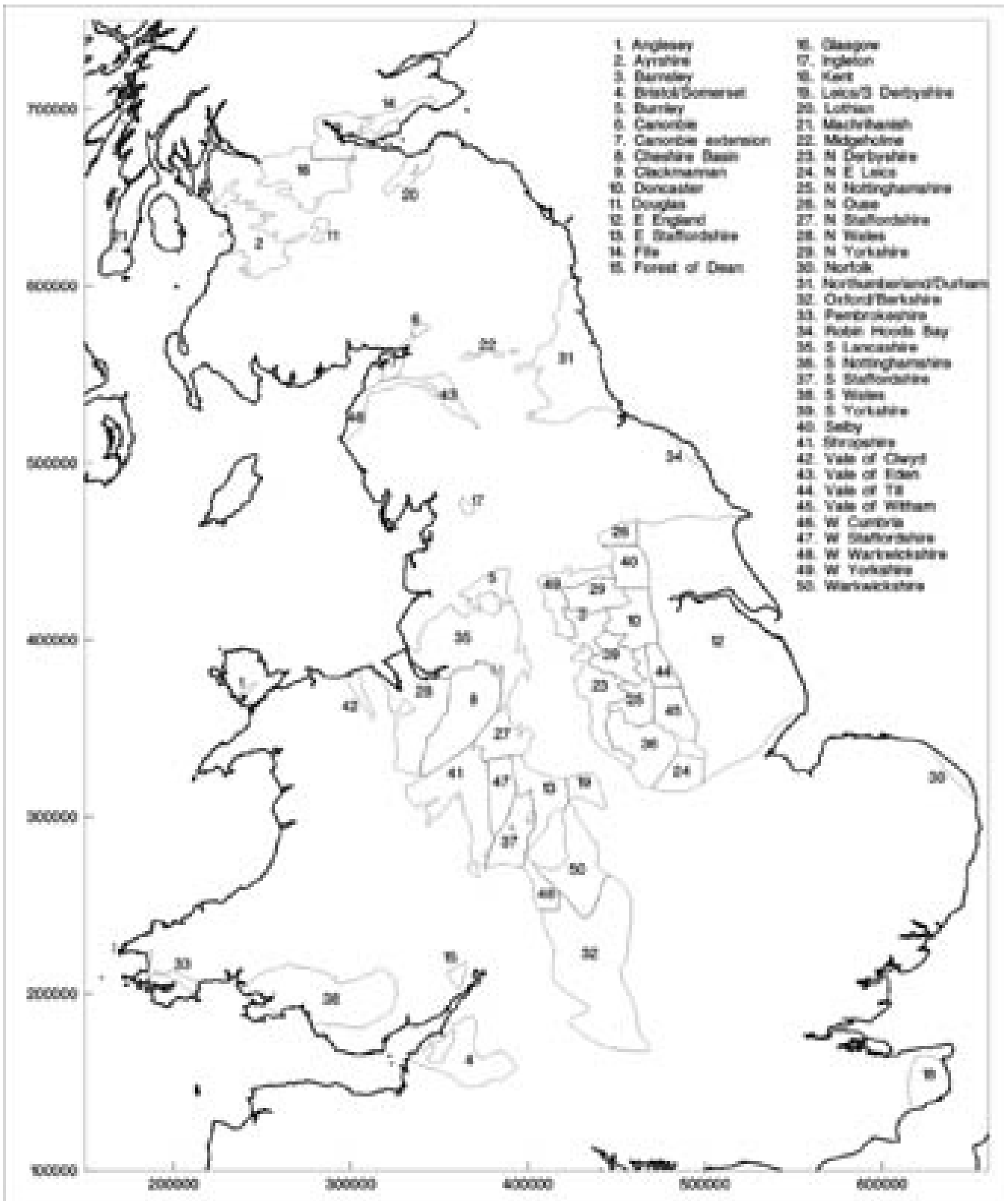

Figure 1: UK coalfield areas

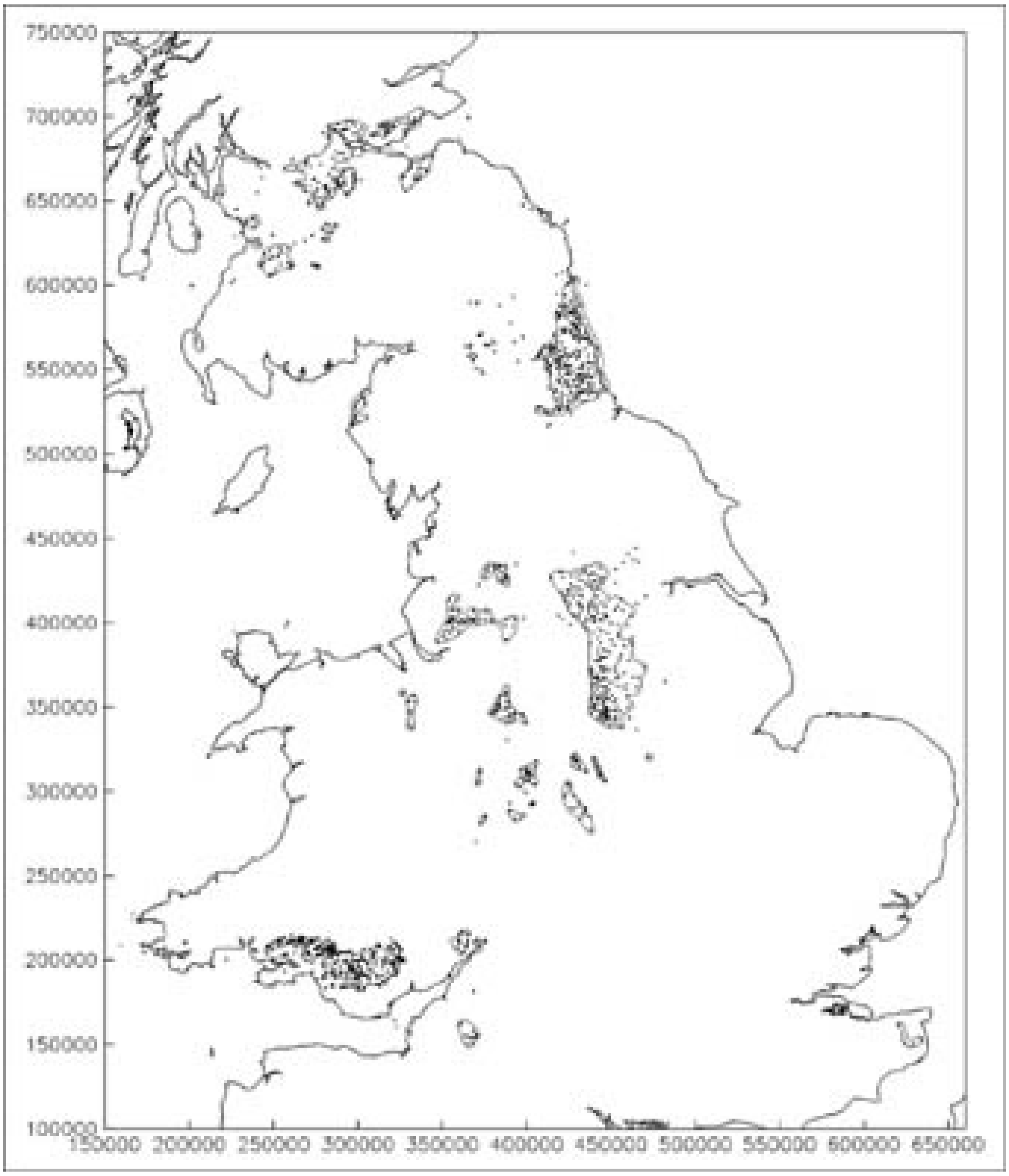

Figure 2: Approximate extent of underground coal mining in the UK

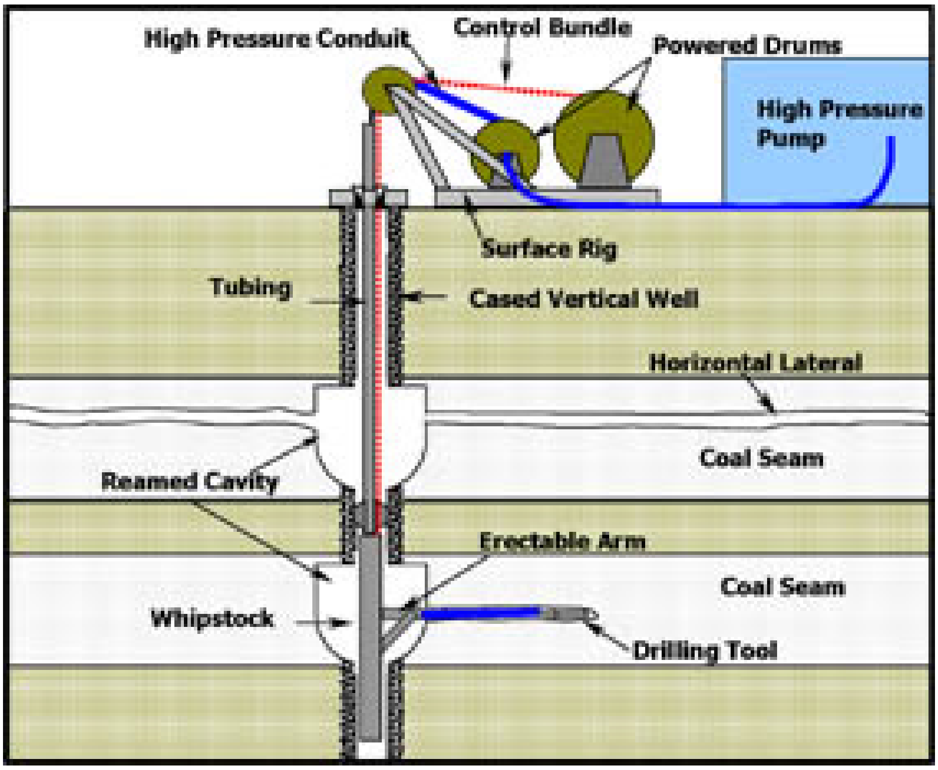

Figure 3: Schematic of the tight radius drilling system.

APPENDIX 1
NOTES ON THE 2nd Annual CBM and CMM Conference, Denver, Colorado, USA, 27-28 March 2001

Introduction

The conference was attended by between 175 and 200 people over a 2 day period with speakers representing industry, research, regulation, policy and environmental issues present. The main topic of discussion was the need in the USA to respond to demand for gas use and to develop its gas industry. CBM is seen as a key element in meeting future gas demands. The increase in gas prices over recent months had renewed interest in CBM exploration and extraction in both existing and new locations.

CBM and CMM face the same challenges as other extractive industries although a number of issues, notably the use and disposal of water, requires further consideration by both industry and the regulators. Regulation has historically been a State matter although there are calls for it to come under federal control.

