VARIABILITY IN COAL SEAM GAS CONTENTS THAT IMPACTS ON FUGITIVE GAS EMISSIONS ESTIMATIONS FOR AUSTRALIAN BLACK COALS[1]

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ABSTRACT

This study was prompted by a need to understand the factors influencing estimates of fugitive greenhouse gas emissions generated from black coal as a by-product during the mining process. Although they comprise some 3% of Australia's net greenhouse gas emissions, they will be increasingly significant with the increase in coal production. Fugitive gas emissions from coal mining and handling are generally estimated by the amount of gas released per tonne of coal mined and handled, less any abatement through gas capture and utilisation. Ideally, each mine monitors, measures and reports their annual emissions that are then tallied at a coalfield, state or basin scale. Where country or basin specific emissions factors are known, this factor can be applied, else a global average is used as a default.

Although gas emissions behaviour is due to an interplay of factors, virgin coal seam gas content is used as a proxy to demonstrate the inherent variability that will impact upon default estimations of fugitive greenhouse gas emissions from black coals. A database of some 2000 boreholes with confidential measurements of gas reservoir parameters of various seams from mines across the Hunter Valley and Central Bowen Basin coalfield were compiled and analysed. These coalfields were chosen as they are known to be different in coal rank, grade and gas reservoir behaviour.

Previous studies demonstrate that gas sorption capacity follows measurable coal properties such as rank and type for differing pressures and temperatures. Actual gas contents do not always match theoretical capacity and all reservoir properties, in particular gas content, vary greatly at the mine scale. This *in situ* variability at the mine scale, coupled with varying approaches to mine gas management makes it almost impossible to develop emissions factors for coalfield or basin scales with a reasonable level of certainty, much more be extrapolated to state and country scales.

As has been suggested by various guidelines for the estimation of fugitive greenhouse gas emissions, the most reliable estimations are made at the mine scale from measurement and monitoring. Mine scale estimations can be improved by taking a domain approach, where depth and pressure relationships are relatively stable and within which the variability of reservoir parameters is reduced to some degree.

Key words: fugitive gas emissions, coal mining, gas content

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[1] Esterle, J.S., Williams, R., Sliwa, R. and Malone, M., 2006. Variability in Coal Seam Gas Parameters that Impact on Fugitive Gas Emissions Estimations for Australian Black Coals. 36th Sydney Basin Symposium 2006: Advances in the Study of the Sydney Basin. 26-28 November, University of Wollongong, Wollongong, Australia, 10p.

INTRODUCTION

This study was prompted by a need to understand the factors influencing estimates of fugitive gas emissions[2] generated from black coal as a by-product of the mining process. Fugitive emissions from fossil fuels were reported to represent 5.5% of Australia's net greenhouse gas emissions, of which the mining and handling of black coal accounted for 58% (National Greenhouse Gas Inventory NGGI, 2002 and Australian Greenhouse Office, AGO, 2005). Guidelines for fugitive emissions estimations from coal mining and handling can be found in the document "Australian Methodology for the Estimation of Greenhouse Gas Emissions and Sinks 2003", published by the Australian Greenhouse Office, Department of the Environment and Heritage[3].

Fugitive gas emissions from coal mining and handling are generally estimated by the amount of gas released per tonne of coal mined and handled, less any abatement through gas capture and utilisation.

Total Emissions = Emissions from Underground Mines
+ Emissions from Surface Mines
+ Post-Mining Emissions
- Emissions Avoided Due to Gas Recovery[4]

Ideally, each mine monitors, measures and reports their annual emissions that are then tallied at a coalfield, state or basin scale (termed the Tier 3 approach). For underground mines, gas emissions can be measured from ventilation and degasification systems. Where mine-specific emissions data aren't available, emissions are estimated based on *in situ* gas contents or a generalised class of gassiness. For surface or open cut mines and post-mining activities, the methodology for estimating gas emissions consists of multiplying coal production by basin-specific emissions factors. Where country or basin specific emissions factors are known, the approach is termed Tier 2. Many of these were derived by a series of studies conducted by different countries in the early 1990's (IPCC, 1997; for Australia Williams et al, 1993). Where they are unknown, a global averaging or Tier 1 method can be used with default emissions factors proposed by the IPCC based on these different studies (Irving et al, 2004). In summary, the Tier approach is as follows:

