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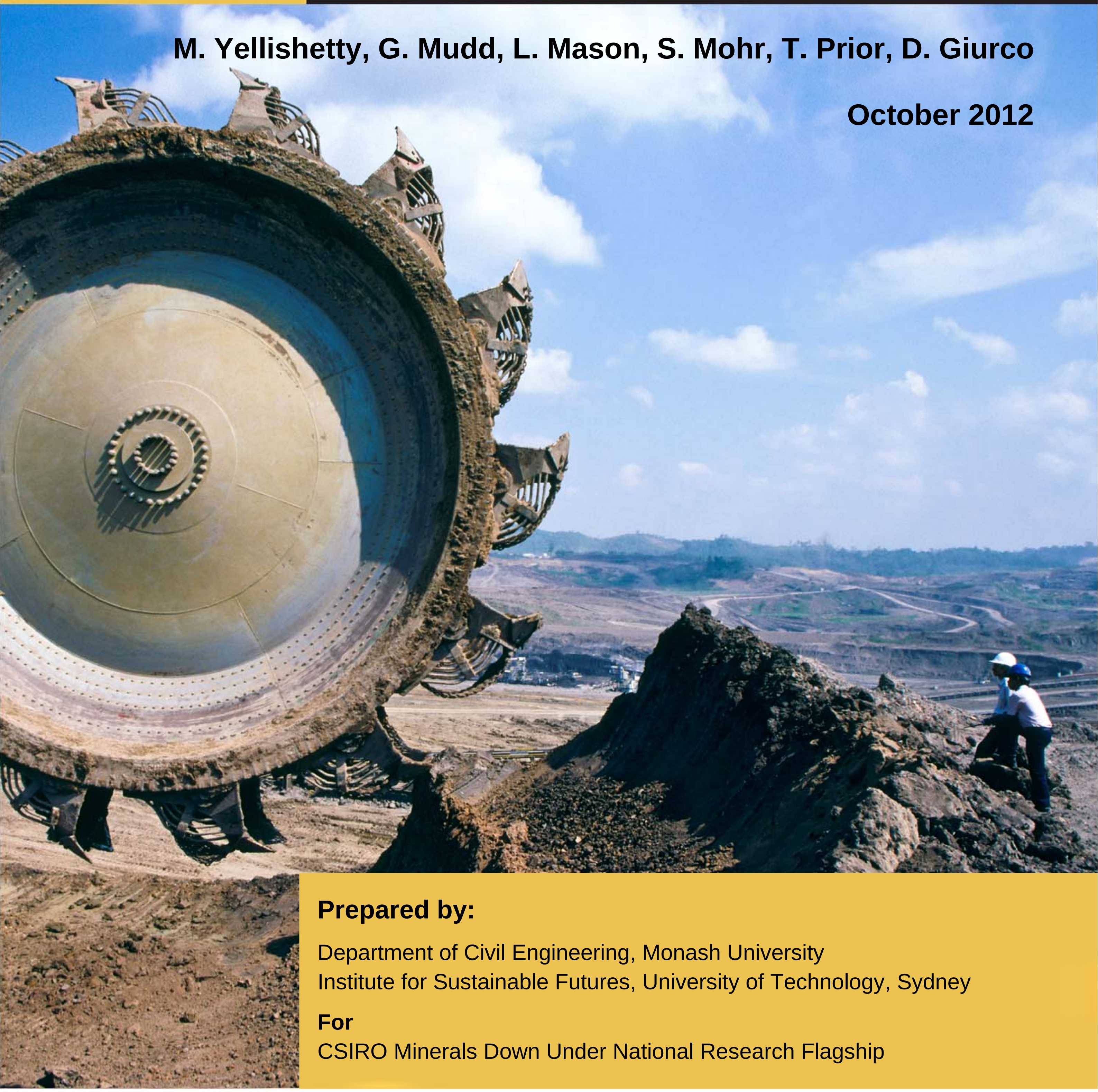
Iron resources and production: technology, sustainability and future prospects



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CSIRO Minerals Down Under National Research Flagship

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1. BACKGROUND

This report is submitted as part of the Commodity Futures component of the Mineral Futures Collaboration Cluster as a case study on iron ore in Australia. The Commodity Futures project focuses on the macro-scale challenges, the dynamics, and drivers of change facing the Australian minerals industry. The Commodity Futures project aims to:

- Explore plausible and preferable future scenarios for the Australian minerals industry that maximise national benefit in the coming 30 to 50 years
- Identify strategies for improved resource governance for sustainability across scales, from regional to national and international
- Establish a detailed understanding of the dynamics of peak minerals in Australia, with regional, national and international implications
- Develop strategies to maximise value from mineral wealth over generations, including an analysis of Australia's long-term competitiveness for specified minerals post-peak.

This report covers the case study on iron ore mining in Australia with a critical reflection on future environmental and technological challenges facing iron ore-related mining and mineral industries in Australia.

1.1. Aim

The aim of this report is to review the link between resources, technology and changing environmental impacts over time as a basis for informing future research priorities in technology and resource governance models. Given that iron ore has shown boom-bust cycles in the past, it is therefore important to assess in detail the current state of Australia's iron ore industry, especially in comparison to global trends and issues, with a view to ensuring the maximum long-term benefit from Australia's iron ore mining sector. This report aims to achieve such a detailed study – examining key trends in iron ore mining, such as economic resources, production and environmental and social issues, and placing these in context of the global iron ore industry. In this manner, it is possible to assess the current state of Australia's iron ore industry, map possible future scenarios and facilitate informed debate and decision making on the future of the sector.

1.2. Introduction

Australia is distinctive among industrialised countries with strong economies (with very high per capita GDP) for its degree of dependence on mineral sector exports and a very low population size besides Canada and Norway (Figure 1). The mining and minerals industry is Australia's largest export industry, which brings substantial economic benefits mainly through foreign exchange earnings. In 2009 the total mineral industry's contribution to GDP was approximately 7.7% (ABARE, 2009). Furthermore, mining has been one of the driving forces for much of the exploration of Australia's remote inland and for Australia's industrial development.

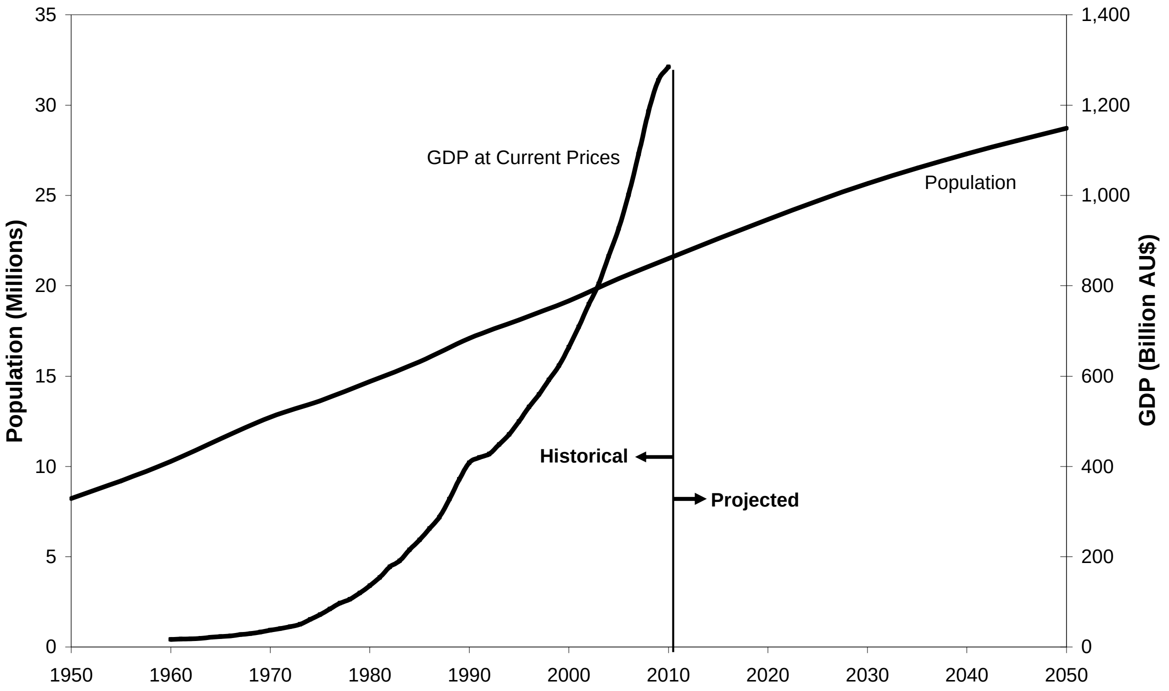


Figure 1: Historical GDP growth and population of Australia

Although Australia's vast endowment of minerals will not be exhausted soon, the extraction of many of these minerals is becoming more challenging with passage of time (Giurco et al., 2010). For example, the declining ore grades are indicative of a shift from 'easier and cheaper' to more 'complex and expensive' processing – in social and environmental terms as well as economic. Declining resource quality has also lead to declining productivity (Topp et al., 2008) and the energy intensity, in terms of $/kWh, has subsequently risen by 50% over the last decade (Sandy and Syed, 2008).

With the global demand for Australian minerals continuing to rise, as a mineral dependent economy, Australia is facing several challenges. For example, the challenges of adapting to carbon constraints and proposed tax changes, land use conflicts, and so on.

This report reviews Australia's current use of its iron ore mineral resources, future issues that will affect processing and use of minerals and metals, and the long term benefits that Australia may derive from such use. This work is part of the Mineral Futures Research Cluster within the Mineral Futures Initiative of the CSIRO Minerals Down Under Flagship comprising the University of Queensland (Centre for Social Responsibility in Mining at the Sustainable Minerals Institute); University of Technology, Sydney (Institute for Sustainable Futures and Department of Civil Engineering Monash University); Curtin University; CQ University; Australian National University and CSIRO.

