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Queensland High Energy Coals for the Asia-Pacific Thermal Coal Market

Report No: 970007

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Summary

The increasing demand for thermal coal for electricity generating power plant, especially in the Asia-Pacific Region, is causing operators to consider a wider range of coals to increase their diversity of suppliers and to lower fuel costs. In Australia, Queensland's state electricity producers operate power plants firing coals which range from the low to medium volatile coals of the Bowen Basin to high volatile coals from the Surat and Moreton Basins.

This report examines the combustion performance of Queensland Bowen Basin coals. These coals are fired in several Queensland power stations. The report focuses on:

- The combustion performance of these medium volatile coals in Stanwell Power Station, the state's newest coal fired station commissioned in 1993. Stanwell has four 350MW units firing coals which have a volatile content of around 23% (daf). These coals are effectively burned in Austa's Power Stations demonstrating good flame stability and low carbon in ash. The low carbon in ash results are achieved by grinding the coals to a fineness of greater than 85% minus 75 μm which is made possible by the soft nature of these coals.
- The pilot scale evaluations conducted at ACIRL's Combustion Test Facility on low volatile coals and the use of these coals in blends has shown that these Bowen Basin coals can be burned in blends with higher volatile coals which will result in better flame stability characteristics and carbon in ash, though the carbon in ash is slightly higher than that calculated based on the combustion performance of the component coals.

The flame stability performance of Bowen Basin coals indicates that these coals may perform better than predicted using techniques developed in the USA. This work relates the heating value of the coal volatile matter to the flame stability characteristics in combustion, and it does not take into account the possible influence of char combustion on stabilising the flame. Further research work is required to clarify the influence of the initial char reactivity on the flame stability characteristics of Queensland low to medium volatile coals.

The carbon in ash of blends incorporating low to medium volatile coals can be improved by grinding the coal to the maximum fineness that can be achieved without an undue increase in mill power consumption. Pilot scale blending studies have shown that mill performance of a blend can be determined by assuming the coal properties of the component coals are additive.

Thermal Coal Demand In Asia

The electric-power industry in Southeast Asia is the most dynamic in the world today. Strong economic growth and rapid industrialisation have prevailed in many countries of the region for a decade or more.

The growth in electricity demand in Asia for the balance of the 1990's and beyond is expected to remain strong though not at the same very high levels of the early 1990's. In many developing countries in Asia, such as the Philippines and Malaysia, there are still problems in meeting the power demand leading to brownouts and restrictions in supply through load-shedding.

It is expected that 60 GW per year of additional capacity will be required in APEC countries through to 2010 to replace old plant and for new plant, with China and India accounting for 23 GW and 7 GW per year respectively (Stuart & others, 1996).

To meet this rapid growth in power demand mainly coal, natural gas and nuclear fueled generating plant will be built. Natural gas is being considered by Thailand, Malaysia and Indonesia as the future fuel for power generation. For example, the Thai Government is giving top priority in the development of a proposed large-scale power plant of up to 1800 MW to be fuelled by natural gas from neighbouring Malaysia.

Japan, South Korea and Taiwan plan to expand their existing nuclear power capacity with Malaysia, the Philippines and Indonesia planning to install new nuclear power capacity.

Coal demand will continue to grow because of the abundant reserves, high supply stability, ease of utilisation and relatively lower energy costs. The anticipated growth in coal demand for coal fired generating capacity in the Asian region is shown in Figure 1 (a), while Figure 1 (b) comparatively shows the growth of coal exports of coal producing countries.

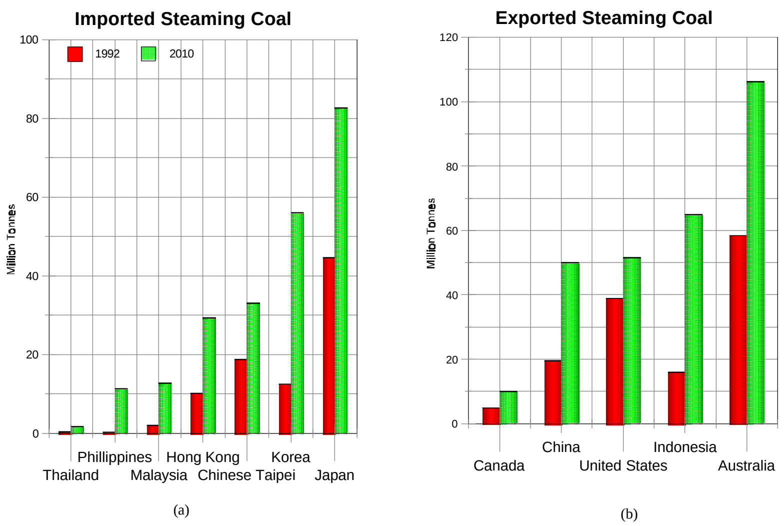


Figure 1: Coal demand and supply in the Asian region (Stuart & others, 1996)

Queensland Coal Resources

Queensland produces over 50% of the coal exported from Australia, the world leading coal exporter. The importance of the emerging economies of Asia to the growth in Queensland coal exports is clearly demonstrated in Figure 2, which shows the strong growth in coal exports to Asian countries.

