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Australia's Bulk Commodity Giants

AUSTRALIAN EXPORT THERMAL COAL:

The Comparative Quality Advantages

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The mining and utilisation of thermal coal in Australia has been a mainstay of the Australian economy during the past 100 years.

On the domestic front the industry (both brown and black thermal coal) has been a very significant regional employer, has provided cheap and reliable electricity to homes and industry, and has allowed many areas of regional Australia to flourish. In 2019, 56 per cent of Australia's electricity was generated from coal.[1]

From an export point of view, the black thermal coal industry has consistently been one of Australia's largest export industries. Australia is the world's second largest exporter of thermal coal behind Indonesia. In 2019-20, Australia exported an estimated 213 million tonnes (Mt) of thermal coal, worth an estimated $20 billion, up from just 100 Mt in 2002-03.[2]

Due to a combination of favourable geography and geology, in addition to prudent development and management, the Australian thermal coal industry has several key advantages over the competition in the international export market. These advantages include the use of highly productive advanced technologies, a stable production environment, world class rail and port facilities, relative proximity to key markets and a track record of reliable supply.

In addition, Australian thermal coal has several quality advantages over competitor coals in the export market. These advantages are conferred by geology but are enhanced by the modern mining and processing technologies used in the Australian industry.

Australia is the world's second largest exporter of thermal coal

THE COMPARATIVE ADVANTAGES OF AUSTRALIAN THERMAL COALS TO THE POWER UTILITY CUSTOMERS FROM A QUALITY PERSPECTIVE AS REVEALED IN THIS REPORT ARE:

- **Higher rank and higher delivered specific energy** of Australian coals enabling less coal to be burnt per kilowatt-hour (kWh) of power station output and lower levels of CO_2 emissions than from lower quality coals
- **Superior combustion properties and boiler efficiency** as dictated by lower moisture, moderate ash, higher ash fusion temperature and satisfactory fuel ratio
- **Higher Hardgrove Grindability Index**, resulting in lower pulverised fuel (PF) grinding costs
- **Lower levels of sulphur and trace element contents** resulting in reduced power utility flue gas emission levels and waste water contamination.

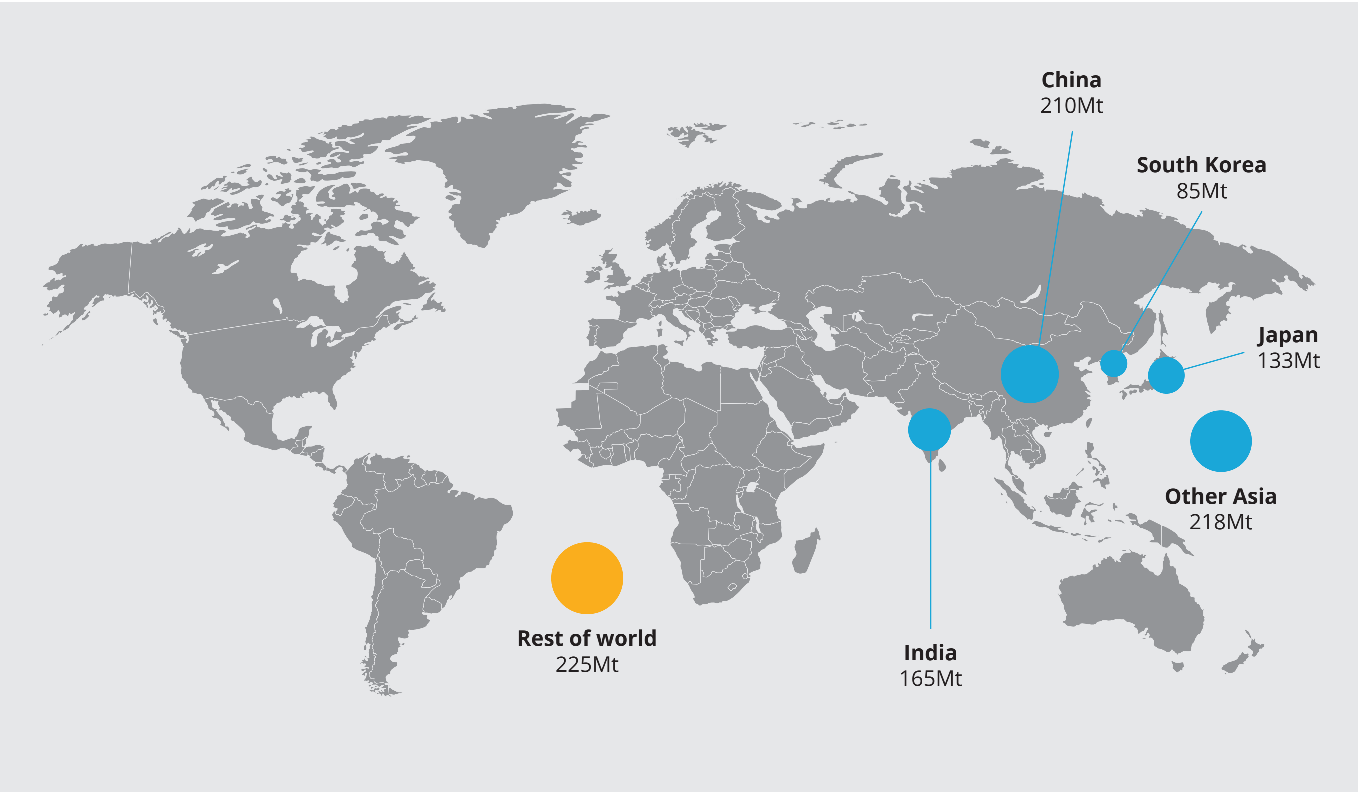
These quality features are important in attracting thermal coal demand to Australian supply. The result is additional economic development, jobs and investment for Australia, especially in regional New South Wales and Queensland, and better environmental and emissions outcomes for end users.