To this objective, this report will comprehensively put-forth several such issues which are strategically important to the mineral industries' long-term sustainability aspects in general and to the iron ore industries' in particular.

2. METHODOLOGY AND DATA SOURCES

This report presents a comprehensive assessment of Australia's iron ore mineral resources, production trends, economic aspects, existing and future production challenges, and links these to sustainability aspects, especially environmental issues such as greenhouse gas emissions (GHGs). The report therefore provides a sound basis for ongoing policy development to ensure that Australia can maintain and enhance the benefits that our iron ore resource endowment brings.

This section presents a brief overview on the methodology adopted and various data sources used in this study. Throughout the report, the tonnages of steel refer to the crude steel (CS) equivalent. All production and exports data is primarily sourced from government statistical reports, industry supported associations or research literature.

Specific sources for global data include:

- Iron ore production and exports: USGS (2010a, b); BGS (2008).
- Iron ore reserves and resources: USGS (2010a, b); (e.g. Tata Steel, Arcelor Mittal, etc.)
- Steel consumption and exports: WSA (2007, 2010b); ISSB (2008).
- Population and GDP: UN (2010a, b); UNSD (2010).

For Australian data, the following sources were used:

- Iron ore production and exports: ABARE (2009); O'Brien (2009); ABS (2010a,b); Mudd (2009a, 2010b).
- Iron ore mineral reserves and resources: GA (var.); O'Brien (2009); individual company reports (e.g. Rio Tinto, BHP Billiton, Fortescue Metals Group, etc.)
- Steel consumption and exports: ABARE (2009); ABS (2010a, b); WSA (2007, 2010b); ISSB (2008).
- Population and GDP statistical information: ABS, 2010a, UN, 2010 a, b and UNSD, 2010.

Steel consumption is estimated as apparent per capita in crude steel equivalents. The modelling of future production and consumption was done using regression analysis of the historical data. The GDP data was reported in nominal Australian dollars.

3. IRON ORE: SOURCES, USES AND FUTURE DEMAND FORECAST

Iron is an abundant element in the earth's crust averaging from 4 to 8.5% in upper continental crust (Borodin, 1998; Wedepohl, 1995), which makes iron the fourth most abundant element in the earth's crust (Rudnick and Gao, 2003). Iron ores abundance results in a relatively low value and thus a deposit must have a high percentage of metal to be considered economic ore grade. Typically, a deposit must contain at least 25% iron to be considered economically recoverable (US EPA, 1994). This percentage can be lower, however, if the ore exists in a large deposit and can be concentrated and transported inexpensively (Weiss, 1985). Most iron ore is extracted in open cut mines around the world, beneficiated to produce a high grade concentrate (or 'saleable ore'), carried to dedicated ports by rail, and then shipped to steel plants around the world, mainly in Asia and Europe.

Over 300 minerals contain iron but five are the primary sources of iron-ore minerals used to make steel: hematite, magnetite, goethite, siderite and pyrite, with mineral composition shown in Table 1. Among these, the first three are of major importance because of their occurrence in large economically minable quantities (US EPA, 1994). Presently the majority of world iron ore production is hematite ores, followed by magnetite and goethite to a minor extent.

Table 1: Economically important iron-bearing minerals (Lankford et al., 1985; Lepinski et al., 2001)

	Hematite	Magnetite	Goethite	Siderite	Ilmenite	Pyrite
Chemical Name	ferric oxide	ferrous–ferric oxide	hydrous iron oxide	iron carbonate	iron–titanium oxide	iron sulfide
Chemical formula	Fe_2O_3	Fe_3O_4	$HFeO_2$	$FeCO_3$	$FeTiO_3$	FeS_2
%Fe (iron, wt %)	69.94	72.36	62.85	48.2	36.8	46.55
Colour	steel gray to red	dark gray to black	yellow or brown to nearly black	white to greenish gray to black	iron-black	pale brass-yellow
Crystal	hexagonal	cubic	orthorhombic	hexagonal	hexagonal	cubic
Specific gravity	5.24	5.18	3.3–4.3	3.83–3.88	4.72	4.95–5.10
Mohs' hardness	6.5	6	5–5.5	3.5–4	5–6	6–6.5
Melt point, °C	1565	1600	-	-	1370	-

Further, iron accounts for approximately 95% of all metals used (on mass basis) by modern industrial society (Belhaj, 2008). The most important use of iron ore (up to 98%) is as the primary input to steel making with the remainder used in applications such as coal washeries and cement manufacturing (IBM, 2007; IBISWorld, 2009), with minor other uses as schematically represented in Figure 2. Therefore, the demand for iron ore is heavily dependent on the volume and economic conditions for steel production.

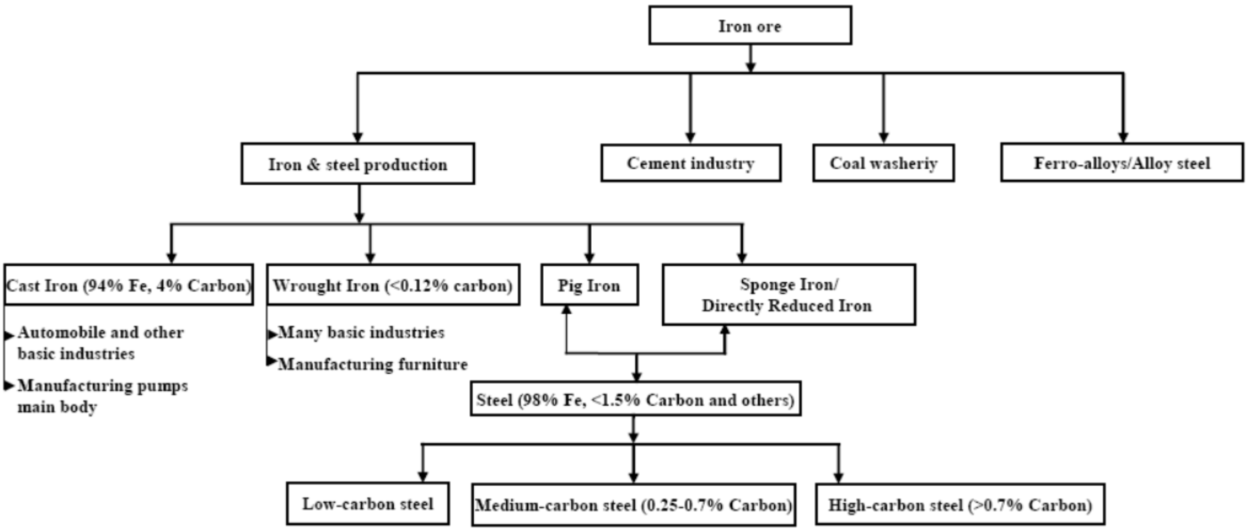


Figure 2: Various uses of iron ore

4. A SNAP-SHOT OF IRON ORE RESOURCES: GLOBAL PERSPECTIVE VIS-À-VIS AUSTRALIA'S POSITION

4.1. A Global Perspective

A mineral resource is a concentration or occurrence of material of intrinsic economic interest in or on the Earth's crust in such form, quality and quantity that there are reasonable prospects for eventual economic extraction and they create value to society by meeting human needs (AusIMM et al., 2004). A mineral deposit is generally defined as an ore with sufficient concentration of an element so as to facilitate its economic extraction of the required quality. Worldwide, iron ore is mainly extracted through open cut methods, with underground methods used to a minor extent. Australian iron ore is mined exclusively by open cut methods. According to Tilton and Lagos (2007), reserves can be defined as the "the metal contained in deposits that are both known and profitable to exploit given the metals price, state of the technology, and other conditions that are currently existing" (pp. 20).

As described above, a mineral resource can, at its most simple, be considered as something that has inherent value to society. A mineral resource can therefore be identified through geological exploration, and when profitable, this can be mined to produce a given mineral or metal. The challenge, therefore, is to ascertain and describe what a potentially profitable mineral resource is. This can vary due to market conditions (e.g. price fluctuations), input costs (e.g. fuels, labour), ore processability (how easily the minerals can be extracted), or even social issues (e.g. bans on mining in national parks). The most important iron ore resources of the world are located in

Australia, Brazil, China, India, Russia and Ukraine. According to the USGS's estimate, the world's total economic reserves ('economically demonstrated resources (EDRs)' according to Geoscience Australia) are estimated at 160 billion tonnes (Gt) crude ore containing 77 Gt of iron (Table 2).

In 2009, Australia had about 12.5% of world's reserves of iron ore and was ranked third after Ukraine (19%) and Russia (16%) (Table 2). In terms of contained iron, Australia has about 13% of the world's reserves and is ranked second behind Russia (14%). Australia produces around 15% of the world's iron ore and is ranked third behind China (35%) and Brazil (18%) (Table 2). The Chinese iron ore tonnages are converted to correspond with world average Fe content.

Table 2: Iron ore reserves in selected countries in the world (2009 data) (USGS, 2010a)

Country	Iron Ore Reserves (Gt)	Iron Content (Gt)	Production in 2009 (Mt)		Rank in 2009	
			Iron Ore	Crude Steel	Iron Ore	Crude Steel
Australia	20	13	370	5.25	3	23
Brazil	16	8.9	380	26.51	2	9
China*	22*	7.2*	900	567.84	1	1
India	7	4.5	260	56.6	4	5
Russia	25	14	85	59.94	5	3
Ukraine	30	9	56	29.75	6	8
USA	6.9	2.1	26	58.14	10	4
World	**160**	**77**	**2,300**	**1,220**	**-**	**-**

*China is based on crude ore, not saleable ore (China has large but low grade, poor quality reserves)

4.2. How is Australia Placed in the World?

In Australia, all mining companies listed on the Australian Stock Exchange (ASX) are required to report details of mineralisation in their leasehold in accordance with the Joint Ore Reserves Committee (JORC) Code (AusIMM et al., 2004). According to the JORC Code, the mineralisation is reported as Ore Reserves and Mineral Resources. Ore Reserves are reported as proved and probable, whilst the Mineral Resources are reported as measured, indicated and inferred resources – the primary basis for both their relative geologic confidence, economic extraction and various modifying factors. Calculations of reserves are based on a high level of geologic and economic confidence, with measured, indicated and inferred resources each having decreasing geologic and economic confidence, respectively. It is possible to report resources as inclusive of reserves, or in addition to – primarily depending on the approach used to quantify economic resources. Therefore, any such estimate of economic mineralisation in the company's tenement are based on several assumptions, such as geological, technical, and economical factors, including quantities, grades, processing techniques, recovery rates, production rates, transportation costs, market prices, environmental constraints, etc.