The direction of the CBM industry, and the US as a whole, on greenhouse gas emissions is unclear with the President recently announcing that the US government will not support any policy which may put added costs on an already difficult energy market. However, CO_2 credit trading is already happening in the US as international companies respond to the global market. Industry is looking very closely at the UK and European experience.

At present about 75% of energy market in the US is met by coal with the world-wide consumption of coal accounting for about 50% of the energy market. Gas drainage techniques are needed at many mines for safety. In the US gas capture from operational mines, termed CMM, has remained constant over the last decade although gas utilisation has increased from 25% to 85%. Most of the gas drained is treated prior to injection into distribution pipelines. While drained gas use has increased to high levels there is significant potential to increase the use of gas contained within the ventilation air and this is an area that advancements in technology should be encouraged.

In the US the term CMM traditional applies to the capture of gas from operational mines by both pre and post drainage techniques. However, there is interest in the extraction of gas from abandoned mines as practiced in the UK. Coal companies are starting to look at revenue from gas sales as part of their business plan, eg, as an energy company rather than a coal producer. Traditionally the market for gas has been for pipeline quality gas and technology has developed to remove nitrogen, carbon dioxide, oxygen and other gases. With the consideration of gas from abandoned mines other end use options are been considered.

Energy Policy

The USDOE outlined the fact that use of gas in the US would grow and that there was strong support from government to develop gas reserves as the use of gas seen as a clean energy. Due to its reduced emissions when compared with coal it is considered the prime fuel for power generation. Natural gas accounts for about 25% of the US energy market with gas consumption predicted to rise by 62% by 2020.

In some locations additional gas is available to the market but insufficient infrastructure is restricting distribution. A number of ‘bottle-necks’ in the national distribution system have been identified and action is needed to be address these problems. Significant gas reserves are available in parts of the US although infrastructure is not in place to allow effective distribution. The construction of new pipelines from such places as Alaska, where gas was presently been re-injected into depleted oil fields, is required as a matter of urgency.

Discussion are on going at government level about the development of a national energy policy to ensure that resources are made available to control the continuing rise in energy uses.

Market Factors

Market conditions in the US have shifted dramatically in the last 2 years with the price of gas rising from about $2 per Mcf too as high as $9 per Mcf. Average gas prices are about $5 Mcf and it is predicted that this price level will be sustainable in the immediate future, with any change in trend likely to be upward. It is suggested that the shortage of clean fuel will maintain this price into the future. The CBM industry is anticipated to account for some 10-12% of gas use by 2010.

The change in gas prices has seen existing operation becoming more profitable and renewed interest in CBM and CMM exploration and extraction. A number of leading independents in the oil and gas industry have acquired an interest in CBM operators, eg, Marathons purchase of Pennaco. CBM is considered an economic alternative gas supply. The interest in CBM operations together with the price rise has resulted in additional resources becoming available to operators looking to expand their existing operations and also develop new areas.

The market for gas from operational mines CMM has traditionally been for pipeline quality gas with other uses including boiler fuel, industrial processes, heating and electrical power generation. The energy market in the US favor’s the sale of gas as a pipeline quality product. Opportunities exist to use more gas for power generation in particular when considering an abandoned mine gas project. The end use of the gas will be determined by local and national market conditions which prevail at the time. Changing energy needs and advancements in technology need to be continually assessed.

Drilling and Completion Technology

Drilling and completion technologies continue to develop with a clear recognition by the industry of the need to consider alternative options not only in different basins but also in adjacent wells. The use of technology varies greatly from the simple shallow wells with little stimulation in the Powder River area to the use of high tech multi fracced operations in the Raton Basin.

The development of technology and a greater understanding of well performance has seen many wells which were considered exhausted re-stimulated to extend their production life. It is anticipated that the use of such techniques as coil tube fraccing developed for CBM in the UK will have wide spread use in the US.

Alternative drilling techniques using guided holes to drill in-seam has been identified as having significant potential in the US for both CBM wells and also as part of the gas drainage needed for safe coal production CMM. Guided drilling may allow coals to be exploited where surface access is restricted and also at depth where existing coal stimulation techniques may not be appropriate. Consol, one of the leading CBM and CMM operators is planning a number of test holes in 2001.

Halliburton's drilling subsidiary Sperry-Sun will carry out some of the drilling using their rotary steerable system. A specialist drilling operator, CDX gas, have demonstrated the use of surface to in-seam guided drilling technology in US coals although the precise details of the technology and application at this stage are confidential. While no detailed assessment can be made of the effectiveness of guided drilling technology a number of key players in the CBM and CMM industry see this technology as vital to exploiting coal reserves, particularly at depth.

Water Disposal

Water disposal is becoming ever more controversial forcing CBM operators to look at disposal options and the potential use in a commercial setting for the water. A number of disposal options where identified including:

- Disposal to land
- Injection wells
- Off-site disposal
- Evaporation
- Specialist disposal

Water disposal to land is the preferred option on an economic basis. In some coal basins water quality is of a drinking water standard and creates little problems, however, poor water quality can be found in coal basins which require an alternative disposal method. The development of a new generation of down well injection pump which do not require the water to be brought to surface, but where hydrogeological condition prevail, injects the water into the targeted disposal horizon within the production well is being followed with interest.

CBM water can be saline and this can provide an opportunity to use the water on a commercial basis for dust control on unpaved roads and for construction purposes (concrete additive) and highway construction.   This is particularly attractive to CBM sites which are often situated in remote mining areas where there is little infrastructure. As while any treatment process effective management control of all aspects are needed to ensure that its use has no detrimental effects on the locality. Verification of the process by analyses monitoring and sampling is essential. Each project will need to consider the economics of treatment and revenue as against disposal.

The discussion on water issues was broadened to include comments from a landowner whose property had been adversely effected by water disposal from a CBM operation in the Powder River basin. A water disposal plan had been developed to control water flow onto farmland and into the water course. As elsewhere in the Powder River basin water makes from CBM wells are in excess of those originally envisaged. The water disposal plan has not been modified to meet these increased water makes and this has resulted in damage to the land through excess flow and contamination.

The example identified a number of issues, many of which could have been avoided through effective management and regulation of the CBM activity. As with all CBM operation the need for good communications is illustrated.

Following a controversial court case in Alabama the EPA are to undertake a review of the effects of hydraulic fraccing on water quality. The study will examine a number of reported incidences and will be subject, following representation from industry, state and government, to external peer review. There is concern that regulatory powers will be moved from individual States to the EPA. It was suggested that such a move would be harmful to the CBM industry as the EPA would be unable to provide the flexibility offered by the individual states.

Project Management

Successful CBM and CMM projects need effective management of financial and operational aspects. The development of many successful CBM and CMM projects indicates these skills are present but it was suggested a more robust methodology should be adopted for all projects:

- Conceptual Engineering – gathering relevant information to assess all potential scenarios to enable a design to be developed
- Project Front End Loading – planning in advance to minimise risk
- Capital Expenditure – covering all elements of the project from land acquisition, drilling and well completion costs, infrastructure and environmental issues
- Operational Variables – to include safety, environmental, personnel, maintenance and water disposal
- Long Term – operating parameters, fixed and variable costs, project expansion, operating efficiencies and economics of scale, cost control and market conditions

Environmental Issues

As part of the environmental debate gas emissions from operational mines were discussed. A representative of the EPA coalbed methane outreach program stated consideration was being given to the emissions benefits of flaring gas at mines where the use of the gas is impracticable and that a trial project was proposed. There are a number of barriers to such a move with safety being the priority.

Alternative Uses

Research is on going into the conversion of gaseous feedstocks, including CBM, to produce Dimethyl Ether (DME) a diesel substitute. DME is a clean fuel with reduced particulates and NO_x emissions. Gaseous fuels have been used in the past to produce methanol although this fuel does not work well in conventional engines. DME is seen as having a number of advantages and a pilot project is to start shortly testing its use as diesel alternative. DME has been tested by General Electric in gas turbines and certified as an acceptable fuel. BP is to construct a DME plant in India using natural gas as a feed stock and contracts are in place to supply 10 million tons of DME by 2010.

Gas Clean Up

Technology already exists for the enrichment of CBM to pipeline quality through the removal of nitrogen, carbon dioxide, oxygen and other trace gases using sieve techniques. Technology is continuing to develop with the Molecular Gate at the fore of technology. The Molecular Gate separates gases by the size of the molecules using a titanium silicate sieve filtration to separate the gas components, the targeted molecules are absorbed while the large methane molecules are excluded. In practice methane is the largest molecule at 3.8 angstroms, with nitrogen (3.6), carbon dioxide (3.3) oxygen (3.5) and other gases like hydrogen sulphide less than 3.8. The pore size of this new sieve can be adjusted.

A number of different technologies are available to improve gas quality to meet pipeline specification. Each system designed on the amount of clean up required to the gas source. Where gas quality is poor, eg, from an abandoned mine or operational mine the cost of clean up may require alternative options such as electrical power generation to be considered.

Carbon Dioxide Emissions Reduction

No formal trading system is presently in place in the USA regarding CO_2 emissions. However some companies are already trading CO_2 credits with over 100 transactions reported. Market opportunities exist for CBM and in particular CMM. The US has traditionally taken the view that emissions trading can make environmental solutions to pollution problems economic. The US is paying attention to Europe and in particular to the UK to assess the benefits and practicality of systems to be introduced shortly.

In the global market a number of US companies are involved in trading CO_2 credits to reduce the risk if a CO_2 policy was developed and implemented in the US or elsewhere. With no guidance from government on what is needed industry is taking the lead, although there are concerns about the value of some credits. BP and Shell have developed internal markets which forces parts of the company to make the necessary investment, or else services are purchased outside the company.

CMM extraction and use is seen as having significant potential for CO_2 credits. The costs of such credits could make marginal projects financially attractive. The main problem at the moment is to determine what constitutes a credit and of what value and vintage. Example arguments include:

1. Gas is extracted from a surface pre drainage borehole prior to mining. If not captured in this way the gas would have been released at the time of mining? Some gas would have been captured in the drainage system and some in the ventilation air. What is the value of the credit, eg, all the gas and when should it be valued from, time of capture or when it would have been released by production?
2. Gas is extracted from an abandoned mine by applying suction to a vent. If this had not been done would all the gas have been emitted to the surface and over what period of time? What would be the effect of rising water on the total emissions? On what quantity of gas is the credit given and from which date, natural emission or that captured via the AMM project?
3. Gas from the drainage system is flared at a mine. This process will only reduce some of the emission. What value should any credit be awarded? Similarly when the gas stream contains gas from older parts of the mine the timing of credits is uncertain.

Based on similar emission trading schemes third party verification of the process is seen as critical. Without guidance from government, CO_2 credits linked to CMM, as discussed above, will be difficult to assess.

Industry needs to look at CO_2 emissions and decide its role.

