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Best in Class:

Australia's Bulk Commodity Giants

AUSTRALIAN METALLURGICAL COAL:
Quality Sought Around the World

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Anthony is a retired metallurgist with an extensive career starting at BHP Steel Port Kembla steelworks where he held operational roles in ironmaking (blast furnaces, sinter plant and coke ovens). In the late 1990s, he joined BHP Minerals marketing and subsequently led BHP's coking coal research team at the company's Newcastle Laboratories. After leaving BHP in 2016, Tony joined Felix Resources and then Yancoal after its takeover of Felix. In recent years he has consulted to a number of Australian coal companies.

Australia is the largest seaborne exporter of metallurgical coal with exports of 184 million tonnes (Mt) valued at AUD$41.3 billion in 2019.[1]

Many of the metallurgical coals produced in Australia are integral components in coal blends of major steel mills around the world due to specific properties that ensure the coke produced from these blends optimises blast furnace (BF) performance.

By using Australian metallurgical coals, BF operators can maximise productivity, enhance the quality of hot metal, minimise the amount of coke needed to produce a tonne of hot metal and reduce the amount of CO_2 produced in the ironmaking process.

Unlike some other bulk commodities, with markets dominated by geographically close customers, the quality of Australia's metallurgical coal attracts customers from around the world and underpins its value.

By using Australian metallurgical coals, blast furnace operators can maximise productivity and reduce the amount of CO_2 produced

[1] Australian Government, Department of Industry, Science, Energy & Resources Historical Data, June 2020.

What is metallurgical coal and what is it used for?

Metallurgical coal encompasses coking coal and pulverised coal injection (PCI) coal (Figure 1) and is primarily used in the production of steel.

Coking coal is 'coked' (heated in the absence of oxygen) in a coke oven (Figure 2 & Figure 3) to produce coke. While it is used in a variety of metallurgical processes, the vast majority of all coke produced globally is consumed in BFs which produce molten iron, or 'hot metal'. The hot metal is then refined into steel in a Basic Oxygen Furnace (BOF).

PCI coal is injected into the bottom of the BF replacing a proportion of the coke required to maintain the hot metal at the desired temperature. PCI coal is less expensive than coke, hence its attractiveness to iron makers.

About 70 per cent of worldwide steel production relies on metallurgical coal via the BF/BOF route (Figure 4) and 30 per cent is via the electric arc furnace (EAF) route (which melts scrap and does not require the use of metallurgical coal).[2]

FIGURE 1: METALLURGICAL COAL IS PRIMARILY USED IN THE PRODUCTION OF STEEL

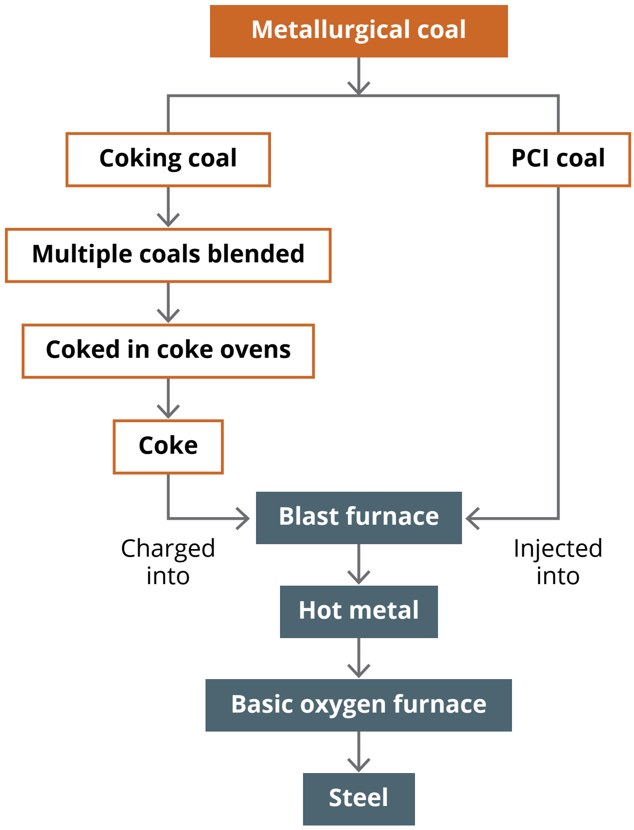


FIGURE 2: INSIDE AN EMPTY COKE OVEN AFTER COKE HAS BEEN DISCHARGED

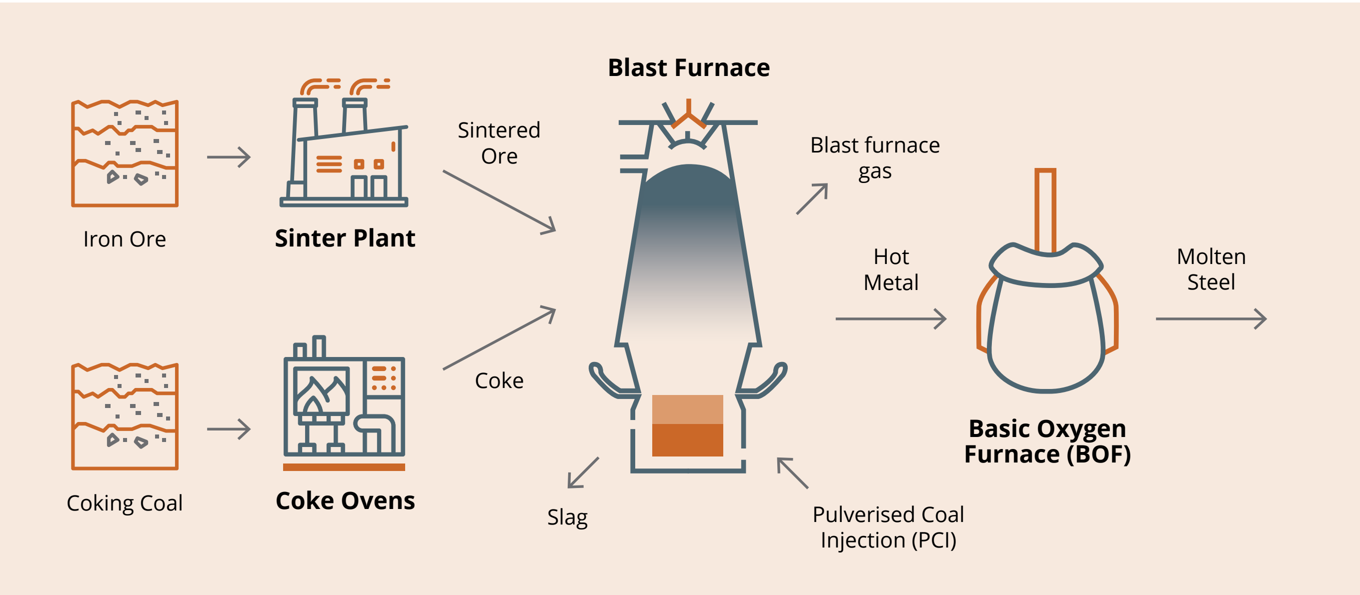
Source: BlueScope Steel.

