wangjiahe mine in the minefield is shown in Figure 19. The total goaf area is estimated as $4.06 km^2$. Based on the "three zones" theory, it is calculated that within the entire mining disturbed area, the total remaining coal resource (including the mineable and unmineable seams) is 2479.03×10^4 t. Table 9 shows the estimates for each seam.

- **Ground water study and mine gas sampling**
  Considerable effort has been made to gain access to the abandoned drift which was selected for gas emission monitoring and potentially for gas extraction in the future. Special ventilation facilities have been arranged to ventilate the section down to the stopping inside the drift to allow the examination of connections to underground voids. While trying to gain access to the mine, water accumulation was found in the drift at elevation level 631m. To ascertain the flooding degree of the entire mine, a borehole was drilled from the inclined shaft to link up with the main haulage roadway, and to investigate whether the flooding has occurred in the main haulage roadway. The schematic map of the borehole location and borehole completion is shown in Figure 21.

  Following the borehole drilling and analysing the information on mine hydrology, it was believed that the main roadway has not been flooded, or if there was water within the roadway, it would have not linked up with the water at the drift bottom.

  Gas samples were collected from the borehole linking up the drift and main roadway. The first gas sample was collected when the casing was completed. In total, four sets of gas samples were obtained. The analysis of these gas samples are given in Table 10a. The data indicated that methane concentration at the time of sampling was high in the abandoned coal mine.

  On 10th November, 2 sets of gas samples were collected from the casing mouth and 8m below the casing mouth. The results are listed in Table 10b. The data indicated that the methane concentration in the collected gas samples was lower than the first set of gas samples. It was believed that the bottom part of the borehole may have collapsed (casing part only 8m) and therefore separated from the main roadway, and prevented mine gas from escaping into the borehole.

- **AMM Resource Estimation**
  Effort has been made to estimate the gas-in-place and technically recoverable resources using calculation methods based upon the mass conservation law, concentration of methane in goafs and the residual gas pressure theory in adjacent seams. Two methods were used by CCRI to estimate the AMM resource:

  (1) Mass Conservation Law:

  $$Q_p = Q_i - Q_1 - Q_2 \qquad [2]$$

  Where, Q_p - the present total gas resource in mine; Q_i - the total gas resource under in-situ condition, which was estimated as: The total remaining coal resource x in situ gas content = $2479.03 \times 10^4 t \times 6 m^3 t^{-1} = 1.4874 \times 10^8 m^3$; Q_1 - the total gas resource discharged during mining, which was estimated as 0.9617_$10^8 m^3$ based on the ventilation data and production records in Wangjiahe Mine; Q_2 – gas resource loss after mine closure, which was estimated about $0.2324 \times 10^8 m^3$.

The calculated gas in-place Q_p = 1.4874_10^8m^3 − 0.9617_10^8m^3 − 0.2324_10^8m^3= 0.2931_10^8m^3

(2) Free State Gas and Residual Gas Pressure Theory in Adjacent Seams:
The total gas resource in the mine Q_p consists of free state methane and adsorbed state methane, i.e.:

$Q_p = Q_f + Q_a$ [3]

Where Q_f - free gas in the goaf area, which is calculated as: The volume of goaf area x methane concentration in the goaf = 3 Mm^3 x 50% = 150 x 10^4m^3; Q_a - total adsorbed gas in the remaining coal, which was calculated on the basis of the residual gas pressure curve and the isothermal adsorption curve, as shown in Figure 20. The residual methane content of various seams was calculated and presented in Table 11, giving the total adsorbed gas in the remaining coal $0.27\times10^8m^3$.

The calculated gas in-place $Q_p = 2737.84\times10^4m^3 + 300\times10^4m^3 = 0.30\times10^8m^3$
The difference from two methods is insignificant and considered rational.

The calculated technically recoverable resource is 0.22×10^8 m^3 (assuming the negative pressure of the suction pressure can attain 0.5 atm. pressure, i.e., 0.05Mpa). Table 12 summarises calculated results of the technically recoverable resource from all gas bearing sources.

- **Key parameters for identification of a favorable site**
  Based upon UK experiences and knowledge acquired through this project, a set of key parameters have been identified by CCRI for the selection of favorable AMM sites in China. These include:

  - the gas in-place resource and technically recoverable gas resource
  - the permeability of coal and rock beds
  - the condition of underground roadway and suction shaft/drift
  - mine hydrogeological conditions, in particular mine water
  - extraction technology, productivity and suction period prediction
  - passive and active gas monitoring
  - surface conditions and gas storage/transmission pipeline
  - local gas market and gas price
  - impact on environment and safety.

