INVESTIGATION REPORT ET/IR143R

THE USE OF WASTE COAL IN POWER STATIONS - GREENHOUSE GAS EMISSION IMPACT

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EXECUTIVE SUMMARY

There are substantial amounts of waste coal to be found in the Hunter Valley which can be viewed as a potentially low cost energy resource. This report examines the impact of using this resource in power stations, not from an economic point of view, but on the greenhouse gas (GHG) emissions associated with electricity generation. The evaluation was made assuming that the normal run of mine coal supplied to the power station had an embedded GHG overhead arising from the GHG emissions produced in the process of supplying the coal. This included the emissions from extraction, transport, fugitive methane and spontaneous combustion. The waste material, on the other hand, was free from such overheads.

The study examined the energy required to re-mine the waste, upgrade and dewater the fines and to transport them to the Liddell power station. The impact of the different fuel quality of the waste on boiler efficiency was calculated as was the potential savings as a result of spontaneous combustion in the waste. As the GHG emissions embedded in ROM coal are low compared with those released by combustion in the power station, potential savings are relatively small, but may be significant in absolute terms.

The major finding of the study is that while GHG savings can be achieved by using waste coal fines from coal washeries the energy cost due to upgrading and de-watering the product can significantly erode the potential benefit to be obtained. The calculations show that the total benefit is up to ~0.3% of the CO_2 that would have been emitted had the power station burned 'normal' coal.

While the relative savings are small in terms of power generation they can be significant for coal producers. There may be opportunities for Macquarie Generation and coal producers to benefit mutually, from the utilisation of the waste. However this would require detailed knowledge of the greenhouse emissions from particular coal mines in order to quantify the likely savings more precisely.

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1. *INTRODUCTION*

There are substantial amounts of waste coal to be found in the Hunter Valley which can be viewed as a potentially low cost energy resource. This report examines the impact of using this resource in power stations, not from an economic point of view, but on the greenhouse gas (GHG) emissions associated with electricity generation.

The GHG emissions that are produced in the extraction and supply of coal (assumed here to be from open cut mines) to a power station come from three main sources:

- The energy of extraction and preparation – mainly due to consumption of electricity and diesel fuel
- Release of fugitive coal seam methane by the mining process
- Spontaneous combustion of waste coal and other carbonaceous substances in the spoil

In addition there are GHG emissions arising from the transport of the coal to the power station.

If a power station is able to co-feed 10% of its fuel as waste coal, then to a first approximation, there will be a corresponding 10% reduction in the amount of GHG embedded in the fuel as a result of its extraction and supply.

In order to set the scene, the likely magnitude of this saving will be presented as an overview. However, as the reduction in GHG emissions will be offset to some degree because of the energy of re-mining and, if necessary, processing the waste and perhaps because of the lower intrinsic energy of the waste coal, the results of more detailed calculations are also presented. Finally the lifetimes of the various stocks of waste coal as well as the total saving in CO_2 are estimated.

2. *TOTAL POSSIBLE SAVINGS*

For NSW, the average amount of CO_2 emitted from the energy consumed in mining open cut coal is 17 kg/t ROM (Williams et al, 1998). The amount of fugitive CH_4 emitted during the mining process is 4.6 m^3/t ROM, equivalent in climate change terms to 63 kg CO_2 /t ROM. Emissions from spontaneous combustion are estimated to be in the range 10-50 kg CO_2 equivalent /t ROM, depending on whether the mine experiences significant spontaneous combustion. Thus about 100 kg CO_2 are emitted for each tonne of coal produced. (It is assumed that there is no upgrading required for power station coal).

Burning one tonne of coal (22 percent ash, 8 percent moisture) produces about 2.1 t CO_2 from which it can be seen that the embedded GHG in the feed coal raises the effective emission by 100 kg to 2.2 t CO_2 for normal coal. Blending in waste coal to provide 10% of the fuel would therefore decrease the GHG emitted by 10 kg CO_2, or 0.5%. For higher percentages of waste coal that could be tolerated in the case of coarse rejects, the embedded GHG emissions in the fuel could decrease by about 30%.

The above figures indicate the maximum savings likely to be possible. There are other adjustments or allowances that have to be made to take into account the energy required to obtain, process and transport the waste coal to the power station from the available dumps. Also the impact of poorer coal quality due to ash and or moisture on power station performance and hence CO_2 emission has to be evaluated. These are dealt with in the following sections. Note that while we have attempted to quantify the GHG emissions associated with any necessary upgrading of some of the waste coal deposits, other technological issues such as handleability are not addressed in any detail.

3. *THE AVAILABILITY AND NATURE OF WASTE COAL*

There are currently 18 coal mines operating the upper Hunter Valley coal field within a 50 km radius of the Liddell and Bayswater power stations.

Figure 1 shows a map of the area with the location of the power stations and mines indicated. The 1997 coal production quantities (1998 New South Wales Coal Industry Profile) for each of these mines broken down in terms of total raw coal production, saleable and waste coal are listed in Table 1. The waste coal shown is from coal washeries and comprises coarse rejects and fine tailings. It can be seen that in just one year, more than 16 million tonnes of waste was produced or nearly 25% of the total coal production from this region.

Several of the mines shown, i.e. Drayton, Muswellbrook No2 and Ravensworth, do not have washery plants and therefore are not shown as producing waste in Table 1. However, these mines would be likely to produce significant quantities of unsaleable material which would nevertheless be suitable as low grade fuel. This material is presumably sent to spoil at present.