[2] World Steel Association, *World Steel in Figures*, 2020.

FIGURE 3: A NUMBER OF INDIVIDUAL OVENS MAKE UP A COKE BATTERY

Source: BlueScope Steel.

FIGURE 4: STEEL PRODUCTION VIA THE BLAST FURNACE/BASIC OXYGEN FURNACE ROUTE



Differences between coking coal, PCI coal and thermal coal

Coking coal, during the coking process, softens (exhibits plasticity) at about 400°C. As heating continues the coking coal agglomerates, then swells and re-solidifies at about 500°C. Heating continues to about 1200°C until coking is complete, which takes at least 18 hours.

The size of coking coal charged into the coke oven is quite fine at <3mm whereas the product coke is lumpy in nature with an average size of about 50mm, as shown in Figure 5.

Coke is generally 85-90 per cent carbon and 10-15 per cent ash.

Thermal coal is primarily used in the generation of electricity. PCI coal is basically high quality thermal coal. Thermal/PCI coals do not possess plastic properties and if heated in a coke oven the coal particles would remain in essentially the same state and would not agglomerate into lumps as does coking coal.

Coking coal and PCI coal are used in steel production, thermal coal is used in electricity generation

FIGURE 5: CRUSHED COKING COAL (LEFT) PRIOR TO COKING AND A LUMP OF COKE (RIGHT) AFTER COKING

Australian exports of metallurgical coal

In the early years of the Australian coal industry (1791-1950s), production was concentrated in the Illawarra and Hunter regions of New South Wales. The impetus for the growth of metallurgical coal production was exports from New South Wales to the burgeoning Japanese steel industry in the 1950s and the development of mining in the Bowen Basin in Queensland in the 1960s.

Currently more than 96 per cent of Australia's metallurgical coal production is exported with the balance used domestically.[3]

Exports have steadily increased over the last three decades commensurate with growing worldwide demand for high quality metallurgical coal, as shown in Figure 6.

High quality metallurgical coal is mined (Figure 7) in the:

- Illawarra and is exported from Port Kembla, New South Wales
- Hunter Valley, Gloucester Basin and Gunnedah Basin and is exported from the Port of Newcastle, New South Wales
- Bowen Basin and is exported from Gladstone, Hay Point and Abbot Point ports in Queensland.

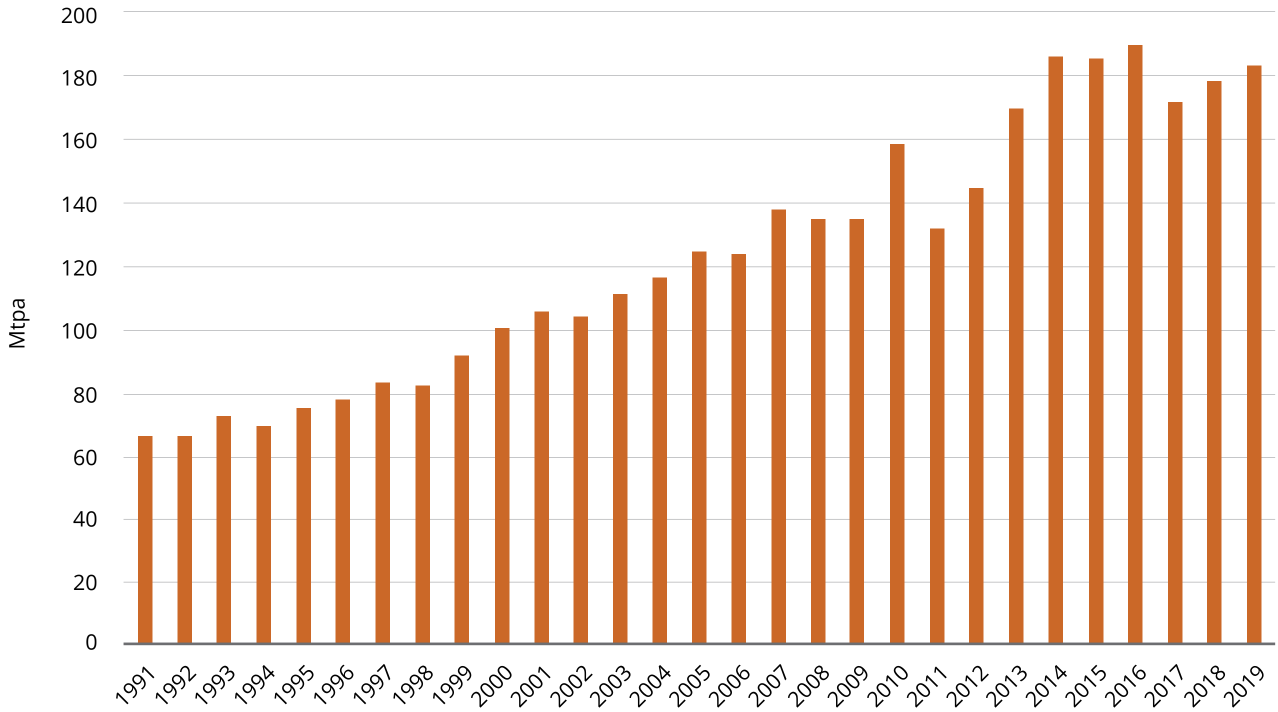
As shown in Table 1, Australia supplied 183 Mt or 61 per cent of the global seaborne metallurgical coal trade of 302Mt in 2019 comprising:

- 123Mt Hard Coking Coal (HCC) and Semi-Hard Coking Coal (SHCC) or 60 per cent of the global seaborne market for HCC/SHCC
- 29Mt Semi-Soft Coking Coal (SSCC) or 62 per cent of the global seaborne market for SSCC
- 31Mt PCI coal or 63 per cent of the global seaborne market for PCI coal.

Total metallurgical coal trade flows, which include land-based flows, are shown in Figures 8 and 9. China is the largest importer of metallurgical coal, primarily from Australia and Mongolia.

Australia exports enough metallurgical coal to produce, without blending with international coals, about 100 million tonnes per annum (Mtpa) of coke and 290Mtpa of crude steel or approximately 15 per cent of total global steel production.[5]

FIGURE 6: AUSTRALIAN METALLURGICAL COAL EXPORTS 1991-2019



Source: Australian Govt, Department of Industry, Science, Energy & Resources Historical Data, June 2020.