In addition, CCRI Xian Branch has made several field investigations in Hegang and Jixi (Heilongjiang Province), Fuxin and Shenyang (Lioaning Province), and Yangquan (Shanxi Province). CCRI also obtained the support of the State ‘10th Five-year Plan’ to undertake further research on development and utilization of AMM. It is hoped that the fundamental research and field investigation work at Wangjiahe coalmine will lay the foundation for an AMM demonstration project and therefore promote such schemes in other areas of China.

This is the 2nd Cleaner Coal Technology Transfer project that CCRI Xian Branch has collaborated with the UK team. The team from Xian Branch has been involved in all the project field activities in China and UK. They have obtained an excellent understanding of the major technical issues involved in the development of an AMM project and acquired practical expertise and field experience to assist such schemes in China.

4.4 China University of Mining and Technology (CUMT)

CUMT has focused on the examination of the conventional methane gas resource assessment methodologies and examined how these techniques could be adapted for abandoned coal mines. CUMT has also developed a conceptual computer visualisation model to assist the development of an AMM project in abandoned mines. Appendix 8 provides a project summary by CUMT.

Major work conducted by CUMT include:

- **Methane storage and transport models:** A critical review of the existing mathematical methods and theoretical models of methane storage and transport in porous coal seams and strata has been conducted to develop a model that could be used to understand the mechanism of methane emissions from abandoned coal mines.
- **Coal mine methane prediction models:** Two evaluation methods and theoretical models for predicting coal mine gas in production mines have been studied to develop a method for predicting gas resources in abandoned mines.
- **Gas prediction case studies:** The above method was used to predict emissions in Li district of Xinzhuangzi Coal Mine, the closed Shengli and Longfeng Coal Mines in Fushun and Wangjiahe Coal Mine in Tongchuan.
- **Methane emission monitoring and prediction:** Effort has been made to correlate the available monitoring data reported in the literature (Cote, 2000) with a numerical model to predict gas reservoir behaviour and gas production potential from an abandoned mine.
- **Computer visualization:** to improve the understanding of AMM schemes, a 3D computer visualisation has been developed to illustrate the process of methane extraction and utilisation from an abandoned coal mine. The model was created on the basis of typical abandoned mines in China.

During this project, CUMT has been involved in all the field study activities in China. They have obtained a good understanding of the key technical issues in an AMM project, in particular, AMM resource and reserve estimation. By adopting conventional CMM prediction methodologies, CUMT has developed a set of numerical equations which could be used to interpret field monitoring data to assist the assessment of AMM reservoir production potential.

5. BENEFITS ARISING FROM THE PROJECT

5.1 Mine Closure in China and AMM Technology Transfer

Since 1997 the Chinese government has launched plans for reducing production capacity and closing coalmines that are illegal or cannot meet safety standards. It is an important strategy to close resource-depleted state-owned coal mines, thus helping restructure the coal industry and relieve these coal mines of poverty. The importance of CMM (including AMM) development of energy supply, environment and mine safety has been recognised by coalmines, local and central governments.

By 1999, China had 94 key state-owned coal companies and about 600 coalmines, of which 1/3 were ageing mines. Statistics has shown that at least 460 key state-owned mines have been abandoned, with an estimated 30 billion tons of coal left in abandoned workings and gob areas of working mines. By the end of 2000, 65 key state-owned coalmines have been approved by the State Council to close, of which 33 mines have been undergoing closure appraisal of legal procedures, and most of these mines have completed the preparation work for closure. Some of these coalmines are very gassy and may have potential for methane gas extraction and utilisation.

In the UK, initial assessment indicates that of the 900 abandoned mines (since 1947), only 100 to 200 are likely to have any AMM potential. Of these, probably some 25 to 50 are commercially viable at present. Based on the field studies in this project, China seems to share a similar situation, i.e., the number of abandoned mines suitable for AMM schemes would be significant less than initially anticipated. Due to mining, geological and technological conditions, the use of extensive longwall caving mining methods has been limited in Chinese coalmines and consequently the extent of de-stressed seams and gob areas. Many of the closed Chinese coalmines tend to be at shallow depth with multiple entries, which would remain open after closure.