Tier 1	Global averaging
Tier 2	Basin or country-scale estimate
Tier 3	Coalfield, basin, state from mine scale

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[2] Fugitive coal seam gas, commonly methane, which is liberated from geological 'enclosure' as a function of mining activity is seen to be a fugitive greenhouse emission, if not for its capture and combustion in the form of waste coal mine gas (http://www.greenhousegas.nsw.gov.au/acp/generation_faqs.asp#coal).

[3] The Australian document and updated workbooks can be downloaded from http://www.greenhouse.gov.au/inventory; Guidelines can also be obtained from the Intergovernmental Panel on Climate Change *Guidelines for National Greenhouse Gas Inventories* are at http://www.ipcc-nggip.iges.or.jp.

[4] A review of mine methane mitigation and utilisation strategies can be found in Shi et al, 2005.

The range of emissions factors derived for different countries is discussed in Saghafi et al (2005) and in the Guidelines for National Greenhouse Gas Inventories (IPCC, 2004). These factors will vary as more data become available, so it is best to use the most recent of reports and visit the website for updates (AGO, 2005)[5]. For Australia, Tier 2 emissions factors do not differ between Queensland and New South Wales for gassy underground mines, but do so for open cut black coal mining (Table 1; AGO, 2005).

Table 1. Tier 2/3 fugitive emission factors for the production of raw coal as carbon dioxide, methane and carbon dioxide equivalence (source NGGI, 2005 cited in AGO, 2005)

	CO2	**CH4**	**CO2-e**
COAL	m^3/t raw coal	m^3/t raw coal	m^3/t raw coal
Gassy underground mines NSW	NA	25.43	534.06
Gassy underground mines QLD	NA	25.76	540.86
Less gassy underground mines	NA	0.80	16.70
Open cut mines NSW	NA	3.21	67.24
Open cut mines Queensland	NA	1.20	25.27
Open cut minesTasmania	NA	1.00	20.98

The main sources of uncertainty in the Tier 1 and 2 estimates, and projections from them, include the level of coal production and, more so, the emissions intensity of that production (AGO, 2003). For underground coal mines there is sufficient data from exploration drilling to examine this variability and model potential emissions factors as a function of the mining process. Models can be validated by auditing gas emissions during pre-mining drainage programs and in the ventilation streams during mining. For open cut mines gas contents are rarely measured as gas contents are commonly too low for safety concerns at these shallow depths. However, due to the need to quantify greenhouse gas emissions and the significant number of open cut coal mines in Australia, work is underway to develop more direct Tier 3 methods of measuring and monitoring gas emissions from open cut mines (Saghafi et al, 2003; 2005).

Levels of production from coal mines with high intrinsic emission intensities have a dominating effect on the total level of fugitive emissions; the higher the total demand for coal production from emissions intensive mines the higher will be the emissions without abatement strategies. What is not well documented is the variability in the emission intensity of different coals and the underlying factors that control it. The objective of this study was to examine the variability of *in situ* or virgin coal seam reservoir properties in Australian black coal that may impact upon future emissions intensity calculations in the absence of mine-site specific reporting. Only the gas content and permeability data are presented here.

[5] http://www.greenhouse.gov.au/workbook/pubs/workbook-2005.pdf

DATA AND METHODS

The approach of this study was to determine relationships between *in situ* coal seam reservoir properties (gas content, composition, and sorption capacity and, where available, permeability, coal seam character and geological parameters) for Australian coals through compiling and analysing available company data in different geological/gas domains in Queensland and New South Wales. The two chosen coalfields were the Central Bowen Basin and Hunter Valley, as these two fields have known differences in coal seam rank and gas reservoir behaviour, and contain abundant gas measurement data from coal exploration drilling data (Williams et al, 2002; Esterle et al, 2002). Coals in the Hunter Valley are commonly high volatile bituminous A[6] in rank whereas those in the Central Bowen Basin range from high to low volatile bituminous[7].