FIGURE 7: METALLURGICAL COAL REGIONS IN AUSTRALIA

TABLE 1: SEABORNE METALLURGICAL COAL TRADE IN 2019[4]

Mt				**Seaborne** 302 ↓			
		Aust ↓	**US** ↓	**Canada** ↓	**Russia** ↓	**Moz** ↓	**Other** ↓
Mt		183 ↓	46	34	28	5	6
	HCC/SHCC ↓	**SSCC** ↓	**PCI** ↓				
Mt	123	29	31				
Australia's market share in each category	**60%**	**62%**	**63%**				

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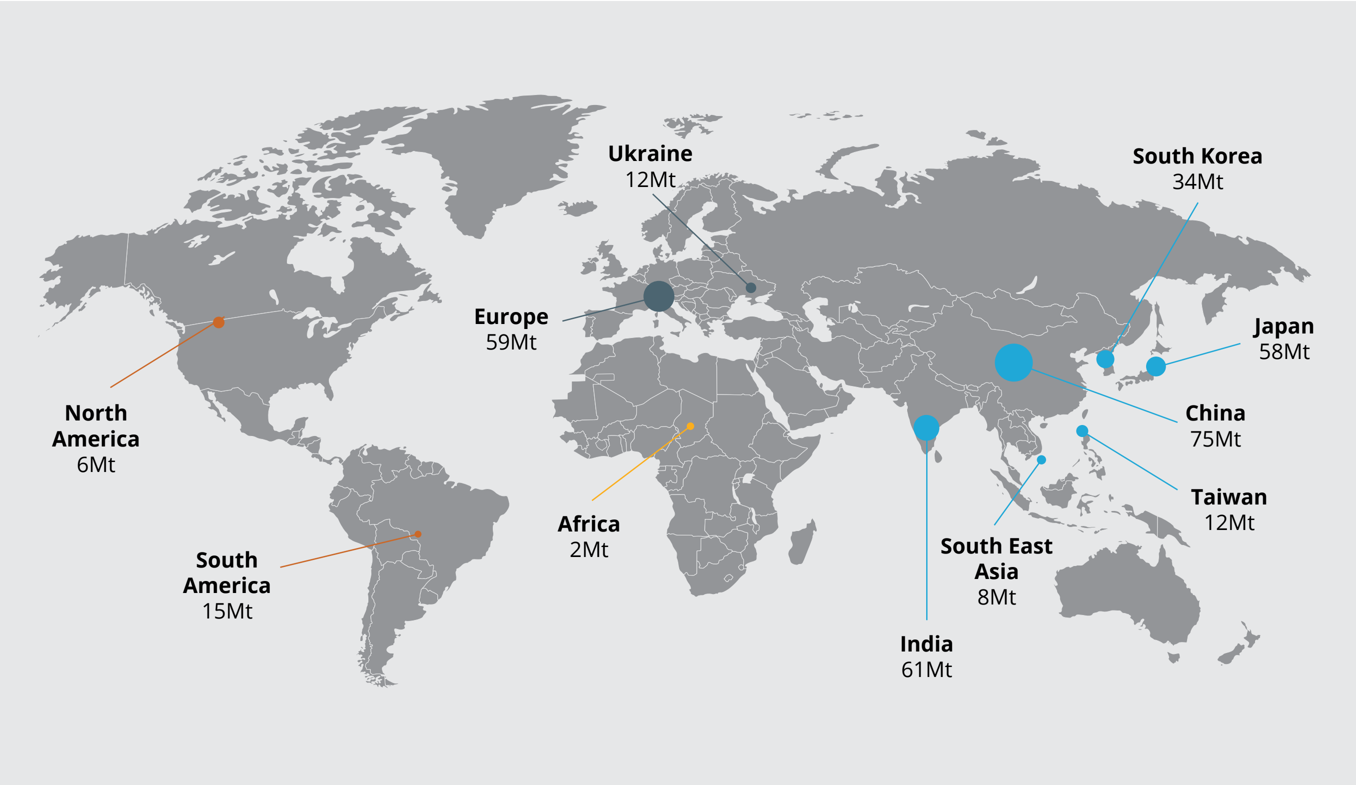
3 Commodity Insights, Market Demand Study: Australian Metallurgical Coal, 12 October 2018, p8.

4 CRU Group, *CRU Metallurgical Coal Cost Model*, 2020.

5 Calculations based on:

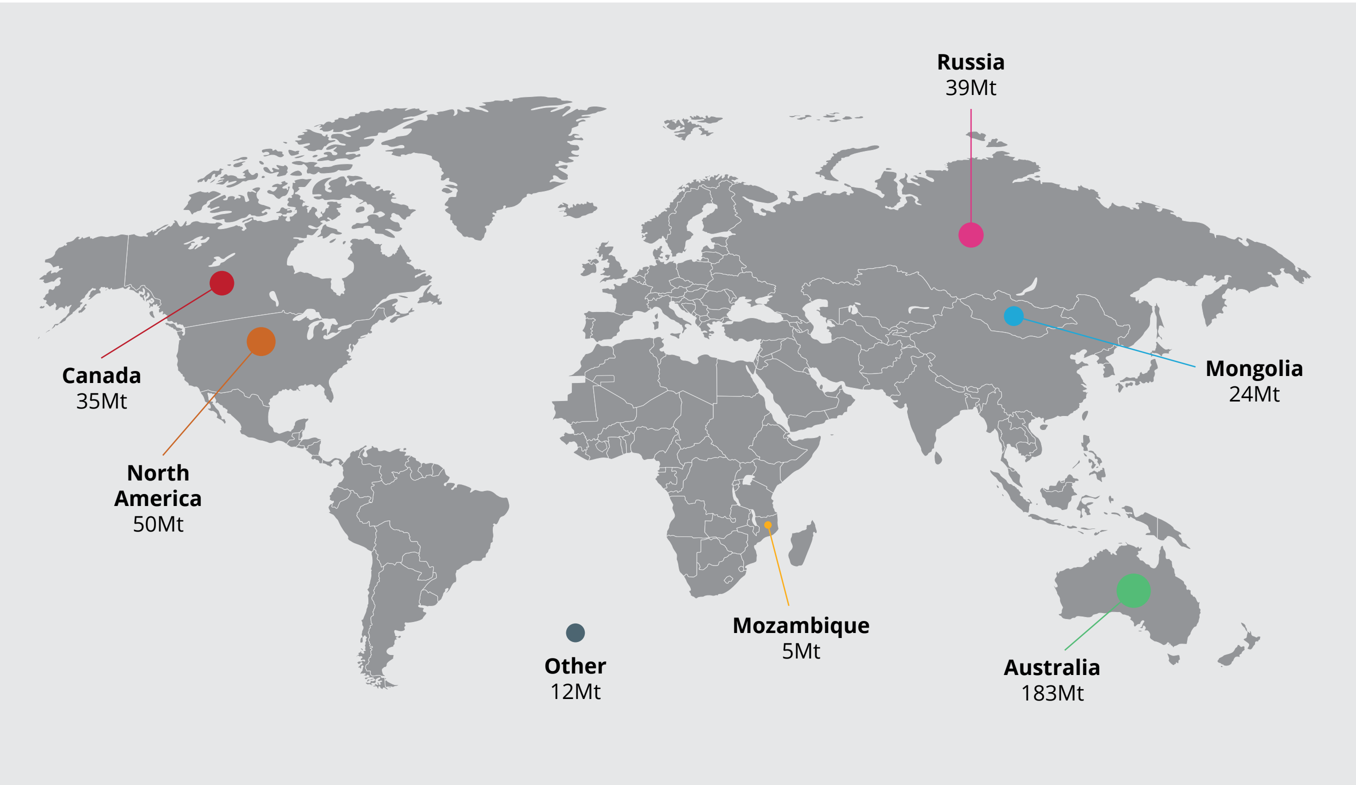
- 123Mt (HCC + SHCC) of VM 23.6 per cent and 29Mt SSCC of VM 31 per cent equating to 152Mt at 25.7 per cent VM, and 31Mt PCI coal (wet)
- 10 per cent Total Moisture for all coals
- Coke/coal ratio 0.64 meaning 152Mt coal produces 98Mt coke
- Assume coke rate of 390kg/thm and PCI rate of 110kg/thm. Hot metal produced from 98Mt coke is 251Mt
- PCI required at 110kg/thm is 251 x 0.110 or 28Mt (dry)
- Assume hot metal ratio of 90 per cent in BOF so total crude steel produced is 251/0.9 or 279Mt