It is worth noting that the concept of abandoned or closed coalmines is viewed quite differently in China from that in the UK. In China, the closure of a large deep coal mine owned by the state would have to be approved by the central government. It has been observed during this project that even after the closure of a mine, it can still be used for other purposes, for instance, de-watering for adjacent mines or ventilating for shallow mines, and in some cases, re-opening for coal mining again by local operators. This can further complicate the development of AMM scheme. Nevertheless, strong interest in developing AMM schemes has been observed during the interactions with China.

For safety reasons, China has over 40 years of experience of methane drainage from operating coalmines. Various methods have been developed in China for draining gas from underground coalmines including horizontal boreholes, surface gob wells and cross-measures boreholes. Most of the methane recovered is used for heating and cooking at mine facilities and nearby residences. Methane is also used for industrial purposes, in the glass and plastics industries, as a feedstock for the production of carbon black, and to a lesser extent, for power generation. Technically, China has the resources and capability to develop AMM projects.

Presently the major driving force for AMM scheme in China would be the environmental and social benefits. Many old mining areas have been undergoing enterprise restructure in order to enhance its competitiveness in the market and as such aging coalmines with poor economic records would have

to be closed and people made redundant. The state-owned abandoned coalmines are mainly distributed in China's old mining areas, especially in the northeast part and southwest part of China. The development of AMM extraction and utilisation in state-owned abandoned coalmines will be beneficial to the improvement of local environment, employment, social stability and inward investment, and therefore has appeal to local governments and mine administrations.

In addition to visits by technical representatives from China, officials from governmental organisations also visited AMM schemes in the UK. There are positive indications that the success of AMM projects has been recognised at a certain level within the administration and financial supports and incentive policies to fundamental research and initiation of a demonstration project are becoming available.

There has been no track record of extracting methane from abandoned mines in China. Like other CBM/CMM project in China, the lack of local infrastructure and a market development means that potential AMM schemes also require capital investment to initiate and therefore may not be appeal to the private investors. The AMM-to-power-scheme developed by UK companies is innovative and unique and is believed to have great potential of technology transfer to China. Presently the market for most CMM schemes in China are in the local domestic sector and these schemes suffer from seasonal variability in demand. The likely option for an AMM scheme would be forming part of an existing mine-related CMM system by stablising the gas supply to meet requirements by industrial users. Supports from the Chinese Government or international aid appear to be needed to kick-start such projects.

5.2 Benefits to the UK

This project has been strongly supported by the UK partners and associated organisations. This project will bring the following benefits to the UK industry:

- recognition by China that UK is the leader in AMM schemes and can offer a range of AMM technologies, equipment, expertise and consulting services
- strong and consolidated contacts and market positions in China to initiate a demonstration project using UK technologies
- opportunities for the design, assembly, installation and commission, or leasing of entire AMM plants involving both extraction and power generation facilities
- identification of specific AMM projects in China with the potential for UK investment in AMM production, distribution and utilisation
- improved opportunities for the supply of gas monitoring and control systems, pump testing and associated equipment.

5.3 Benefits to China

Following the previous CBM technology transfer project with China, this project has provided further opportunities for Chinese experts and representatives to gain insight into the AMM schemes developed in the UK. Major benefits to China include:

- identification and recognition of the fact that large quantities of methane exists in some abandoned coal mines, and which can be captured and utilised in an environment-friendly and commercial way

- recognition that AMM schemes have been successfully developed in the UK and this technology is transferable to China
- awareness of the scale of coalmine abandonment in China and the social, environmental and economical benefits that can be gained from AMM schemes
- understanding of the key technologies, methodologies, procedures and principals in selecting a favourable AMM sites
- appreciation of the importance to consider the market and other commercial factors when developing AMM schemes
- anticipation of operational difficulties, market barriers and government policies and their impact on AMM developments
- improved contacts with UK companies and organisations for intermediate and long-term collaboration
- technical preparation for AMM projects in China - a Chinese team with improved technical and communication capability to promote AMM schemes in China.

6. CONCLUSIONS AND RECOMMENDATIONS

Methane emissions from abandoned coalmines pose a threat to the environment and safety in the vicinity of the mining areas. The pioneering work carried out by companies in the UK has proven that this hazardous industrial waste product can be harnessed and used as a valuable green energy resource for generating electricity and heat, thus reducing the overall global warming burden on the environment.

The climate for the commercial development of AMM projects in the UK has changed significantly in recent years. The introduction of the Coal Act in 1994, which clarified the gas ownership problem, combined with de-regulation of the electricity supply and distribution industries, has removed the principal regulatory barriers to CBM and CMM development in the UK. In addition, environmental considerations, in particular concerns about greenhouse gases, have also provided an impetus for capturing coalmine methane that might otherwise be vented.