Gas content data for different seams were available for some 1300 boreholes across sixteen mines and deposits in the Central Bowen Basin, and for some 1000 boreholes across six mines in the Hunter Valley drilled over the past 5 to 10 years. All gas contents are reported in cubic metres per ton (m^3/t) and normalised to 15% ash at 20ºC and 101.3 kPaa (Qm15), unless otherwise stated.

RESULTS AND DISCUSSION

Figure 1 shows the variability in coal seam gas content as a function of depth for samples available to this study. For a coal of given rank, gas content commonly increases with depth of cover but variability can be very high at the scale of a basin, a mine site or even a single borehole. Gas content should increase with depth because the gas adsorption capacity of a given rank of coal will increase with increasing pore pressure (assuming that temperature variation is minor). In early fugitive gas emission studies in the US, it was hoped that variation in rank between basins could be used as a guideline for estimating gas contents (Masemore et al, 1996). Given the difference in coal rank ranges between the Hunter Valley and the Central Bowen Basin samples, one would expect better discrimination between the two basins, but the scatter is too great.

Although volumes of gas, in particular CH_4 and CO_2, are produced during coalification, only a fraction is retained in the coal. Gas retention in the coal is dependent upon a complex interplay of factors (Levine, 1993) controlling the gas holding capacity of the coal, its permeability, the sealing nature of the overlying rocks, and the pressure of the rocks and fluids in the overburden. Areas or domains where gas content appears to be “abnormally” low or high for a given depth are indicative of geological (and hydrological) irregularities at some point in the geological history of that seam (Scott, 2002). For example, the extremely low gas contents (<2%) across depths down to 500m in the Hunter Valley data (Figure 1) reflect the gas loss across all seams approaching the Mt Arthur monocline (from Williams in Esterle et al, 2006).

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[6] random vitrinite reflectance Rvo ~ 0.75%; volatile matter, dry ash free basis Vmdaf ~ 39%

[7] Rvo=1.9%, Vmdaf=14% random vitrinite reflectance Rvo ~ 0.9% to 1.92%; volatile matter, dry ash free basis Vmdaf ~ 31 to 14%