This paper focuses on seaborne export coals. A comparison of Australian coals with domestic sourced coals (e.g. in China and India) was beyond the scope of this paper due to data limitations.

1 BP *Statistical Review of World Energy*, 2020.

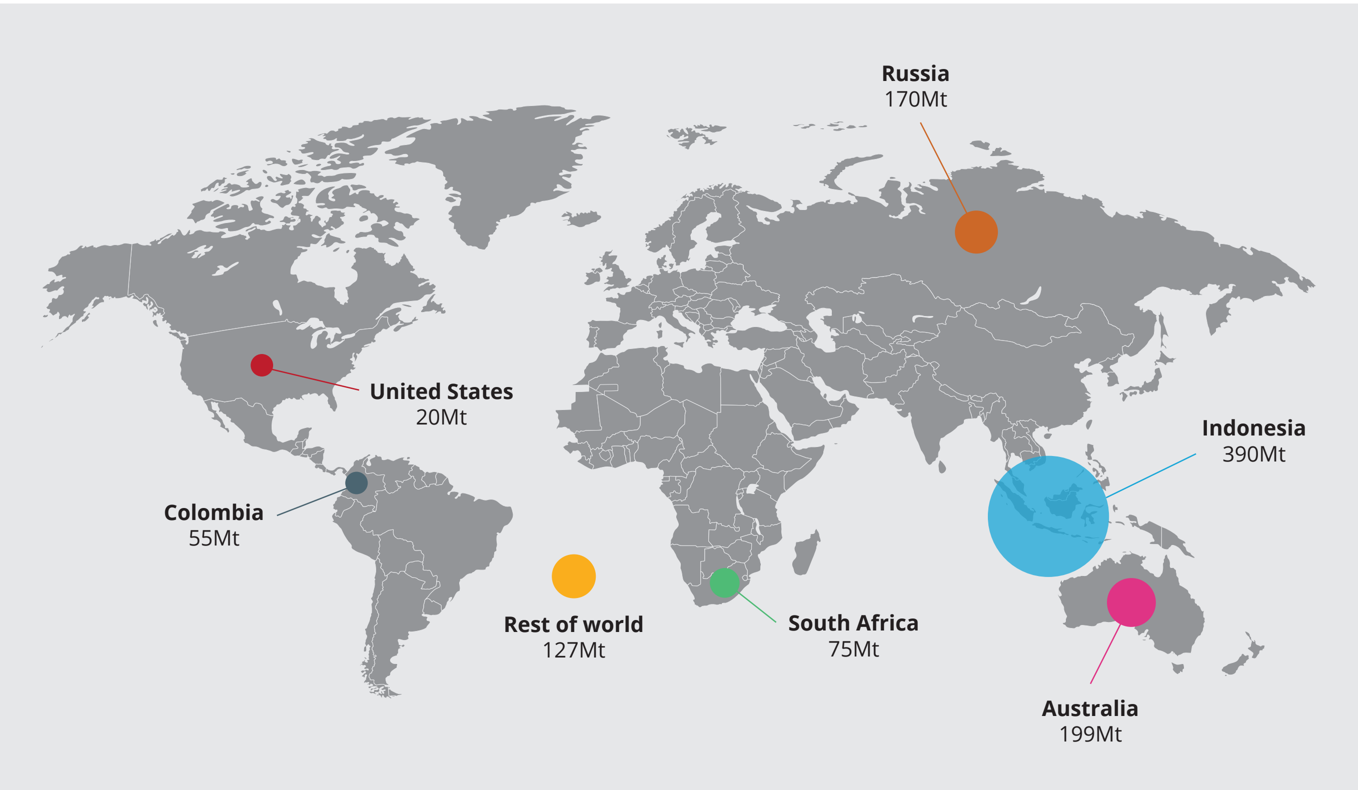
2 Department of Industry, Science, Energy and Resources, *Resources and Energy Quarterly*, June 2020.