Table 1. Annual Waste Coal Production for Selected Hunter Valley Coal Mines (JointCoal Board, 1997)

Mine	Raw Coal (Mt)	Saleable Coal (Mt)	Waste Coal (Mt)	Percentage Waste	Approx Distance From P/S (km)
Bayswater No2	3.8	3.12	0.68	17.9	5
Bulga/Sth Bulga	8.81	6.09	2.72	30.9	45
Camberwell	3.22	1.86	1.36	42.2	20
Cumnock No1	2.7	2.16	0.54	20.0	5
Dartbrook	1.49	1.45	0.04	2.7	30
Drayton	3.72	3.72	0	0.0	5
Howick	5.04	3.97	1.07	21.2	5
Hunter Valley	6.66	4.94	1.72	25.8	20
Lemington	3.99	3.06	0.93	23.3	20
Liddell	2.27	1.69	0.58	25.6	5
Mount Owen	2.41	1.58	0.83	34.4	15
Mount Thorley	5.86	4.22	1.64	28.0	40
Muswellbrook No2	1.87	1.87	0	0.0	15
Ravensworth	6.15	6.15	0	0.0	10
Rixs Creek	1.42	0.81	0.61	43.0	25
United	1.45	1.03	0.42	29.0	25
Wambo	3.25	2.28	0.97	29.8	25
Warkworth No1	5.6	3.53	2.07	37.0	30
Total	69.71	53.53	16.18	23.2	

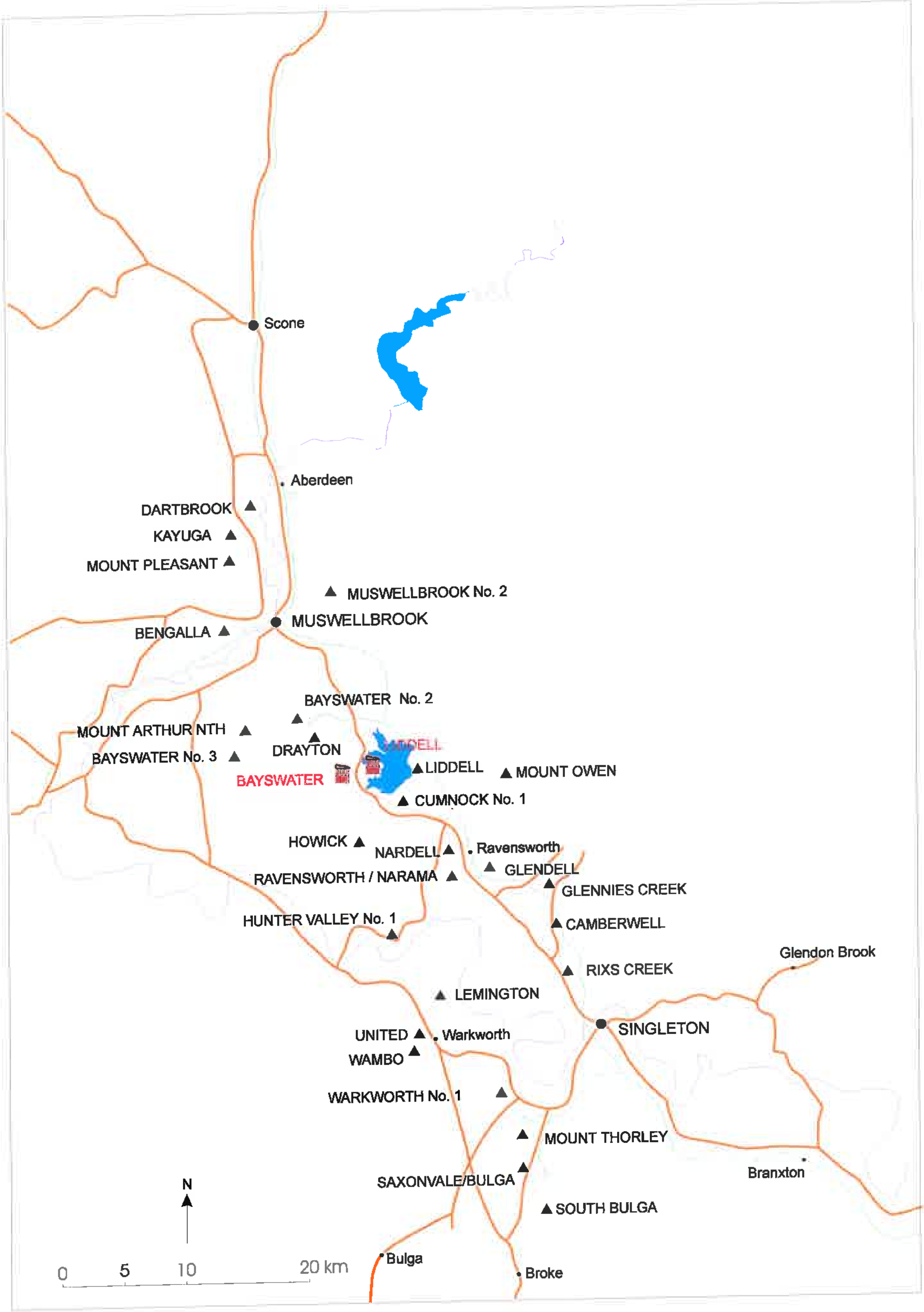

Figure 1. Map of the upper Hunter Valley showing the location of the coal mines in the area. The Liddell and Bayswater power stations are also shown.

As well as the mines shown in Table 1 there are several proposals for new mines including Bengalla which is due to start operation this year. It is obvious therefore that the quantities of waste coal available are very large and potentially represent a significant source of fuel for power generation.

As part of this project we attempted to estimate the extent and quality of the material which is readily available for use and which is suitable for use in the existing power stations. In general we found that the quantities and quality of the waste material are not well characterised. However, in some cases, information was provided by mine personnel and this was used to determine the approximate quantities of material available and its quality. These data are shown in Table 2 along with the upgrading of the material required before it can be utilised.

Each of the above sources is described in further detail below.