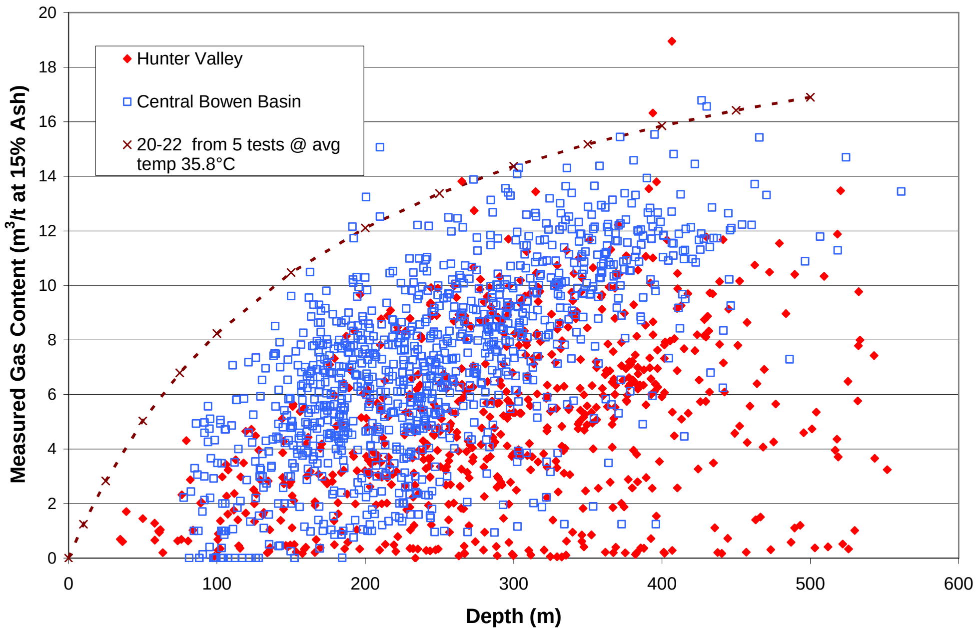

Figure 1 Variation of coal seam gas content against depth for Bowen Basin and Hunter Valley sample sets, overlain by a methane gas isotherm at the boundary of medium and low volatile rank coal (volatile matter =20- 22% dry ash free)

The change in gas content with depth or cover can be used to identify domains in which the gas gradient is relatively uniform (Figure 2). In such domains, the gas content is normally predictable to within +/- 0.7 m^3/t, according to depth and ash yield, and it is mappable as defined areas on a plan (Williams and Yurakov, 2003). Domain boundaries can be related to geological features, usually faults or changes in the geometry and character of the seam (Esterle et al, 2000). The gas domain approach was examined as a method for improving the allocation of gas emission intensity for a given basin or area.

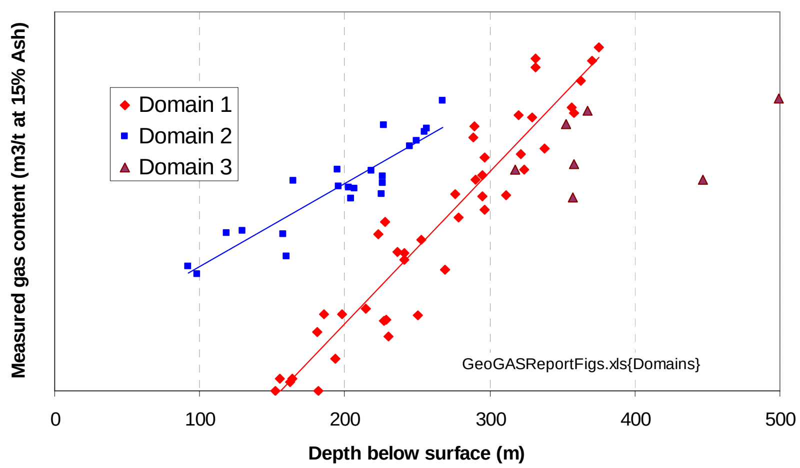

Figure 2 Example of Gas Content Depth Gradients Grouped As Domains

The Bowen Basin and Hunter Valley coals exhibit a wide range of gas contents as indicated by the depth/gas content gradient trend lines from gas domains across the different minesites (Figure 3). In the Bowen Basin, some relatively high gas contents occur at shallow depths (eg 6 to 8 m^3/t at 100 m depth). In other cases, depths of up to 190 m need to be reached before there is any measurable gas content in the coal. The single trend line of reducing gas content with depth is supported by extensive data, and occurs over a wide area in the Bowen Basin. This aberrant loss of saturation with depth occurs in an area of complex coal seam splitting and subsequent faulting.