Location of iron ore mines and the steel mills in Australia are indicated in Figure 3. Figure 4 below represents Australia's EDRs (Reserves according to the USGS classification) as well as sub-economic/inferred for iron ore resources reported by Geoscience Australia (GA, 2009).

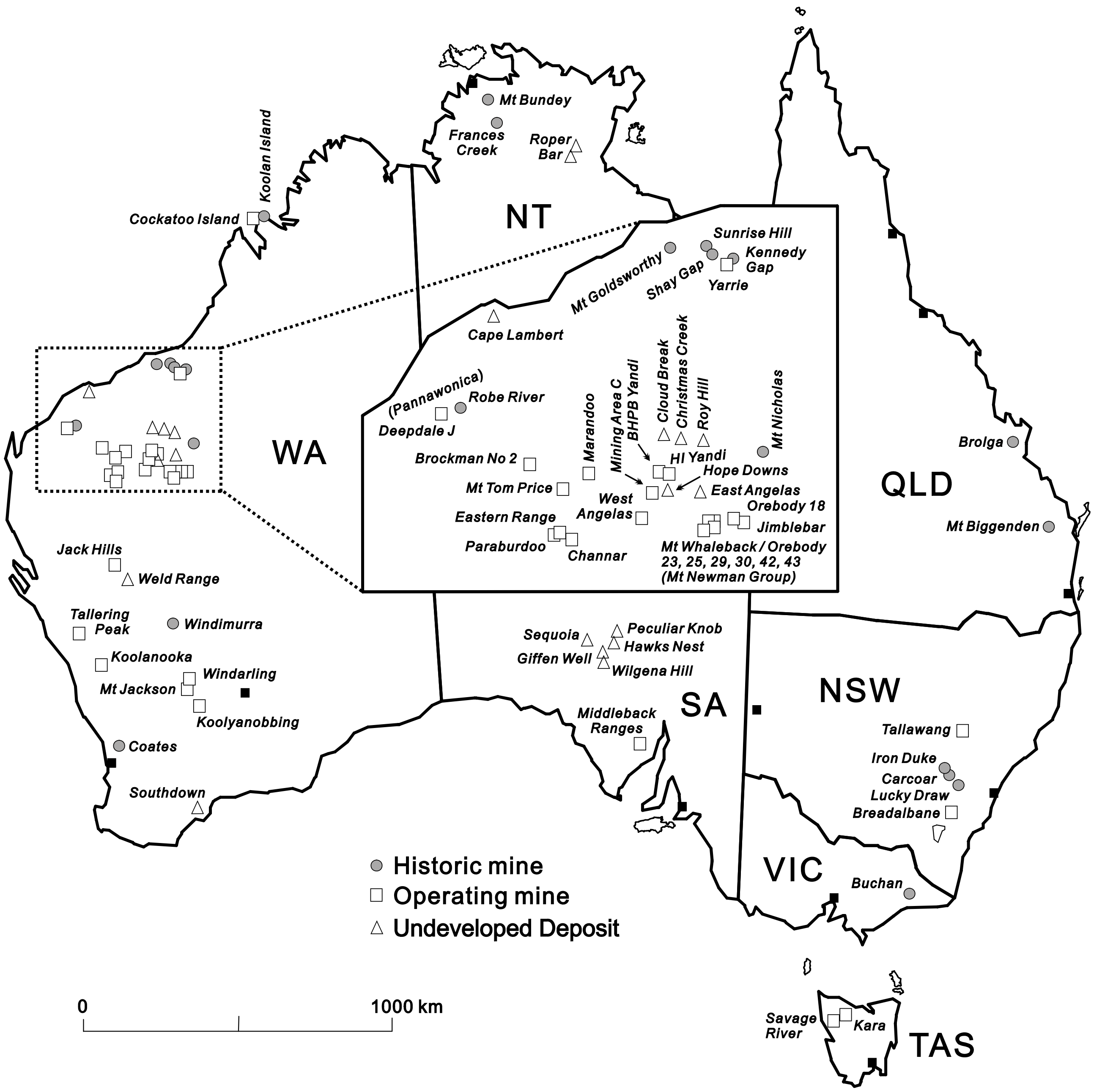


Figure 3: Australian iron ore mines and deposits (Mudd, 2009a)

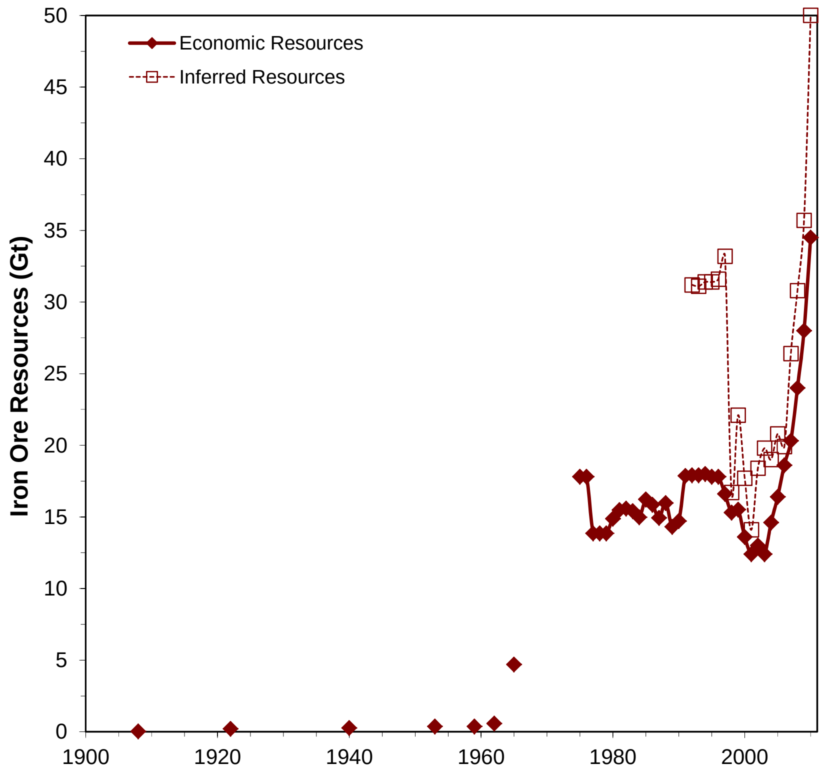


Figure 4: Trends in Economic Demonstrated Resources (EDR) and sub-economic and/or inferred resources for iron ore in Australia (GA, var.; Mudd, 2009a).

As an additional check on the quality (or accuracy) of reserves data, the iron ore mineral resources reported by various companies in Australia was compiled in Tables 4 and 5, while Figure 5 presents percentage and quantity split by ore type. For Australia, the three major miners are Rio Tinto, BHP Billiton and more recently Fortescue Metals Group, producing 202.2, 106.1 and 27.3 Mt ore in 2009 compared to total reserves and resources of 16,700 Mt ore grading 60.5% Fe, 13,054 Mt ore grading 59.7% Fe and 7,960 Mt ore grading 58.9% Fe, respectively. Many companies have interests in additional iron ore resources internationally (not included in Tables 4 and 5). The USGS reports 20 Gt of ore reserves containing 13 Gt iron, respectively, for Australia, while the sum of all of Australian iron ore companies reserves and resources (using JORC terminology) is 55,235 Mt ore grading 57.3% Fe. Furthermore, Geoscience Australia reports 23.9 Gt iron ore as accessible economic resources, with an additional 30.8 Gt in sub-economic resources (GA, var.).

The main limitation in current reporting is the impurities in iron ore, which is vital in judging resource-related sustainability issues. For example, impurities such as phosphorous (%P), silica (%SiO2) or alumina (%Al2O3) are critical to slag volume, chemistry, need of additional flux, extra fuel, volume of material processed, etc.. These impurities are also critical to the quality of steel production and steel production costs yet they are not required to be reported – although many companies voluntarily report impurities, some do not (see Tables 4 and 5, later).

The Pilbara Block of Western Australia encompasses some of the largest known iron ore accumulations in the world. More importantly, several deposits in the region contain extensive high-grade iron ore resources hosted in banded iron formations (BIF) of the 2.5 km thick, late Archaean/early Proterozoic Hamersley Group (Silva et al., 2002). The following ore classification has been developed (based on Ramanaidou, 2009; Silva et al., 2002; Ramanaidou et al., 1996;

Harmsworth et al., 1990; Morris and Fletcher, 1987; Morris, 1983, 1985, 2002; and Morris et al., 1980):

H = dominantly hematite
G = dominantly goethite
M = dominantly magnetite

h = minor hematite
g = minor goethite
m = minor magnetite

On the basis of nomenclature given in the parenthesis, the following common names used for iron ore deposits are classified as following and shown in Table 3.