FIGURE 1: TOTAL IMPORTS OF THERMAL COAL IN 2020 (MT)



Source: Department of Industry, Science, Energy and Resources, Commonwealth of Australia Resources and Energy Quarterly March 2021.

FIGURE 2: TOTAL EXPORTS OF THERMAL COAL IN 2020 (MT)



Source: Department of Industry, Science, Energy and Resources, Commonwealth of Australia Resources and Energy Quarterly March 2021.

Australian coal reserves and production

Reserves

Australia has substantial reserves of both black and brown coal. Total proven reserves as at the end of 2019 are estimated at 149,079 Mt. These reserves are split about equally between higher rank (anthracite and bituminous) and lower rank (sub-bituminous and lignite) coal. This represents 13.9 per cent of the world's reserves, giving Australia the third highest reserves of any country (Table 1).

Production

After peaking in 2014, the production of black coal in Australia has remained comparatively steady over recent years at around 450Mt. Of this, approximately 270Mt is thermal coal and 180Mt is metallurgical coal (Table 2).

From an international perspective, the production from all countries is dwarfed by that of China, which in 2019 produced 47.6 per cent of all coal.[3] This was followed by Indonesia at 9.0 per cent, the United States at 8.5 per cent, Australia at 7.8 per cent and India at 7.6 per cent.

TABLE 1: WORLD PROVEN COAL RESERVES AT THE END OF 2019

COUNTRY	RESERVES (MILLION TONNES)	SHARE OF WORLD TOTAL
United States	249,537	23.3 per cent
Russian Federation	162,166	15.2 per cent
Australia	149,079	13.9 per cent
China	141,595	13.2 per cent
India	105,931	9.9 per cent
Indonesia	39,891	3.7 per cent
Germany	35,900	3.4 per cent
Ukraine	34,375	3.2 per cent
Poland	26,932	2.5 per cent
Kazakhstan	25,605	2.4 per cent
Rest of World	99,476	9.3 per cent
Total	**1,069,636**	

Source: BP *Statistical Review of World Energy*, 69th Edition, 2020

Production of coal in Australia is about
60 PER CENT THERMAL
and 40 per cent metallurgical

More than 80 per cent of Australian
THERMAL COAL
is exported

TABLE 2: AUSTRALIAN BLACK COAL PRODUCTION - ACTUAL AND FORECAST (MT)