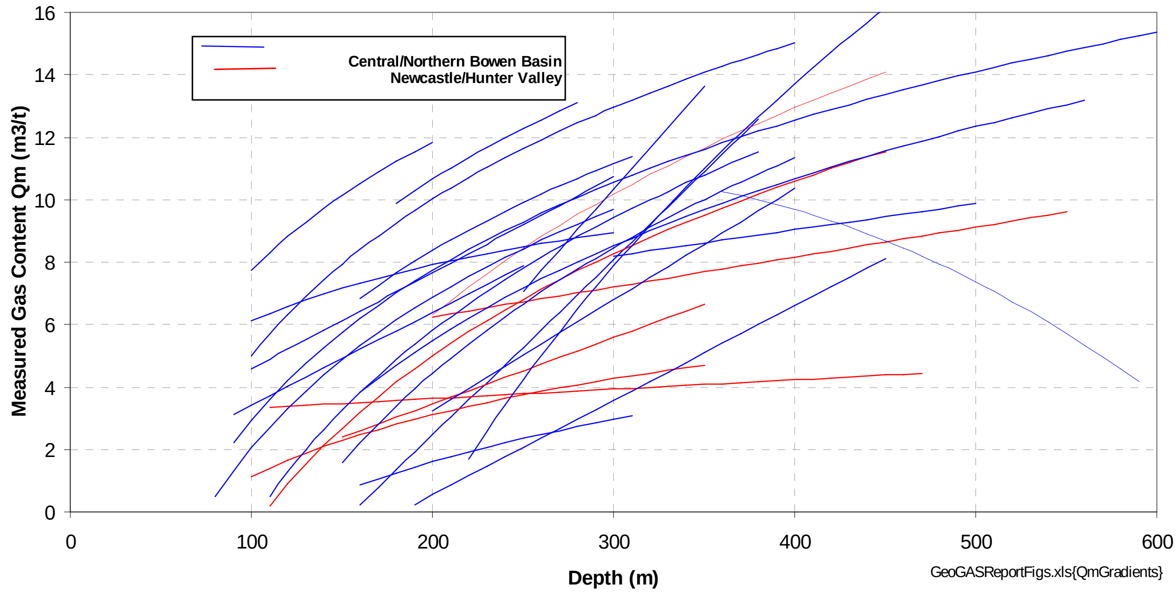

Figure 3 Gas Content Gradients from Gas Domains in Coals from Hunter Valley and Bowen Basin

Gas content data for both basins are sparse at the shallow depth range of 0-120m, which would represent the limit of open cut mining with current practice, but can be extrapolated to vary from <1 to 8 m^3/t (Figure 3). This variability demonstrates the difficulty in applying an average factor at a coalfield or basin scale. Gas content increases in the deeper ranges but at different rates in each of the mines, which is also reflected in the gas gradient plots. Variability in the 220-281m depth range, where sample numbers are generally good for each mine, is also high ranging from <2 to 11 m^3/t for the Bowen Basin mines and 3 to 9 m^3/t for the Hunter Valley mines. Considering the tight rank range for the Hunter Valley coals, Rvo ~ 0.78-0.8%, versus those in the Bowen coal samples, Rvo ~ 0.9 to 1.92%, the range in gas contents is quite wide.

Gas content gradients are highly variable between mine sites for both basins, ranging from 0.5m^3/t to 4.7m^3/t per 100m depth of cover. The number of mine sites in the Hunter Valley data set are too few to derive a frequency distribution, but the spread of gradients is narrower and with lower values than the Bowen Basin data set. Again, standard deviations are high, making it difficult to state differences between the mines.

Gas content gradients were averaged for the different coal-bearing stratigraphic units in the two basins (Figure 4). Younger coals don’t necessarily mean shallower coals in this analysis, as each unit traverses the depth ranges shallow to deep. Variability in gradients between units is greater in the lower rank Hunter Valley coals, but on average, lower than the higher rank Bowen coals. The Fort Cooper Coal Measure has a surprisingly high gas gradient, but the sample is small (only 3). Coal in these measures is not currently mined due to its quality, but it is exposed in some open pits.