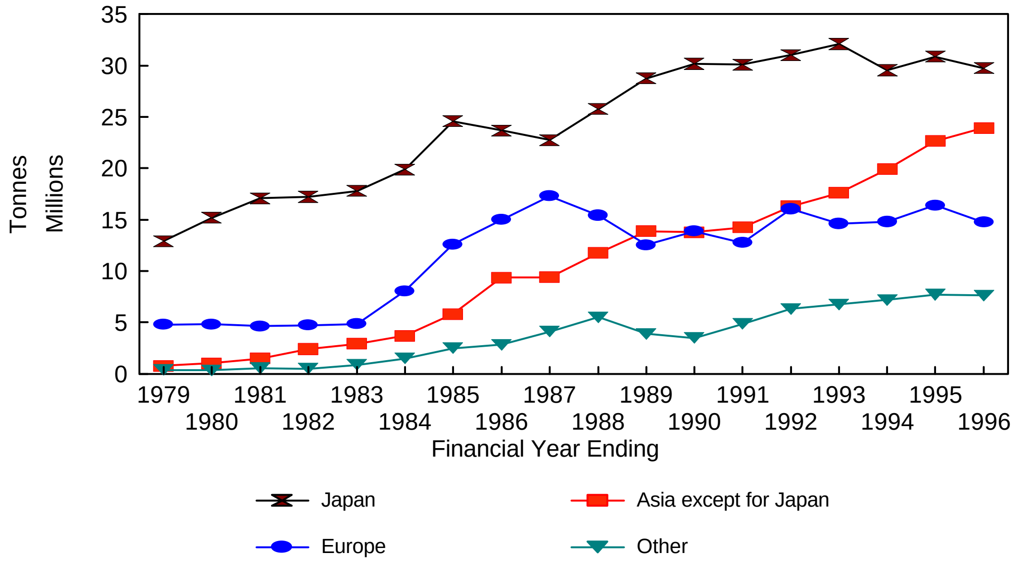


Figure 2: Queensland Coal Exports

Queensland has sufficient resources of black coal, ranging from sub-bituminous thermal coals through coking coal to anthracite, to support the State's mining industry for the foreseeable future. Two major coal regions of the State - the Bowen Basin in Central Queensland and the Surat-Moreton Basin in the southeast are known to contain some 30 billion tonnes in situ coal resources.

The State currently has 30 opencut and 13 underground coal mines in operation, producing 99.4 million tonnes of saleable coal of which 78.97 million tonnes were sold in the export market in the year ending June 1997. Almost all new mine development has been in the Bowen Basin where both coking and thermal coals are produced.

The thermal coals produced in central Queensland are detailed in Table 1.

Table 1: Thermal coals currently produced from Central Queensland.

Colliery	Total Moisture	Moisture	Volatile Matter		Fixed Carbon	Ash	Total Sulphur	Gross Specific Energy	Hardgrove Grindability Index	Ash Fusion (Deformation Temp. Red.)	Crucible Swelling Number
	% a.s.	% a.d.	% a.d.	% d.a.f.	% a.d.	% a.d.	% a.d.	MJ/kg a.d.		°C	
ADVANCE QLD RESOURCES & MINING P/L											
Jellinbah East	8.0	1.5	14.5	16.4	74.0	10.0	0.53	31.6	80 - 85	1250	1
BHP COAL PTY LTD											
Blackwater	8.0	2.0	24.0	28.9	59.0	15.0	0.70	29.3	65	1200	
Blackwater	10.0	2.0	25.0	28.2	63.5	9.5	0.55	-	68		3 ½
Moura	10.5	2.5	32.0	35.9	57.2	8.3	0.42	31.3	53	1270	6
Moura	10.5	2.5	30.5	34.9	57.0	10.0	-	30.4	53	1250	-
South Walker Ck	8.5	2.0	13.3	15.8	69.7	15.0	0.70	28.9	83	1210	-
South Walker Ck	9.0	1.2	12.8	14.2	77.5	8.5	0.65	32.3	85		1
BURTON COAL PTY LTD											
Burton	8.0	1.8	20.2	24.0	64.0	14.0	0.35	30.1	80	1450	1 - 2
CALLIDE COALFIELDS PTY LTD											
Boundary Hill	19.0	11.7	25.1	33.2	50.4	12.8	0.33	22.2	89	1270	0
Callide	15.5	10.9	23.7	33.8	46.5	18.9	0.26	21.1	85	1334	0
COLLINSVILLE COAL COMPANY PTY LTD											
Blake West	6.0	1.3	20.5	25.7	59.2	19.0	0.82	27.7	82	1500	1 ½
Bowen raw	-	1.3	20.2	24.0	64.0	14.5	1.29	30.6	82	1340	4
COOK RESOURCE MINING PTY LTD											
Cook	8.5	1.6	24.0	28.1	61.4	13.0	0.32	30.1	70	1250	-
CURRAGH QUEENSLAND MINING LTD											
Curragh	-	1.7	18.6	22.6	63.7	16.0	0.35	29.3	75	1175	1 ½
ENSHAM RESOURCES PTY LTD											
Ensham	10.0	4.0	26.5	30.8	59.5	10.0	0.60	29.3	57	1350	0 - 1
Ensham	10.0	4.0	25.5	30.7	57.5	13.0	0.60	28.1	57	1350	0 - 1
GORDONSTONE COAL MANAGEMENT PTY LTD											
Gordonstone	8.0	2.0	31.0	36.5	54.0	13.0	0.65	29.3	55	>1600	
NEWLANDS COAL PTY LTD											
Newlands	8.3	2.3	26.3	31.6	56.9	14.5	0.50	28.5	53	1550	
PACIFIC COAL PTY LTD											
Blair Athol	16.0	7.5	27.2	32.2	57.3	8.0	0.30	27.3	60	1550	½
Meandu	12.0	5.3	27.5	41.2	39.2	28.0	0.29	21.8	53	1485	1
SOUTH BLACKWATER COAL LTD											
South Blackwater	8.0	2.0	25.5	29.7	60.5	12.0	0.65	29.7	65	1250	1 - 2 ½
YARRABEE COAL COMPANY PTY LTD											
Yarrabee	9.0	2.0	9.5	10.8	78.5	10.0	0.65	31.2	68	1200	

In recent years there has been an increase in the exploration activities in the Bowen Basin, this has been driven by:

- Release of land by the Queensland Government. The Central Queensland Coal Area, Restricted Area 55, was abolished March 1993 resulting in significantly boosted exploration for thermal coals of export quality.
- Increasing coal demand in the Asia Pacific region is expected to result in an annual thermal coal demand growth rate of around 5% over the next 10 years.
- The increase in thermal coal demand resulted in increased coal prices with the thermal coal price to Japan increasing by 17% to US$40.30 (A$54) in 1995. This has enabled mine operations with higher operating costs to be considered. However, recently price falls have reduced profitability impacting heavily on many Australian operations.
- Increase in the use of coal as an injected fuel into blast furnaces used in steel making. The lower volatile high energy coals of the Bowen Basin are well suited to Pulverised Coal Injection.

New developments in the Bowen Basin have the potential to increase Queensland coal exports by over 20 million tonnes per year over the next 5 years. Table 2 summarises the coal deposits that are currently being actively explored. A significant fraction of these new developments produce low to medium volatile coal.