FIGURE 8: TOTAL IMPORTS OF METALLURGICAL COAL IN 2019 (MT)



Source: CRU Group.

FIGURE 9: TOTAL EXPORTS OF METALLURGICAL COAL IN 2019 (MT)

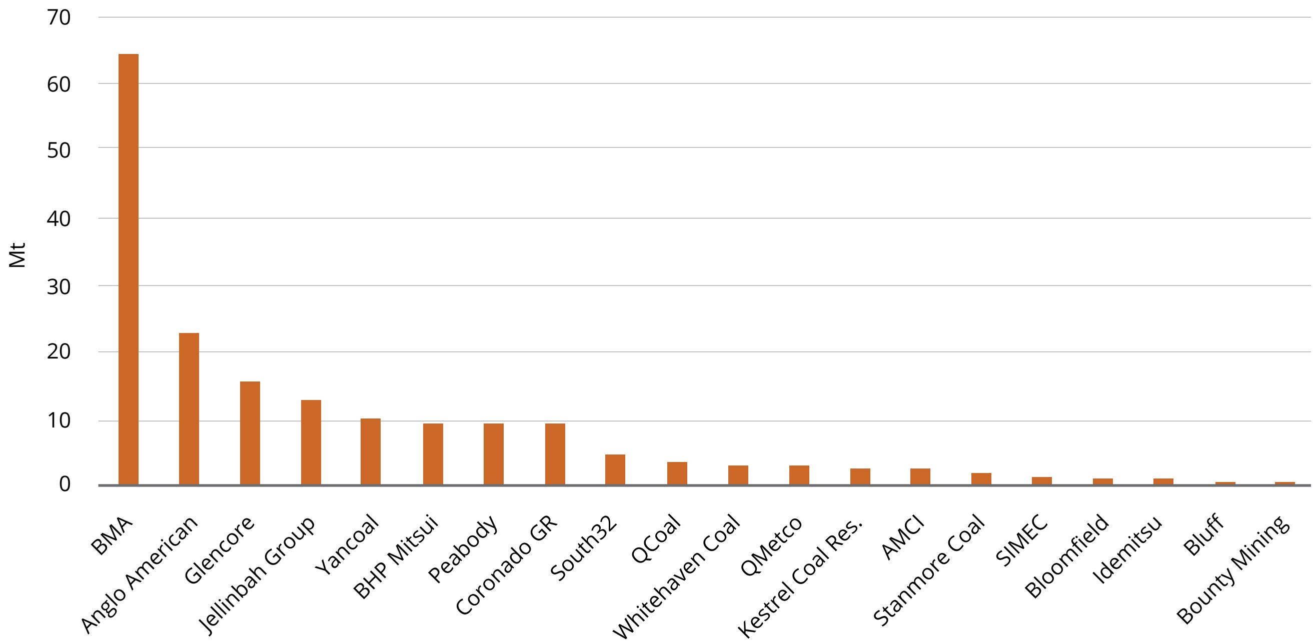


Source: CRU Group.

Companies producing metallurgical coal in Australia

As shown in Figure 10, there is a diverse range of companies producing metallurgical coal in Australia.

FIGURE 10: COMPANIES PRODUCING METALLURGICAL COAL IN AUSTRALIA - 2019



Australia supplied 183Mt or 61 per cent of the global seaborne metallurgical coal trade in 2019

Major markets for Australian metallurgical coal

India, China and Japan are the three major markets for Australian metallurgical coal, as shown in Figure 11. The Indian market is expected to provide substantial growth for Australian producers as steel production there grows over the next two decades.

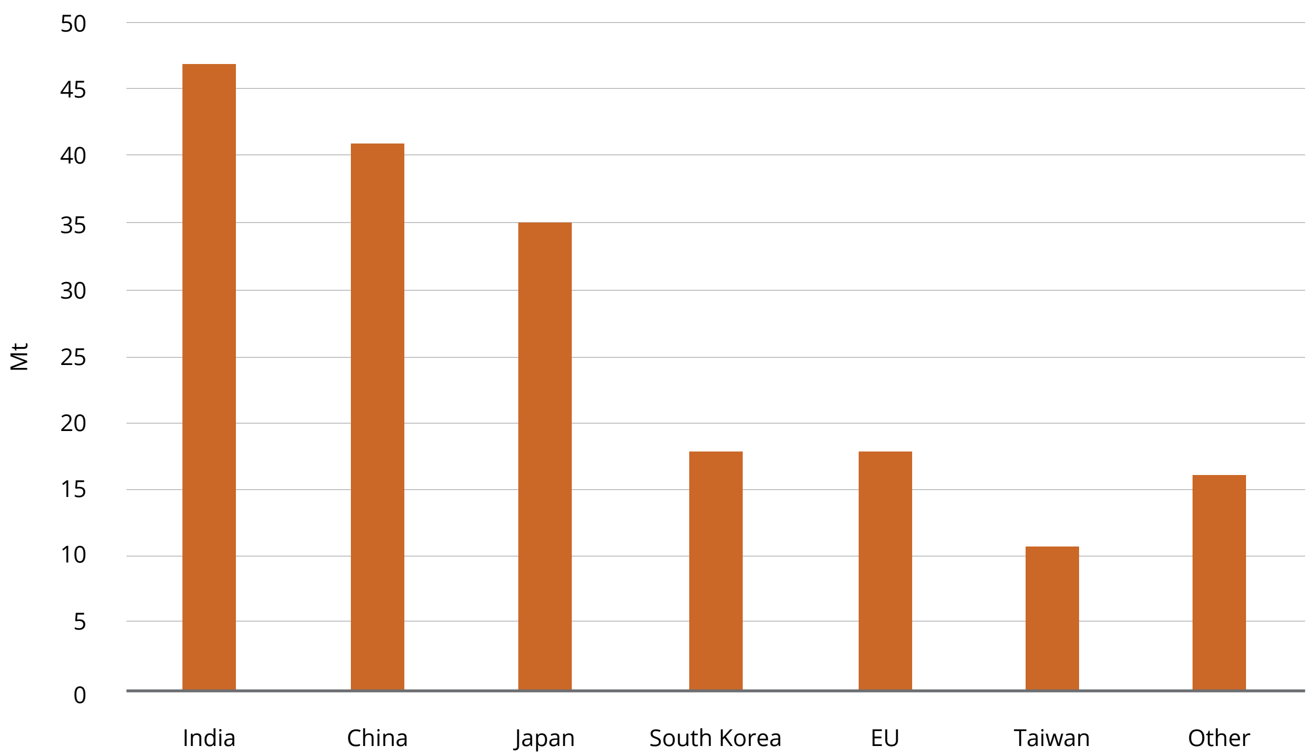
The Australian metallurgical coal industry is renowned for offering a diverse range of superior quality products and reliable delivery performance – attributes cementing Australia's position as the dominant metallurgical coal exporting country in the world.