Table 3: Genetic ore groups and ore types in the Hamersley Province, Australia

Genetic Ore Group	Genetic ore type	Dominant mineralogy	Symbol
BIF-derived iron deposits (BID)	Low P Brockman (LPB)	Haematite (-goethite)	H-g
	High P Brockman (HPB)	Haematite-goethite	H-g
	Marra Mamba (MM)	Haematite-goethite	H-g
Channel Iron deposits	CID (Pisolite)	Goethite-hematite	G-h
Detrital iron deposit (DID)	DID (Detrital)	Hematite (-goethite)	H

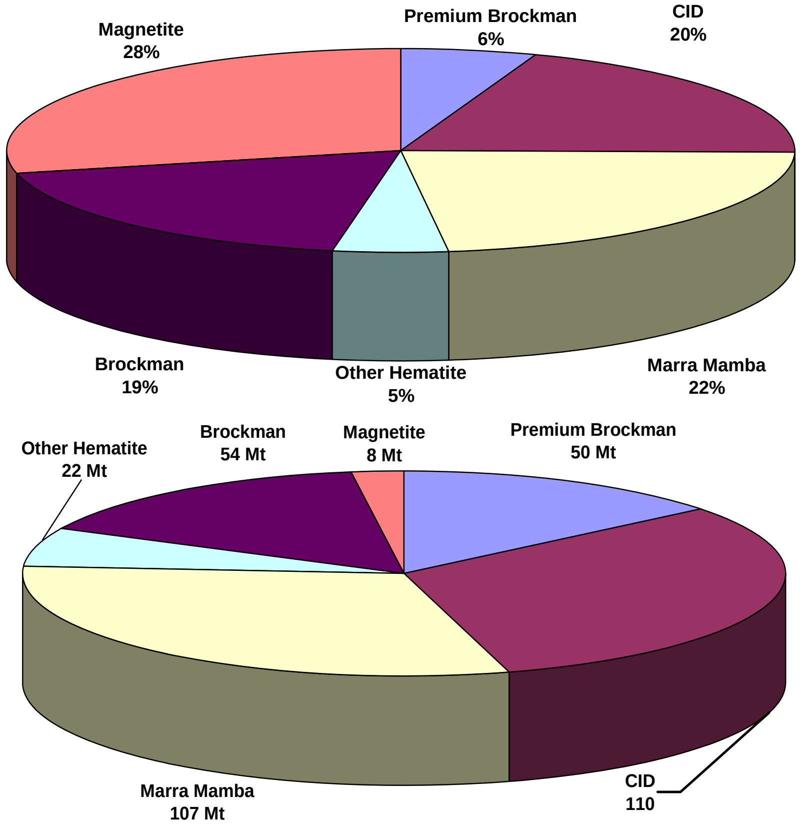


Figure 5: Australia's EDRs by product type (top) as of 2008; and their production in year 2008 (bottom) (O'Brien, 2009).

The geology and mineralogy of each major ore type is now briefly reviewed, and the same are discussed the following sub-sections (O'Brien, 2009).

a) Premium Brockman iron deposits

The Premium Brockman ores are secondary enrichments of the Brockman Iron Formation, a Pre-Cambrian banded iron formation (BIF). The deposits contain high grade, low phosphorus, hard, microplaty hematitic ore. Currently there are only two deposits in Australia that produce Premium Brockman ore, that is, Mount Whaleback and Mount Tom Price. Typical composition for Premium Brockman ores is about 65% Fe, 0.05% P, 4.3% SiO_2, and 1.7% Al_2O_3.

b) Brockman iron deposits

Brockman (BM) iron deposits typically have hematite as the dominant iron mineral. BM deposits also have goethite in variable amounts and have varying phosphorus content and physical characteristics. The variation exhibited by BM deposits is a result of different degrees of dehydration of goethite to microplaty haematite which also affects the amount of residual phosphorus content. A typical BM ore has 62.7% Fe, 0.10% P, 3.4% SiO_2, 2.4% Al_2O_3 and 4.0% LOI (loss on ignition, which effectively includes moisture and carbon).

b) Marra Mamba iron deposits

Marra Mamba (MM) deposits all have goethite hematite mineralogy, with a greater proportion of goethite compared to BM ores. There is also a range of physical properties exhibited within MM deposits. The iron content of most high grade MM ores is about 62 per cent but can vary significantly. A typical MM ore contains about 62% Fe, 0.06% P, 3% SiO_2, 1.5% Al_2O_3, and 5% LOI.

c) Channel iron deposits

The Channel Iron Deposits (CIDs) were formed in ancient meandering river channels. As bedded iron deposits were eroded by weathering, iron particles were concentrated in these river channels. Over time these particles were rimmed with goethite deposited by percolating iron-enriched ground water approximately 15-30 million years ago, which also fused the particles together. CIDs are quite different from bedded ores. Their chief characteristic is their pisolitic 'texture': rounded hematitic 'pea-stones', 0.1mm to 5mm in diameter, rimmed and cemented by a goethitic matrix. The ore is brown-yellow in colour. They typically contain minor amounts of clay in discrete lenses. Typical composition of CID is about 58% Fe, 0.05% P, 4.8% SiO_2, 1.4% Al_2O_3 and 10% LOI.

d) Detrital iron deposits

Detrital iron deposits (DIDs) are found where weathering has eroded bedded iron deposits and deposited ore fragments in natural traps formed by topography, usually drainage channels or valleys. Some DIDs are loose gravels while others are naturally cemented (hematite conglomerate). Both types are often found in the same deposit. The quality of the iron ore in these deposits is dependant on the bedded iron ore deposit which was the source of the ore particles. Typically these deposits are valued for the high proportion of high quality lump contained within them, as lump sized particles have a greater tendency to be captured in the trap site.

e) Hematite

The primary mineralogy is hematite and that they do not fit into one of the other product types explained above. The composition of other hematites can range from Pardoo where reserves contain 57.4% Fe, 0.09% P, 7.07% SiO_2, 2.4% Al_2O_3 and 4.0% LOI to Koolan Island where reserves contain 63.8% Fe, 0.017% P, 6.13% SiO_2, 1.01% Al_2O_3 and 0.46% LOI.

f) Magnetite

These deposits consist largely of magnetite and are most commonly BIF derived, although hydrothermal and igneous derived deposits do contribute significantly to economically demonstrated resources. Savage River pellets typically assay 66.3% Fe, 0.02% P, 1.9% SiO_2, 0.4% Al_2O_3 and 1.0% LOI. Large magnetite resources at Balmoral, Cape Lambert and Karara are increasingly attractive developments in the face of ever increasing demand.

Table 4a: Pilbara iron ore resources for Rio Tinto, Rio Tinto-Robe River and Rio Tinto-Hope Downs Joint Ventures (2010)

Hamersley operating mines	Type	Prod.	Ore (Mt)	%Fe	%P	%SiO_2	%Al_2O_3	%LOI
Brockman 2	H-g	112.706 Mt	52	62.6	*not reported.*	*not reported.*	*not reported.*	*not reported.*
Brockman 4	H-g		658	62.1				
Marandoo	H-g		390	62.7				
Mt Tom Price (Brockman)	H		248	62.0				
Mt Tom Price (Marra Mamba)	H		37	61.5				
Nammuldi (Detrital)	H		77	60.6				
Nammuldi (Marra Mamba)	H-g		290	62.6				
Paraburdoo (Brockman)	H-g		115	63.3				
Paraburdoo (Marra Mamba)	H-g		2	60.8				
Yandicoogina (Pisolite)	H		176	58.6				
Yandicoogina ('Process Product')	H		91	58.6				
Yandicoogina (Junction)	H		627	58.1				
Turee Central (Brockman)	H		96	62.0				
Western Turner Syncline (Brockman)	H		351	62.2				
Channar (Brockman)	H-g	11.016 Mt	100	62.5				
Eastern Range (Brockman)	H-g	9.206 Mt	90	62.6				
Hope Downs 1 (Marra Mamba)	H-g	31.720 Mt	418	61.5				
Hope Downs 1 (Detrital)	H		8	59.5				
Robe River–Pannawonica (Pisolite)	G-h	31.277 Mt	568	56.3				
Robe River–West Angelas (Marra Mamba)	H-g	28.363 Mt	534	61.8				
Robe River–Miscellaneous (Detrital)	H		6	60.2				
Hamersley undeveloped resources								
Robe River–Miscellaneous (Pisolite)	G-h		1,709	58.0	*not reported.*	*not reported.*	*not reported.*	*not reported.*
Robe River–Miscellaneous (Marra Mamba)	H-g		441	60.8				
Robe River–Miscellaneous (Detrital)	H		33	61.0				
Hope Downs 4 (Brockman)	H-g		315	62.6				
Hope Downs Miscellaneous (Brockman)	H-g		116	61.9				
Hope Downs Process Ore (Brockman)	H-g		207	56.9				
Hope Downs (Marra Mamba+Detrital)	H-g/H		210	61.6				
Hamersley–Miscellaneous (Brockman)	H-g		3,652	62.5				
Hamersley 'Process Ore' (Brockman)	H-g		1,375	57.3				
Hamersley–Miscellaneous (Marra Mamba)	H-g		3,091	62.0				
Hamersley–Miscellaneous (Channel Iron)	G-h		2,591	57.1				
Hamersley–Miscellaneous (Detrital)	H		635	61.0				

Table 4b: Pilbara iron ore resources for BHP Billiton and Joint Ventures (2010; production given as wet tonnes basis)