COAL TYPE	2016-17	2017-18	2018-19	2019-20 FORECAST	2020-21 FORECAST	2021-22 FORECAST
Thermal Total	254	267	272	268	263	276
Thermal Export	202	203	210	213	208	221
Thermal Domestic	52	64	62	55	55	55
Metallurgical Total	184	183	189	184	178	191
Total Production	**438**	**450**	**461**	**452**	**441**	**467**

Source: Department of Industry, Science, Energy and Resources, *Resources and Energy Quarterly*, June 2018, 2019 and September 2020

3 BP *Statistical Review of World Energy*, 69th Edition, 2020.

Australian exports of thermal coal

Australia is the world's second largest exporter of thermal coal. Actual and forecast export tonnages from 2019 are given in Table 3. Note the predominant position of Indonesia.

As shown in Table 2 export tonnages from Australia are expected to be maintained over the forecast period. This is on the back of continued strong demand for coal-based electricity from Asia. The Australian government estimates that Asian countries imported over 900Mt of thermal coal in 2019. This represents close to 80 per cent of total world thermal coal trade.

Japan has traditionally been the major customer for Australian thermal coal and this continues to be the case. In 2018-19, Japan accounted for 45 per cent of the total value of all exported Australian thermal coal. Japan was followed by China (16 per cent), South Korea (15 per cent), Taiwan (12 per cent), Malaysia (4 per cent) and Vietnam (3 per cent).[4]

It is interesting to note the recent growth of markets in both Malaysia and Vietnam, reflecting the continued interest of these emerging economies in having coal fired power as a part of their energy mix.

A recently updated market demand study for Australian thermal coal by Commodity Insights confirms that despite the impact of the 2020 COVID-19 pandemic, and strong international competition, strong seaborne demand growth is expected out until 2030. The seaborne market in Asia is predicted to grow from 834Mt in 2019 to 1109Mt in 2030.[5] The demand growth is broad based including India, Vietnam, Philippines, Thailand and Malaysia.

In a 2018 report, Commodity Insights commented on the comparative desirability of Australian thermal coal due to:

> the generally higher quality of Australian thermal coal (higher energy and lower impurities), power plant design dependency on Australian thermal coal in north Asia, end-user mine and infrastructure equity agreements, take or pay contracts which supply stability and visibility and strong stability in the historically important markets of Japan, Korea and Taiwan.[6]

TABLE 3: ACTUAL AND FORECAST THERMAL COAL EXPORTS (MT)

COUNTRY	2019 (ACTUAL)	2020 (FORECAST)	2021 (FORECAST)	2022 (FORECAST)
Indonesia	445	404	422	423
Australia	212	203	225	230
Russia	169	173	179	184
Colombia	75	55	68	75
South Africa	76	69	74	77
United States	34	20	22	24

Source: 2019 (actual) – CRU; and Forecasts – Department of Industry, Science, Energy and Resources, *Resources and Energy Quarterly*, September 2020

4 Australian Bureau of Statistics (2020), *International Trade in Goods and Services*, Cat. No. 5368.0.

5 Commodity Insights, *Market Demand Study: Australian Export Thermal Coal*, October 2020.

6 Commodity Insights, *Market Demand Study: Australian Export Thermal Coal*, 13 June 2018, page 4.

International comparison of thermal coal quality

Australia's major competitors in the export thermal coal market both now and into the foreseeable future are Indonesia, Russia, Colombia, South Africa and, to a much lesser extent, the United States.

It is instructive to compare the 'average' quality of coals from each of these countries. Where data is available, the 'tonnage weighted average' qualities have been calculated based on the quality of the exported thermal coals from the major thermal coal mines of each country during calendar 2019. Quality data for at least 80 per cent of the total thermal export tonnage from each country has been used based on CRU's quality data base.[7]

The CRU data has been augmented with additional industry data for some coal properties. The CRU information draws from approximately 94 mines across six countries and includes export tonnage, total moisture, proximate analysis, specific energy and sulphur content.