Australian producers can produce single coal types or blends of uniform quality that match customer requirements by virtue of sophisticated stacker/reclaimer systems at the various loading ports in New South Wales and Queensland.

Automated sampling systems that comply with international standards are used at each port to ensure that representative samples are taken of each shipment.

The Australian metallurgical coal industry offers a diverse range of superior quality products and reliable delivery

FIGURE 11: MAJOR MARKETS FOR AUSTRALIAN METALLURGICAL COAL IN 2019



Source: Historical Data, June 2020, Department of Industry, Science, Energy & Resources.

Importance of metallurgical coal in the production of hot metal

Blast furnace process

The blast furnace (BF), as shown in Figure 12 and Figure 13, is a continuous process where coke, iron ore and fluxes are charged alternately into the top of the furnace and slowly descend over about an eight-hour period whilst hot air or 'blast' enters the bottom of the furnace through tuyeres where it reacts with carbon in the coke to produce carbon monoxide (CO). The CO ascends the furnace reducing the iron-ore to iron ($Fe_2O_3 + 3CO \rightarrow 2Fe + 3CO_2$).

Heat is transferred from the ascending gases smelting the descending iron ore producing hot metal and slag, both of which are cast through a taphole from the hearth of the furnace. Slag is a by-product of the process. The temperature of the molten hot metal and slag is about 1500°C and 1550°C respectively.

The composition of the hot metal is approximately 94.5 per cent iron and 5 per cent carbon with small amounts of silicon, sulfur, phosphorus and minor elements. The subsequent steelmaking process removes most of the carbon and 'fine-tunes' the other elements to produce the required quality steel.

FIGURE 12: SCHEMATIC OF A BLAST FURNACE

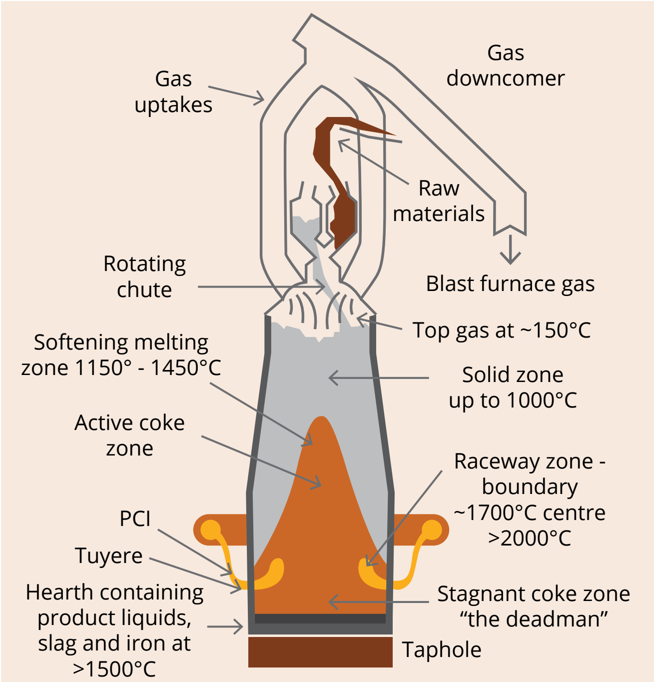


FIGURE 13: #5 BLAST FURNACE – PORT KEMBLA

Source: BlueScope Steel.

Coke in the blast furnace

Coke performs three main functions in the BF:

1. Provides most of the BF's thermal requirements. Oxygen in the hot air which is blown through tuyeres at the bottom of the furnace reacts with carbon in the coke generating temperatures of approximately 2000°C
2. Provides the majority of CO gas which is the principal reducing agent for the reduction of iron oxides to iron in the furnace
3. Physically supports the iron ore in the furnace and provides permeability to gas flow through the furnace and for slag and hot metal to flow down into the hearth.

The productivity (tonnes of hot metal produced per unit of time) of a BF is largely dictated by the volume of air that can be blown into the furnace which in turn is a function of the permeability to gas flow in the furnace.

If the permeability to gas flow is low then less air can be blown into the furnace and productivity reduces.

Coke properties greatly influence the permeability to gas flow in the furnace.