HEXHAM

The Hexham site is the site of a disused coal washery which the current owners plan to redevelop into a rail bulk coal handling facility. This site is approximately 100 ha in area and contains about 1.6 Mt of fines and a further 1.5 Mt of coarse material. The owners would like to extract the fine material for sale before starting the redevelopment work and with this in mind have completed a coring program to asses the quality of the resource. Results of that work show that the fines have a calorific value (about 23 MJ/kg, air dried), however, because of the high moisture content, the fine material is difficult to handle and is unsuitable for transport in conventional road or rail trucks. It has therefore been suggested that the material could be mixed with water to produce a slurry which could be carried in rail tanker wagons.

LIDDELL

Liddell open cut, unlike most of the mines in the region, has a very good understanding of the tailings held on their lease. In 1996/1997 they engaged consultant geologists to conduct a detailed coring and sampling program to "prove" the resource. Processing the coal from this mine (like many others) did not commence until the late 1950s with fines processing starting about five to ten years later. This means that there is a significant amount of high quality fines available. There are a number of emplacements of washery rejects on the Liddell site which are readily accessible by re-mining techniques currently in operation at the mine.

The fine rejects at the Durham North site on the Liddell lease are at depths of the order of 20 m with a high ash band near the surface. The quality of the material increases with depth. Typically, the material has a moisture content well in excess of 20% (as received).

In general, the coarse rejects have a high ash content of around 65% but with local variations. The moisture content of this material is lower than the fines and is usually between about 10 to 15%.

Details on the total quantity of material are not available, however, a report by Garling Mining suggests that there are at least 5 Mt of fines available. Similar quantities of coarse material are probably available. Given the length of time that the mine has been operating it is likely that these estimates are conservative.

The reject emplacements on this lease are occasionally subject to spontaneous combustion but the mine operators have management procedures in place.

CUMNOCK

The Cumnock mine has a small emplacement of about 10,000 t of reject material in a pit. Like the material from the Hexham site, some handling problems are anticipated so, it is proposed that it be blended with fresh coarse reject to improve its handling characteristics.

WAMBO

Wambo has a large slurry pond which is nearing capacity. This pond is estimated to contain about 1.5 Mt of fines, however, the slurry is difficult to settle and dewater so some reprocessing would be required before it could be used as fuel.

Table 2. Characteristics of Waste Coal Resources Considered in this Study

Site	Material Type	Approx Quantity (t)	As Rec'd Moisture (%)	Ash Content (%, ad)	Specific Energy (MJ/kg, ad)	Processing Required	Transport Mode
Bulga		1.5×10^6	~30	10			Rail
Cumnock OC	Fines	5000	25	32	21		
	Coarse	5000	12	71	7		
Howick	Oxidised Coal		15	40	15		Conveyor
Liddell OC	Fines	5×10^6	28	35	20		
	Coarse	5×10^6	12	65	8		
Wambo	Fines	1.5×10^6	30	7	30		Truck
Warkworth	Fines	10×10^6	25	12	28	Jameson cells then blend or briquette	
	Coarse						
Hexham	Fines	1.6×10^6	30	32	23	Add water to form slurry	Rail tanker
	Coarse	1.5×10^6					

WARKWORTH

Warkworth is a relatively new mine having commenced operations in 1981. They have access to more than 30 coal seams, and believe they could supply unprocessed material, which might otherwise be dumped, to Bayswater and Liddell power stations. They also have in excess of 3 Mt of recoverable tailings which was evaluated as a fuel for the Redbank power station. In common with other mines, the fine material has very poor handling characteristics and would need to be either briquetted or blended with coarse material prior to shipping.

The coarse rejects at Warkworth have very high ash contents which have been typically around 70% but are currently tending to more than 80%.

Warkworth management envisages that, over the next 20 years, they will mine small areas of oxidised coal that may suit Macquarie Generation.

DARTBROOK

Dartbrook is one of the few underground mines in the region. They have a band of material they term "black carbonate" which at present is waste material. They see potential for use of this material as a fuel.

HOWICK

The Howick mine is already a significant supplier of coal to Macquarie Generation. They currently mine 15 seams some with in situ ash of up to 40% that may be suitable for use in Bayswater and Liddell power stations. They also have some oxidised coal with about 15% moisture and a specific energy around 15 MJ/kg which could be used as a fuel, but this material has handleablity problems.

BULGA

The Bulga mine has an estimated 1.5 Mt of low ash fines (~10%) on their lease. This material has a high moisture content and it is likely that it would be subject to the handleablity problems associated with fine material at other locations. Hence it would probably require some processing and/or blending before it could be efficiently transported.

4. *METHODOLOGY*

The method for estimating the cost in greenhouse gas emission terms for using waste material can be summarised by Figure 2.

Greenhouse gases will result during re-mining of the waste, from energy used as a result of any necessary processing, from transport from the mine to the power station and finally, the effect of the material itself on the efficiency of the power station. Each of these factors is considered in detail below.