Why be a Buyer

- Hedging risk, currently credits have a low cost
- Develop credit portfolio
- Proprietary trading
- Policy development
- Green public image
- Learn by doing

Why be a Seller

- Maximise financial return on asset
- Improve cash flow
- Finance projects
- Fund technology
- Brand recognition
- Policy development
- Learn by doing

A detailed evaluation of CBM and CBM emissions and the potential financial revenue of CO_2 credits was outlined including the effects on revenue streams for various rates of emission and CO_2 credit. The vintage of any emission reduction has to be clearly shown. Validation will include review of gas quality, quantity and time of release together with other operational factors.

Powder River Basin

The development of VCBM in the Powder River basin has been one of the major success stories over the last few years. The basin had previously been assesses and discounted due to its apparent low gas content. This initial assessment followed the then CBM industry view of site selection criteria based on the San Juan and Black Warrior basin experience. Subsequent development of the Powder River basin has led the industry to reassess how its evaluates CBM potential sparking renewed interest in other coal basins and areas previously considered unsuitable.

The Powder River basin is a relatively simple geological structure with coal seams in excess of 20ft thick at depths of between 175ft to 1600ft. The shallow depth of the coal has allowed initial CBM development to use relatively simple water well drilling equipment with a 600ft well typically costing $60k to $80k and deeper wells $120k. Well completion involves setting the casing above the target coal seam and then under reaming the coal to increase surface contact area. A water pump is set and de-water is commenced. At present only one seam is targeted at a time due to concerns about controlling water migration between different horizons.

The coal has a relatively low gas content but permeability is very high from 900 to1000mD. This high permeability means the coal has a high water content but once de-watered gas recovery of between 67% to 80% is anticipated. It is the extreme permeable nature of the coal that was previously overlooked - if you can affect a large area and achieve efficient recovery, gas content may not be critical.

VCBM experience in the Powder River basin has identified three main issues relevant to the whole CBM industry:

- The need to develop infrastructure with sufficient capacity to match output and demand
- The environmental and practical logistics of drilling 5000 plus CBM wells per annum
- Disposal of water.

Other Opportunities

Results of drilling exploration were presented which indicated that there was a significant CBM potential in Alaska. Exploration had to date been limited to around existing pipeline infrastructure. Alaska has significant natural gas and CBM resources. Although at present protected from further exploration the government has stated that to meet the US energy needs consideration will be given to the development of Alaska’s gas and CBM resources including the need for additional infrastructure.

Gas resources are available off-shore of Florida’s coastline. Due to the tourist industry it is unlikely these resources will be exploited in the near future.

Potential markets outside of the USA were discussed with China and India seen as the main areas of interest. The USA had been involved in projects in China which identified a significant CBM potential with a number of issues requiring further assessment prior to greater involvement:

- Access to market
- Tax position
- Infrastructure
- Coal characteristics
- Government support/participation
- Management and control of projects.

Previously,anthracite coals had been considered unsuitable for VCBM extraction due to the internal structure of the coal and lack of a developed cleat system. However, a number of anthracite coalfields were now identified as having a CBM potential including China’s Qinshui Basin, Jincheng mining area and possibly also the South Wales coalfield in the UK.

APPENDIX 2
WORKSHOP ON TECHNOLOGY FOR THE EXTRACTION AND USE OF CBM, 27 June, 2001

Bullet points used in the presentations.

PROJECT AIMS
- World-wide activities
- UK status
- Innovative developments
- Drivers, barriers and inhibitors
- Way forward

PROJECT TASKS
- Information search
- Consultations
- Survey
- Critical review
- Reporting
- Workshop

OCCURRENCE OF CBM
- Generation during burial
- Storage in coal seams
- Coal seam permeability

CBM SOURCES
Terminology
- CBM - generic
- VCBM - virgin coalbed methane
- CMM - coal mine methane
- AMM - abandoned mine methane

PERMEABILITY CONSTRAINTS

High permeability
- Good for VCBM
- Good for CMM pre-drainage
- OK for CMM post-drainage
- Poor for AMM?

Low permeability
- Poor for VCBM
- OK for CMM post-drainage (longwall)
- Good for AMM (longwall)

COAL SEAM AQUIFERS

- High permeability
- High gas flow potential
- Possible biogenic gas
- Water disposal problem
- Shallow
- Gas content measurements understated

GROUNDWATER AND CBM

- VCBM: remove water, gas flows
- CMM: de-watered for mining but strata water can disrupt gas drainage
- AMM: rising water fills old workings. Gas trapped but too costly to de-water

ENVIRONMENTAL ASPECTS

Benefits

- Greenhouse gas emissions reductions
- Displacing coal use
- Clean fuel
- Waste minimisation

Drivers

- Policy
- Image
- Carbon credits
- Market

Barriers

- Climate change levy

VCBM PRODUCTION

Recent Developments

- New geological potential
- ECBM
- Biological treatment

VCBM TECHNOLOGY ADVANCES

- Clean completion
- Coiled tubing to aid fraccing
- Surface to in-seam drilling

AMM TECHNOLOGY ADVANCES

- AMM reservoir models
- Modularised production equipment
- Monitoring and control systems

CBM PRODUCTION TECHNOLOGIES APPLICATIONS
- Country specific
- Coalfield specific

CBM UTILISATION TECHNOLOGIES
- Boiler fuel
- Pipeline gas
- Power generation - I C engines
  Turbines
  Micro-turbine
  Fuel cells
- Chemical feedstock

CBM UTILISATION CONSTRAINTS
Financing
- Market - customer, price
- Costs - capital, ownership
- Supply
- Regulations
- Risk

CMM USE TECHNOLOGY ADVANCES
- Enrichment
- Flaring
- Use of mine ventilation air:
  Combustion air for IC engines
  ultra lean burn turbines
  thermal oxidiser
  catalytic oxidiser
- Small-scale generation using:
  micro-turbines
  fuel cells

USA
- VCBM dominance (7% of natural gas)
- Water disposal
- Powder River basin
- Raton basin
- New technologies for CMM
- Government assistance

CANADA
- VCBM - large resource (17 - 85 tm^3)
  - good gas price
  - CO_2 sequestration
  - no production
- CMM - no schemes
- AMM - untried

AUSTRALIA
- VCBM support
- CMM - Appin, Tower, West Cliff
- AMM - emissions R&D
- CBM - pipeline, power generation
- R&D

CHINA
- Annual 7% to 8% growth
- 1 billion tpa coal production
- $1x10^{12}$ coal reserves
- 2,400 medium & large mines
- 2,700 fatalities, first half year 2000
- >30,000 mine closures in 1999

VCBM in China
- >200 surface wells
- No commercial production
- VCBM 10 billion m_ by 2010
- 11 PSC's with foreign companies
- Government incentives

CMM in China
- >120 mines with gas drainage
- >50 CMM utilisation schemes
- Domestic CMM uses
- International aid
- Government incentives

AMM initiative – DTI

Opportunities in China
- Foot-in-the-door
- Emissions credits
- Market entry
- Equipment
- VCBM
- CMM
- AMM

Risk Management
- Know business partners
- Due diligence
- Patience

INDIA

- Modest coal resource
- VCBM exploration and incentives
- CMM - 90% mines room-and-pillar
- UNDP, GEF programme
- AMM - untried
- Market?
- Opportunities

COMMERCIAL PRODUCTION

- VBCM - USA, Australia
- CMM - USA, Australia, France, China, UK, Poland, Czech Republic, Germany,
- Former Soviet Union, Japan
- AMM - UK, Germany, USA, Czech Republic
- Pipeline dependency - USA, Australia, China

CBM Activities in the UK

VCBM schemes

- 9 wells drilled up to 1999
- 5 virgin wells drilled
- 3 de-stressed wells
- introduction of clean completion techniques

CMM schemes

- 2 schemes total $22MW_e$
- electrical power generation
    - gas turbine CHP scheme
    - spark ignition engines

AMM

- 6 schemes total $42.5MW_e$
    - 4 electrical power generation
    - 1 direct burner tip use
    - 1 combined generation and direct use

Access for AMM schemes

- 2 unfilled shafts
- 1 filled shaft
- 3 unfilled drifts

Future development

- virgin and de-stressed CBM wells planned
- consideration of options to maximise gas use at working mines
- AMM schemes to use existing mine entries plus access via surface boreholes

CBM Barriers in the UK

Town and country planning
- Lack of guidance
- Grid connections
- Climate change levy
- Drilling regulations
- MDL v PEDL

R & D needs in the UK
- In-seam drilling from surface
- AMM emissions model for credits
- Biotechnological enhancement
- Use of waste heat from generation schemes
- Evaluation of new utilisation technologies
- CMM resources and reserves
- AMM resources and reserves

CONCLUSIONS

- Technology developments in drilling and gas utilisation options
- VCBM prospects not rank or gas content limited
- UK a leader in AMM production technology
- Technologies exist to reduce ghg emissions but incentives needed
- Relative importance of VCBM, CMM & AMM varies from country to country
- Overseas opportunities for UK firms.

APPENDIX 3
GREENHOUSE GAS EMISSIONS TRADING

Introduction

Emissions reduction is being targeted on the premise that rising concentrations of carbon dioxide, methane and other gases released by man's activities will lead to irreversible climate changes detrimental to mankind. International emissions trading would enable reductions achieved in one country to be offset against emissions targets in another country. The Kyoto Protocol allows for international emissions trading to operate from 2008. However, the rules have not yet been defined. For instance, there could be a requirement to set and adhere to actual carbon dioxide targets rather than allow the total flexibility of carbon dioxide equivalents

A voluntary trading scheme is to be introduced into the UK to encourage cost-effective delivery of greenhouse gas emission reductions. Those businesses achieving emission savings can sell their credits to companies who are net emitters to enable targets to be met. It is anticipated that the domestic trading will start in April 2001 (DETR, 2001).

Emission credits

A value or 'credit' can therefore be assigned to the environmental benefits of some CBM schemes by measuring greenhouse gas emission reductions achieved as a result of the operations.

A carbon, emission or greenhouse gas credit is a measure of a specific greenhouse gas emission reduction. It is usually represented in tonnes of carbon or of carbon dioxide equivalent. The global warming potential of methane is 21 times that of carbon dioxide (100 year time span) and $71.5m^3$ of methane is equivalent to 1 tonne of carbon dioxide (Fernandez, 2000).

Current carbon credit trading is purely speculative as there is no legislative basis. However, some companies are purchasing credits to control risk. There is a strong possibility that binding emission targets could be set by individual countries at some time in the future in accordance with the Kyoto Protocol (or some variant introduced to mollify the USA). Once binding or voluntary targets are agreed, the cost and value of credits are likely to increase considerably.

Natsource in London (2001) have brokered some 100 transactions amounting to some 45 million tonnes of carbon dioxide equivalent although not necessarily related to CBM sources. A US broker reported approximately 20 million tonnes of carbon dioxide traded in 1999 (Fernandez, 2000).