Table 2: Some potential thermal coal developments in the Bowen Basin, Queensland

Project (Operator)	Type	Volatiles (% daf)	Production	Status
Bee Creek (BHP Coal)	opencut thermal	16.8	not yet determined	Uncommitted, if market accepts the low volatile product, mining could quickly proceed.
Clermont (Pacific Coal)	opencut thermal	32.2	reaching 10-13 mtpa	Will be phased in to replace Blair Athol, site works may commence in 2000 with production from 2004.
Coppabella (Australian Premium Coal Pty Ltd)	opencut thermal	18.0	not yet determined	Exploration, feasibility and marketing studies are well advanced.
Cullin-la-ringo (Qld Govt)	underground thermal	35.8	not yet determined	Exploration area held by Queensland Government, development unlikely before 2005.
Daunia (BHP Coal)	opencut thermal	23.4	not yet determined	Uncommitted, if market accepts the lower volatile product, mining could quickly proceed.
Dawson Valley (AQC)	opencut thermal; semi-anthracite	13.6	not yet determined	Uncommitted, development unlikely in the short term.
Gordonstone West (ARCO)	underground thermal	35.3	4.0 mtpa with full longwall development	Uncommitted, awaiting favourable market conditions.
Hail Creek (Pacific Coal)	opencut coking and thermal	22.1	5 mtpa coking only, thermal coal later	Coking coal production may commence by 2000; thermal coal production delayed pending market opportunities.
Humboldt (South Blackwater Coal)	underground thermal	33.1	not yet determined	Development not committed, ongoing market assessment to identify opportunities.
Kemmis Creek (BHP Coal)	opencut thermal	20.9	not yet determined	Uncommitted, if market accepts the lower volatile product, mining could quickly proceed.
Lake Vermont (QCMM)	opencut thermal and coking	22.8	0.5 increasing to greater than 1.0 mtpa	Exploration, feasibility and marketing studies continuing, possible start by 2000.
Minerva (New Hope Collieries)	opencut thermal	35.6	0.8 mtpa	Grant of Mining Lease imminent, development to follow as markets become available.
Poitrel / Winchester (BHP Coal)	opencut thermal and coking	25.7	not yet determined	Uncommitted, development likely to occur in conjunction with the Daunia deposit.
Red Hill (BHP Coal)	opencut thermal and coking	29.6	not yet determined	Exploration continuing, further work required prior to feasibility studies.
Rolleston (MIM)	opencut thermal	36.3	not yet determined	Awaiting favourable market conditions and infrastructure establishment.
Rugby (BHP Coal)	underground thermal	30.8	not yet determined	Exploration continuing, development not scheduled.
South Walker Creek (BHP Coal)	opencut thermal	15.3	up to 3 mtpa	Now operating as a trial mine, further development depends on market acceptance of low volatile coal.
Suttor Creek (MIM)	opencut and underground thermal	32.0	not yet determined	Production will supplement output from Newlands, an opencut mine will be developed prior to underground operations.
Theodore (Shell)	opencut and underground thermal	38.1	3.5 mtpa, potential to expand	Not yet committed, opencut production will be followed by underground developments.
Togara North (Janmex)	underground thermal coal	34.1	3.0 mtpa, expand to 7 mtpa	Construction could commence in late 1997 with production in 1998.
Togara South (Ingwe)	underground thermal coal	-	4 mtpa, expand to 8 mtpa	Prefeasibility study completed, development delayed but mining to commence by 2005.
Valeria (Pacific Coal)	opencut thermal coal	39.0	About 5.0 mtpa	Awaiting market opportunities.
West Nebo (BHP Coal)	opencut thermal, anthracite	7 to 9	not yet determined	Awaiting market opportunities.
Winchester South (Pacific Coal)	opencut thermal coal	25.0	not yet determined	Awaiting market opportunities

Use of Low to Medium Volatile Coal for Power Generation

Queensland Power Stations have successfully burnt low to medium volatile coal in pulverised fuel boilers for over 30 years. Some of these boilers are only 30 MW_e capacity but demonstrate the ability to burn these types of fuels successfully. The stations burning low to medium volatile coals are detailed in Table 3. These stations have burnt a variety of coals but the predominant coals are shown in Table 4.

Table 3: Queensland power stations firing low to medium volatile coal

Power Stations	Unit Size	Firing Arrangement
Collinsville	4 x 30 MW_e 1 x 60 MW_e	Downshot Tangential
Mica Creek	5 x 30 MW_e	Wall & Downshot
Gladstone	6 x 280 MW_e	Wall
Stanwell	4 x 350 MW_e	Opposed Wall

Table 4: Low to medium volatile coals fired in Queensland's power stations

Station	Coal	Volatiles % (daf)	Fuel Ratio
Collinsville and Mica Creek	Collinsville Blake and Collinsville Bowen	25.7 24.0	2.3 3.2
Gladstone	Blackwater Curragh Callide	28.2 22.6 33.8	2.5 2.8 1.96
Stanwell	Blackwater Curragh	28.2 22.6	2.5 2.8

While all these coals would be ranked under American Society for Testing and Materials' (ASTM) Standards as medium volatile except for Callide which is just within the high volatile rank, Curragh at 22.6% volatiles is at the lower limit for medium volatile ranking. The following is a brief summary of the experiences to date, burning Curragh coal at Stanwell Power Station.

Total tonnes of Curragh coal burnt to date at Gladstone and Stanwell are 21.5 million tonnes and 6 million tonnes respectively. Typical analysis of a coal similar to Curragh coal is given in Table 5. The majority of this coal has been burnt without blending with other coals, however in the last few years at Gladstone a blend of approximately 66% Curragh and 33% Callide has been used to reduce NO_x emissions.

Stanwell Power Station

The Stanwell boilers were supplied by Babcock Hitachi built to an American Babcock and Wilcox (B&W) Carolina design, with three opposed rows of five burners with each row of burners supplied by a 10E10 pulveriser.

Furnace size is 14.5 m wide, 12.8 m deep and 48.6 m in height from the bottom of the ash hopper to the furnace top. The boiler is a split rear pass configuration with reheater temperature controlled by controlling gas flow in the reheater pass.

Because of the volatile level of the coal expected to be burnt the pulverising plant was designed to produce a product with 80% passing through 75 microns at a coal flow of 120% of maximum continuous rating (MCR) requirement.

The burners are a standard B & W single air register type except for a modified fuel nozzle. The nozzle is an adaption of the Babcock Hitachi low NO_x burner technology and uses a coal flame stabilising ring to assist in NO_x reduction in the flame recirculation zone. Figure 3 shows a cross section of the burner.

Each pulveriser group of five burners has its own windbox with airflow controlled to each of the six windboxes.