Operating mines	Type	Prod. (wet)	Ore (Mt)	%Fe	%P	%SiO_2	%Al_2O_3	%LOI
Mt Newman JV (Brockman)	H-g	37.227 Mt	3,097	60.6	0.12	5.2	2.6	4.7
Mt Newman JV (Marra Mamba)	H-g		1,164	59.7	0.07	4.1	2.5	7.2
Jimblebar (Brockman)	H-g		1,687	60.0	0.12	5.1	3.1	5.2
Jimblebar (Marra Mamba)	H-g		403	59.7	0.08	4.6	2.5	6.8
Mt Goldsworthy JV (Nimingarra)	H	1.452 Mt	169	61.5	0.06	8.2	1.2	1.0
Mt Goldsworthy JV Area C (Brockman)	H-g	39.531 Mt	1,979	59.6	0.12	5.5	2.7	5.8
Mt Goldsworthy JV Area C (Marra Mamba)	H-g		1,153	61.0	0.06	3.7	1.9	6.5
Yandi JV (Brockman)	H-g	38.102 Mt	2,318	59.0	0.15	5.0	2.4	7.3
Yandi JV (Channel Iron)	G-h		1,541	56.5	0.04	6.3	1.8	10.7
Undeveloped resources								
BHP Iron Ore Exploration (Brockman)	H-g		1,213	59.6	0.14	4.0	2.5	7.4
BHP Iron Ore Exploration (Marra Mamba)	H-g		348	59.6	0.06	4.8	2.5	6.0

Table 4c: Pilbara iron ore resources for Fortescue Metals Group and Hancock Prospecting (2010)

Fortescue Metals Group	Type	Prod. (wet)	Ore (Mt)	%Fe	%P	%SiO_2	%Al_2O_3	%S	%LOI
Cloudbreak-Christmas Creek	H	40.857 Mt	3,683	58.71	0.053	4.13	2.39		7.78
Chichester	H		695	52.78	0.064	8.64	5.49		7.66
Solomon Stage 1	H		1,844	56.5	0.075	7.07	3.10		8.44
Solomon Stage 2	H		1,014	56.0	0.081	7.32	3.84		8.06
Glacier Valley	M		1,230	33.1	0.105	38.8	1.59		7.65
North Star	M		1,230	32.0	0.097	40.3	2.10		6.43
Hancock Prospecting									
Roy Hill	H-g		2,420	55.9	0.054	6.74	4.18	0.047	6.99

Table 4d: Miscellaneous Western Australian junior iron ore mines (2010)

	Type	Prod.	Ore (Mt)	%Fe	%P	%SiO_2	%Al_2O_3	%S	%LOI
North Pilbara	H	2.117 Mt	436.33	56.3	0.11	6.9	2.3	0.01	9.3
Jack Hills (Murchison)	H	1.676 Mt	3,218	32.2	0.03	42.6	1.1		2.5
Koolyanobbing	H	8.5 Mt	99.3	62.0					
Cockatoo Island	H	1.4 Mt	2.3	67.6					
Koolan Island	H	3.121 Mt (wet)	74.3	62.6	0.01	8.77	0.84		
Tallering Peak	H	3.228 Mt (wet)	11.2	61.1	0.04	6.07	2.70		
Spinifex Ridge	H	0.055 Mt (wet)	7.27	58.6	0.15	9.2	1.6	0.007	4.6

Table 4e: Miscellaneous Western Australian iron ore resources (2010)

	Type	Ore (Mt)	%Fe	%P	%SiO_2	%Al_2O_3	%S	%LOI
Extension Hill	H	23.1	58.4	0.06	7.42	1.91		
Nullagine	Gh	101.6	54.1	0.017	4.54	3.23	0.015	12.4
Karara	M	2,409	35.9	0.09	42.9	1.1	0.12	
Maitland River	M	310	34.7	0.06	42.0	1.4		0.09
Iron Valley	H	259.1	58.3	0.17	5.4	3.2		6.9
South Marillana-Phil's Creek	H	15.1	55.6	0.10	7.2	4.2		8.1

	Type	Ore (Mt)	%Fe	%P	%SiO_2	%Al_2O_3	%S	%LOI
North Marillana	H	46.8	50.0	0.05	9.5	7.7		10.4
Lamb Creek	H	40	59.4	0.11	8.1	3.3		6.2
Koodaideri South	H	107	58.6	0.14	5.1	2.5		7.9
Bungaroo South	H	241.6	57.2	0.15	7.0	2.4		8.1
Dragon	H	21.5	55.4					
Rocklea	H	79.0	59.9	0.03	8.2	3.5		11.2
Mt Bevan	M	616.8	32.1	0.05	47.4	3.4	0.13	
Mt Ida	M	530	31.94	0.074	45.88	1.10	0.201	
Mt Mason	H	5.75	59.9	0.064	7.4	3.5		3.0
Blue Hills	H	6.9	59.9	0.10	8.4	1.2	0.08	3.4
Blue Hills	M	46	41.4	0.09	35.6	0.5	0.03	
Mungada Ridge	H	13.1	61.1	0.14	6.3	2.0	0.17	3.9
West Pilbara (Aquila)	Gh	1,067	56.5	0.081	6.77	3.44	0.017	8.32
West Pilbara (Aquila)	Hg	156	61.5	0.134	3.66	2.45	0.008	5.43
West Pilbara (Atlas)	H	38	53.6	0.04	7.5	4.8		9.3
Midwest	H	12	60.0	0.06	6.3	4.8		3.7
Ridley	M	2,010	36.5	0.09	39.3	0.08	0.05	4.1
Balla Balla	M	456	45					
Koolanooka	M	569.85	36.25					
Jack Hills (Sinosteel Midwest)	H	15.4	59.7					
Weld Range	H	246.9	57.32					
Robertson Range	H	70.8	57.47	0.109	6.00	3.50		7.37
Davidson Creek	H	212.6	56.23	0.082	6.14	3.62		8.90
Mirrin Mirrin	H	63.6	53.01	0.100	6.29	3.40		8.77
Balmoral South	M	1,605	32.7					
Beyondie	M	561	27.5					
Mt Dove	H	2	58.5					
George Palmer-Sino Citic Pacific	M	5,088	23.2					
Cape Lambert	M	1,556	31.2	0.025	40.5	2.24	0.14	6.48
Cashmere Downs	H	192	32.9					
Cashmere Downs	M	822	32.5					
Central Yilgarn Iron Ore Project	H	42.6	58.6	0.13	4.2	1.3		9.6
Irvine Island	H	452	26.5	0.03	53.9	3.39	0.11	
Lake Giles-Macarthur	H	25.02	55.2	0.07	8.2	4.5	0.17	7.7
Lake Giles-Moonshine	M	427.1	29.3	0.05	42.1	1.1	0.5	0.02
Lake Giles-Moonshine North	M	283.4	31.4	0.04	22.7	0.7	0.2	0.89
Lake Giles Group	M	539.8	28.8					
Magnetite Range	M	391.1	29.98					
Marillana	H	1,528	42.6					
Marillana	G-h	101.9	55.6	0.094	5.3	3.7		9.7
Mt Alexander	M	392.9	29.5					
Mt Bevan	M	617	32.1					
Parker Range-Mt Caudan	G-h	35.1	55.9	0.020	6.4	2.8	0.08	8.9
Peak Hill-Mt Padbury	M	850	27.3					
Prairie Downs	H	1,400	23.5	0.03	38.6	15.5		8.1
Prairie Downs	H-g	23.3	44.2	0.04	21.9	5.2		8.0
Southdown	M	654.4	36.5					
Steeple Hill	H	19	58.4	0.01	7	6		1.6
Victory Bore	M	151	25	0.013	28.6	14.8		0.56

	Type	Ore (Mt)	%Fe	%P	%SiO_2	%Al_2O_3	%S	%LOI
West Pilbara-Hamersley (Winmar-Cazaly)	G-h	241.6	54.3	0.04	11.8	4.3		5.6
West Pilbara (Midas)	G-h	11.5	53.1					
Wiluna West	H	127.2	60.2	0.06	7.1	2.4		3.7
Yalgoo (Ferrowest)	M	552.2	27.21	0.059	48.30	5.03		
Yalgoo (Venus)	M	698.1	29.3	0.04	48.6	2.2		1.6
Yandicoogina South	H	4.3	55.8	0.07	7.7	3.3		8.9
Mt Forrest	M-h	19	42.3					
Mt Forrest	M	1,430	31.5					
Speewah	M	3,566	14.8					
Pilbara (Flinders)	H	550.1	55.6	0.07	9.6	4.6		5.7
Pilbara (Flinders)	H-g	113.0	58.5	0.10	5.4	3.6		6.3

Table 4f: Miscellaneous South Australian iron ore mines and resources (2010)

Operating mines	Type	Prod.	Ore (Mt)	%Fe	%P	%SiO_2	%Al_2O_3	%S	%LOI
Middleback Ranges Group	H	6.195 Mt	191.3	57.9					
Middleback Ranges Group	M	1.556 Mt	395.4	38.3					
Cairn Hill	M	0.324 Mt	11.4	49.5					
Undeveloped resources									
Wilgerup	H		13.95	57.6					
Bald Hill East-West	M		28.7	27.5					
Koppio East-West	M		39.6	29.7					
Iron Mount	M		6.7	37.2					
Carrow North-South	M		51.9	31.2					
Bungalow Western-Central-Eastern	M		29.3	38.3					
Gum Flat-Barns	H-g		3.6	46.2					
Gum Flat	M		99.3	24.4					
Peculiar Knob-Buzzard-Tui	H		37.6	62.8	0.04	8.0	0.8		0.7
Hawks Nest-Kestrel	M		220	36	0.06	38	0.9		0.7
Hawks Nest-Others	M		349	35.2					
Wilcherry Hill	M		69.3	25.9	0.06	32.0	7.9	0.3	7.1
Hercules	H		3.58	41.86	0.09	21.51	8.32	0.08	7.73
Hercules	G		36.03	40.75	0.20	27.79	3.16	0.03	7.62
Hercules	M		154.33	23.58	0.19	49.19	2.37	0.09	4.11
Hercules South	M		21.7	33.27					
Maldorky	M		147.8	30.1					
Murphy South	M		1,006	16.7	0.09	52.8	12.6		0.7
Boo-Loo	M		328	17.3	0.09	52.4	11.5		2.1
Razorback Ridge	M		568.6	25.4	0.19	43.6	6.9		
Sequoia	M		22	28.4					