Trading is arranged by brokers and the price is based on the purchaser's perceived value of the credit. The current price (March 2001) ranges from \$1.0 to \$2.5 per tonne of carbon dioxide equivalent (Natsource, 2001).

CBM Application

Mine gas (CMM) projects are considered ‘good buys’ as they are readily verifiable, the technology of emission reduction is well proven and they represent a major greenhouse gas source (Fernandez, 2000). Nevertheless, there are some complexities. For instance, if pre-drainage is practised a credit could not be claimed until the mining has taken place which would have released the gas. Further discussion of these complexities is included in Appendix 1.

Abandoned mine gas may be more difficult to verify than drained mine gas as all the gas extracted may not necessarily have been emitted to the atmosphere in the absence of an extraction scheme. Mine workings tend to flood at a finite rate and once the disturbed coal seams are immersed they no longer emit significant flows of gas. If the mine remained totally dry and imperfectly sealed then theoretically a combination of diffusion and atmospheric pressure effects could lead to the escape of a high proportion of the gas over a long period of time, amounting possibly to thousands of years.

AMM utilisation schemes could significantly reduce greenhouse gas emissions so a satisfactory verification method is required. One approach could be to relate the credits to a baseline study using measured emissions at vents or in mine entries prior to initiation of a scheme and then extrapolate over time using a scientifically verified model. Currently, the USEPA is developing a methodology for estimating emissions from abandoned coal mines in the USA (Cote, 2000). A tentative 7600 tonnes of methane was estimated by Wardell Armstrong for the annual emission from abandoned mine vents in the UK in 1994/5 as part of an IEA study.

VCBM schemes would not attract credits in their own right but when used to enrich mine gas they could increase the volume of mine gas used and hence indirectly contribute to the number of verifiable credits.

The benefits of carbon trading could impact on mine gas project feasibility, making marginal projects attractive and increasing revenue on existing projects.

For example, a modern 6MW_e power generation scheme consuming 414l s^{-1} pure methane would reduce emissions by the equivalent of 182,600 tonnes carbon dioxide per year. At a credit price of $1.50 per tonne (carbon dioxide (£1.05 t^{-1}), the revenue would be increased by $273,900 (£191,730) per year. Assuming an electricity price of say 3.5p kWh^{-1}, the project revenue would be increased by nearly 9.5% by the sale of credits.

Carbon credits could make flaring of mine gas commercially viable. There is no precedent for flaring in UK mining legislation but if the safety issues were addressed to the satisfaction of the Mines Inspectorate then it may represent an option. An attraction of flaring would be that the capital costs of power generation equipment and grid connection would be avoided and there would be no UK climate change levy to pay.

APPENDIX 4
GENERAL APPRAISAL OF AMM PROSPECTS IN THE UK COALFIELDS

Table 1: AMM prospects in S England and South Wales

Name (area no on Fig 1)	**Main coal-bearing strata**	**Main mines** (**Bold type: working mine)** (Figures in brackets: either known closing date or last appearance in Colliery Guardian 'Guide to the Coalfields')	**Coal Rank and Gas Content**	**Flooding**	**Comments**
Kent (18)	14 main seams, numbered in descending order: No. 1: up to 1.3m but splits. Nos. 2-5: thin and unworkable. No. 6: 0.9-1.2m in centre of coalfield. No. 7: 1.3-2.0m in Chislet. Nos. 7-11: economically valuable in places, but tend to split, coalesce and vary in thickness. Nos. 12-14: thin and unworkable. Upper Coal Measures up to 670m thick, predominantly sandy, contain seams 1-6. Lower-Middle Coal Measures, 215m thick, predominantly shaly, contain seams 7-14.	Only five collieries ever produced coal: Betteshanger (1989), Tilmanstone (1986), Chislet (1969), Snowdown (1988), Shakespeare Cliff (1915) Major workings largely confined to seams No. 1 (Snowdown and Tilmanstone), No. 6 (Betteshanger, Snowdown & Tilmanstone), No. 7 (Betteshanger, Chislet). Plan of workings to 1959 in Plumptre (1959).	Rank: Medium volatile bituminous. Seam gas content: $2.3m^3\ t^{-1}$ in No. 6 seam (Creedy, 1986, 1988)	Not known, but likely to be completely flooded as there were high pumping rates and problems with water ingress from overlying strata during mining (eg Plumptre, 1959). Coal Measures are overlain by major aquifers.	Prospects considered poor. (Mines likely flooded) Large areas have not been mined. Coalfield extends offshore beneath English Channel.
Oxfordshire and Berkshire (32)	Mainly Upper Coal Measures. Lower-Middle Coal Measures present (mainly in Berkshire) but contain volcanic rocks and little coal. Typically, the coal is in many thin seams, totalling up to 15.6m. Thickest recorded seams are 1.46m and 1.49m (in Apley Barn borehole).	None	Rank: High volatile bituminous. Seam gas content: $0.4m^3\ t^{-1}$ (Creedy, 1991)	N/A as unmined	Unprospective for CMM
Bristol and Somerset (4)	Lower-Upper Coal Measures present. Many mainly thin coals, eg in Newbury and Vobster pits, 12 seams varying between 0.75m and 1.9m thick were worked.	15 NCB collieries in 1948: Charmborough (1949), Coalpit Heath (1949), Foxcote (1949), Marsh Lane (1949), Springfield (1949), Camerton (1950), Radstock (1954), Braysdown (1956), Bromley (1957), Pensford (1958), Old Mills (1966), Norton Hill (1966), New Rock (1972), Kilmersdon (1973*), Writhlington (1973), plus Harry Stoke Drift (opened 1954, closed 1963). * combined with Writhlington in 1969	Rank: High volatile bituminous. Gas content: Not measured but almost complete absence of firedamp in mines, the exception being in the Lower – Middle Coal Measures on the southern margin of the Somerset coalfield	No pumping since 1973. Continuous pumping was needed in Somerset coalfield, except in summer months. All major mines may be flooded.	Prospects perceived as very poor (few coalfields so free of methane, main mines likely flooded). Long history of mining. Some areas and seams extensively mined. Workings at depths of up to at least 550m. After closure, mine shafts in the nationalised mines were backfilled with colliery waste and topped off.

Table 1: cont….

Name (area no on Fig 1)	Main coal-bearing strata	Main mines (**Bold type: working mine**) (Figures in brackets: either known closing date or last appearance in Colliery Guardian 'Guide to the Coalfields')	Coal Rank and Gas Content	Flooding	Comments
Forest of Dean (15)	Only Upper Coal Measures present. 19-22 seams in a 610m thick succession with total coal up to 9.75m. Thickest seams are Trenchard (1.4m, split in north, mined only in south) and Coleford High Delf (1.0–1.5m). Extent of mining in Lowery and Coleford High Delf seams shown in Aldous, Smart & Black (1986) Fig. 2.	Six NCB collieries in 1948: Norchard (1957), Eastern United (1959), Arthur and Edward (1959), Cannop (1960), Northern United (1965), Princess Royal (1965). For location of main shafts and adits, see Trotter (1942), Fig. 5.	Rank: High volatile bituminous, non-caking. Gas content: Not measured. Worked with naked flames – suggests very low gas content	Groundwater rebound complete. All deep basin workings now abandoned and flooded	Perceived as having no prospects (flooding of deep levels, little gas, little remaining coal). Best seams heavily worked. Workings at depths of up to approx. 500 m. Small outlier at Newent has poor potential (8 seams present, none >2 m thick, no major collieries).
South Wales (38)	Lower, Middle and Upper Coal Measures present. Total coal thickness commonly 12-25m.	c. 270 NCB collieries in 1948, 38 in 1978, 14 in 1988: Abernant (1988), Betws New Mine, Blaenant (1990), Cynheidre (1989), Deep Navigation (1991), Lady Windsor (1988), Marine/Six Bells (1989), Merthyr Vale (1989), Oakdale/Celynen North (1990), Penallta (1991), Taff Merthyr (1992), Tower/Mardy, Trelewis Drift (1989)	Rank: Mainly low volatile bituminous to anthracite. Rank increases from E to W. Gas Content: Average $13.7m^3\ t^{-1}$ – highest in Britain. Measurements of $16.2m^3\ t^{-1}$ in Cynheidre, $17.9m^3\ t^{-1}$ in Betws and $15.0m^3\ t^{-1}$ in Abernant	Minewater recovery situation extremely complex. At least partial recovery shown by minewater treatment plants at Ynysarwed and Blaengwynf. Blaenant discharging water by 1999.	As a generalisation, prospects perceived as fair (high seam gas levels, much unmined coal). However, good prospects may exist. Detailed assessment of prospects beyond scope of this report. In particular, not enough easily accessible data to assess location, size and interconnection of workings or minewater levels. Heavy working, especially around margins and eastern valleys. Offshore extension in Swansea and Carmarthen Bays
Pembrokeshire (33)	Thin, poorly known coals. Lower to Middle Coal measures	Hook New Drift (1948) Glynavon (1952) Little information on location and extent of earlier mining.	Anthracite	Not known but recovery assumed complete	Prospects very poor to absent (lack of large deep longwall mines)

Table 2: AMM prospects in the English Midlands

Name (area no on Fig 1)	Main coal-bearing strata	Main mines (Bold type: working mine) (Figures in brackets: either known closing date or last appearance in Colliery Guardian 'Guide to the Coalfields')	Coal Rank and Gas Content	Flooding	Comments
West Staffordshire (Cannock coalfield) (47)	Westphalian Coal Measures. Thickness of L-M Coal Measures decreases progressively southwards, and coals become less common, thinner and less laterally persistent. Heavily worked around Cannock.	Main mines were: Lea Hall (1992), West Cannock No. 5*, Cannock Wood (1978), Cannock (1978), Littleton (1993) – shafts filled and sealed July 1994. *Workings joined to Littleton	High volatile bituminous $3.7m^3\ t^{-1}$ at Littleton	Littleton: recovered to base of overlying aquifer Mid Cannock, controlled recovery Lea Hall: early stages of recovery Therefore mix of flooded and recovering	Prospects need to be considered on a mine-by-mine basis, due to possibility of minewater rebound.
South Staffordshire (37)	Westphalian Coal Measures. Thick Coal (up to 8m thick) is most heavily exploited seam. Other thinner coals also present.	Last remaining deep mine was Baggeridge (closed 1968)	Seam gas content not known	Presumed flooded due to age of workings	Lack of gas content and minewater recovery information precludes proper prospect assessment. Very heavily worked, mined to exhaustion by 1968.
East Staffordshire (13)	Westphalian Coal Measures present but unmined	Not mined	High volatile bituminous. Measured seam gas content = $1.5m^3\ t^{-1}$	N/A	No prospects
Leicestershire and South Derbyshire (19)	Westphalian Coal Measures. Thick Coal (up to 8m thick) is most heavily exploited seam. Other thinner coals also present.	The last ten mines were: Cadley Hill (1988), Rawdon (1989), Donisthorpe (1990), Snibston 1986 or 87), Whitwick(1986), S. Leicester(1986), Ellistown (1989), Bagworth (1991), Desford (1985 or 86), Measham (1986).	High volatile bituminous. Seam gas content = $0.5m^3\ t^{-1}$	Pumping from old colliery workings has ceased. The two coalfields are probably not hydrogeologically linked across the Ashby Anticline. Leicestershire coalfield divided into 2 ponds: minewater level c. 100m above OD in northern pond, main workings probably also flooded in southern pond.	Prospects perceived as very poor (very low seam gas content, at least partial minewater recovery in Leics).