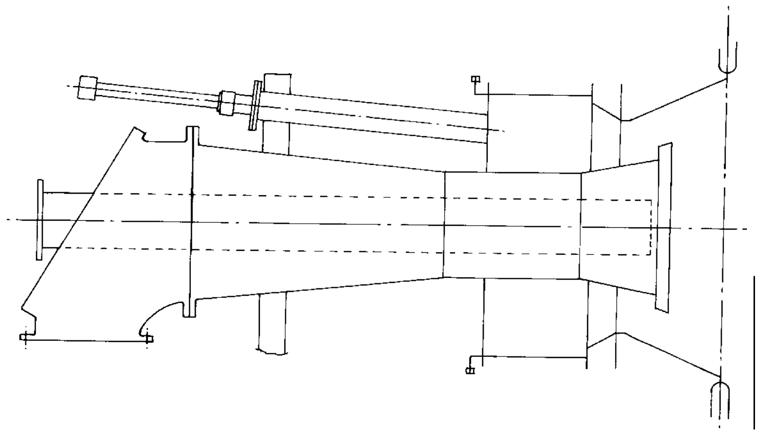


Figure 3: Stanwell burner design

Operation At Stanwell

The first of the four 350 MW units at Stanwell was placed in commercial service in March 1993 with the subsequent units commissioned at yearly intervals. The station has operated with good availability since commissioning and has achieved availabilities in the 95% to 96% range over the last few years.

These results have been attained with minimum levels of operational staff. The plant has a fully integrated control and monitoring system with the control room being unattended for long periods of time. Operational issues such as auxiliary plant changeover, e.g. mills and standby plant, and plant tests are carried out during normal working hours, that is between 7 a.m. to 5 p.m. weekdays. At other times, under normal operating conditions, only two staff members are at the station. These people, called "plant minders", are responsible for normal plant inspection duties and only become involved in plant operations during times of plant malfunctions. A paging system relays any critical plant alarms to the minder. The plant output is remotely controlled by the Queensland Electricity System Control Centre by an Automatic Generation Control System.

Each unit normally achieves full load on 4 of its 6 mills depending on the heating value of the coal being burnt. The normal automatically controlled load range for various mill combinations is:-

5 mills in service   210 to 350 MW
4 mills in service   180 to 350 MW
3 mills in service   140 to 240 MW

One significant feature of the plant is its ability to achieve a turn down of between 50% and 60% with a medium volatile coal. The lower limit is generally set by burner stability while burning the "worst" coal and allowing a margin for the normal firing rate variations particularly under reducing load situations.

The Stanwell burners suffered from ash and furnace clinker build up in the fuel nozzle area when the burners were out of service. There was also a problem with clinker deposits in the flame stabilising rings. While this paper is not about slagging problems the results of performance of the standard and modified burners gives an indication of the combustion performance. While the burner modifications were relatively minor, the results are dramatic as shown by the test results given in Table 5. The modified burners gave approximately 50% higher carbon in ash and 40% higher NO_x production. This only highlights the difficulties of testing in large coal fired boilers. Subsequently all boilers have had their burners modified and routine performance monitoring suggests the performance of the original and modified burners are similar.

Table 5: Stanwell burner performance test results with Curragh coal

	Unit 3 (unmodified burners)		**Unit 4 (modified burners)**	
	Test 1	**Test 2**	**Test 1**	**Test 2**
Coal Analysis				
Volatile Matter (% dry, ash-free)	27.4	27.8	28.3	28.2
PF Fineness (% minus 75 μm)	89.4	92.6	89.2	88.3
Precipitator Inlet				
Carbon in ash (% dry)	1.6	1.95	2.77	2.6
Oxides of Nitrogen (ppm)	425	430	590	605

Pilot Scale Evaluation of Lower Volatile Coals for Power Generation

Since its formation in 1985, the Australian Combustion Technology Centre (***ACTC***) has conducted pilot scale combustion test work on more than 100 thermal coals from Australia (Queensland, New South Wales, and Western Australia), South Africa, China, Indonesia, Malaysia, New Zealand and South America. The test facility and the test procedures used are fully described by Baker & others (1987). This paper draws on work funded by the Australian Coal Association on the blending of low volatile coals with typical export thermal coals conducted in 1989 and a recently completed project on blending of overseas lower rank coals with typical Australian thermal coals. The properties of the coals used in the 1989 project are given in Table 6, details of the more recent blending project are reported by Conroy and Bennett (1997).

Table 6: Coal properties used in low volatile blending study

	Component Coals				Blends			
	HV1	**HV2**	**LV1***	**LV2**	**40% HV1 60% LV1**	**60% HV1 40% LV1**	**40% HV2 60% LV2**	**60% HV2 40% LV2**
Proximate Analysis (%, ar)								
Moisture	8.7	11.5	8.0	3.9	8.3	8.4	7.5	9.4
Ash	13.4	13.9	10.3	13.9	11.5	10.9	13.9	13.8
Volatiles	31.8	36.3	17.6	18.5	23.2	26.7	25.8	29.3
Fixed Carbon	46.1	38.3	64.1	63.7	57	54.0	52.8	47.5
Volatiles (% daf)	40.9	48.6	21.6	22.6	29	33	32.9	38.2
Fuel Ratio	1.45	1.06	3.64	3.44	2.45	2.03	2.04	1.62
Specific Energy (MJ/kg, ar)	26.3	25.5	29.4	29.3	28.2	28.3	27.6	27.0
Ultimate Analysis (%, daf)								
Carbon	82.6	81.1	88.9	88.9	86.4	85.7	85.7	83.9
Hydrogen	5.53	6.3	4.53	4.55	4.93	5.09	5.26	5.67
Nitrogen	1.88	1.58	1.84	1.70	1.86	1.86	1.58	1.58
Sulphur	1.24	0.66	0.5	0.34	0.8	0.92	0.49	0.54
Oxygen (diff)	8.8	10.4	4.2	4.5	6	6.4	7	8.3
Hardgrove Grindability Index	44	39	75	72	61	54	55	46
Abrasion Index mgFe/kg	35	15	11	5	25	27	11	12

* LV1 is a similar coal to Curragh coal fired at Stanwell power station.