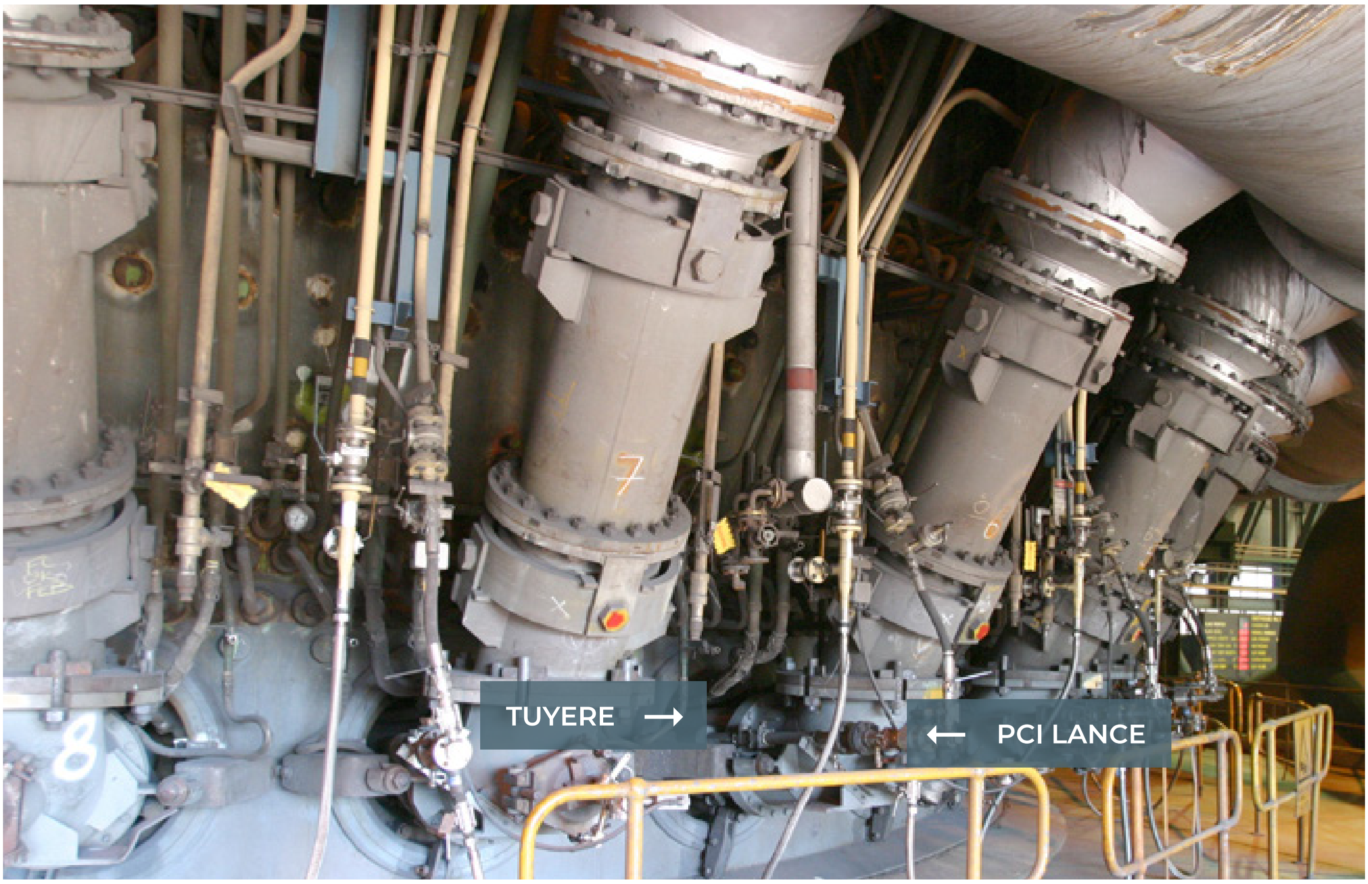
Superior quality coke has good 'cold strength' such as abrasion and breakage resistance, which means it doesn't degrade significantly when conveyed to the BF after being dropped through chutes, into stock bins, charged into the furnace and as it descends through the upper shaft of the furnace.

Superior quality coke must also possess good 'hot strength' which means it must not break down to a significant degree when subjected to very high temperatures (>1000°C) and on reaction with CO_2, which is present in the furnace as the gaseous product of the reduction of iron oxides.

If coke possesses poor cold and hot strength it will break down prematurely, resulting in poor furnace permeability and low BF productivity.

The main reason many Australian HCCs and SHCCs are valued so highly worldwide by coke makers and iron makers is that they produce coke of superior hot and cold strength.

FIGURE 14: PCI IS INJECTED THROUGH TUYERES INTO THE BLAST FURNACE

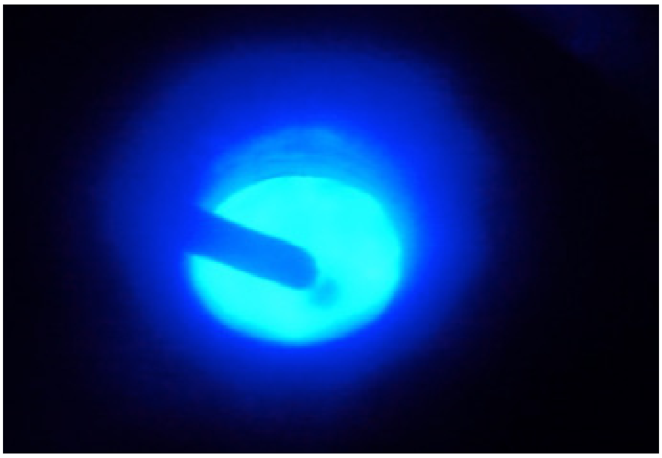


Pulverised coal injection in the blast furnace

Pulverised coal injection (PCI) coal is significantly cheaper than coke and is therefore an economical replacement for coke in the BF.

PCI coal is ground finely before being injected into the BF (Figure 14 and Figure 15). The higher the carbon and energy content (calorific value) of a PCI coal the higher the coke replacement ratio, that is the more coke it can replace in the BF.

FIGURE 15: PLUME OF PCI COAL COMBUSTING AT THE END OF A LANCE



Source: BlueScope Steel.

Replacement ratios vary from about 0.7 to 0.9, that is, one kg of PCI coal can replace 0.7 to 0.9 kg of coke.

There is a limit to the amount of PCI coal that can be injected and most BFs operate at a ratio of 60-70 per cent coke and 30-40 per cent PCI coal.

Australian PCI coals are valued worldwide because of their high energy content and high coke replacement ratio in the BF.

The increased usage of PCI coal worldwide has meant superior hot and cold strength of coke has become even more important in order to maintain BF productivity. This is because as the amount of PCI coal injected increases there is less coke to:

1. Support the same amount of iron ore in the furnace
2. Provide sufficient permeability to gas flow in the furnace.

The cost effectiveness of using PCI coal therefore relies significantly on the availability of high-quality coking coal from sources like Australia.

The use of Australian coking coals to produce high strength coke enables iron makers to operate blast furnaces at relatively low coke rates

Classification of coking coal

Classification of coking coals by rank

Coal rank is a measure of coal maturity i.e. how far along the coalification sequence the coal has progressed. It is influenced by depth of burial of plant material, time buried and temperature. The higher the rank, the more mature the coal. Rank is an important parameter for coke makers when designing coal blends.

Coking coals are generally classified into Hard Coking Coal (HCC), Semi-Hard Coking Coal (SHCC) or Semi-Soft Coking Coal (SSCC).

- **HCC:** high rank producing strong coke and commanding premium prices
- **SHCC:** medium to high rank producing reasonable strength coke and discounted from HCC price
- **SSCC:** low rank producing weak coke and significantly discounted from HCC price.

The use of SSCC significantly reduces the cost of a coking coal blend.

Australian metallurgical coal production includes all types of metallurgical coal, as shown in Table 2.

Coking coal blends

It is rare for coke makers to charge a single coal into a coke oven as a single coal will not possess all of the properties required to produce coke suitable to meet BF specifications for ash, sulfur, phosphorus, size and coke strength. Coke makers use multiple coals when formulating a coking coal blend in order to meet these specifications.