The additional data in Table 4 has been obtained from a variety of industry sources including Quality of Australian Black Coals (ACARP Project C17053).[8]

Regarding this comparison, it is important to note:

- Comparative colour coding of quality averages is indicative only
- Each data point is a tonnage weighted average for 2019 exports
- While average country data may be acceptable, the quality range between mines from all countries is sometimes high
- CRU data covers the properties in Table 4 down to Sulphur. Below that industry data has been used. This data is incomplete
- Insufficient data on elemental ash analysis could be found for international coals. As a result, ash analysis has not been included.

TABLE 4: INTERNATIONAL COMPARISON OF EXPORT THERMAL COAL QUALITY 2019

COUNTRY/STATE	AUSTRALIA	INDONESIA	RUSSIA	COLOMBIA	SOUTH AFRICA	USA	TOTAL
Exports Mt	212	445	169	75	76	34	1011
Per cent of exports	21.1	44.0	16.7	7.4	7.5	3.5	100
Total Moisture per cent ar	10.6	24.9	10.2	11.8	8.3	11.7	
Inherent Moisture per cent ad	3.6	13.8	2.6	7.6	3.2	5.1	
Ash per cent ad	13.7	5.5	12.2	7.1	13.8	7.9	
Volatile Matter per cent ad	31.2	38.9	30.8	35.9	25.8	37.5	
Fixed Carbon per cent ad	51.5	41.8	54.4	49.4	57.2	49.5	
Fuel Ratio	1.6	1.1	1.8	1.4	2.2	1.3	
Specific Energy MJ/Kg nar	25.0	19.4	23.4	24.5	24.2	25.0	
Specific Energy Kcal/Kg nar	5980	4640	5590	5860	5780	5980	
S per cent ad	0.57	0.49	0.40	0.62	0.80	1.40	
HGI	56	51	57	54	47	50	
AFT deformation ºC	1390	1170	1390	1290	1440	1220	
P per cent db	0.04	0.02	0.03	0.03	0.01	0.02	
Cl per cent db	0.03	0.01	0.04	0.03	0.06	0.01	
F ppm	73			72	437		
As ppm	1.3			2.6	7.0		
B ppm	30			57	21		
Cd ppm	0.05			0.17	0.10		
Hg ppm	0.02			0.04			

Source: CRU, Industry data

Inferior | Marginal | Satisfactory for general boiler performance

7 CRU Coal Quality Data Base, August 2020.

8 UST, *Quality of Australian Black Coals*, ACARP Project C17053, January 2010.

Trace elements

While some trace element data is shown in Table 4, it is incomplete. Nevertheless, a generic discussion on the comparative levels of trace elements is still possible based on the 2013 work of Dale, *Guide to Trace Elements in Coal*.[9] The CSIRO has established a database of the trace element levels in major exported thermal coals. Average concentration levels from this database show as Dale's Guide concluded:

> Australian coals have significantly lower levels of the trace elements of major environmental concern namely, arsenic, boron, mercury and selenium, up to one-third lower than the levels found in the international coals.[10]

TABLE 5: COMPARATIVE AVERAGE TRACE ELEMENT CONCENTRATIONS IN EXPORT THERMAL COALS

ELEMENT PPM	AUSTRALIAN EXPORT COALS	INTERNATIONAL COALS
Arsenic (As)	0.93	3.3
Boron (B)	21	59
Cadmium (Cd)	0.09	0.07
Chlorine (Cl)	320	310
Fluorine (F)	98	100
Lead (Pb)	5.8	7.2
Mercury (Hg)	0.021	0.066
Selenium (Se)	0.47	1.4

Inferior   Satisfactory for general boiler performance

Source: L Dale, *Guide to Trace Elements in Coal*, Lindsay Juniper Pty Ltd., 2013.

9 L Dale, *Guide to Trace Elements in Coal*, Lindsay Juniper Pty Ltd., 2013.
10 Ibid, page 16.

Advantages of Australian thermal coal to the power utility customer

Australian thermal coals are world leading on the key quality parameter of specific energy, and very competitive on other parameters such as moisture content, ash, volatile matter and impurities.

The following are comments on comparative quality, as outlined in Tables 4 and 5.

- **Total Moisture (TM):** The total amount of water in the coal including inherent and surface moisture. As the moisture uses heat to be evaporated on combustion, the lower the level the better. Higher moisture coals have lower boiler efficiencies.