Milling

Mill testing of the component and blended coals was conducted in the ***ACTC*** pilot scale vertical spindle mill. The mill and test procedures used in this project are described by Conroy and Sligar (1991). The mill is a Raymond bowl EVT Model RP153 mill with a 400 mm diameter table, 3 rolls and an integral double cone classifier. The mill is hot air swept and has a coal feed rate capability of between 100 kg/hr and 600 kg/hr, with the nominal capacity being 500 kg/hr. Air flow rates are variable, as are the classifier and grinding pressure applied to the grinding rolls.

The blending of coals which have high Hardgrove Grindability Index (HGI) (coals LV1, LV2) with harder coals which have low HGI (coals HV1, HV2) allowed the impact of blending on mill performance to be determined.

Mill Power

The blends have a sightly lower HGI than if the HGI of the blends was calculated assuming the HGI of the components coals was additive. Figure 4 shows the specific mill power, which is the power required to produce one tonne of minus 75 μm product. Generally, blends followed the relationship between HGI and mill energy found for a range of coals.

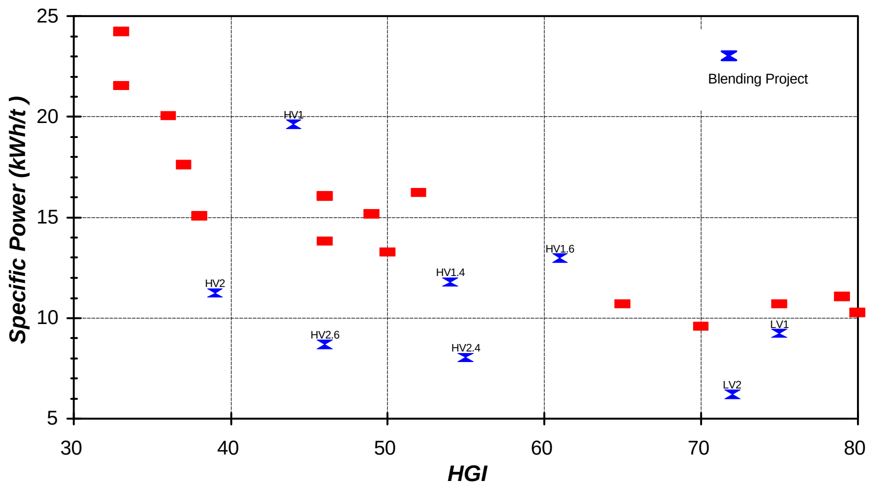


Figure 4: Variation in mill specific power (kWh per tonne of 70% minus 75 μm) with Hardgrove Grindability Index

Fineness

After determining the "optimum" roll pressure (Conroy & others, 1989) for each component coal and blend at 500 kg/h (100% MCR), a series of tests was carried out to establish the relationship between product size distribution and feed rate. These test were conducted at the optimum roll pressure, a fixed classifier setting of 15° and at feed rates which represent 60% to 120% of pulveriser MCR.

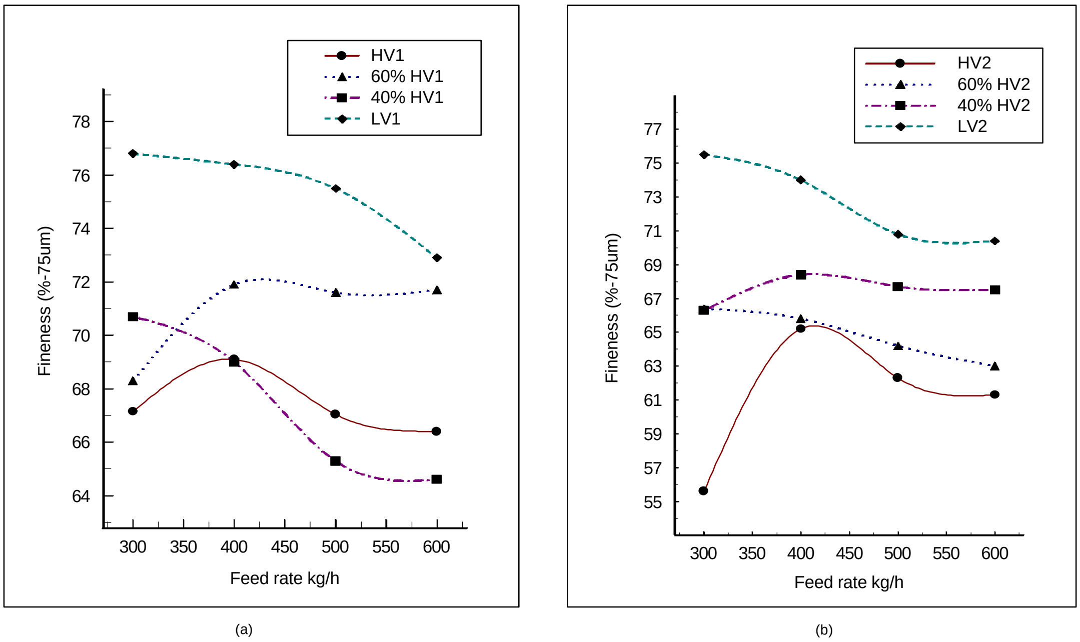


Figure 5: Variation of fineness with pilot mill feed rate at a classifier setting of 15° and at the optimum roll pressure for each component coal and blend.

Figure 5 (a) and (b) shows the variation in product size distribution for the component coals and blends. The performance of the blends mostly lies between the performance of the component coals. The blend of 40% HV1 and 60% LV1 component coals does indicate poorer performance characteristics than the hard HV1 component coal. This may be due to the roll pressure used in the test being set slightly higher than required.