Table 2: cont….

Name (area no on Fig 1)	Main coal-bearing strata	Main mines (**Bold type: working mine)** (Figures in brackets: either known closing date or last appearance in Colliery Guardian 'Guide to the Coalfields')	Coal Rank and Gas Content	Flooding	Comments
Warwickshire (50)	Warwickshire Thick (av. 6m, up to 8m, splits to south). Several other seams present. Areas of unworked Thick Coal remain, particularly in S. Proportion of coal diminishes to S.	Last 4 mines to close were: Birch Coppice (1986), Baddesley (1989), Newdigate (1982) Coventry (1996) **Daw Mill** still open	High volatile bituminous. Seam gas content averages 1.9 $m^3 t^{-1}$ Measurement of 2.5$m^3 t^{-1}$ in Thick coal in Daw Mill	Recovery complete in most areas except Daw Mill, where still pumping	Prospects perceived as poor (low measured seam gas content, minewater recovery).
West Warwickshire (48)	None as unmined. Presence of coalfield inferred from seismic reflection data.	No mines	No data	Not applicable	No prospects.
Shropshire (41)	Coalbrookdale and Forest of Wyre heavily worked. three workable seams totalling 2m in Hanwood, Leebotwood and Dryton coalfields. Some areas have little or no coal.	Last working pit was Granville (closed 1979)	High volatile bituminous. Seam gas content not known.	Fully recovered except possibly Coalbrookdale where numerous soughs (drainage adits) are present and possibly remain functional	Prospects poor outside Coalbrookdale (minewater recovery).Prospects in Coalbrookdale not known, due to lack of seam gas content data and detailed information on minewater recovery..

Table 3: AMM prospects in E and N England

Name (area no on Figure 1)	Main coal-bearing strata	Main mines (**Bold type: working mine**) (Figures in brackets: either known closing date or last appearance in Colliery Guardian 'Guide to the Coalfields')	Coal Rank and Gas Content	Flooding	Comments
NE Norfolk (30)	None as unmined (Small concealed area of Westphalian Coal Measures; ?simple, seaward-dipping strata. Presence of coal not proven)	No mines	No data	N/A as unmined	No prospects.
Eastern England + Vale of Till, Vale of Witham (12, 44, 45)	None as unmined (Large concealed area of Coal Measures continuous with, but east of, mined Yorks/Notts coalfields. Geology possibly similar to Yorks/Notts coalfields)	No mines	Seam gas content 1.5-5.9m^3 t^{-1} where measured	N/A as unmined	No prospects.
N E Leicestershire (Vale of Belvoir) (24)	Westphalian Coal Measures. Only worked around Asfordby, working complicated by igneous rocks.	Only mine was Asfordby (1996?)	High volatile bituminous Seam gas content 0.6m^3 t^{-1}	Dry mine but limited workings.	Prospects perceived as poor (very low initial seam gas content, limited workings).
South Nottinghamshire (36)	Westphalian Coal Measures. Heavily worked.	12 pits working in 1978 – all now closed: New Hucknall, Annesley-Bentinck (2000), Pye Hill (1986), Newstead (1987), Linby (1988), Hucknall (1986), Calverton (1999), Moorgreen (1985), Babbington (1986), Gedling (1991), Cotgrave (1991).	High volatile bituminous Average seam gas content 1.8m^3 t^{-1}. Average of five samples in Moorgreen = 3.8m^3 t^{-1}	Water recovery in shallow isolated outcrop workings. Water in deeper workings controlled by working mines.	Prospects perceived as good if remaining seam gas content high enough.
North Derbyshire (23)	Westphalian Coal Measures. Very heavily worked, thicker seams almost totally worked out	15 pits working in 1978 – all now closed: High Moor (linked underground to Kiveton Park, closed 1994), Markham (1993), Shirebrook (1993), Pleaseley (1983 – linked to Shirebrook 1979), Bolsover (1991), Renishaw Park (1989), Warsop (1989), Arkwright (1986), Westthorpe (1986), Whitwell (1986), Glapwell, Ireland, Oxcroft, Langwith (1978)	High volatile bituminous No seam gas content data	Some recovery in shallow seams but workings interconnected into the Nottinghamshire coalfield and water flows in that direction	Prospects good. Mine gas extraction already taking place at Shirebrook and Markham

Table 3: cont….

Name (area no on Fig 1)	Main coal-bearing strata	Main mines (**Bold type: working mine)** (Figures in brackets: either known closing date or last appearance in Colliery Guardian 'Guide to the Coalfields')	Coal Rank and Gas Content	Flooding	Comments
North Nottinghamshire (25)	Westphalian Coal Measures . Heavily worked	15 mines in 1978: **Harworth**, **Welbeck, Thoresby, Clipstone,** all still open. Bilsthorpe (1997), Ollerton (1994), Bevercotes (1993), Rufford (1993), Sherwood (1992), Teversal (1989?), Silverhill (1992), Creswell (1991), Sutton (1989), Blidworth (1989), Mansfield (1988), Steetley	High volatile bituminous Average seam gas content $5.1 m^3 t^{-1}$	Open mines pump 'small amounts' of water. Water recovery complete in shallow isolated workings. Recovery in deeper workings controlled by pumping to protect working mines	Prospects good. Mine gas extraction already taking place at Steetley (production started March 1999)
Doncaster (10)	Westphalian Coal Measures Heavily worked	13 mines in 1978: **Hatfield,** Askern, Carcroft, Frickley, S. Elmsall, Brodsworth (1990), Bentley (1993), Markham Main, Goldthorpe, Highgate, Hickleton, Thorne (last worked 1956, on care and maintenance, intermittently connected to Hatfield), Yorkshire Main (1985)	High volatile bituminous Average seam gas content $5.1 m^3 t^{-1}$. Measurements up to $9.1 m^3 t^{-1}$ in Brodsworth	Shallow isolated workings fully recovered. Some deeper collieries already recovered, eg minewater treatment site at Woolley Colliery.	Prospects considered good by analogy with North Notts and North Derbyshire.
Barnsley (3)	Westphalian Coal Measures	23 pits working in 1978 – all now closed: Newmillardam, Royston Drift, Bullcliffe Wood, Denby Grange, Shuttle Eye, Caphouse, Emley Moor, Park Mill, Woolley, N. Gawber, South Kirkby, Grimethorpe, Ferrymoor, Houghton, Dearne Valley, Darfield, Barrow, Dodworth, Wentworth Silkstone, Birdwell, Rockingham, Barley Hall, Smithywood	High volatile bituminous Average seam gas content $6.1 m^3 t^{-1}$	Water flow to deeper workings controlled by pumping and by dams and seals within the workings. E.g. currently 0.5M litres water/day is being pumped from Car House shaft to protect active workings at Maltby. See Burke and Younger (1999) for details. On cessation of pumping water recovery in deeper mines will proceed.	Heavily worked. Prospects good if mines not flooded.

Table 3: cont….

Name (area no on Fig 1)	Main coal-bearing strata	Main mines (**Bold type: working mine**) (Figures in brackets: either known closing date or last appearance in Colliery Guardian 'Guide to the Coalfields')	Coal Rank and Gas Content	Flooding	Comments
South Yorkshire (39)	Westphalian Coal Measures	Deep mines in Rotherham area ultimately integrated into four large areas of interconnected workings: 1) Treeton (closed 1991), 2) Thurcroft (ceased dewatering Oct. 1992), 3) Silverwood / Roundwood/ Rotherham Main /Car House/Aldwarke (Silverwood ceased dewatering May 1995) 4) **Maltby** Other deep mines working in 1978 but now closed: Barnburgh, Wath, Manvers, Cadeby, Cortonwood, Elsecar, Kilnhurst, New Stubbin.	High volatile bituminous Average seam gas content 7.0m^3 t^{-1}		Prospects good if mines not flooded.
Selby (40)	Westphalian Coal Measures. Single seam working in Barnsley seam	None in 1978. **Riccall, Stillingfleet, Wistow** all open at present	High volatile bituminous Average seam gas content 5.4m^3 t^{-1}	Not applicable as still working.	No prospects until mines closed.
West Yorkshire (49)	Westphalian Coal Measures. Heavily worked and abandoned.	None in 1978 (all abandoned)	High volatile bituminous No seam gas content data	Not known but coalfield long since abandoned	Prospects perceived as poor in general, but if dry workings can be found, prospects could exist.
North Yorkshire (29)	Westphalian Coal Measures (heavily worked)	20 pits in 1978: Peckfield, Ledston Luck, Rothwell, Gomersal, Lofthouse, Newmarket Silkstone, Savile, Wheldale, Fryston, Kellingley, Glass Houghton, Park Hill, Manor, St Johns, Walton, Sharlston, Nostell, Ackton Hall. Only **Prince of Wales, Kellingley, Rossington** still open	High volatile bituminous Seam gas content 4.1m^3 t^{-1}	As per South Yorkshire	Prospects perceived as good by analogy with other areas of Yorks/Notts/Derbys.
Robin Hoods Bay (34)	Concealed area of Westphalian Coal Measures. Only 0.6m poor coal recorded. Offshore extension.	No mines	No data	Not applicable	No prospects (unmined)

Table 3: cont…

Name (area no on Fig 1)	Main coal-bearing strata	Main mines (**Bold type: working mine)** (Figures in brackets: either known closing date or last appearance in Colliery Guardian 'Guide to the Coalfields')	Coal Rank and Gas Content	Flooding	Comments
Northumberland and Durham (31)	Westphalian Coal Measures (c. 26 seams, best seams worked to exhaustion). Mining extends offshore beneath North Sea. West of the coalfield are large areas with numerous generally thin pre-Westphalian coals which have been mined from generally small collieries	53 mines in 1978, of which only **Ellington** is still open.	High volatile bituminous to (locally) anthracite in Durham (adjacent to igneous intrusions); rank increases to west in Durham. Seam gas content = $1.3 m^3 t^{-1}$ in Low Main seam in Durham Coalfield. Seam gas content likely to be low in Northumberland, but possibly higher in parts of Durham	At least some areas fully recovered. Water recovery controlled by pumping. Minewater treatment plants at Skinningrove, Quaking Houses	As a generalisation, prospects perceived as poor due to relatively low measured seam gas contents. However, pockets of good prospectivity may exist.
Midgeholme and associated outliers (22)	Westphalian Coal Measures. No seams >2 m thick. 11 seams present, typically 0.3-1.5m thick; Upper Craignook worked most extensively - 1.07m thick. Maximum aggregate total coal >7m. Namurian Little Limestone Coal can be up to 1.52m thick	Only old mines – none in 1978	High volatile bituminous, locally anthracite adjacent to dolerite intrusion. Seam gas content not known	Not known	Prospects perceived as poor (relatively small mines, coalfields long since abandoned). Relatively shallow coals, extensively worked.