As an example, in order to meet BF requirements, a coking coal blend might comprise:

40 per cent HCC, 30 per cent SHCC and 30 per cent SSCC

Consideration will also be given to the volatile matter (VM) content of the coal blend. During the coking process, VM is driven out of the coal to form coke ovens gas which is primarily hydrogen, methane and carbon monoxide. Coke ovens gas has a high calorific value and is used to heat coke ovens and other processes within the steel works. The lower the VM content of the coal, the less gas and more coke is produced and the higher the VM content of the coal, the more gas and less coke is produced.

If a steel works requires additional energy the VM of the coking coal blend may be increased in order to produce more coke ovens gas.

TABLE 2: METALLURGICAL COAL TYPES PRODUCED IN EACH REGION

CLASSIFICATION/ REGION	HCC	SHCC	SSCC	PCI
Illawarra	✓	✓		
Hunter Valley			✓	✓
Gloucester Basin		✓		
Gunnedah Basin			✓	✓
Bowen Basin	✓	✓	✓	✓

FIGURE 16: HOT COKE AFTER BEING DISCHARGED FROM A COKE OVEN

Source: BlueScope Steel.

Quality attributes of Australian coking coal

BF operators greatly value consistent coke and PCI coal quality as variable quality can create furnace instability.

Hot metal and slag can only be removed by casting through tapholes from the hearth of the furnace so any instability leading to a drop in furnace heat level and consequential increase in slag viscosity can lead to major problems with slag and hot metal removal.

If hot metal production decreases then steel production is also affected so BF operators value consistent raw material quality in order to mitigate operational disruptions.

Table 3 outlines the properties of Australian coking coals compared to international alternatives.[6]

Coke strength after reaction

The coke strength after reaction (CSR) test was developed to determine the extent to which coke degrades under BF conditions i.e. high temperatures and reaction with CO_2. As CSR increases the 'hot strength' of coke increases. Japanese researchers found that permeability to gas flow in a BF improved as CSR of the coke charged increased.[7]

As larger BFs are constructed worldwide it is imperative that coke quality is sufficient to provide permeability to gas flow and to physically support the increased iron ore volumes in the furnace.

Australia is by far the largest seaborne exporter of coking coals that produce high CSR coke, as shown in Figure 17.

The high CSR of Australian HCC and SHCC from the Bowen Basin and the Illawarra region is the main reason they are highly sought and are the cornerstones of many coking coal blends around the world.

Carrying capacity

Australian HCCs are renowned for their 'carrying capacity' with the capability to 'carry' weaker coking coals in coal blends. This means that weaker coking coals can be blended at relatively high proportions with Australian HCC, thus creating a cheaper blend without a significant decrease in the quality of coke produced.

TABLE 3: PROPERTIES OF AUSTRALIAN COKING COALS AND COMPARISON TO INTERNATIONAL ALTERNATIVES

COKING COAL PROPERTY	SIGNIFICANCE	TYPICAL AUSTRALIAN QUALITY[6]	COMPARISON TO INTERNATIONAL ALTERNATIVES
Ash	Increases slag volume in the BF. Reduces BF productivity. Lower ash is preferred.	6.0–10.5 per cent (air-dried basis)	Comparable
Sulfur (S)	S is deleterious to steel quality and costly to remove in the steelmaking process. Lower S is preferred.	0.3–1.3 per cent (air-dried basis)	Comparable
Phosphorus (P)	P is deleterious to steel quality and costly to remove in the steelmaking process. Lower P is preferred.	0.01–0.12 per cent (air-dried basis)	Comparable
Alkalis (K_2O + Na_2O)	Alkalis condense in the BF shaft and build-up or form accretions on the furnace wall which can detach suddenly causing operational problems. Lower alkali content is preferred.	1.5 per cent in ash (dry basis)	Comparable
Rheology	Fluidity – viscosity of plastic phase during heating. Dilatation – expansion and contraction during heating. Both assist coke makers in formulating coal blends that produce strong coke.	Broad range	US coals superior but Australian comparable to others
Coke cold strength	Abrasion and breakage resistance for optimisation of BF permeability.	Broad range	Superior
Coke hot strength (Coke Strength after Reaction - CSR)	Hot strength for optimisation of BF permeability. Preferred coke CSR for large BF 65-70 per cent.	55-74 per cent	Superior

6 CRU, Coal Quality Data, 2019.

7 N.Nakamura et al, *Behaviour of Coke in Large Blast Furnaces*, The Metals Society, 1977.

Oven wall pressure

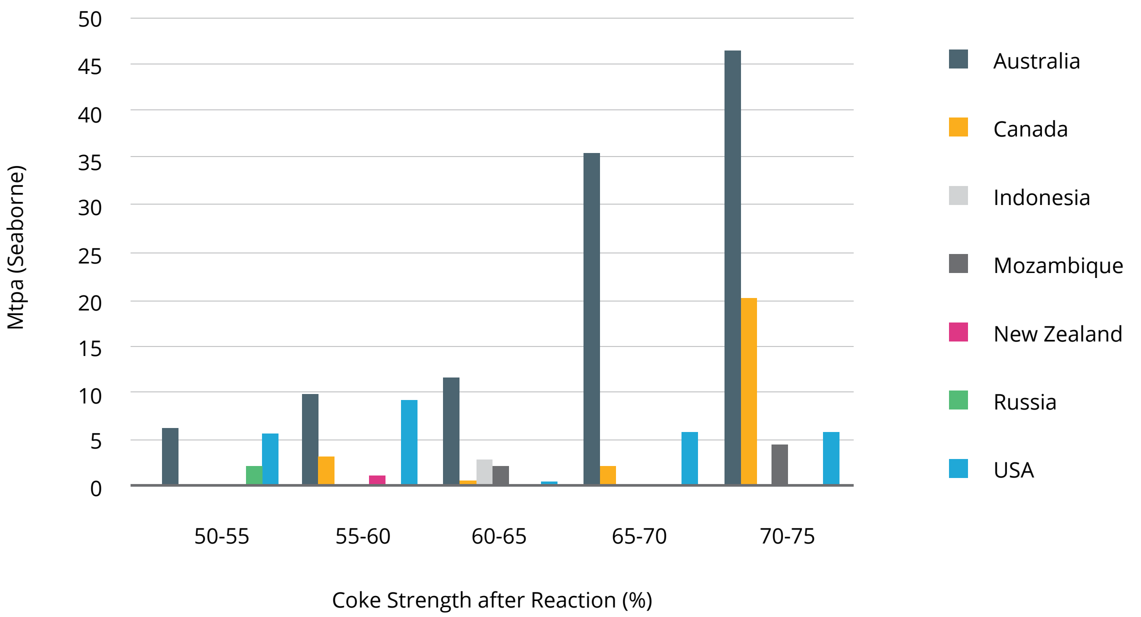
Australian HCC and SHCC are renowned for not producing high oven wall pressure (OWP) during the coking process.[8] OWP is caused by a build-up of gas within the plastic layers in the latter stages of the coking process. Pressure on coke oven walls can be immense and high rank coals are particularly prone to producing high OWP. Some high rank, low volatile coals from the United States produce very high OWP during coking and are therefore limited in many coking coal blends. Coke ovens are constructed to last for at least 50 years but their lifespan can be severely curtailed if OWP is not controlled by prudent blending of coals.