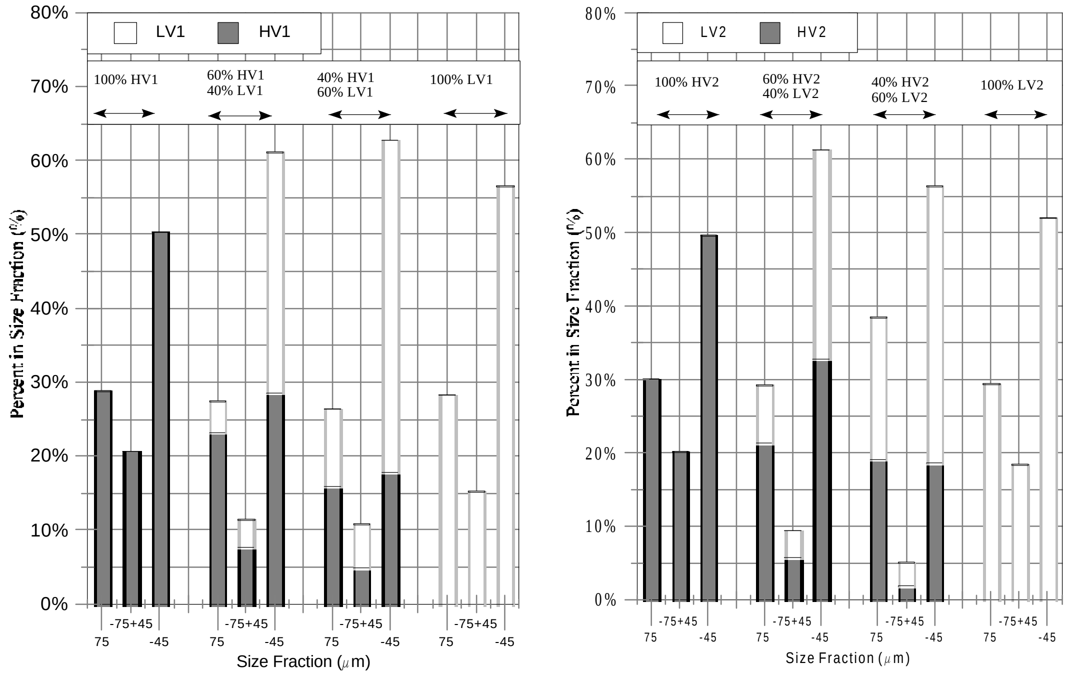
The distribution of the component coals in the size fractions of the pulverised coal blends was roughly determined by volatile content of each size fraction. Figure 6 (a) and (b) gives the distribution of each component coal in pulverised product of the blends. This figure shows that there is preferential grinding of the softer low volatile coal with more softer coal reporting to the fine fractions and more of the harder coal reporting to the coarse fractions.

At the same mill power required to mill a typical thermal coal (HGI 50) to 70% minus 75 μm the softer low volatile coals achieve a fineness of about 80% minus 75 μm.

Mill Wear

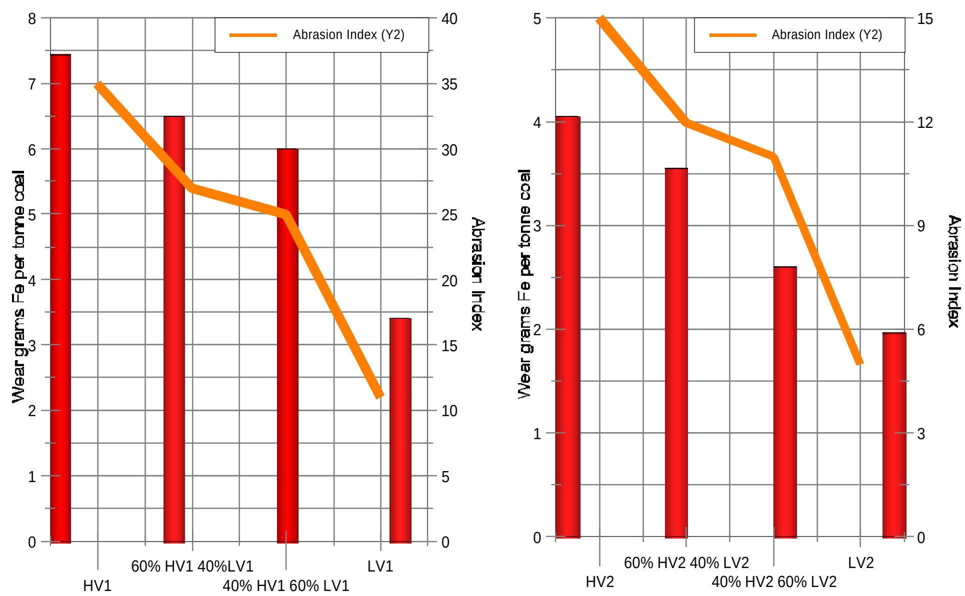
In determining mill wear, the Abrasion Index is normally used to rank the impact of coal properties on wear. The Abrasion Index of the blends was close to, though in all cases slightly higher, than that calculated by linear interpretation of the component coals' Abrasion Index. The Abrasion Index does seem to be an additive property for most blends as also found for blends of lower rank coals with typical thermal coals (Conroy & Bennett, 1997).

Figure 7 (a) and (b) gives the mill wear (kg Fe per tonne coal) as measured during the high load mill tests. For this data set, a strong linear relationship exists between the measured mill wear and the Abrasion Index of the component coals and blends there of. This is consistent with past



(a) (b)

Figure 6: Distribution of component coals in different size fractions.



(a) (b)

Figure 7: Pilot scale wear and Abrasion Index for component coals and blends.

pilot scale test results on coals with an Abrasion Index below 30 mgFe/kg, above this value there is little correlation between Abrasion Index and mill wear (Bennett, 1996).

Burnout

The Pulverised Fuel (PF) burnout test were performed on the component coals and their blends pulverised to 70% < 75 μm, at a furnace load of 150 kW, the load at which normal combustion testing is carried out as it allows for better discrimination between coals. The temperature profile at this load is slightly lower than that achieved in a full scale furnace (Baker & others, 1986).

In a review of Electric Power Research Institute' s (EPRI) Coal Quality Impact Model (Bennett, 1996) it was found that an empirical burnout model, developed by Blake and Robin (1982), did give a reasonable fit to pilot scale burnout data over a wide range of coals, if the heat release rate over the furnace was adjusted to better match pilot scale conditions. The burnout model estimates the impact of furnace heat release rate, dry mineral matter free (dmmf) volatile matter, fineness of the PF and excess air levels on carbon burnout. Figure 7 shows that the model gives a reasonable estimate of carbon burnout for the lower volatile coals (LV1 and LV2) and coal HV2 . The pilot burnout test result for coal HV1 showed the same scatter as other coals tested that lay in volatile range of 30 to 40 % daf.