  Australian coals are mid-range at 10.6 per cent, with Indonesian coals at a clear disadvantage at around 25 per cent TM. The bulk of these Indonesian coals are sub-bituminous in rank.

- **Proximate Analysis:** This includes the percentage of moisture (air dried), ash, volatile matter (VM) and fixed carbon (FC). The ash (or mineral matter) in the coal is a diluent, which needs to be disposed of after combustion as fly ash or bottom ash. Lower levels are therefore preferred.

  South African, Australian and Russian coals are higher in ash at 12 to 14 per cent while Indonesian, Colombian and US coals are all less than 8 per cent.

  While the relationship is sometimes complex, volatile matter content impacts the pulverised fuel (PF) burnout, the residual level of carbon in ash and boiler efficiency. In general, higher levels of VM are favourable. The Fuel Ratio (FR) which is the ratio FC/VM is sometimes specified to judge PF burnout. Levels are often utility specific, but typically in the range 1.5 to 2.5 is desirable.

  The FRs for Australian and Russian coals are satisfactory, while Indonesian, US and Colombian coals are lower and South African FRs are higher than normally desired.

- **Ultimate Analysis:** This includes the percentage of the main organic constituents of the coal and is made up of carbon, hydrogen, nitrogen, sulphur and oxygen. Of most importance here is the level of sulphur. The sulphur in the coal forms sulphur oxides SO_2 and SO_3, on combustion. Lower levels are desirable.

  Australian, Indonesian and Russian coals all exhibit lower levels of sulphur (<0.6 per cent), Colombian and South African coals are moderate to high (0.6 to 0.8 per cent), while coals from the USA are very high (1.4 per cent) and are not normally burnt without blending with lower sulphur coals.

- **Specific Energy (SE):** This is the amount of heat liberated per unit mass of coal when it is burnt. Clearly, the higher the SE the better for lower cost electricity production.

  The SE data in Table 4 is reported on a net as received (nar) basis. This adjusts the SE for moisture content. This data indicates that Australian and US coals have the higher SE at 25 megajoules per kilogram (MJ/kg) nar. Indonesian coal is low at 19.4MJ/kg with coals from the other countries intermediate.

  For the same heat input into a given power station fewer tonnes of the higher SE Australian coal are required than for lower SE coal.

- **Ash Analysis:** This is the chemical composition of the ash in the coal, reported as oxides. Various chemical constituents in the ash can impact ash fusion temperature, ash slagging and fouling in the boiler and fly ash properties.

  Unfortunately, insufficient data could be found for international producing nations to make meaningful comment.

- **Ash Fusion Temperature (AFT):** This is the temperature at which the ash in the coal melts. It is normally measured in a reducing atmosphere and correlates with various melting properties of the ash in the boiler. Again, specification levels are boiler specific, but in general, initial deformation temperatures in excess of 1200ºC are desirable.

  With the exception of Indonesian coals at 1170ºC and US coals at 1220ºC all other coals were on average satisfactory, with AFTs in excess of about 1300ºC.

- **Hardgrove Grindability Index (HGI):** This is an empirical test which measures how easily a coal can be ground. This can impact the fineness of PF grind, the number of mills required and the parasitic load within the power station to run them. Generally, HGI of greater than about 45 to 50 is desirable.

  As shown in Table 4, on average Australian, Russian and Colombian coals are satisfactory with HGIs in excess of 50. South African, Indonesian and US coals have lower HGIs and on average will be harder to grind.

- **Trace Elements:** These are chemical elements which occur in the coal at low concentrations which can be released into the environment on utilisation of the coal. Trace elements often stipulated by power utilities include fluorine, arsenic, boron, cadmium, mercury and selenium. Lower levels are desirable.

  Australian coals have significantly lower levels of arsenic, boron, mercury and selenium than international coals. The levels of cadmium, chlorine, fluorine and lead are similar in Australian and international coals.