The extraction of methane from abandoned coalmines has the advantage that the permeability of gas-bearing strata has been greatly increased as a result of extensive mining activities. Nevertheless, not all abandoned mines are suitable for such schemes. Successful project development at abandoned mine sites will require both adequate methane quality and quantity and an identified gas user. Mine water rebound and air ingress due to shallow workings and poor seals would have to be addressed at all stages of an AMM project.

Most UK AMM schemes use methane on-site to generate electricity using spark ignition engines, with the rest providing methane to end users using dedicated local pipelines. The stand-alone AMM-to-power-scheme developed by UK companies has strong appeal to the Chinese. The various options available for AMM use include power generation, on site use in boilers and space heating, and local low pressure pipeline supply to industry or domestic consumers. It is likely that such schemes would be integrated into an existing CMM system to make gas supply more reliable and attractive in terms of mine safety, environment and financial viability.

The project extensions have added extra value to the original planned work in allowing representatives from Heilongjiang province to examine and understand the AMM project development in the UK. The workshop provided a platform for the dissemination and discussion of key issues and broad prospect of AMM project development. The field visits to Jixi and Hegang provided the opportunities for the project team to gather field data for the pre-feasibility study, explain the technologies and examine specifically the abandoned coalmines and their suitability for AMM projects.

Technologies for the location, extraction and commercial utilisation of methane from abandoned coalmines, has been successfully developed in the UK. This project has introduced the concept and relevant technologies associated with such schemes into China. Valuable knowledge has been gained by the Chinese team in aspects such as site investigation, gas monitoring and testing, gas reserve assessment procedures and engineering methods for mine closure to assist subsequent AMM exploitation. It was generally accepted that there are no significant technical problems to the development of AMM projects. UK companies are well placed in China and there are opportunities to provide technologies and associated equipment, provided that successful demonstration commercial projects are developed following a proper process of project development and planning.

In China, most of the small illegal mines and many of the older mines using other mining methods other than longwall faces have no AMM potential. The study and analysis to date has indicated that none of the project sites appear to be capable of supporting a major commercial AMM extraction and utilisation scheme. Most sites exhibit features which would make air-tight sealing difficult to achieve although some extraction of gas at small suction pressures might be possible. As many mines in China, in general, will have similar conditions, an experimental project can be justified to determine the potential for gas recovery in such conditions. Such a project could be carried out at Erdaohezi mine in Heilongjiang Province to examine how to adapt the proven UK AMM technology to suit more difficult gas extraction conditions in Chinese mines, although there could be many other sites which have not yet been identified. Depending on the results of initial testing, the experimental project could be extended into a semi-commercial utilisation trial.

Presently, coal makes up the bulk, over 63%, of China's primary energy consumption, and China is both the largest consumer and producer of coal in the world. Historically, natural gas has not been a major fuel in China, but given China's domestic reserves of natural gas and the environmental benefits of using gas, China has embarked on a major expansion of its gas infrastructure. In short term, CBM projects (including AMM schemes) are unlikely to make a huge impact on the Chinese energy market at a national level. It is, however, likely to have an impact on local energy structures, particularly in areas with coal mining history. The future prospects of AMM in the UK and China, and elsewhere, will depend on the ability of schemes to deliver gas to meet customer requirements whilst at the same time generating a profit for the operator. The national and local energy market for gas use is continually changing and schemes must be flexible to accommodate these changes to maintain customer satisfaction.

In China and the UK, a number of deep coalmines have been closed and this trend is likely to continue over the next few years. The commercial attractiveness together with the environmental benefits of extracting gas following abandonment have been recognised by the coal industry. There is a need to develop a systematic procedure which can be implemented while these mines are in operation, with the consideration of incorporating appropriate engineering measures to maximise the recovery of methane gas from worked out areas, as well as the control of hazardous gas emission following mine closure. These measures would include:

- ground water control measures to prevent parts of the mine becoming isolated and divert water flows
- engineering measures to effective seal surface mine entries and the inclusion of pipework through well constructed surface caps and stoppings
- installation of monitoring systems at strategic points within the abandoned workings to monitor water levels and gas concentrations.

The number of open mine entries suitable for gas extraction is likely to be limited, regardless of other factors. Most future AMM schemes will access the abandoned workings by boreholes drilled from the surface to intersect the underground roadways. To ensure that the target roadway is intersected, guided drilling techniques will be used. The use of this technique provides greater flexibility for access to the underground workings, surface location and gas supply at the point of end use, e.g., AMM schemes can be developed adjacent to the customer.