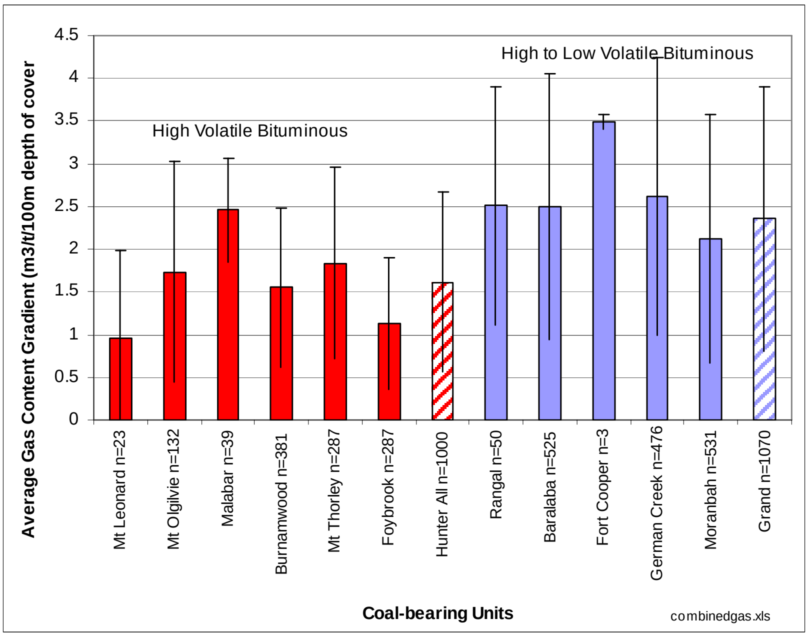

Figure 4 Average gas content gradients for coal-bearing stratigraphic units in the Hunter Valley (red) and Bowen Basin (blue). Units are ordered older to the right. Error bars show standard deviations.

Data were not available to examine the detailed relationship between gas content gradients and coal rank and type for all samples from each of the basins. Therefore samples were assigned an average rank (by vitrinite reflectance) to investigate relationships (Figure 5). Again, the variability in gas content gradients for the Hunter Valley samples is high, given the narrow range in rank. The Bowen Basin samples show more of an increase in gradient with increasing rank. Enough samples with maceral composition data were available in the medium volatile coals from the Bowen Basin to suggest that gradients may also increase with increasing vitrinite content, albeit with high standard deviations (Figure 6).

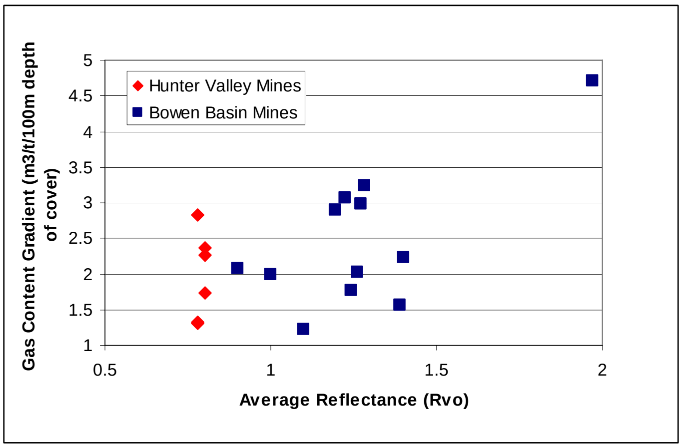

Figure 5 Gas content gradient for coals of varying ranks

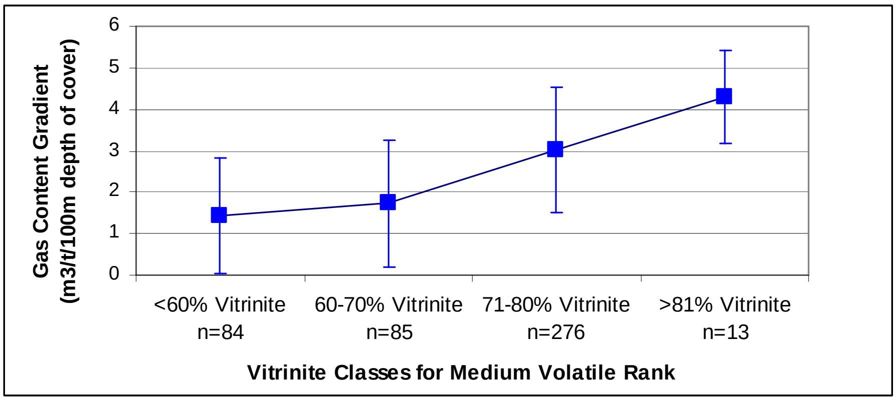

Figure 6 Gas content gradient for coals of varying vitrinite contents for Bowen Basin data set, medium volatile bituminous rank.