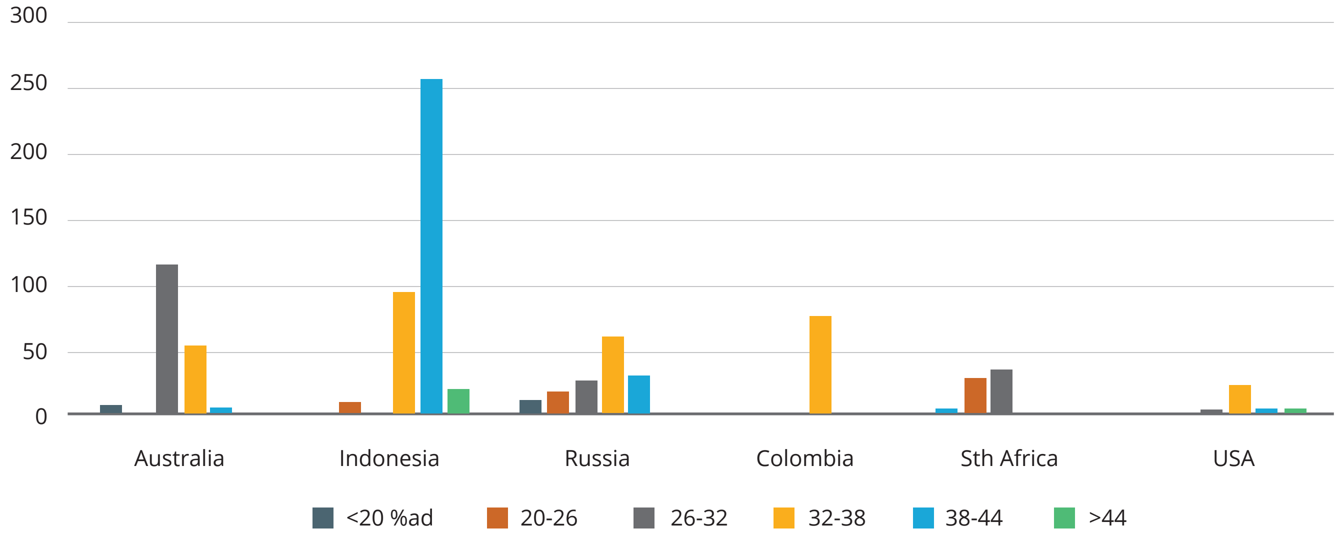
- **CO_2 Emissions:** Carbon dioxide emissions on combustion of coal vary with both the technology used and the coal properties. For commentary on the role of modern, high efficiency low emission (HELE) plants in achieving lower CO_2 emissions see below.

As far as coal properties are concerned, CO_2 emissions can be calculated from the specific energy and the ultimate analysis. This data is unavailable for all the international coals reviewed in this paper. In general lower rank coals (such as the sub-bituminous coals from Indonesia) generate higher levels of CO_2 than do bituminous coals (such as exported from Australia).[11]

By using VM as a proxy for coal rank, the proportion of higher and lower rank coals exported from major seaborne suppliers can be seen in Figure 3.

The figure shows that Australia's export coals tend to have VM contents predominantly in the range < 32 per cent indicative of higher rank. In particular, note the high proportion of exported coal from Indonesia with a VM content in excess of 38 per cent indicative of lower rank. This rank difference is further supported by the high TM and low SE contents of the Indonesian coals as shown in Table 4.

FIGURE 3: DISTRIBUTION OF VOLATILE MATTER BY EXPORT TONNAGE 2019



[11] M Campbell, *Coal Quality Effects on CO_2 Emissions*, ACIRL Pty Ltd, 2008.

Preferred levels of thermal coal properties in the international market

In simple terms, the advantageous levels of the above coal quality properties for utilisation in modern supercritical coal boilers are shown in Table 6, which also includes a comparison with Australian export coal properties from Tables 4 and 5. It should be noted that most utilities have defined coal specifications which are dependent upon the design of their boilers and flue gas clean-up systems, operating and maintenance philosophy and environmental requirements in their local area. Power station operators are focused on minimising the cost of sent out power from their facilities whilst meeting all applicable regulations. This requires them to optimise between the purchase cost of the coal and the coal's properties which impact generation operating costs and waste disposal costs.