Table 4g: Miscellaneous Tasmanian iron ore mines and resources (2010)

Operating mines	Type	Prod. (Mt)	Ore (Mt)	%Fe	%P	%SiO_2	%Al_2O_3	%S	%LOI
Savage River	M		306.1	52					
Kara	M		18.58	47.7					
Undeveloped resources									
Livingstone	H		2.2	58	0.09	5.3	1.8	0.03	7.1
Mt Lindsay	M		30	33					
Nelson Bay River	M		12.6	36.1					

Table 4h: Miscellaneous Northern Territory iron ore mines and resources (2010)

Operating mines	Type	Prod. (Mt)	Ore (Mt)	%Fe	%P	%SiO_2	%Al_2O_3	%S	%LOI
Frances Creek	H		10.06	58.1	0.11				
Frances Creek	G		1.28	53.2	0.11				
Undeveloped resources									
Mt Peake	M		160.9	22.3		34.3	8.3		
Roper Bar	H		311.8	39.9	0.01	28.4	2.7		9.4
Roper Bar-Hodgson Downs	H		100.0	48.3	0.08	18.8	2.63		

Table 4i: Miscellaneous Queensland and New South Wales iron ore resources (2010)

New South Wales	Type	Prod. (Mt)	Ore (Mt)	%Fe	%P	%SiO_2	%Al_2O_3	%S	%LOI
Cobar-Mainline	M		627	10.3					
Frances Creek	M		1,400	15.5					
Queensland									
Constance Range	H		295.96	53.1	0.02	10.38	1.63		11.19
Ernest Henry	M		105	27.0					

Table 5: Summary of iron ore resources by ore types (2010)

Ore Type	Count	Ore (Mt)	%Fe	%P	%SiO_2	%Al_2O_3	%S	%LOI
G	2	37	41.2	0.20	~27	~3.1	~0.03	~7.5
G-h	10	7,968	56.9	~0.06	~6.8	~2.7	~0.02	~9.5
H	63	20,466	49.0	~0.06	~18.5	~3.8	-	~6.5
H-g	32	28,133	60.2	~0.11	~5.1	~2.8	-	~6.2
M	54	35,802	27.9	~0.08	~42.5	~3.0	~0.1	~2.7
M-h	1	19	42.3	-	-	-	-	-
Total	162	92,425	44.9	0.08	22.7	3.1	-	5.2

4.2.1. Declining ore grades

Declining ore grades or quality is a fundamental problem facing the global mining industry (e.g. Schandl *et al.,* 2008; Mudd, 2007a, b, 2009a, b, 2010a, b; Cook, 1976). The average grades of iron ores for Australia and the world are shown in Figure 6. Short term variations (until the 1950s) are related to changing mines and ore sources, especially due to the patchy nature of deposits mined (mainly for New South Wales ores). As noted previously, impurities and ore grades must also be considered in conjunction with ore quality (especially the ease of processing with existing technology). For Australian iron ore grades, a major difficulty is that grades are estimated based on saleable production and not raw ore, despite the majority of iron ore requiring beneficiation before use (Mudd, 2009a, 2010b). Despite the issues with the data, the long-term trend is a gradual ore grade decline for saleable iron ore.

Figure 6: Iron ore grade data: Australia and World

This declining trend in ore grades means that for extracting each tonne of metal we would have to mine more ore, creating more tailings and waste rock and requiring more energy, water and other inputs per unit mineral production (Mudd, 2007a, b, 2010a, b). In addition, as ore grades decline, it is common to require finer grinding to maintain optimum extraction efficiency – a reflection on the declining quality of ores as well as grades. The end result is significant upward pressure on the environmental footprint of mineral production – at a time when the world is facing both peak oil and climate change due to anthropogenic greenhouse gas emissions. As such factors are addressed through such schemes as emissions trading or a carbon tax, this will inevitably link with metals prices.

Eighty per cent of the world's steelmaking is through the blast furnace route and hence the role of iron ore as a raw material and its quality become very critical to achieve steel with the best quality from hot metal. Iron ores consist of various impurities in the forms of Al, P and Si, and this poses major beneficiation problems especially in fines processing (see Upadhyay and Venkatesh, 2006; Abzalov et al., 2007; Zhu et al., 2009). The presence of these elements along with sulfur adversely affects the quality of iron ores and has a great bearing on performance of blast furnaces and steel quality (Upadhyay and Venkatesh, 2006).

5. TRENDS IN IRON ORE AND STEEL PRODUCTION

5.1. Historical Perspective

The Australian iron ore production has been steadily increasing since 1950 until 2009 and it is expected to increase exponentially in the near future (left of Figure 7); with Australia's share of iron ore production on the right of Figure 7. Currently, China is clearly driving global demand for iron ore, being the largest and fastest growing market for seaborne trade in iron ore. The increasing production trends are largely attributable to economic progress, population growth coupled with industrial development in the world. It is widely expected that mineral production will continue to grow given the growing and substantial demand for minerals from developing and transition countries such as Brazil, Russia, India and China (the so-called 'BRIC' countries) (Yellishetty et al., 2011). Australia's share of world's iron ore production has been increasing ever since the discovery of Pilbara in 1960's. Figure 7 (right side) presents historical Australia's share of world iron ore since 1980, which clearly signifies the strategic position of Australia in the world's iron ore production.

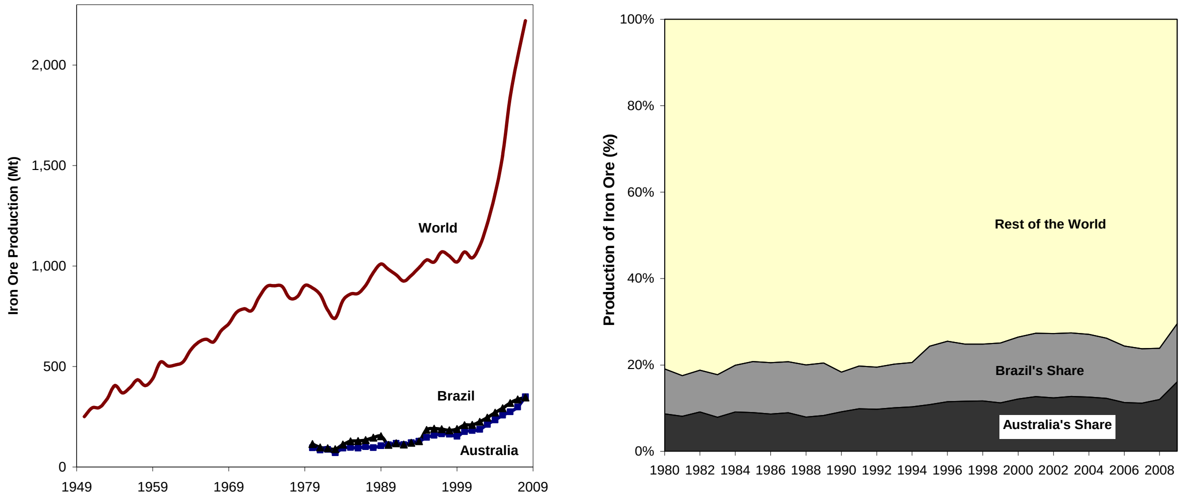


Figure 7: Historical global production of iron ore (left); and the share of Australia (right)

Figure 8 (below) presents Australian iron ore production, consumption, imports and exports (left) as well as Australia's share of world iron ore exports (right). It is clearly evident that, historically, Australia has been a net exporter of iron ore – much of which was exported to Japan, Korea, Europe and more recently to China. Australia's share of world iron ore exports have been increasing since 1980 - with 35% in 2008 (right side of Figure 8).

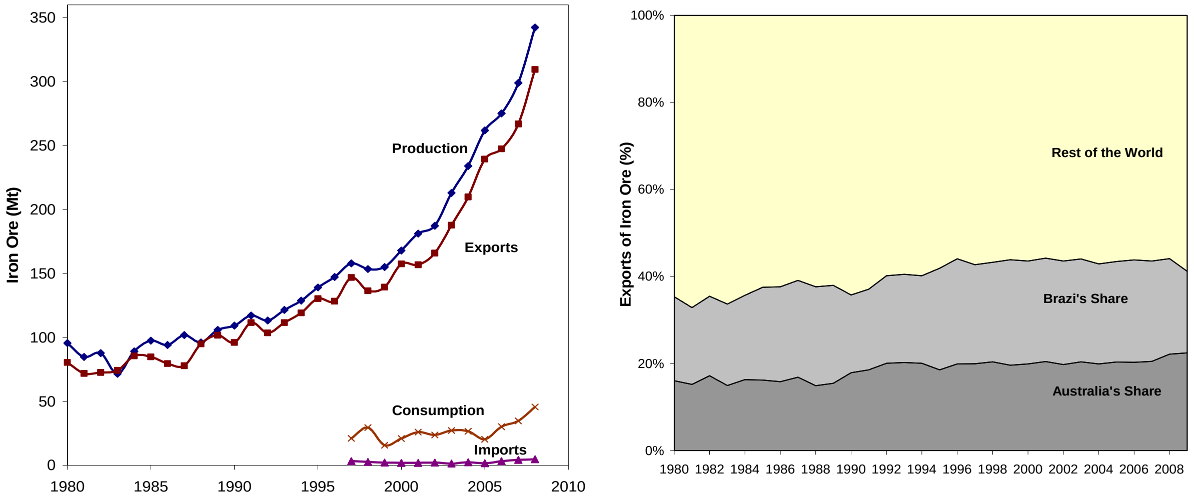


Figure 8: Australian iron ore production, consumption, imports and exports (left); Australia's share of world iron ore exports (right)

Iron ore production by ore type since 1965 is illustrated in Figure 9. It is evident that since 1970s, total iron ore production has been growing whereas the production of Premium Brockman ore has remained steady since 1973. The development of MM and CID can also be clearly distinguished at an increasing rate up to present. The change in the blend of Australian iron ore shows that the change from small production of other hematite followed by the development of premium BM production and the subsequent inclusion of MM, Brockman and limonite.