Table 4: AMM prospects in NW England, North Wales and Canonbie

Name (area no on Fig 1)	Main coal-bearing strata	Main mines (**Bold type: working mine**) (Figures in brackets: either known closing date or last appearance in Colliery Guardian 'Guide to the Coalfields')	Coal Rank and Gas Content	Flooding	Comments
North Staffordshire (27)	Westphalian Coal Measures. Exposed and adjacent concealed coalfield extensively worked, but much coal remains	Chatterley Whitfield (1977), Norton (1977), Victoria (1982), Wolstanton (1985), Holditch (1989), Hem Heath (1997), Florence (1992) Silverdale (1998).	High to low volatile bituminous Average seam gas content 7.1m^3 t^{-1}	Silverdale partially recovered, Hem Heath recovering. Recovery elsewhere advanced to complete.	Prospects good in unflooded mines. Gas drainage system in operation when mines were working.
Anglesey (42)	Westphalian Coal Measures. Two seams >2m thick, ?about eight seams in all.	Not known – none this century	No rank data. No seam gas content data	Not known but full recovery assumed as below sea level	Prospects very poor to non-existent.
Vale of Clwyd (42)	None. Westphalian Coal Measures present, but stratigraphical sequence, coal thickness and rank all unknown. Up to c.525m of Permo-Triassic cover interpreted	No mines	No rank data No seam gas content data	N/A	No prospects.
North Wales (28)	Westphalian Coal Measures. Offshore extension at Point of Ayr and Deeside.	Gresford, Bersham (1986), Point of Ayr (1996)	Mainly medium volatile coking coal Average seam gas content = 7.1m^3 t^{-1}	Fully recovered, some mines on coastal plain flooded by sea inrush	Prospects good if any mines are not flooded.
Cheshire Basin (8)	Westphalian Coal Measures present. Depth 2000m - >4000m	Poynton coalfield, last mined 1935, on western flank of basin	No rank or seam gas content data	Assumed fully recovered	Prospects poor
South Lancashire (35)	Westphalian Coal Measures	Last remaining mines were: Cronton, Bickershaw (1992), Parsonage, Golborne, Parkside (1992), Kirklees, Agecroft, Bold & Sutton Manor	High to medium volatile bituminous Average seam gas content = 8.2m^3 t^{-1}	Cronton, Bickershaw, Parsonage, Golborne, Parkside recovering, Kirklees, Agecroft controlled, others (Bold, Sutton Manor) not known	Prospects good if not flooded.
Burnley (5)	Westphalian Coal Measures. Thin extensively worked coals and low total thickness of coal	Last mine was Hapton Valley (1986)	Medium to low volatile bituminous No gas content data	Recovery expected to be complete: minewater emissions in Burnley and Bacup blocks. The minewater treatment plant at Old Meadows (Bacup) is close to the southern margin of the Burnley coalfield.	Prospects poor (minewater recovery).

Table 4: cont….

Name (area no on Fig 1)	Main coal-bearing strata	Main mines (**Bold type: working mine)** (Figures in brackets: either known closing date or last appearance in Colliery Guardian 'Guide to the Coalfields')	Coal Rank and Gas Content	Flooding	Comments
Ingleton (17)	Westphalian Coal Measures. Small coalfield with little remaining coal. Thickest recorded coals are the Nine Foot (2.5m) and Ten Foot (3m) in the SE of the coalfield. Up to 6 coal seams may have been present.	Only fairly shallow old workings – up to 240m at New Ingleton Colliery (1935)	No rank or seam gas content data	Recovery expected to be complete	Prospects probably non-existent (little coal remains, ?no longwall mining).
Vale of Eden and Stainmore Outlier (43)	Westphalian Coal Measures. 12–20 seams at Stainmore, thickest thought to be up to 2.4m thick; no coal yet proved in Vale of Eden	Only old workings in Stainmore – none in 1978. No workings in Vale of Eden	No rank or seam gas content data	Not known	Prospects non-existent
West Cumbria (46)	Westphalian Coal Measures. Coal more or less worked out onshore. Subsea extension to west, also worked close to shore. Commonly <15 seams, aggregate thickness c. 28 m.	Nine NCB mines at nationalisation: Allbright Drift, Clifton, Gillhead, Risehow, Solway (1973), St Helens No. 3, Walkmill, Haig (1986), William. Mainband (1985-90)	High volatile bituminous, with strong caking properties. Average seam gas content of Main Band at Haig Colliery = 7.5m^3 t^{-1}	All blocks substantially recovered to natural levels.	As a generalisation, prospects poor (minewater recovery). Any extensive dry workings would have good prospects.
Canonbie (6)	Westphalian Coal Measures. Six thick coal seams in a 70m interval: Six Foot (2.13m), Nine Foot (5.79m), Three Foot (1.62m), Five Foot (1.62m), Black Top (1.47m) and Seven Foot (1.57m). Total coal c. 12-16m.	None in 1978.	Bituminous; British Coal rank range 500-600. Average seam gas content in boreholes in unmined area south of Rowanburn Fault = 6.3m^3 t^{-1} and reaches at least 7.2m^3 t^{-1}	Not known	Prospects poor. Mined area very shallow and no workings post nationalisation. No workings south of Rowanburn Fault.

Table 5: AMM prospects in Central Scotland

Name (area no on Fig 1)	Main coal-bearing strata	Main mines (**Bold type: working mine**) (Figures in brackets: either known closing date or last appearance in Colliery Guardian 'Guide to the Coalfields')	Coal Rank and Gas Content	Flooding	Comments
Sanquhar-Thornhill (not numbered on map)	No coal at Thornhill. About 300m of Lower and Middle Coal Measures at Sanquhar. These are commonly oxidised and reddened, but to a lesser degree than at Thornhill. No Limestone Coal Formation at either place	Sanquhar – all mines closed. Last mines were: Fauldhead, Roger, Gateside, Tower. None at Thornhill	High volatile bituminous, caking to non-caking (coal rank 600-800) Gas content not known	No data	Prospects not known (not enough data). Extensive workings at Sanquhar, limited area and reddened strata
Ayrshire (2)	Limestone Coal Formation and Westphalian Coal Measures. Total thickness of coal in Limestone Coal Formation is, in general, less than 8m. In Dailly there is exceptionally >18m of coal. Best Westphalian is in New Cumnock area (>40m in >640m of strata)	Last mines were: Knockshinnoch Castle, Kames, Cairnhill, Highhouse, Barony, Sorn, Bank, Beoch, Pennyvenie, Minnivey, Maxwell, Dalquharran, Killochan, Blair, Lochlea, Auchincruive Nos 4& 7, Killoch, Littlemill. All now closed. Extensive old workings in Westphalian Coal Measures and Limestone Coal Formation, except in deepest part of Mauchline Basin.	High volatile bituminous, caking to non-caking (coal rank 700-800) Gas content at Killoch in: Ayr Hard = $2.8 m^3 t^{-1}$ Main = $2.0 m^3 t^{-1}$	No data	Prospects uncertain, but note relatively low initial seam gas content and unknown minewater recovery. More data required for proper assessment.
Douglas (11)	Limestone Coal Formation and Coal Measures. Coal Measures contain c. 39m coal, 18-33 seams over 0.3m thick.	All mines closed. Last mines were: Douglas, Auchmeddan, Auchlochan, Glentaggart, Kennox, Rankin, Douglas Castle, Wilson. Abundant old workings but deepest parts of the coalfield untouched	High volatile bituminous, caking to non-caking Gas content not measured	Not known	Prospects not known
Lothian (20)	Limestone Coal Formation and Westphalian Coal Measures	All mines now closed. Last mines were: Moncktonhall (flooded 1990's), Newcraighall, Dalkeith, Easthouses, Lingerwood, Lady Victoria (1981), Roslin, Bilston Glen. Heavily worked onshore, also worked offshore beneath Firth of Forth.	High volatile bituminous, caking to non-caking Gas content of Stairhead seam measured at $0.8 m^3 t^{-1}$	Minewater recovery assumed to be well advanced. Minewater treatment site at Moncktonhall	Prospects not known, but at least some mines flooded, and low average intial seam gas content.
Clackmannan syncline (9)	Limestone Coal Formation, Hirst Coal (Passage Formation) Westphalian Coal Measures. Hirst (Passage Group) is currently the most consistently exploited seam in Longannet area	**Longannet** still open. Kinneil, Valleyfield, Blairhall, Bogside, Castle Hill, Comrie, Solsgirth, Dollar, Manor Powys, Polmaise all closed.	Upper Hirst $0.4\text{-}2.7 m^3 t^{-1}$ (Creedy, 1986). Gas content $8\text{-}10 m^3 t^{-1}$ in LCF in Clackmannan syncline at Airth (Coalbed Methane Ltd)	Not known	Prospects not known

Table 5: cont…

Name (area no on Fig 1)	Main coal-bearing strata	Main mines (**Bold type: working mine**) (Figures in brackets: either known closing date or last appearance in Colliery Guardian 'Guide to the Coalfields')	Coal Rank and Gas Content	Flooding	Comments
Central coalfield (16)	Westphalian Coal Measures (very heavily mined), Limestone Coal Formation and Passage Group.	All mines now closed. Last were: Cardowan, Wester Auchengeich, Bedlay, Gartshore Nos 9 & 11, Easton, Riddochhill, Whitrigg, Polkemmet (1984), Shotts, Kingshill Nos 1 & 3, Overtown	High volatile bituminous, very strongly caking. Gas content 1.5-4.9$m^3 t^{-1}$ (Creedy, 1986).	Not known., but at least patchy minewater recovery - minewater treatment site at Polkemmet	Prospects not known, but Cardowan, Bedlay, Auchengeik in a gassy area, with known problems with gas emerging at surface at Chryston.
Fife (14)	Limestone Coal Formation, Westphalian Coal Measures	Minto, Randolph, Lochhead, Wellesley, Michael, Frances (care and maintenance 1987, closed 1990's), Seafield (linked with Frances late 1970's, closed 1987).	High volatile bituminous, very strongly caking to non-caking Gas content 0.6-1.2$m^3 t^{-1}$ in Lower Coal Measures. Not measured in Limestone Coal Fm.	At least partial water recovery. Mine water pumping facilities to be installed to control water recovery	Prospects perceived as poor (low measured seam gas content, at least some major mines flooded). Minewater treatment sites at Minto, Frances and Michael. However, methane flaring at Valleyfield for some time after closure.
Machrihanish (21)	Probably none, possibly Limestone Coal Formation	Argyll (developing 1947, closed) Westphalian Coal Measures not mined. Limestone Coal Formation mined from outcrop in SW	High volatile bituminous, non-caking Gas content not known	Not Known	Prospects perceived as non-existent. (?no longwall mining or large mines). Little data available

APPENDIX 5
COMPUTERISED CBM MODELLING TECHNIQUES AND SIMULATION TOOLS

Introduction

Computer modelling of gas reservoir has become a powerful useful tool to study the behaviour of CBM and production well bore performance. CBM reservoir model development was initiated in 1980 by US Steel, Penn State University and GRI in parallel with defining the unique CBM production mechanisms. By the mid to late 80s, a number of organisations had modified their existing in-house black oil models or built new reservoir models specific to CBM production and several reservoir models became commercially available.