The development and success of AMM schemes in the UK in a highly competitive energy market has demonstrated to the energy industry and financial markets, the potential for small-scale AMM schemes to operate commercially. A number of UK operators have been successful in raising funds

to develop and expand their business activities. Partnerships between AMM operators and energy suppliers continue to be developed strengthening the market for the extraction and use of AMM.

Increasing importance is attached by government, industry and the public for measures to reduce greenhouse gas emissions. Planned changes in the energy market relating to climate levy charges and emissions trading is likely to offer further encouragement for AMM use focusing on its “green” image. Europe, and the UK in particular, probably leads the world in AMM production. These schemes have yet to realise their full potential in the UK and certainly there is an overseas market for technology transfer. Such utilisation schemes should be encouraged by governments and international aid agencies, particularly in China.

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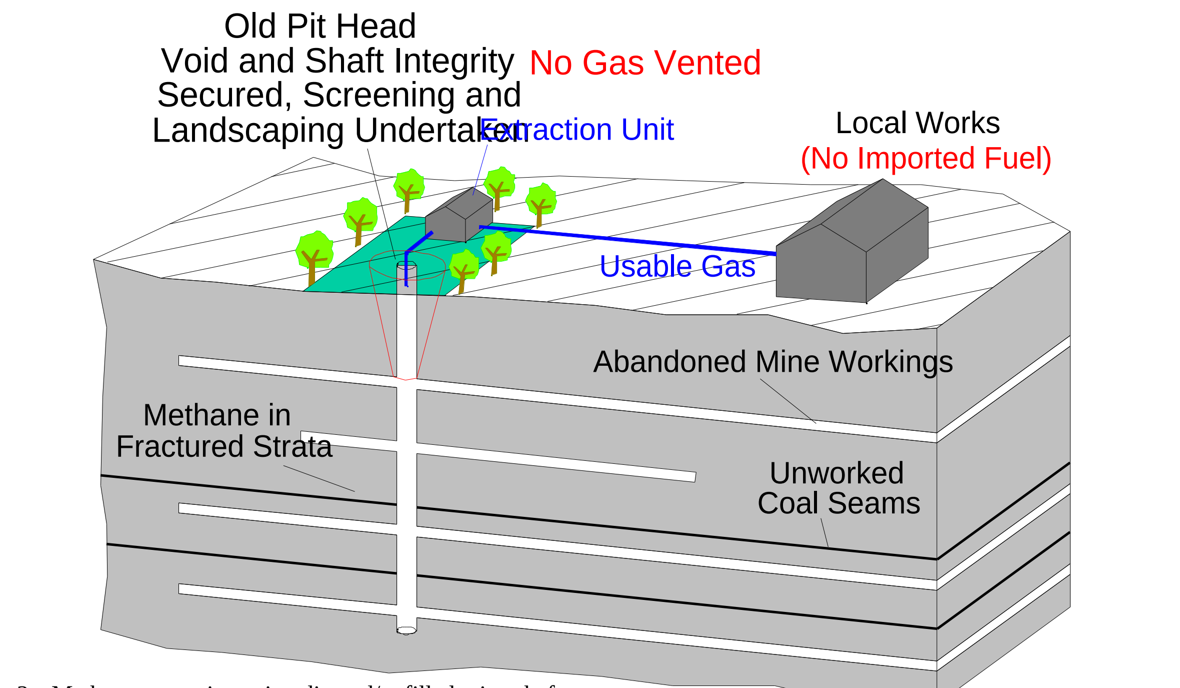
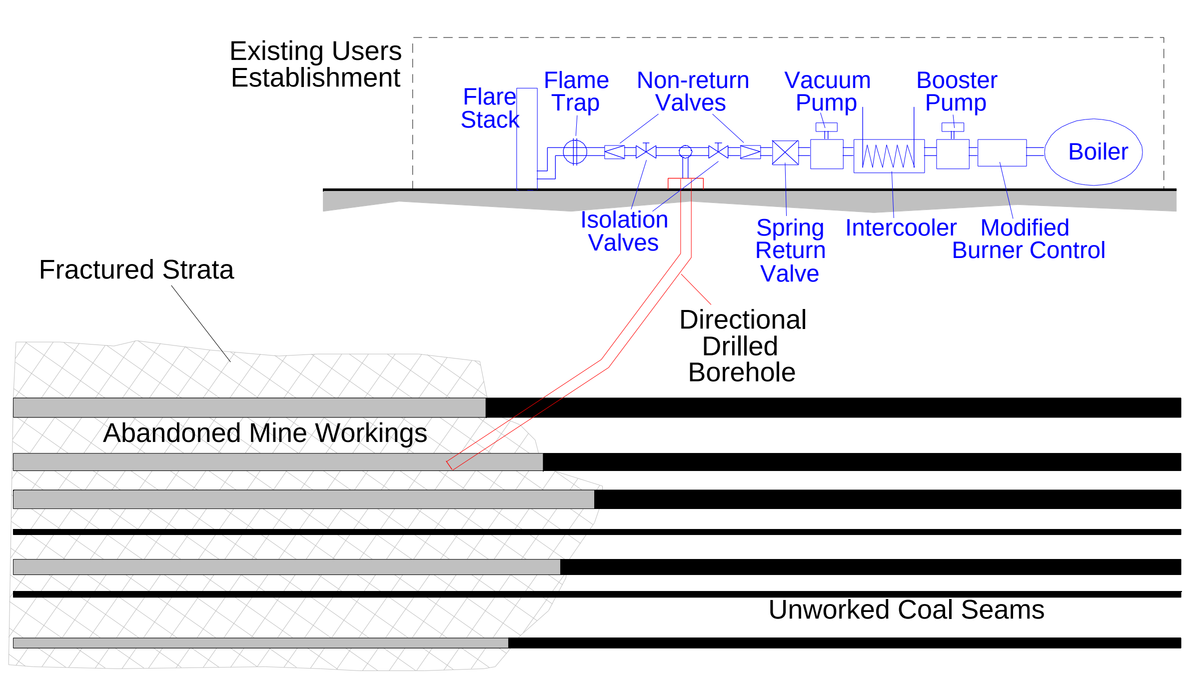
Figure 1. AMM scheme development - production test at a former Colliery