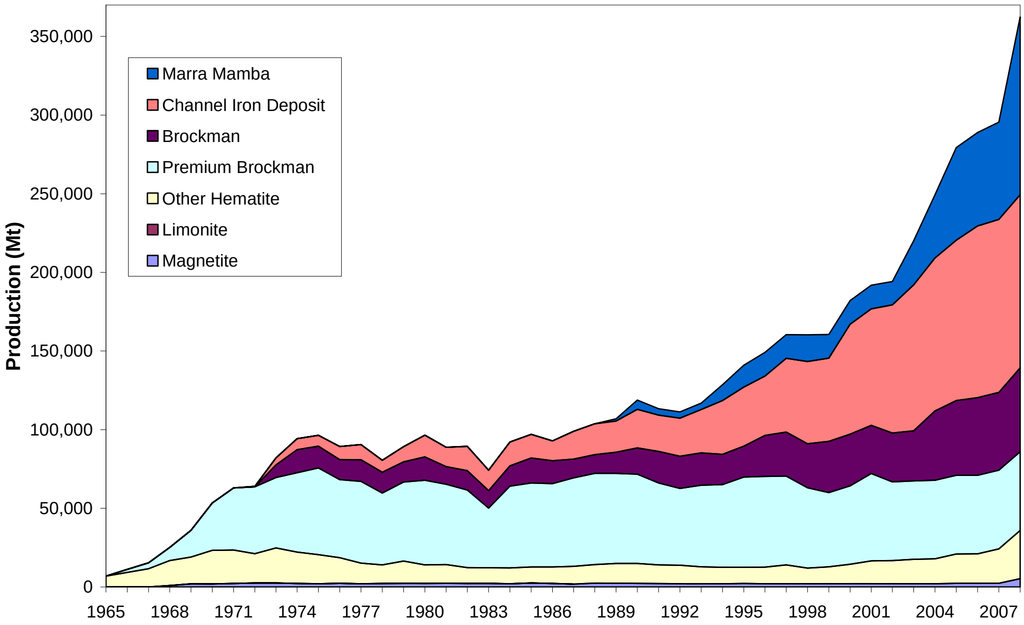


Figure 9: Production or iron ore split by ore type since 1965 (O'Brien, 2009)

5.2. How are different regions contributing to Australia's iron ore and steel production?

Since 1960, after the discovery of Pilbara, Western Australia (WA) dominates the Australian iron ore industry with nearly 97% of the total production of Australia (Figure 10 and Table 6). However, there are a few iron ore mines that operate in the Northern Territory, South Australia, Tasmania and New South Wales, but the production from these areas is negligible when compared to WA. In 2009-10, Australia produced 423 Mt with 97% produced in Western Australia. Exports in 2009-10 totalled 390 Mt with a value of AU$34 billion.

Table 6: Region wise production of iron ore in Australia (kt ore) (ABARE, 2009)

Region	99/00	00/01	01/02	02/03	03/04	04/05	05/06	06/07	07/08	08/09	09/10
WA	162.96	176.35	181.79	207.11	216.61	246.26	258.39	281.16	313.51	341.54	410.21
SA	2.69	2.90	3.22	3.48	2.67	3.48	3.49	4.70	8.14	6.92	8.28
Tas	1.60	1.89	2.20	2.29	2.21	2.17	1.93	1.84	2.44	2.33	2.36
NT											
Australia	167.94	181.71	187.21	212.88	221.49	251.92	263.82	287.69	324.69	353.00	423.39

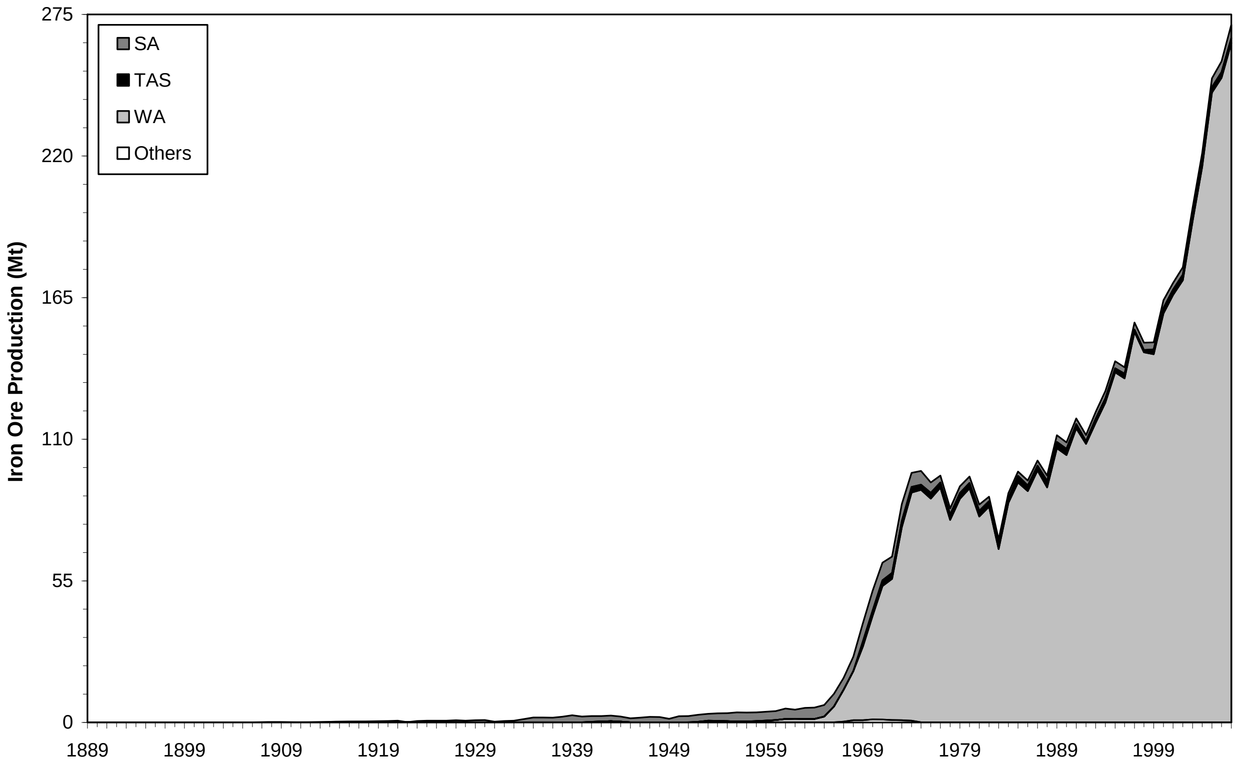


Figure 10: Region wise production of iron ore in Australia (1929-2008)

The iron ore mining industry is highly concentrated, with mines operated by the two largest firms, namely Rio Tinto and BHP Billiton, accounting for 70% of total production (left, Figure 11) with all of their mines located in the Pilbara region of Western Australia (Table 4). The iron and steel manufacturing industry is also highly concentrated, with two major players accounting for 85% of the total production. High concentration reflects the economies of scale available in the industry, the relatively small size of the domestic market and the modest role played by exports (right of Figure 11).

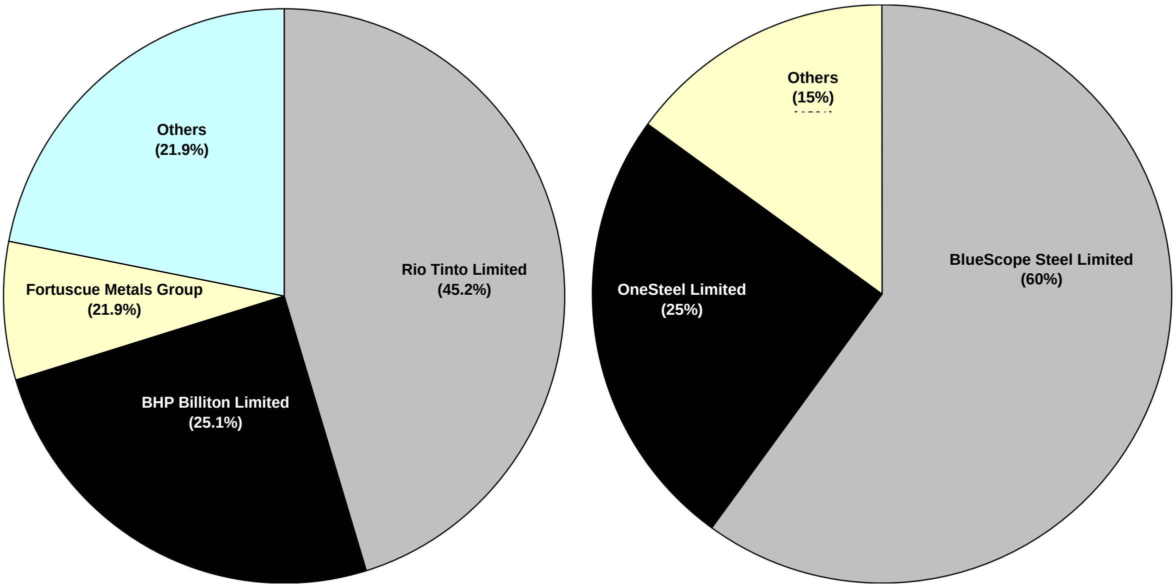


Figure 11: Market shares of companies in Australian iron ore (left); and steel production (right)

5.3. How much of the World's Iron Ore Demand Can Australia Supply?

5.3.1. Peak iron of Australia – a projection into the future using the logistic growth curve

Mineral resources are generally considered finite in potential supply since they cannot be renewed by natural processes over human time frames, and combined with the difficulties in finding more deposits with available technologies; this has led to many forecasts of resource depletion. If a resource is consumed faster than it is replenished it will unmistakably be subject to depletion. From this premise, the term peak iron ore can be defined as the maximum rate of the production of iron ore in any area under consideration, recognizing that it is a finite natural resource and subject to depletion.