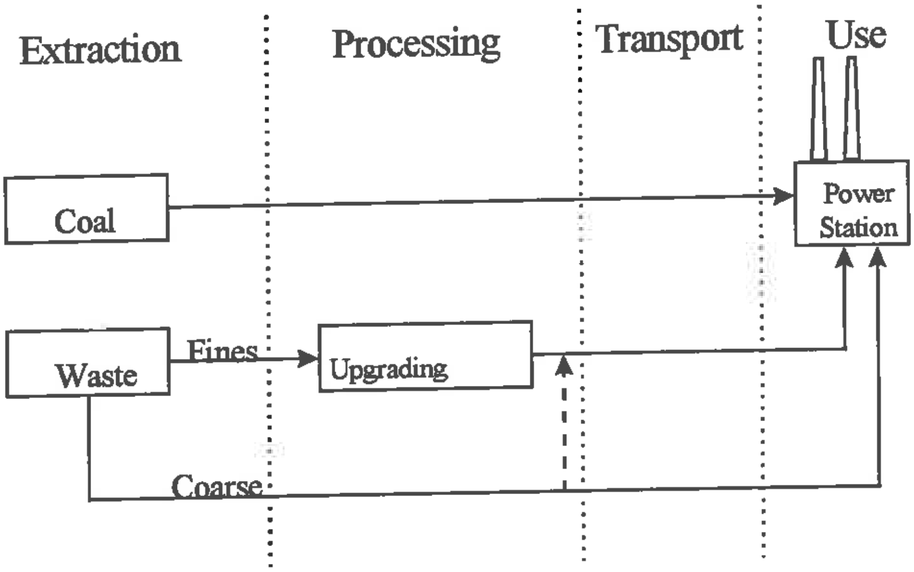

Figure 2. Schematic of the processes important for greenhouse gas emissions for the use of coal waste in power stations.

4.1 *RE-MINING*

Most of the reject emplacements are readily accessible to current re-mining techniques and would not therefore present any significant problems with regard to recovering the material. The energy of re-mining these materials has been estimated by reducing the energy of extraction of open cut coals by the stripping ratio ie the ratio of the overburden material removed to that of the coal extracted. For the sites studied we have assumed a value of 10. This gives rise to an equivalent CO_2 emission rate of 1.7 kg CO_2/t of waste material ie 10% of the average energy of extraction, for NSW open cut coal mines.

4.2 PROCESSING

4.2.1 *Flotation and dewatering*

The coal currently used by the Bayswater and Liddell power stations is essentially run of mine coal, i.e. it is not processed in a washery. Thus there are no GHG emissions associated with processing the coal. On the other hand, if reject material were to be used as a fuel supplement, some processing would probably be required, particularly in the case of fines.

The fine stream from washery plants is usually pumped into large settling ponds as a slurry so it contains a high proportion of water. This slurry sometimes forms a gel-like material which is difficult to handle and it would therefore need some treatment before if could be used as a fuel. It has been suggested that the most appropriate method would be to process this material in Jameson cells to break up the gel structure followed by filtration to remove excess water. Jameson cells would also upgrade the material by reducing the ash content of the product.

Dewatering processing of any type will require energy usage and hence there will be GHG emissions from this step. An IEA report (Thambimuthu, 1994) estimated that the energy usage for dewatering coal slurries was between about 70 and 300 kcal/kg. On the basis of these values, and assuming an initial moisture content of 30% and a solids feed rate of 30 t/hr, the CO_2 emission from processing equates to about 3 to 13 kg CO_2/t of product. For comparison, we also estimated the emissions using design data for a flotation cell provided by, Sedgman Pty Ltd. These data yielded a similar result of about 4 to 11 kg CO_2/t of product.

The energy needed to process the fines using a Jameson cell and a bowl centrifuge has also been estimated at 11.5 kWh/t product, assuming 50% yield, with a moisture content of 25% (B. Firth, CSIRO, private communication). This is equivalent to 11.4 kg CO_2/t of product. We have used the latter figure in this report.

4.2.2 *Briquetting*

Generally, the handleability of the fine reject is very poor and some operators see the need to briquette this material before it could be used and this would be an additional source of GHG emissions. Briquetting would require as a first stage a drying operation and it has been estimated that the energy consumption for drying material with an initial moisture content of 25% would be about 173 kWh/t. The briquetting process itself would consume a further 6 to 9 kWh/t, giving a total energy requirement for the process of at least 180 kWh/t. This is equivalent to ~180 kg CO_2/t.

Coarse material is characterised by high ash contents (60 to 80%) but the moisture content is usually not too different from product coal and is unlikely to require any processing before transporting. Some mine operators have suggested, however, that some of the coarse rejects may be blended with fines to improve the handleability of the fine material. Provided the fuel properties of coarse materials weren't too low this would probably have little effect on GHG emissions.

4.3 *TRANSPORT*

Most of the mines in the Upper Hunter Valley transport product coal by rail to Newcastle although several (Lemington, Muswellbrook No2, United and Wambo) first truck coal from the mine to a rail facility where it is loaded onto trains to be taken to port. A number of others (Hunter Valley, Mount Thorley and Warkworth) use conveyors instead of trucks to move coal to the rail facility.

In the case of Bayswater No2, Howick and Ravensworth mines, conveyor systems are in place to carry coal directly to Liddell and Bayswater power stations. Thus, for these mines, transport of waste coal to the power stations would not be a significant issue and would not be expected to have any significant impact on the greenhouse gas emissions due to transportation.

For other mines, however, this infrastructure does not currently exist and in the short term at least other forms of transport would be required. Most of the mines with which we had discussions indicated that they saw rail as the preferred transport mode but this would, of course, necessitate the construction of additional rail facilities. Others, such as Wambo envisaged that road transport would be the most cost effective method.

4.3.1 *Road and rail*

In terms of greenhouse gas emissions, rail has a significant advantage over road transport. Lilley and Williams (1998) measured the fuel consumption of a triple locomotive train hauling 5880 t of coal over a 21.6 km distance in the Hunter Valley. The results of this study showed that the total fuel used by the three locomotives was significantly less than that required for single or double bogie trucks to move an equivalent load under the same conditions. For a single bogie truck, approximately 8 times more fuel is consumed while a double bogie truck would be expected to use about 6.5 more fuel than a train. The results are summarised in Table 3

Table 3. Specific Fuel Consumption Rates for Coal Transport

Specific Fuel Consumption (kg/t/km)	
Train	0.00159
Single Truck	0.01248
Double Truck	0.010275

The corresponding CO_2 emission rates are shown in Table 4.