Also shown in Figure 8 is the predicted burnout for a typical full scale plant firing 70% minus 75 μm PF at 20% excess air. The predicted full scale burnout for coal LV1 based on the pilot

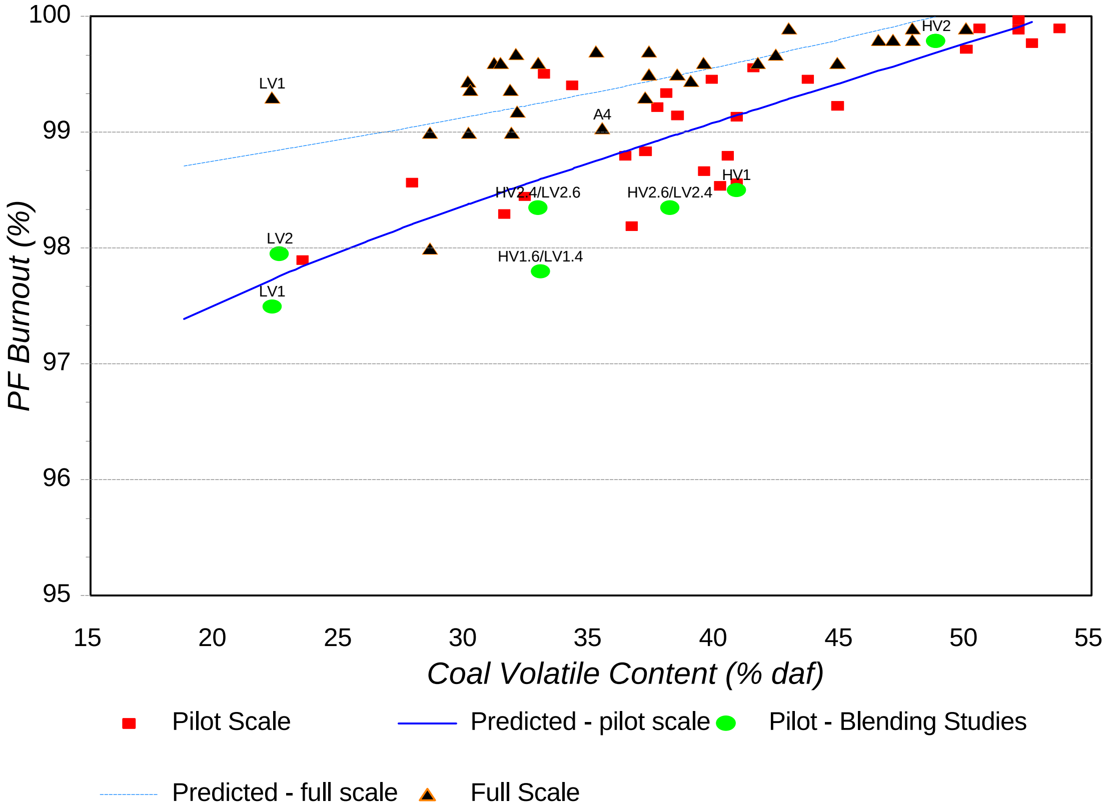
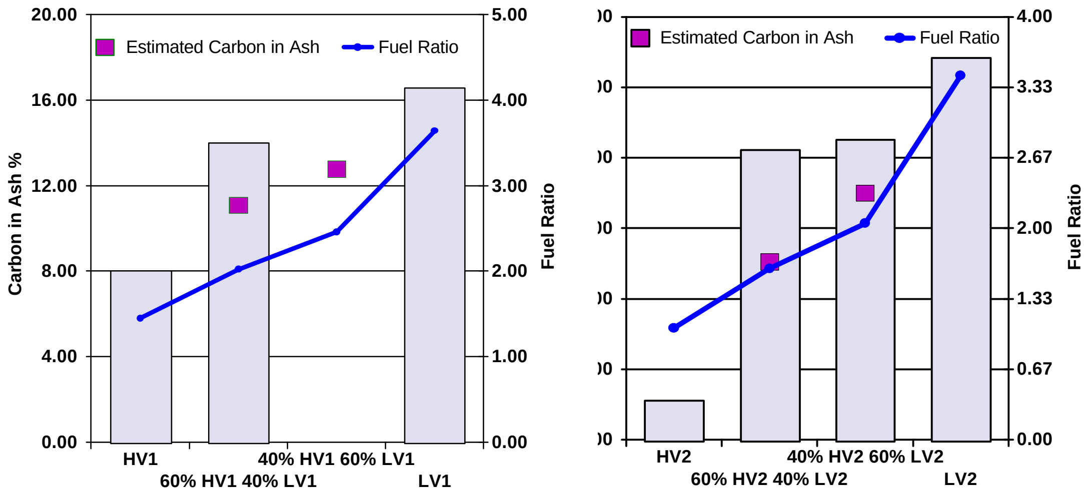


Figure 8: Variation of burnout with volatile matter at the pilot and full scale (from Conroy and Bennett, 1996).

scale result, allowing for higher temperatures and finer grind (90% minus 75 μm) at the full scale, is 99.76% which corresponds to a carbon in ash of 1.89%. This is close to the actual figures for carbon in ash given in Table 4 for the unmodified burner.

The combustion performance of a blend can be determined assuming that each coal in a blend performs as though it was fired by itself. If this was the case then the carbon in ash of the blend could be determined from the burnout performance of the component coals (Conroy and Bennett, 1997).

The carbon in ash of the blends and the estimates using the burnout of the component coals are given in Figure 9 (a & b). The actual carbon in ash for the blends are higher than the estimated



(a) (b)

Figure 9: Carbon-in-ash for component coals and blends from pilot scale tests at a fineness of 70% minus 75 μm. Note: The carbon in ash for pilot scale results are higher than those that would be achieved in a full scale plant.

values and there is no evidence that the finer size distribution of the low volatile coal in the blend enhanced its combustion performance.

Based on pilot scale blending studies the following observations can be made:

- The combustion performance of the blend is additive when the combustion performance of the component coals are not significantly different.
- In blending a high volatile coal (eg HV1) with a low volatile coal (eg LV1) the higher reactive coal dominates the early combustion reducing the oxygen availability for combustion of the lower reactive coal. In addition, the delayed combustion of the lower volatile coal may be detrimental to the reactivity of its char (Hurt & others, 1995). These changes to the environment and char reactivity will reduce the burnout of the lower volatile coal.
- If blending results in a hotter combustion zone than achieved with either of the component coals then burnout of the blend may be better than that estimated from the component coals.

An alternative to blending is co-firing two component coals separately through burners with the lower volatile coal being fired through the bottom burner level. This will reduce the material handling equipment costs associated with blending, but will mean greater attention to mill and burner setup and the logistics of feeding the mill fed bins with different coals. The main advantages of this approach are:

- mills and burners can be tuned to a type of coal for maximum efficiency, minimum emissions and best service life,
- it minimises the interactions between coals, and
- reduces the risks to boiler operation caused by fluctuating coal quality due to blending problems.