2a. Methane extraction using disused/unfilled mine shaft



2b. Methane extraction using.boreholes drilled into old workings or de-stressed gob areas

Figures 2a/b. Concept of methane extraction from abandoned coal mines
(Courtesy of Alkane Energy PLC)

Figure 3. AMM scheme at the Shirebook Green Energy Park

Figure 4. Gas extraction House at the former Silverdale Colliery

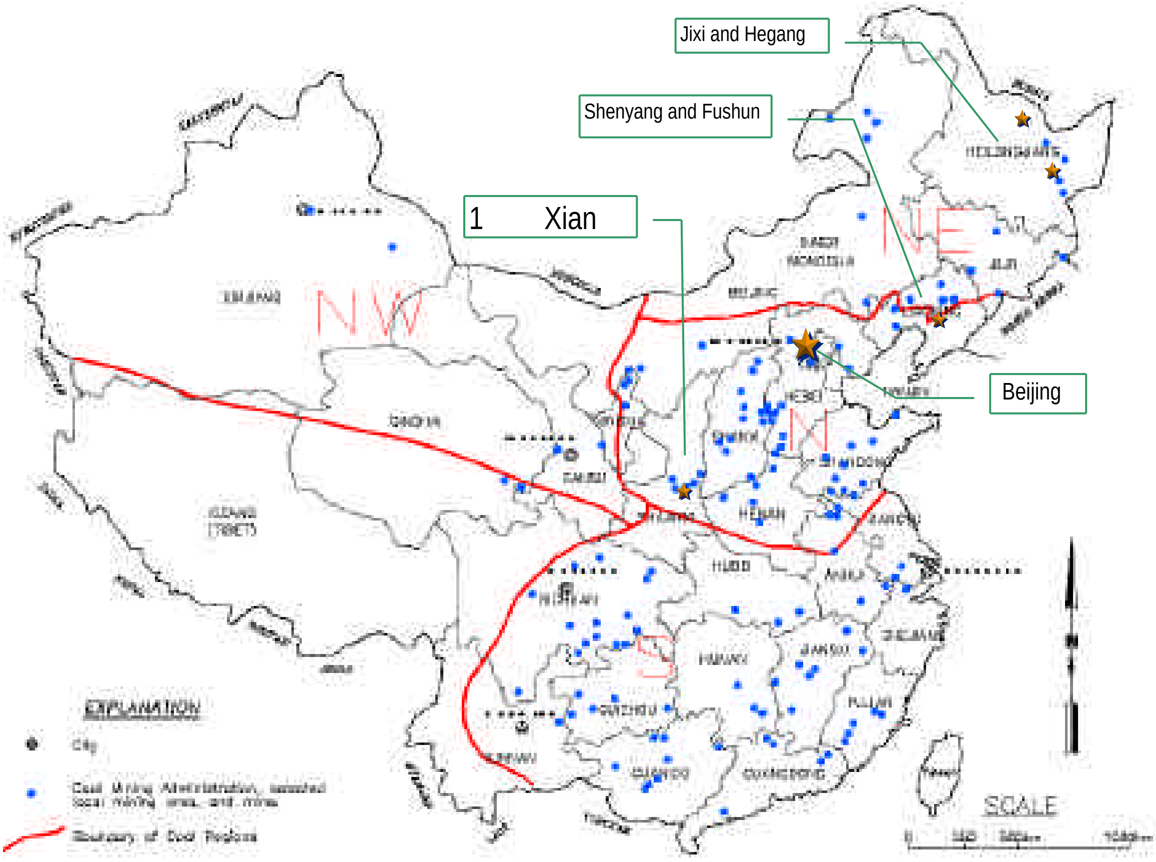


Figure 5. Locations of UK team field visits in China