Table 4. CO_2 Emissions for Transport by Rail or Road

Train	**Truck**	
	Single	**Double**
(kg CO_2/t/km)	(kg CO_2/t/km)	(kg CO_2/t/km)
5.0 x 10-3	3.9 x 10-2	3.2 x 10-2

4.3.2 *Conveyors*

For conveyors, we estimated power consumption from published data (Australasian Institute of Mining and Metallurgy, 1990). The power required to drive a conveyor, P_t, was calculated from the expression:

$$P_t = P_e + P_h + P_l$$

where P_e is the power needed to drive the empty belt, P_h is the power to carry the load horizontally and P_l is the power to raise the load vertically. For these calculations we assumed a conveyor capacity of 1000 t/hr, a belt speed of 5 m/s and a belt width of 800 mm. The length of the belt and approximate vertical distances were estimated from topographic maps of the region. Values of the components P_e, P_h and P_l were determined from the tabulated data. The power requirements were converted to the equivalent CO_2 emission rate of 0.14 kg CO_2/t/km.

5. *EFFECT OF WASTE COAL ON GHG EMISSIONS FROM POWER STATIONS*

5.1 *EFFICIENCY CONSIDERATIONS*

The overall efficiency of a power station is determined by the thermal efficiency of the boiler and the turbine efficiency according to the expression:

$$E_{overall} = E_{boiler} \times E_{turbine}$$

For the Liddell Power Station, the turbine efficiency is about 37% which, provided the inlet steam pressure and temperature are maintained at 16.5 MPa and 540 °C respectively, should remain constant. The boiler efficiency, on the other hand, is affected by the quality of the fuel and varies between about 86 to 90% (J. Beckwith, Macquarie Generation, private communication). This yields an overall efficiency for Liddell of between about 32 to 33%.

Boiler efficiency is obviously an important issue for power station operators because it affects the amount of fuel required to maintain a given thermal output. Consequently, it is monitored by Macquarie Generation staff who have quantified the relationships so as to calculate thermal efficiency at different ash and moisture contents of the feed coal (J Beckwith, Macquarie Generation, private communication).

Using this relationship for the Liddell power station we calculated the coal feed rate and corresponding CO_2 emissions for various fuel ash contents ranging from 22 to 35% (Table 5). The moisture content was assumed to be 8% for each case shown in Table 5. For these calculations, the specific energy of the base case feed coal (i.e. 22% ash and 8% moisture) was taken as 33.95 MJ/kg (daf) and the carbon content of the coal was 82.3% (daf). The thermal output of the boiler was set at 845.6 MW for all cases.

The specific energy of the feed was assumed to vary in direct proportion with the amount of ash and moisture present. Coal consumption rates shown were calculated on the basis of maintaining a thermal output of 845.6 MW and the specific energy of the feed. For the purpose of calculating the rate of CO_2 emission, we assumed that all of the carbon in the feed coal was completely combusted within the furnace.

Table 5 shows varying the ash content from 22 to 35% (with 8% moisture for all cases) resulted in a drop of thermal efficiency of less than 1.6 percentage points from about 87.2 to 85.7%. This suggests that most of the thermal energy required to heat the ash in the furnace is recovered before it leaves the boiler.

Table 5. Effect on Boiler Efficiency of Varying the Ash Content of the Feed Material

Ash Content (%)	Boiler Efficiency (%)	Carbon in Raw Feed (%)	Raw Feed Specific Energy (MJ/kg)	Coal Consumption (t/hr)	CO_2 Emission Rate (t/hr)
22	87.23	57.6	23.8	146.8	310.2
23	87.13	56.8	23.4	149.1	310.5
24	87.02	56.0	23.1	151.5	310.9
25	86.92	55.1	22.7	154.0	311.3
26	86.81	54.3	22.4	156.5	311.7
27	86.69	53.5	22.1	159.1	312.1
28	86.58	52.7	21.7	161.8	312.5
29	86.46	51.8	21.4	164.6	313.0
30	86.33	51.0	21.0	167.5	313.4
31	86.2	50.2	20.7	170.5	313.9
32	86.07	49.4	20.4	173.6	314.4
33	85.93	48.6	20.0	176.9	314.9
34	85.79	47.7	19.7	180.2	315.4
35	85.65	46.9	19.4	183.7	315.9

The rate of CO_2 emitted was relatively unaffected by the amount of ash in the feed as shown in Figure 3.