Data can be summarised for Bowen Basin and Hunter Valley mine sites using a depth range approach (Figure 7) and some gross generalisations made. In the shallow depth range 0-120m the average gas contents are low and standard deviation too high to discriminate between the areas with any certainty. Again, this reduces the reliability of a Tier 2 and Tier 1 approach to estimating emissions intensity, even using the domain approach. At greater depths the average gas contents are higher in the Bowen Basin, and this probably reflects the increased rank (gas sorption capacity) plus higher gas saturation.

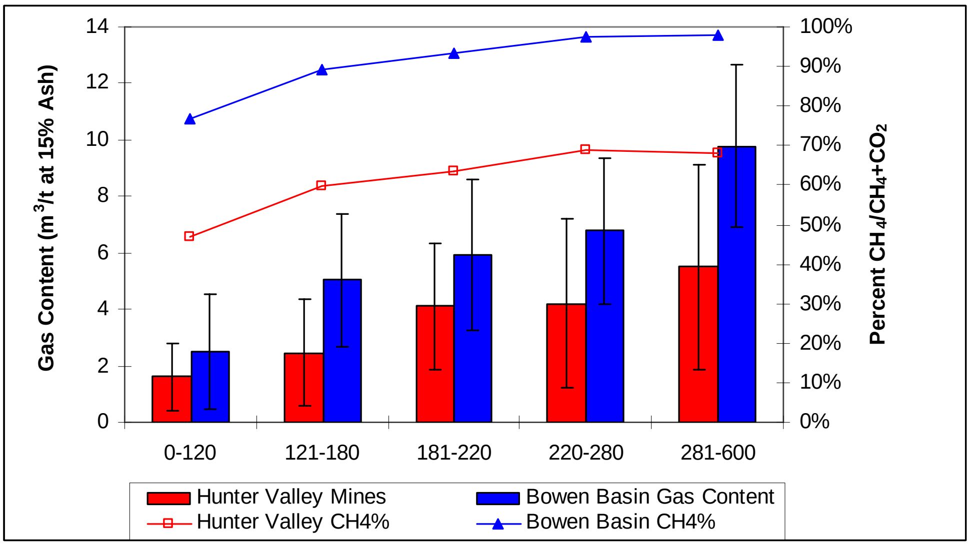

Figure 7 Gas content and composition averages for depth ranges in the Bowen Basin and Hunter Valley mines. Standard deviations overlain on gas contents.

The domain approach may be a better method for deriving Tier 2 estimations of emissions as it takes into account the strong, albeit variable, depth control on gas contents.

CONCLUSIONS

Based on the data analysed in this study, the gas content variability is so high that existing emission factors are unreliable even at a regional level and should not be used as estimates from individual mines. As has been suggested by various guidelines for the estimation of fugitive greenhouse gas emissions, the most reliable estimations are made at the mine scale from measurement and monitoring. Mine scale estimations can be improved by taking a domain approach, where depth and pressure relationships are relatively stable and within which the variability of reservoir parameters is reduced to some degree. However, even this approach will not allow a blanket emissions factor to be derived.

Methods should be developed to allow individual mines to estimate their emissions, which would need to allow for the following factors - local variation in gas content, rates of release of gas during and post mining, gas retained in coal as it leaves the mine lease (and projects such as this are being conducted). Although it was outside the scope of this study, the next logical step is to conduct a series of Tier 3 mine scale studies and then compare them to estimations made by applying Tier 2 formulae and/or to develop of calibrated emission models that take account of both the varying reservoir properties and the mining process.

ACKNOWLEDGEMENTS

The authors are indebted to the coal companies in the Hunter Valley and Bowen Basin that made confidential and sensitive data available to this project. They also thank ACARP and its monitors for their financial support and patience through this project.

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