Co-firing is being tested in a new boiler at Kobe Steelworks in Japan and is being considered for a new IPP project in Thailand.

Flame Stability

Flame stability or flame standoff measurements at the pilot scale are useful in the ranking of coals. Flame standoff, the distance from the quarl to the point of ignition of the coal with zero swirl, is an indication of the ignition characteristics of a coal, the greater the standoff distance corresponds to poorer flame stability performance. For a constant coal feed rate, the standoff distance would generally be determined by the quantity, heating value and rate of release of volatile matter, as well as the velocity and the temperature of primary air. In pilot scale testing of flame stability the primary air stoichiometric ratio, that is - the velocity of the primary air, is varied while all other operating conditions are held constant.

Figure 10 shows how flame standoff distance, for different primary air stoichiometric ratios (SRp), varies with the higher heating value of the volatile matter per mass of coal (HHV_{vol}) for component coals and their blends. Also included in this figure are the results of another project (Smith & others, 1989) examining the combustion behaviour of low volatile coals.

There are general trends of standoff distances decreasing with increasing HHV_{vol} and decreasing primary air stoichiometric ratio. The addition of the high volatile Surat Basin coal (HV2) does greatly improve the flame stability performance.

The same trend between flame stability performance and HHV_{vol} was found by Pohl (1985) for pilot scale test results and by Rohrer & others (1987) for a bench scale test (Rohrer-Breen apparatus). The results of Rohrer & others are shown in Figure 11. The work of Rohrer, Breen and co-workers has been used to evaluate potential low volatile coals to replace high sulphur coals in power plants on the east coast of USA. Their criteria for a safe stable flame was for the HHV_{vol} to be greater than 8.43 MJ/kg coal (3636 BTU/lb coal), yet for a Bowen Basin coal (JE) with a HHV_{vol} of 7.7 MJ/kg coal the Rohrer-Breen test did not show any instability problems under a range of conditions.

The scatter in the pilot test results is partly due to small variations in the thermal environment under which the pilot tests are performed, as the pilot test conditions are influenced by the coal's combustion performance. Under the more controlled environment of the Rohrer-Breen

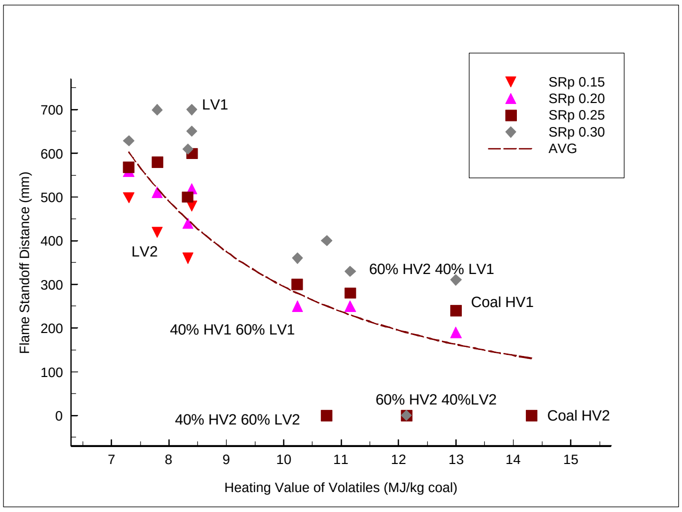


Figure 10: Flame standoff distance at zero swirl for increasing primary air flow rates

apparatus there is still scatter in the results for coals with a HHV_{vol} of 8 to 9 MJ/kg. Zhang & others (1992) examining the ignition characteristics of a range of Australian coals found that the initial ignition of coal may be heterogeneous. That is, the initial combustion on the coal surface can play a significant role in stabilising the coal flame in addition to the role played by the combustion of the volatiles. This is further supported by the work of Hunt (1993) which identified initial rapid combustion of the char at low carbon conversions.

Heterogeneous ignition of the Bowen Basin coals may explain why these coals exhibit better flame stability characteristics than expected from the HHV_{vol}, as seen by the performance of coal JE in Figure 11. Curragh coal has a HHV_{vol} of 8.4 MJ/kg, just below the Rohrer-Breen value for a stable flame, though no flame stability problems with this coal has been found in the operation of Stanwell power station. Further research work is required to clarify the influence of the initial char reactivity on the flame stability characteristics of Queensland low to medium volatile coals.

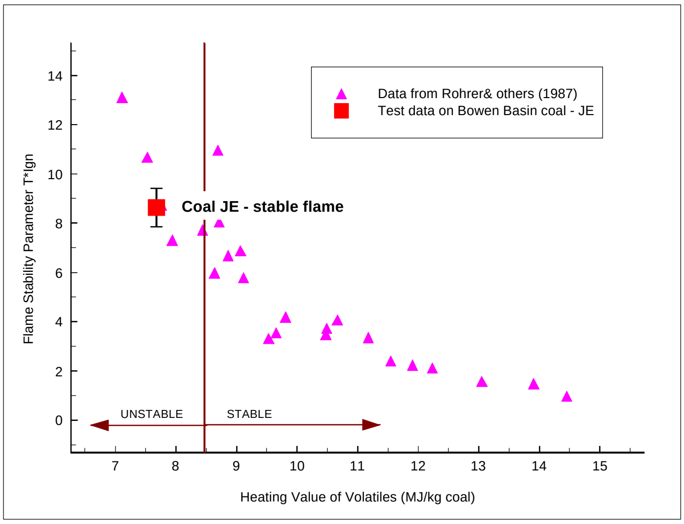


Figure 11: Influence of the heating value of the volatiles on flame stability.

Conclusions

Queensland resources of medium volatile and high energy coals of the Bowen Basin are effectively burned in the State's power stations demonstrating good flame stability and low carbon in ash. The low carbon in ash results are achieved by grinding the coals to a fineness of greater than 85% minus 75 μm which is made possible by the soft nature of these coals. These coals can be burned in a blend with higher volatile coals which will result in better flame stability characteristics and a carbon in ash slightly higher than that calculated based on the combustion performance of the component coals. The carbon in ash of blends incorporating low to medium volatile coals can be improved by grinding the coal to the maximum fineness that can be achieved without undue increase in mill power consumption. Pilot scale blending studies have shown that mill performance of a blend can be determined by assuming the coal properties of the component coals are additive.

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