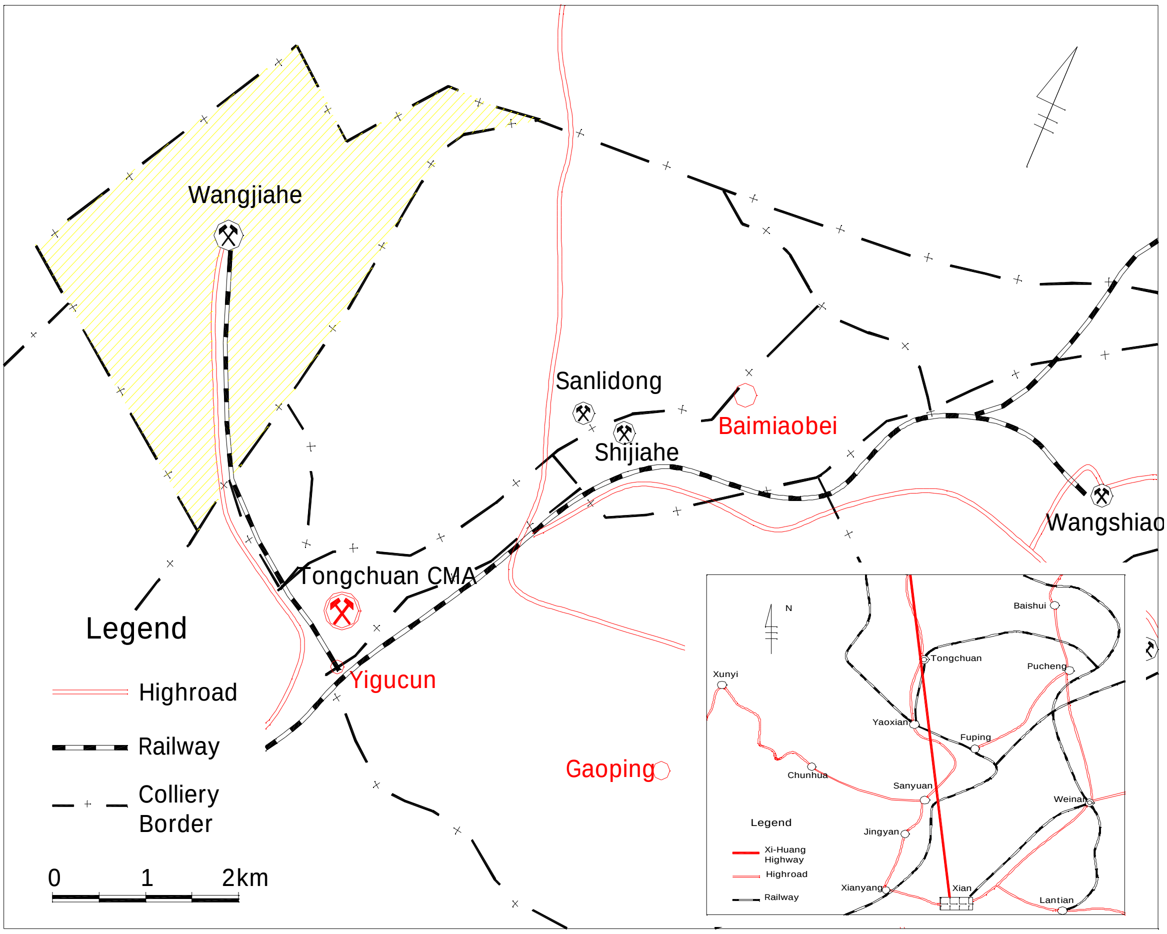


Figure 6. Location map of TCMA and Wangjiahe Mine

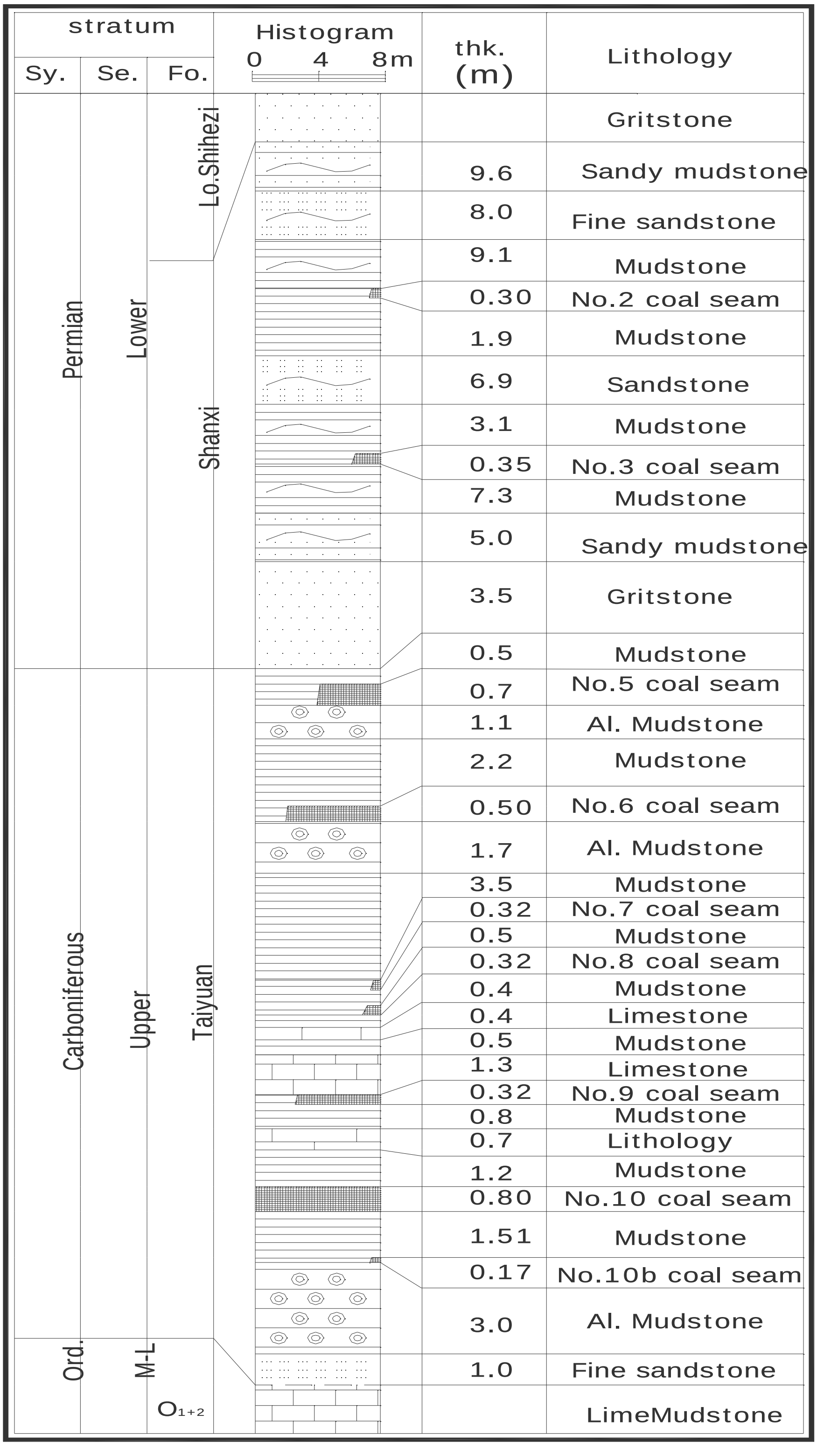


Figure 7. A generalised stratigraphy section of the coal-bearing strata in Wangjiahe Mine