Nearly 40 CBM simulators are described in the literature. King and Ertekin (1989, 1994) provided a comprehensive review of distinct mathematical models for simulating and predicting methane flow from coalbed. These models methods are mostly based on the principles of gas flow in porous permeable media and can be classified by the treatment of the gas sorption (desorption/adsorption) process, typically, equilibrium (pressure-dependent) sorption models, and non-equilibrium (pressure and time-dependent) sorption models.

Equilibrium (pressure-dependent) sorption models are theoretically derived models which account for the physics of the adsorption/desorption process. In this approach, it is assumed that gas desorption from coal surfaces and diffusion through the micropore system is sufficiently rapid, so that equilibrium with the gas phase pressure is continuously maintained. Consequently, these models are single porosity reservoir models. An approach of this type does not account for the time lag (time-dependence) incurred during transport through the micropore system. Non-equilibrium sorption models (pressure and time-dependent) take this transport into consideration.

Non-equilibrium sorption formulations are essentially modified forms of conventional dual porosity models. These modifications to the conventional dual porosity models arise because:

- in coal seams methane is considered to be compressible;
- methane in the micropore structure of coal is in adsorbed state;
- gas transport through the micropore system is a diffusion process.

As with conventional dual porosity models, two approaches have been used to formulate CBM models: Pseudo steady-state formulations use a discretised form of Fick’s First Law to describe gas transport through the micropore system, while unsteady-state formulations use Fick’s Second Law.

Although non-equilibrium sorption models provide a better description of methane flow from coal, the equilibrium sorption approach was often chosen due to its simplicity. These models were solved by both analytical and numerical techniques, including finite difference as well as finite element methods.

Computer Models for CBM

Various computer simulators are used to model the production of methane with time for given coal seams. This section examines the most commonly used commercial CBM software and techniques as well as the latest developments in this area. Contacts are also given at the end of each section.

COMET 3D - GRI/ICF

The COMET 3D (coalbed methane) simulation software is a non-equilibrium, pseudosteady state formulation based on the Warren and Root (1963) model of dual-porosity reservoirs (Paul et al., 1990; Sawyer et al., 1990). As applied to coal beds, the orthogonal natural fractures (cleats) are treated as a system of connected pipes which divide the matrix into small elements (the distance between cleats is about 0.6cm or 0.25in.). The matrix elements, which can be slabs, cylinders or spheres, act as the source of gas that diffuses, by Fick's first law, into the cleats.

Desorption of methane is described by a Langmuir isotherm, which relates matrix gas content, V(P), to the coalbed cleat pressure, P, according to:

$$V(P)=V_L P/(P+P_L)$$

where V_L is the maximum amount of gas that can be adsorbed, and P_L, a characteristic pressure, is a measure of residence time for a gas molecule on the surface. Both V_L and P_L can be determined from gas desorption measurements on coal core samples. The above equation provides the necessary boundary condition at the matrix-cleat interface.

The COMET 3D computer model is fully three-dimensional to account for vertical wells intercepting multiple coal seams, structural features such as reservoir dip and no-flow barriers (faults and shale breaks), and gas-water gravity segregation. Other unique features of coal reservoirs that are modeled are stress-induced changes in cleat porosity and permeability, and matrix shrinkage due to release of adsorbed gas. The COMET 3D simulator can be used for the following tasks:

- test how well the geologic model describes the real reservoir by matching performance history
- provide a basis for forecasting future production as a function of various operating strategies such as variations in well spacing
- determine the ultimate economic recovery for a field, that is the gas rate versus time
- confirm the physics of a recovery process such as simulating a laboratory desorption test
- discover and diagnose production problems such as wells which are performing below potential
- determine areas of the reservoir least depleted in order to properly locate infill wells
- design the best well completion scheme, such as single versus multiple seam
- predict gas recovery from degasification of underground coal mines using both gob wells and horizontal boreholes

· determine sensitivity of simulated production to changes in various data and identify weaknesses in critical data.

Data inputs for the simulator may be grouped into three types:

a) reservoir description data, such as geometry, structure, depth, net thickness, stratification and initial water saturation and pressure,

b) fluid PVT (pressure-volume-temperature) data, such as gas viscosity and composition and

c) time-dependent well data, such as fluid rates and bottomhole pressures.

The following data are considered a minimal data set for simulation:

· absolute cleat permeability which determines rate of gas recovery

· initial gas content for determining gas-in-place and the recovery target

· adsorption isotherm for determining timing of initial gas show and ultimate gas recovery

· cleat porosity which is the site of water storage in coal beds and determines volume of water produced.

COMET 3D has been extensively used worldwide for CBM exploration.

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SIMEDII - University of New South Wales and CSIRO

The simulator was developed jointly by the University of New South Wales and CSIRO Division of Petroleum Resources, has been successfully used to study Bowen Basin coals (Kilingley, 1996). SIMED II takes virtually every physical process in a CBM reservoir into account, in three dimensions, including, but not limited to, multi-component gases adsorption and desorption, gas diffusion, relative permeability, capillary pressure, dual porosity, matrix permeability and porosity as a functional of reservoir pressure. The multicomponent formulation allows for the investigation of enhanced methane recovery via injection of other gases, typically nitrogen or carbon dioxide, into seam.

Unlike other simulators, which take computational short-cuts such as assuming steady-state flow conditions in the coalseam reservoir, SIMED II is a rigorous simulation model developed with the primary purpose of providing the most accurate predictions possible. The model can be configured to perform large field-scale simulations, virtually limited only by the capabilities of the computing equipment it is mounted upon.

Inputs to the model include: well spacing; seam depth and thickness; coal density, porosity and permeability; seam pressure; temperature and degree of water saturation;

gas composition and Langmuir adsorption parameters for all gases involved, plus information on characteristics of the well bore.

SIMED II applications include:

- ***Enhanced Gas Recovery***: The model is capable of unsteady-state, multi-component gases 3D reservoir simulation. With SIMED II, predictions of production and reserves recoveries can be made under conditions where nitrogen and/or carbon dioxide gases are injected into the coalbed reservoir to enhance the total recovery of CBM.

- ***Optimum Well Orientation***: To determine how CBM producing and/or injection wells should be located in the field to optimise the recovery of CBM under either conventional or enhanced CBM recovery production techniques.

- ***Optimum Well Spacing***: SIMED II's capabilities in multi-component gases modelling enables the prediction of optimum well spacing under a variety of producing conditions and scenarios, including varying wellbore completion techniques, stimulation treatments, and varying production methods.

- ***Optimised Reservoir Production Management***: SIMED II could provide answers to questions regarding when and how various production and reserves recovery improvement techniques should be employed, such as infill drilling, stimulation or re-stimulation of well bores, and injection of nitrogen, carbon dioxide or a combination thereof.

- ***Optimum Well Completion Design***: SIMED II can predict increases in well productivity and reserves recovery for varying wellbore completion configurations and stimulation techniques.

- ***History Matching***: To quantify key CBM reservoir properties, historical gas and water production data can be used to determine porosity, permeability, induced fracture properties, and coal diffusional properties. SIMED II's unsteady-state mathematics also enable the utilisation of short-term production or test data to quantify these key reservoir properties. This enables the early use of this data in optimising well completion, stimulation treatment design, well spacing, and overall reservoir management.

- ***Long Term Production Forecasts***: SIMED II can predict production and reserves recoveries under varying scenarios over long periods of time. As a result, well and facilities designs can be implemented and field life cycle economic analyses may be performed.

The SIMED II model has been extensively used in the UAs and Australia to perform field-scale evaluations of CBM reservoirs, for both research and commercial purposes. The SIMED II model has also been extensively validated, and tested against the GRI/ICF COMET 3D model.

SIMED II simulation code is written in Fortran. SIMED II utilises an extensive and sophisticated menu-driven data input, simulation, data output and graphical presentation system to facilitate the formulation of input files, to perform the simulation modelling, to review and analyse the simulation results, and to generate tabular and graphical output. SIMED II is available for use on mainframe computers, mini-computers, workstations and microcomputers.

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SABRE, COALGAS and SHALEGAS - Holditch & Associates Inc.

The software is a two-phase, 3D finite-difference CBM reservoir simulator developed by S.A Holditch & Associates, Inc. (SAH) primarily for solving production and reservoir engineering problems (1995). The model also includes features specially for coal mining activities. The model is now commercially available.

To use this model for simulating production from coal reservoirs, the reservoir is divided into discrete blocks. Each grid block is assigned reservoir properties such as permeability, porosity, adsorbed gas content, water saturation, etc. using available geologic and engineering data. The software offers similar functionality to COMET, including:

- Performance forecast for a hydraulically fractured coalbed methane wells
- Simulating multi-layered coalbed methane reservoir/full scale simulation of a coalbed methane reservoir
- Simulating longwall mining operations: COALGAS also has the ability to estimate the volume of gas inflow which will occur during roadway development.

The software is managed by a Simulation Manager within an integrated environment in which the user can create and modify multiple input datasets, run simulations, and analyse simulation results. The Simulation Manager provides practical, powerful PC-based reservoir simulation running on MS-DOS, Windows 95 or Windows NT

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Floorgas and Roofgas - Lunagas Pty Ltd

These are PC, Windows™ based geomechanical and gas release simulation programs, regarding coal seam gas release phenomena that produce a graphical representation of strata relaxation, gas release and shear zones, associated with mining activities in underground mines. These programs can be used as engineering and planning support tools in the following underground mining fields:

- Definition of strata relaxation and active gas sources zone shape
- Design of optimum parameters for cross-measure, in seam and directional drainage holes, as well as surface gas wells
- Precise specification of strata relaxation and gas make prediction coefficients for the local geological and mining conditions
- Planning for CBM utilisation.