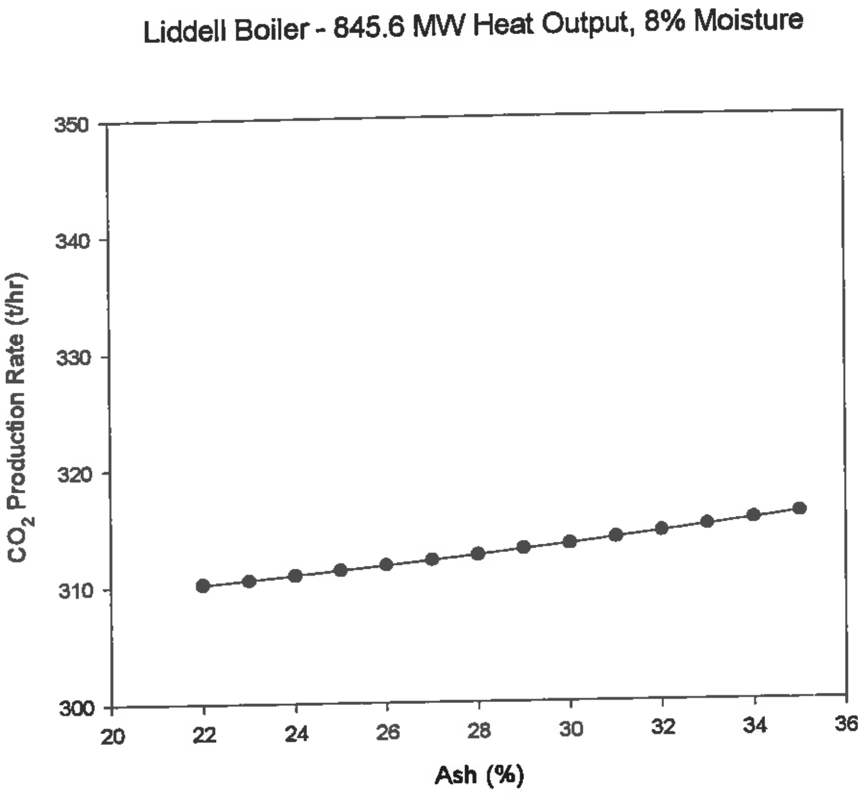

Figure 3. Rate of CO_2 emission as a function of ash content of the fuel

The effect of moisture on the boiler efficiency was much more pronounced than was the case for ash since most of the heat used to vaporise the water is lost to the flue gas. Table 6 shows the effect of increasing moisture content in the feed on boiler efficiency, coal feed rate and CO_2 emission rate, again for a boiler output of 845.6 MW. The ash content was fixed at 26.5%.

Here, boiler efficiency dropped from about 86.7% at 8% moisture to around 82.7% with 26% moisture in the feed. Replotting these data in terms of the rate of CO_2 omitted yielded the curve shown in Figure 4.

Table 6. Effect on the Boiler Efficiency of Increasing Moisture Content of the Fuel for an Ash Content Fixed at 26.5%

Moisture (%)	Boiler Efficiency (%)	Carbon In Raw Feed (%)	Raw Feed Specific Energy (MJ/kg)	Coal Consumption (t/hr)	CO_2 (t/hr)
8	86.75	53.9	22.2	157.8	311.9
10	86.42	52.3	21.6	163.4	313.1
12	86.06	50.6	20.9	169.4	314.4
14	85.68	49.0	20.2	175.9	315.8
16	85.28	47.3	19.5	182.9	317.3
18	84.84	45.7	18.8	190.4	318.9
20	84.37	44.0	18.2	198.6	320.7
22	83.87	42.4	17.5	207.6	322.6
24	83.33	40.7	16.8	217.4	324.7
26	82.73	39.1	16.1	228.2	327.0

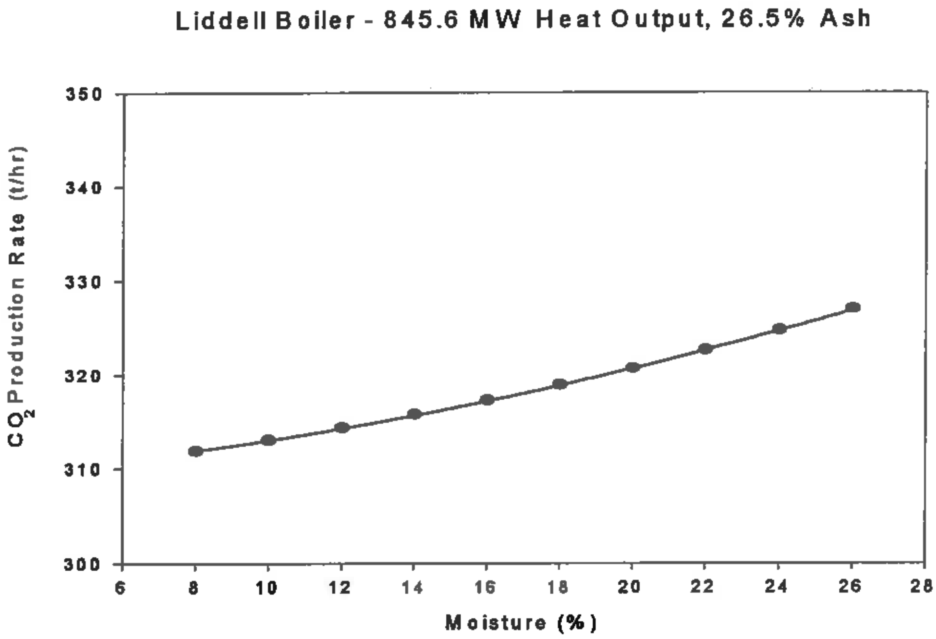

Figure 4. Rate of CO_2 emission as a function of ash content of the fuel

The combined effect of ash and moisture on the CO_2 emissions were determined using boiler efficiencies calculated by the Liddell power station model for a range of moisture and ash contents. CO_2 emission rates were calculated for each combination as described above which were then plotted as a three-dimensional mesh plot as shown in Figure 5.

This Figure clearly shows that, as would be expected, at high levels of moisture and ash the rate of CO_2 emission increases rapidly. In the worst case considered here (34% ash and 26% moisture) the hourly CO_2 emission is about 335 tonnes compared 310 tonnes for the base case of 22% ash and 8% moisture, an increase of about eight%. At lower ash and moisture contents, however, CO_2 emissions are only slightly increased. The implication is that burning low grade fuel (i.e. high ash and particularly high moisture) in the boiler would result in significantly increased CO_2 emissions for a given output. However, if the low grade fuel were to be blended with high quality coal in such a ratio to ensure that the average ash and moisture content were kept to acceptable levels, then only minor increases in CO_2 emissions would result.

Note that milling of the waste material and ash disposal have been assumed to be unaffected by the blending of waste material (J. Beckwith, private communication). We have made the same assumption for bag filter operation.