Australian SSCC

SSCC is produced in the Hunter Valley, Gunnedah Basin and Bowen Basin although coal properties vary in each region. Hunter Valley SSCCs generally have good rheological properties for their rank, Gunnedah Basin SSCCs tend to have very low ash and sulfur whilst Bowen Basin SSCCs are lower in VM (around 25-28 per cent compared to 33-38 per cent in New South Wales). Therefore, coke makers have a range of Australian SSCC qualities to select from to complement HCC in their coal blends.

Japanese, Korean and Taiwanese mills have used Australian SSCC in their blends for many years in order to reduce the cost of coke and to meet coke specifications targets.

FIGURE 17: CSR AND VOLUMES OF AUSTRALIAN SEABORNE EXPORTS OF COKING COAL COMPARED TO COMPETITORS



Source: Wood Mackenzie data.

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[8] S.Deplechin, P.Pernot, *Coal Blending Optimization in Arcelor Coke Plants*, La Revue de Metallurgie, 2005.

[9] I F Kurunov, The blast-furnace process – is there any alternative, Researchgate, July 2012.

[10] K De Ras et al, Carbon capture and utilisation in the steel industry: Challenges and opportunities for chemical engineering, Current Opinion in Chemical Engineering, Volume 26, Dec 2019, pp 81-87.

[11] Materials Processing Institute, Blast Furnace 2030 – A Vision for Sustainable Iron Production, Sept 2017.

[12] The Japanese Iron & Steel Federation, JISF Long Term Vision for Climate Change Mitigation, 2019.

[13] McKinsey & Co., Decarbonisation Challenge for Steel, April 2020.

[14] Calculation based on:

- A decrease in coke CSR of 1 per cent increases blast furnace coke rate by 1.3-2.2kg/thm .
- Base case assumes an average of 40 per cent Australian HCC/SHCC of 23.6% VM(ad) in coal blends producing 211Mtpa coke and 604Mtpa hot metal at 350kg/thm coke rate and 150kg/thm PCI rate.
- 123Mtpa Australian HCC/SHCC taken out of the market of weighted average 66.4 per cent CSR and replaced with 123Mtpa other HCC/SHCC of 60 per cent CSR.
- It is estimated that replacing Australian HCC/SHCC with other HCC/SHCC results in a decrease in coke CSR of 3-6 percentage points in coking coal blends, e.g. if average coke CSR was 68 per cent then CSR decreases to 62-65 per cent increasing blast furnace coke rate by 4-13kg/thm.
- Assume 5 per cent of carbon input into BF reports to hot metal and 95 per cent to BF top gas.
- Assume all CO ultimately converted to CO_2.
- Increase in CO_2 produced is calculated on the same amount of hot metal (604 Mtpa) being produced in the base case and the case where Australian HCC/SHCC is replaced.

[15] S V Filotov et al, *Ideal Blast Furnace Process*, 7th European Coke and Ironmaking Congress, Sept 2016.

[16] ThyssenKrupp Steel, Schwelgern Blast Furnace 1, Fuel rate v CSR graph, Jan 1995 - June 1998.

[17] A.Babich et al, *Ironmaking*, RWTH Aachen University, 2008.

Technologies to reduce emissions and the potential impact on metallurgical coal

The future of the metallurgical coal industry is inextricably linked to the future of the blast furnace (BF).

The BF has come a long way since the first furnace was built in the 14th century. Modern large furnaces can produce around 13,000 tonnes of hot metal per day. The cost of producing hot metal has declined due to economies of scale as larger furnaces are built and cheaper raw materials such as PCI coal are used.

As stated previously, approximately 70 per cent of steel produced worldwide is via the BF route and 30 per cent by the EAF route. EAFs produce steel by melting scrap and, while projections are that the production of steel via the EAF route will increase over time as more scrap becomes available, particularly in China, the BF will in all likelihood remain integral to steelmaking well into the future.[9]

There is pressure on ironmakers to reduce CO_2 emissions and a number of technologies are being investigated to decarbonise the BF including Carbon Capture and Storage (CCS) and Carbon Capture and Utilisation (CCU).[10,11] These technologies may be incorporated into the BF process in the future.

There are research projects which are investigating the partial replacement of carbon monoxide with hydrogen as a reductant in the BF.[12] These projects aim to reduce CO_2 emissions but not eliminate them. Coke would remain the primary heat and reductant source in the BF process so there would still be an ongoing requirement for metallurgical coal.

Research is also being conducted into technologies that use hydrogen, produced from electrolyzers using renewable energy, as a reductant to produce direct-reduced iron (DRI), which is then fed into an EAF furnace.[13] These technologies would potentially replace the BF and would not require metallurgical coal but the operating costs are likely to be very high.

Alternative ironmaking processes to the BF that do not require metallurgical coal have been developed but none have been able to compete on a scale, cost and productivity basis with the BF to date. Some of these processes have been in operation for decades where energy, such as natural gas, is inexpensive. However, on a worldwide basis they have not been a viable alternative to the BF.

There will undoubtedly be accelerated deployment of existing low emissions technologies and an increased emphasis on research and development into new and emerging technologies to ensure emission reduction goals are met. However, whatever the future holds it is clear that so long as BFs remain in operation, high quality Australian metallurgical coal will be sought by iron makers around the world.

BENEFITS OF UTILISING AUSTRALIAN METALLURGICAL COAL IN THE PRODUCTION OF HOT METAL

The use of Australian coking coals to produce high strength coke enables iron makers to operate BFs at relatively low coke rates, that is, the amount of coke required to produce a tonne of hot metal is lower than if poorer quality coke is used. The volume of CO and CO_2 in the BF gas (BFG) per tonne of hot metal produced decreases as the coke rate decreases. BFG leaving the top of the furnace contains CO, CO_2, H_2 and N_2. It is subsequently combusted to heat BF stoves and coke ovens so that all of the carbon in coke, apart from 4.5-5 per cent that enters the hot metal, is ultimately converted into carbon dioxide.

If Australian HCC and SHCC were not available and had to be replaced by coking coal from alternative sources, which would be of inferior quality, it is estimated that the amount of CO_2 produced from BFs that currently use the Australian products may increase by 7-25 Mtpa or 0.8-2.8 per cent.[14,15,16,17]

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