The following inputs are needed for the programs:

<u>Geomechanical data:</u>
- mechanical properties of the roof strata - expressed as a Uniaxial Compression Strength value;
- Strata stresses expressed as a horizontal stress direction and a horizontal to vertical stress ratio.

<u>Lithological Data</u>
- A geological description and/or sonic velocity log of the strata;
- Floorgas -100m below the working seam;
- Roofgas - at least 100m above the working seam (up to a maximum of 200m)

<u>Mining and Gas Data</u>
- Longwall block geometry (including pillars)
- longwall advance rate
- coal seam gas properties
- gas flow characteristics.

Floorgas generates a cross-section as a colour map of vertical stresses in the strata down to 100m below the working seam using the Boundary Element Approach. Whilst Roofgas generates a cross-section as a colour map of strata relaxation zones up to 200m above the working seam using the Sequential Bed Separation Method.

The software is primarily designed to identify the potential gas release regions around the workings by assessing the stress distribution patterns and does not provide specific methane emission rate. Prediction results were compared with more that 20 longwall extractions in Australia and Poland. A high degree of accuracy for gassiness predictions (10-15%) was indicated when the appropriate input data were available.

The package has recently be used incorporation with PORFLOW, a Computational Fluid Dynamics modelling tool developed by Analytic & Computational Research, Inc., ACRi (http://www.acricfd.com/), to study the emission and extraction of methane from abandoned underground coalmines.

The programs are commercially available.

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METSIM – Imperial College

Imperial College has been involved in CBM research and methane simulator development since 1979, investigating the geotechnical and gas flow behaviour of mined and unmined coal seams as natural gas reservoirs. Through this work, a finite element procedure, which is able to model the phenomenon of dynamic fracture generation and propagation around underground coal faces, was developed. The model incorporates mining engineering and petroleum reservoir engineering principles developed to simulate multiphase flow (gas/water) in coal seams. This is a non-equilibrium sorption, pseudo-steady state, 3D, dual permeability model accounting for flow in matrix and in cleat as well as including the desorption process in the coal matrix. The model accounts for the solution of one phase in another; incorporates the adsorption/desorption process; improves on the convergence performance of current simulators and implements fully the concept of dual porosity/dual permeability. The stress and pressure dependent permeability behaviour of coal is also accounted for by the implementation of a ‘dynamic permeability concept’.

The model developed (METSIM) was validated using published data from US coalbed methane flow simulation studies, UK coal seam characteristic data obtained from industry and data from previous research by the investigators.

Recently the functionality of this model has been investigated as a tool for abandoned mine gas production planning and design.

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Fluid Flow-Rock Mechanics coupled CBM/CMM Model - University of Nottingham

Numerical models have been developed at the University of Nottingham to simulate the migration of methane gas through permeable strata. The models incorporate the relationships of stress-permeability relationship of coal measure rocks derived from laboratory tests and geotechnical modelling of stress and fractures distributions resulting from underground excavations and can be used to predict the spatial methane migration pattern towards underground openings such as coalfaces or methane capture boreholes. The modelling is based upon Computational Fluid Dynamics (CFD) and geotechnical constitutional models and has the ability to handle two phase and multicomponent flow. Typically, the models can be used to study:

- Methane migration patterns around an excavation such as wellbores or a longwall face.
- The effect of induced fractures methane capture.
- The relative importance of various parameters of methane well bores such spacing and suction pressure.
- Methane well bore production rate.

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STARS and GEM for CO_2 Sequestration - Computer Modelling Group Ltd.

STARS and GEM have recently been used to study the effect of carbon dioxide sequestration to enhance CBM recovery (DTI, 2000).

STARS is an advanced processes simulator for modelling the flow of three-phase, multi-component fluids. It enables the users to model with or without dispersed solids, through complex geological formations, including naturally or hydraulically fractured.

GEM is a general equation-of-state (EOS) based compositional reservoir simulator for modelling the flow of three-phase, multi-component fluids. GEM is a robust, fully compositional simulator used to model any type of reservoir where the importance of the fluid composition and their interactions are essential to the understanding of the recovery process.

Both packages can be run on UNIX workstations from IBM, SGI and SUN as well as Intel Based PCs running Windows 98, 2000 and NT 4.

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Conclusions and Discussions

Reservoir simulation can be a powerful tool to gain insight into gas well performance in complex coal seam gas reservoirs. Reservoir models are an excellent way to assess the impacts of reservoir properties on production and organise data for a given prospect in an orderly manner.

The primary constraint in the application of a simulator is the lack of adequate data with which to characterise reservoir performance. It is therefore essential that reservoir simulation is used not as a stand alone analytical tool, but as an integral part of other data collection programs designed to assist in the evaluation CBM reservoir.

A major benefit of reservoir simulation is an economic one: a simulator can be run many times at little expense while the field can be produced only once.

APPENDIX 6
ENGINEERING FOR AMM PRODUCTION: UK CASE STUDIES

Practical experiences have been gathered from UK sites at which AMM schemes have been developed in order to assist future operators avoid some of the engineering pitfalls and to encourage the detailed consideration of possible AMM exploitation requirements at mine closure.

Case Study One

As part of a closure strategy, which had considered the future use of gas from the abandoned mine, an 18" pipe was installed through the drift stopping. An additional 10" pipe was also left through the stopping and connected to the former methane drainage range (18") which extended from the surface to the underground workings some 3km plus. The two pipes were connected outbye of the top stopping wall and the portal entrance was backfilled. The design did not include any access provision to maintain the connection. Following completion of the works and restoration of the surface problems were identified with the gas extraction scheme, which indicated the 10" pipe had become blocked. Re-excavation of the backfilled drift entrance and subsequent investigation confirmed the 18" pipe installed through a stopping had become blocked with water and debris. Attempts to remove the blockage failed and a number of drill rods were lost inside the pipe. Further review of details of the as built design suggested that the position of the 18" pipe through the stopping had changes from roof level at the inbye end of the stopping to floor level at the outbye end resulting in water accumulating in the extraction pipe.

Appropriate grading of the pipe and adequate supervision of the installation would have prevented this problem. Although gas continues to be extracted through the 10" pipe the pressure loss over the full length of the pipe has a significant effect on gas flow. The pipe will eventually become blocked with water and will be ineffective in extracting gas from other worked areas.

Case Study Two

Assessment of the risk of uncontrolled surface gas migration as part of the closure review identified the need to install a vent pipe through the drift stopping to control gas migration and prevent the build up of pressure. Subsequent interest in gas utilisation identified the pipe as the preferred surface extraction point, initial tests suggested that surface air was been drawn through the stopping into the pipe when a negative suction pressure was applied. Investigations confirmed the pipe installed was not suitable for gas extraction as it used a screw joint method of pipe connection, which allowed air to be drawn in when suction was applied.

Remedial works were undertaken which involved the re-excavation of first 50m of the drift into competent strata and replacement of the pipe with a fully welded gas tight pipework. A stopping wall was constructed at 50m and the pipe set in concrete. The excavation was backfilled to the surface. Correct specification and installation of the pipework together with a second pipe would have prevented this problem.

Case Study Three

Engineering works undertaken as part a mine closure included the provision to leave one of the shafts open to its full depth with a passive vent installed. The other shaft was infilled with no venting provision installed. Subsequent observations reported gas within the filled shaft under pressure beneath the cap. A passive vent was retrospectively installed. Further investigations recorded gas migrating from beneath the cap in the vicinity of a service duct. Trial pit excavation adjacent to the shaft cap showed it to be constructed on a permeable stone layer surrounded by madeground. It was concluded that uncontrolled gas migration was occurring from the shaft via the stone layer and also through untreated surface ducts. Remedial works were undertaken involving the excavation around the shaft cap, plugging of service ducts and placement of a low permeability barrier around the cap keyed into natural ground.

A gas extraction scheme is planned for the mine using the open shaft as the extraction point. Reported uncontrolled surface gas emissions suggest a migration pathway between the shafts. Treatment works undertaken to effectively seal the infilled shaft will prevent future air ingress when suction pressure is applied as part of the gas extraction scheme.

Case Study Four

Assessment of the risk of surface gas migration on closure of a mine resulted in the up cast shaft being left open to vent. The assessment identified a potential for water to accumulate in the pit bottom area, which could isolate the open shaft. Engineering works were carried out in pit bottom prior to abandonment to minimise the accumulation of water and isolation of roadways. These involved the installation of pipework through the roadway swilley and also through the concrete plug at the base of the open shaft.

Due to the depth of madeground the cap was not constructed at rockhead. A cap was constructed on the shaft liner with the fan drifts not sealed. Pipework passed through the cap was connected to passive vents. Subsequent use the shaft for gas extraction and utilisation identified air ingress around the top of the shaft. Remedial works were undertaken to construct an effective seal around the top of the shaft. This involved forming an effective stopping and seal in the fan drift. The cap was re-excavated and a further concrete structure was cast above and around the cap to form a seal.

Case Study Five

Consideration was given to potential future extraction and use of gas from the abandoned workings as part of the closure strategy. A review of options to maximise gas availability identified the preferred surface location using an existing mine entry and connecting inclined drift. Engineering works were undertaken underground including the removal of stoppings and seals, opening sealed pipes and diverting water to minimise potential accumulations which may isolate roadways or parts of the mine. Particularly important was the removal of a stopping in the former intake drift that had originally been constructed to minimise gas migration from abandoned areas.

At the top of the drift a stopping, about 265m, was constructed though which 2x12" pipes passed. The pipes extended a further 450m down the drift to minimise air been drawn in from the surface. The pipes are connected on the surface and extended to an on-site power generation station.

Case Study Six

A mining block was identified having potential for an AMM scheme. The mining block covered a large heavily worked area of former workings in three principal coal horizons. No specific provision had been incorporated in the closure plan to monitor rising water levels. A review of the mining block identified an up dip area of workings in the lower coal horizon at a relatively shallow depth (325m bgl).

A surface location was selected to intersect a goaf area which was connected to the wider mining block which would pass through the least number of worked seams above the target horizon. The borehole was drilled to a depth of 310m and the casing grouted in. The final 15m, which intersected the goaf area, was open holed. No water was encountered but gas was recorded under pressure. The results from the monitoring borehole confirmed that the water was below a specific level and therefore a significant volume of the gas reservoir was accessible for gas production. Additional information from the investigation borehole also confirmed the gas composition and allowed the free void to be calculated. Future drilling risks were also reduced using the information provided in the drillers log.

Case Study Seven

The potential to extend an existing gas extraction and utilisation scheme following closure was identified as part of the closure strategy. Pipework was installed through the drift stopping (case study one). Although the modern deep mine was relatively dry, water ingress from connected shallow outcrop workings was controlled during the operation life of the mine by a water pumping scheme. Evaluation of the feasibility of gas extraction post closure suggested that it was financially feasible to continue the water pumping facility with revenue from the AMM scheme financing the pumping operation.