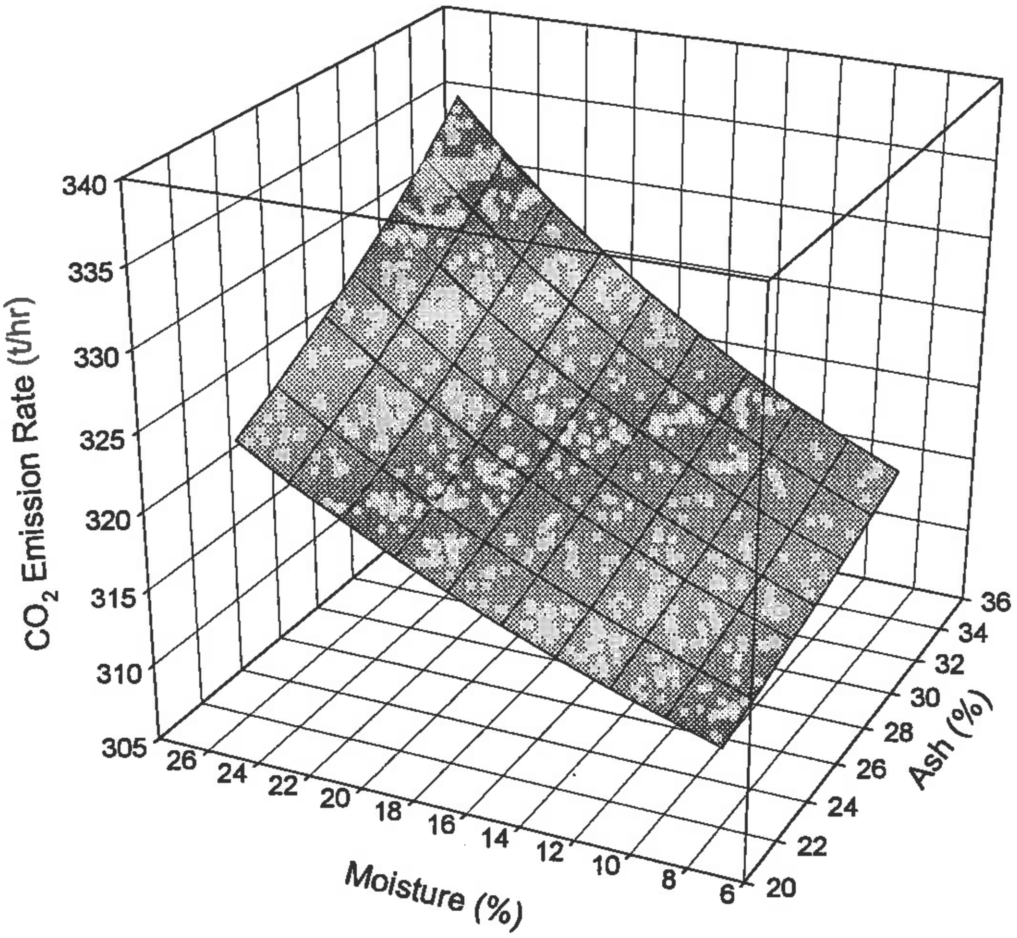

Figure 5. Plot of CO_2 emission rate as a function of ash and moisture content

5.2 *CO_2 EQUIVALENT OF ELECTRICITY.*

In considering the energy usage of processes which use electricity it was necessary to estimate the amount of CO_2 emitted per unit of electricity consumed. Using data provided by Macquarie Generation on boiler efficiency and internal power station losses for Liddell, we estimated the coal feed rate to maintain a thermal output from the boiler of 845.6 MW. Details of the fuel and power station operating conditions are shown in Table 7.

1000 kg / MWh .

~1t / MWh = $10^3 \times 8 \times 10^3$

for hiddel pn =

8×10^6 t / y

=

4t / m^3

CO_2 = 240 kg ∴ $30 \times 10^6 \ m^2 / y$

CH_4 60 kg

= ~~4 × 10~~ 30 km^2/y.

300t coal / h 2.4×10^6 t coal

150t sa / h = 1.2×10^6 s..

$30 \times 10^6 \times 60 \times 10^{-3}$

1.

Table 7. Power Station Operating Parameters and Fuel Specifications

Operating parameters	
CO_2 (t/h)	310.2
Boiler Output (MW, thermal)	845.6
Boiler efficiency (%)	87.23
Turbine efficiency (%)	37
Station Losses (% of output)	3.8
Overall Efficiency (%)	31.05
t CO_2/MWh electricity	1.031
Fuel	
Carbon Content (%, daf)	82.3
Moisture (%)	8
Ash (%)	22
Specific energy (MJ/kg, daf)	33.95
Boiler Output (MW, thermal)	845.6

Table 8 shows the calculated relative savings for the GHG emissions for each of the sources of raw materials.

The data in Table 8 show that in the case of coarse rejects, the extra ash (ie inerts) that come with the waste coal degrades the overall performance of the power station by almost 2%, thus offsetting the potential saving of ~0.5 due the lower GHG debt embedded in the fuel containing waste coal.

Table 8 shows that for the fines the extra energy of processing and transport causes an amount of GHG emissions equal to about 40% of that associated with ROM coal. This, together with the extra water reduces the potential benefits from this approach.

Table 8. Effect of Blending Waste Coal on GHG Emissions from Electricity Generation

Site	Type of Material	Amount Reject (%)	Feed Ash (%)	Feed Moisture (%)	Total CO_2 per MWhe (kg)	Diff from Std Fuel (%)
Bulga	Fines	12	20.6	10.0	1075.6	-0.23
Cumnock	Fines	12	21.2	10.0	1076.8	-0.12
	Coarse	26	34.7	9.0	1096.8	1.74
Liddell	Fines	12	21.2	10.0	1076.9	-0.11
	Coarse	30	34.9	9.2	1095.8	1.64
Wambo	Fines	12	20.3	10.0	1075.1	-0.28
	Briquetting	12	20.3	7.6		
Warkworth	Fines	12	20.8	10.0	1080.07	0.24
	Briquetting	12	20.8	7.6		
Hexham	Fines	12	21.2	10.0	1076.8	-0.12
R'worth	**ROM coal**	**0**	**22**	**8**	**1078.1**	**0.00**

5.3 *LIFETIME OF THE RESOURCE*

The coal feed rate is about 150 t/h, which leads to the lifetimes listed in Table 9, assuming 50% recovery of the resource. It should be borne in mind that some of these stockpiles or tailings dams are active, ie constantly receiving new material, so that in some cases the lifetime of the resource will be greater than indicated in Table 9.