As a result, power station operators rarely burn a single coal. More typically two to three coals are blended prior to combustion.

A detailed discussion of the various properties of thermal coals and relationship to power station performance can be found in Juniper.[12]

The comments below are therefore general in nature and will vary by end user.

The advantages of Australian thermal coals to the power utility customers from a quality perspective are clear and can be summarised comparatively as:

- Higher rank and higher delivered specific energy of Australian coals enabling less coal to be burnt per kilowatt-hour (kWh) of power station output and lower levels of CO_2 emissions than from lower quality coals
- Superior combustion properties and boiler efficiency as dictated by lower moisture, moderate ash, higher ash fusion temperature and satisfactory fuel ratio
- Higher HGI, resulting in lower pulverised fuel grinding costs
- Lower levels of sulphur and trace element contents resulting in reduced power utility flue gas (non-greenhouse gas) emission levels and waste water contamination

TABLE 6: PREFERRED THERMAL COAL PROPERTY LEVELS

COAL PROPERTY	PREFERRED LEVELS	TYPICAL SPECIFICATIONS	AUSTRALIAN EXPORT
Total Moisture per cent ar	Lower	< 15	10.6
Ash per cent ad	Lower	< 15	13.7
Fuel Ratio (FC/VM)	Within specified range	1.5 – 2.4	1.6
SE MJ/kg nar	Higher	>24	25
S per cent ad	Lower	<0.5	0.57
HGI	Higher	>50	56
AFT Initial Deformation ºC	Higher	>1200	1390
Cl per cent db	Lower	<0.1	0.03
F ppm	Lower	<100	98
As ppm	Lower	<0.8	0.93
B ppm	Lower	<40	21
Cd ppm	Lower	<0.1	0.09
Hg ppm	Lower	<0.1	0.021
Se ppm	Lower	Variable	0.47

Satisfactory for general boiler performance

Source: Australian export column up to 'Cl per cent db' from Table 4; rest of column from Table 5.

[12] L Juniper, *Thermal Coal Technology*, Queensland Department of Mines and Energy, 1999.

Technologies to reduce emissions

The accelerated deployment of existing low emissions technologies, as well as further research and development of emerging technologies, will be required to ensure the world is able to achieve the emissions reduction goals of the Paris Agreement.

With the drive towards reduction in greenhouse gas emissions and tighter emission standards, international power station operators are installing advanced technology equipment with boilers operating at higher steam temperature and pressures to improve station efficiency. Low nitrogen oxides (NOx) burners, re-burners and staged combustion systems and selective reduction are also being installed to reduce NOx emissions.

HELE power stations are now common, particularly in Asia. The progression from sub-critical to supercritical (SC), to ultra-supercritical (USC) and advanced ultra-supercritical (A-USC) steam conditions is well underway. Plant efficiencies are increasing from 35-38 per cent (sub-critical) to 49-51 per cent (A-USC). This can reduce coal consumption per kWh of electricity production from about 400g down to 300g.

Carbon emission levels will decrease accordingly from a CO_2 intensity factor of around 900-1000g CO_2/kWh for sub-critical plant to about 650-700g CO_2/kWh for A-USC plant. When integrated with Carbon Capture and Storage (CCS) emissions can further reduce to less than 100g CO_2/kWh.

A-USC plants are now under development and are anticipated to be in operation in 2026-2028. A good review of this subject is covered in a 2020 ACARP Report by Lee et al.[13]

The current suite of export thermal coals is already being used in the HELE power stations in Asia (both SC and USC). The current level of understanding of the impact of coal quality on the operation of HELE plants is somewhat limited. Further research is required, particularly with regard to coal ash composition, ash slagging and fouling characteristics, boiler tube corrosion and heat transfer at the higher HELE operating temperatures. In general, however, the higher quality coals suitable for sub-critical boiler operation also appear to be suitable for HELE operation.

High quality Australian coals are are being sought for use in the export market with the further transition to HELE technology.

[13] S Lee, et al., *A Comprehensive Technical Review of HELE Pulverised Coal Combustion Technologies for Power Generation*, ACARP Project C28063, April 2020.

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