Table 9. The Lifetime of the Waste Coal Resource at the Modelled Feed Rates.

Site	Type of Material	Amount (Mt)	% of feed	Rate of use of resource (kt/y)	Lifetime (y)
Bulga	Fines	1.5	12	300	5
Cumnock	Fines	0.0046	12	300	Low
	Coarse	0.0057	26	650	Low
Liddell	Fines	5	12	300	16
	Coarse	5	30	750	7
Wambo	Fines	1.5	12	300	5
Warkworth	Fines	10	12	300	32
Hexham	Fines	1.5	12	300	5

5.4 *TOTAL CO$_2$ SAVING*

Table 10 shows the CO$_2$ saving (or expenditure for coarse reject) over the life of the resources considered in this report.

Table 10. Total CO$_2$ Saving for the Life of the Resource

Site	Material	Total CO$_2$ Basecase (Mt)	CO$_2$ Saving (kt)	CO$_2$ Saving (kg)/t of Waste
Bulga	Fines	13.69	33.83	45.1
Cumnock	Fines	0.04	0.06	25.0
	Coarse	0.04	-0.66	-115.6
Liddell	Fines	45.21	58.38	23.4
	Coarse	28.85	-467.37	-93.5
Wambo	Fines	13.76	40.71	54.3
	Briquetting	14.29	-16.45	-21.9
Warkworth	Fines	9.093	178.86	35.18
	Briquetting	94.46	-202.17	-40.4
Hexham	Fines	13.56	18.84	25.1

While the possible savings represent a small fraction of the emissions from power generation, the utilisation of the waste and prevention of spontaneous combustion would represent a major saving for an open cut coal mine with spontaneous combustion. This may be an avenue for obtaining greenhouse credits which Macquarie Generation may wish to pursue.

5.5 *SENSITIVITY CALCULATIONS*

The calculations presented above use industry wide values for the CO$_2$ required to mine the coal. The estimate uses a typical value for emissions from fugitive emissions (coal methane and spontaneous combustion) across the industry for the Hunter Valley. In some cases where there is high methane and severe spontaneous combustion these offsets would increase the likely GHG saving. In the current study, however, little spontaneous combustion was encountered in the waste materials considered. This is because most of the fines examined contained large amounts of associated moisture. Attempts to measure the emissions for the Liddell fines, which had previously experienced spontaneous combustion but are now managed to prevent spontaneous combustion, showed emissions similar to natural ground indicating that spontaneous combustion is not currently significant for this source.

The above considerations highlight the sensitivity of the calculated savings in GHG emissions to the assumptions made in the calculations. For instance, the amount of fugitive emissions (from coal methane and spontaneous combustion) assumed in the calculation was 63 kt CO_2/t ROM coal. Table 11 shows the effect of varying this number by ± 50%.

Table 11 shows that the uncertainty in fugitive emissions alone could give rise to a factor of four variation on the potential savings of GHG emissions from, for example, the Bulga fines.

Table 11. Results of a Sensitivity Analysis where the GHG Fugitive Emissions for the ROM Coal were varied by ± 50%.

		ROM Emission 70 kg CO_2 /t	**ROM Emission 100 kg CO_2 /t (Base Case)**	**ROM Emission 130 kg CO_2 /t**
Site		**Diff from standard fuel (%)**	**Diff from standard fuel (%)**	**Diff from standard fuel (%)**
Bulga	Fines	-0.10	-0.25	-0.39
Cumnock	Fines	0.00	-0.14	-0.27
	Coarse	1.83	1.73	1.62
Liddell	Fines	0.01	-0.13	-0.26
	Coarse	1.79	1.62	1.46
Wambo	Fines	-0.14	-0.30	-0.45
Warkworth	Fines (briquetted)	0.41	0.20	0.02
Hexham	Fines	0.00	-0.14	-0.27

6. *CONCLUSIONS*

The major conclusion of the study is that while GHG savings can be achieved by using waste coal fines from coal washeries, the energy cost of upgrading and de-watering the product significantly erode the potential benefit to be obtained. The calculations show that the total benefit is up to ~0.3% of the CO_2 that would have been emitted had the power station burned 'normal' coal.

While the relative savings are small in terms of power generation they can be significant for coal producers. There may be opportunities for Macquarie Generation and coal producers to benefit mutually, from the utilisation of the waste. However this would require detailed knowledge of the greenhouse emissions from particular coal mines in order to quantify the likely savings more precisely.

7. *REFERENCES*

Beckwith, J. Liddell Power Station, personal communication.

Firth, B. CSIRO, personal communication.

Lilley, W.E. and Williams, D.J., (1998). Emission factors for in-use diesel locomotives and comparison of rail freight emissions with those of road freight. To be published.

Cost Estimation Handbook for the Australian Mining Industry, (1990). The Australasian Institute of Mining and Metallurgy, Monograph 20.

Thambimuthu, K., (1994). Developments in coal-liquid mixtures. IEA Coal Research, London.

Williams, D.J., Carras, J.N., Mallet, C., Mark, M., Cooke, D.and Randall, C., (1998). Scoping study on the management and abatement of greenhouse gas emissions. Report to the Australian Coal Association. CSIRO Division of Energy Technology Report CET/IR46.

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