A model for extrapolation of production curves of finite resources was at first proposed by Hubbert (1956, 1962). This approach assumes that production begins at zero, before the production has started, and ends at zero, when the resource has been exhausted. Hubbert (1956, 1962) was the first to treat the issue of depletion quantitatively and observed that cumulative production of an exhaustible resource as a function of time (t, years) usually (but not always) followed a logistic growth curve, given by:

$$Q(t)=\frac{Q_{\max}}{(1+a\exp(bt))} \qquad \text{(Equation 1)}$$

Where, Q_{max} is the total resource available (or ultimate recoverable resource), Q (t) the cumulative production at time t, and a and b are constants.

The primary assumptions Hubbert (1956, 1962) used to underpin the application of 'peak curves' to analyse non-renewable resource production are (e.g. Giurco et al., 2009; Mohr and Evans, 2009; Bentley, 2002):

- The population of producing fields is sufficiently large so that the sum of all fields approaches a normal distribution.
- The largest fields are discovered and developed first.
- Production continues at its maximum possible rate over time.
- Ultimate recoverable reserves are known.

Using Equation 1 and iron ore production data from 1850 to 2009, we have determined the parameters a, b, and Q_{max} in Equation (1) that best fit these data. The determined values of Q_{max} = 33.72 Gt, a = 72275, and b= −0.06 (Figure 12); Q_{max} = 64.52 Gt (EDR + Sub-economic and Inferred Resources), a = 151778, and b= −0.06 (Figure 12); with a base year of 1850.

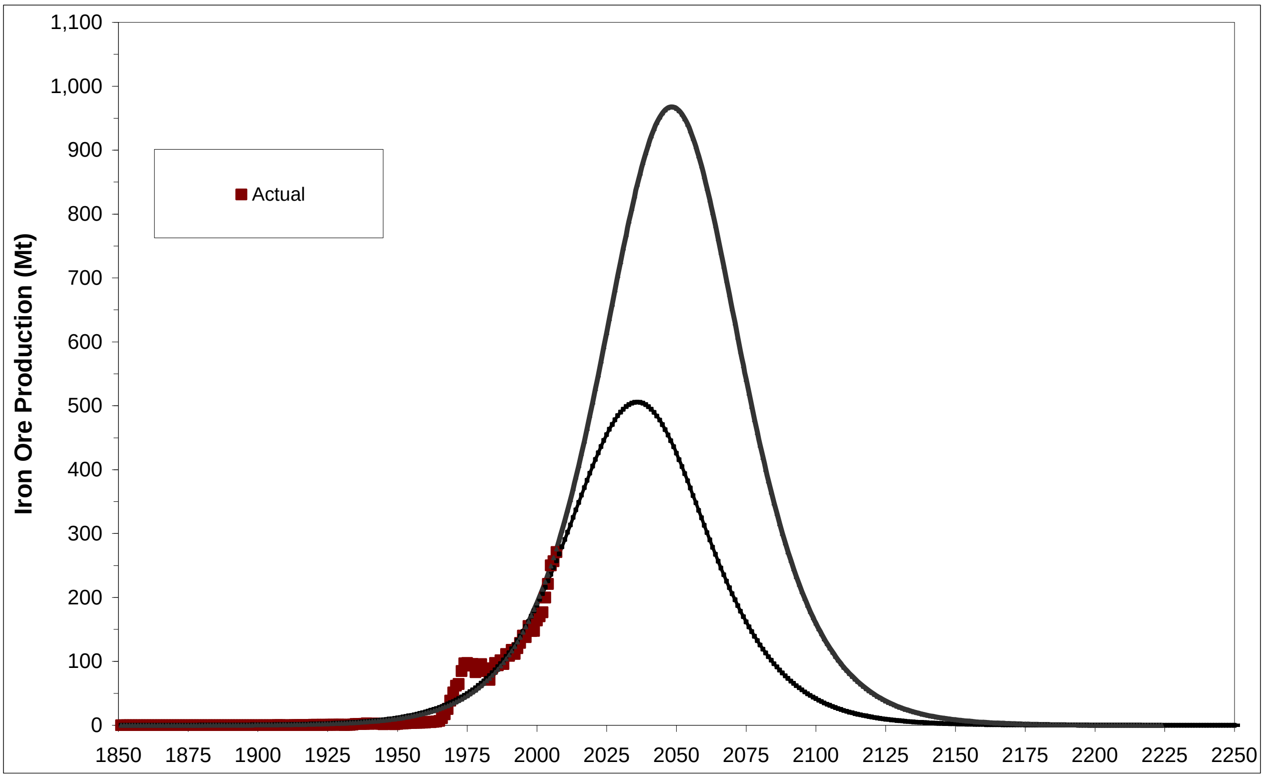


Figure 12: Australia's iron ore production and production from logistic growth models: with Q_{max} = 33.72 Gt (left); with Q_{max} = 64.52 Gt (EDR + Sub-economic and Inferred Resources)

For iron ore, Australia's mineral resources rank highly by world standards and their indicative life is considerable (Table 2, 3 and 4). This is (after late 1960's) the starting point for Australia's ability to profitably exploit this abundant natural resource on a sustained long-term basis, thus resulting in higher commodity revenues. At the same time, the Australian iron ore production has increased manyfold and it is expected that this trend will continue for some time into the future (Figure 12).

However, according to Papp et al. (2008) there are numerous views on the factors that will influence metals' prices in the world: 1) according to business analysts, supply-demand balance is what determines the prices of metals; 2) investment analysts say that expectations play an important role in determining metals' price; 3) the commodity analysts argue that the prices increase as the number of weeks of supply in stocks diminishes; and 4) the financial market analysts say that increased speculative investment in metals causes the price to rise. In reality, commodity prices are affected in combination by all of the above reasons – plus of course changes in the cash cost of mineral production (fuels, labour, capital, and so on).

6. ENVIRONMENTAL AND SOCIO-ECONOMIC BENEFITS, THREATS AND OPPORTUNITIES

According to the major international report '*Our Common Future*', sustainable development (SD) means "development that meets the needs of the present without compromising the ability of future generations to meet their own needs" (WCED, 1987). Assessment of sustainability in the case of mining requires the knowledge of SD indicators, such as production trends, number of jobs created, community benefit, electricity, fuel, water used, solid wastes generated, land rehabilitated, health and safety issues, royalties, economic resources and so on.

6.1. Iron ore industry and environmental sustainability

Mining is an energy intensive sector and therefore improving the performance would eventually cut-down the greenhouse gas emissions over the full life cycle of products. The world iron ore mining industry's GHG emissions are almost exclusively linked to energy consumed during mining and removing of vegetation during the production process, providing an environmental challenge for the industry. Some 95% of the mining industry's GHG emissions are associated with the combustion of fossil fuels, principally diesel and coal-fired electricity (MAC, 2007).

In Australia, it is mandatory for companies to maintain compliance with both the National Greenhouse and Energy Reporting Act (NGERA) (2007) and Energy Efficiency Opportunities Act (EEOA) (2006). This also includes the development of an internal database to track greenhouse emissions and energy data and the independent verification of Australia's emissions profile.

The compiled data for specific energy and water consumption (per tonne) of iron ore railed as well as the land area used, is presented in Table 7 below. This data was extracted from reported data by Rio Tinto iron ore operations in Western Australia in their annual suitability reports. From the data presented (in Table 7), it is clear that the most critical area of growing environmental interest is that of energy consumption and its associated greenhouse gas (GHG) emissions. Since 2001, the total emission rose by 155% while the iron ore production grew by 200%. This clearly indicates that GHG emissions are not increasing proportionate to the increases in production, but overall the quantity of GHG emitted is on rise. In contrast, the water consumption per tonne of ore railed rose by 52% since 2001 (i.e. water per tonne increased while GHG per tonne fell). In the absence of the Australian specific data on processing methods for lower grade ores, it is not clear whether this could be as a result of changed mining methods which has increased water consumption but reduced energy or this clearly indicates that as we are processing increasing lower grade ores (Figure 5), there is an upward pressure on resources.

Table 7: Environmental indicators of iron ore mining activities in Western Australia[#]

Year	Total emissions (k t $CO_{2\text{-}e}$)	kg $CO_{2\text{-}e}$/t ore railed		Land area in use (ha)	Land rehabilitated (ha)		Freshwater used (ML)	Rate (L/t)
2001	728	7.3		9,901	3,943		10,818	155
2002	836	7.9		9,867	4,462		8,899	127
2003	933	7.9		16,670	4,483		25,291	215.4
2004	1,068	8.3		17,271	4,632		20,640	162.9
2005	1,143	7.6		11,860	4,665		24,652	174
2006	1,195	7.9		12,943	4,707		20,683	154
2007	1,398	8.6		15,181	5,085		29,780	191
2008	1,737	10.16		-[*]	267		39,159	229
2009	1,862	9.13		-[*]	-[*]		48,144	236

-[*] No data was given; [#]Rio Tinto

As a result of beneficiation of iron ore, which typically occurs in a liquid medium, the iron ore industry requires very large quantities of water. In addition, many pollution abatement devices, such as water sprinkling on haul roads, stock piles, etc., use water to control dust emissions. At a given facility, these techniques may require between 2,200 and 26,000 litres of water per ton of iron concentrate produced, depending on the specific beneficiation methods used (US EPA, 1994). It was further observed that the amount of water used to produce one unit (l t of ore) has increased considerably (in 1954, approximately 1,900 litres of water was used and the same in the year 1984, had risen to 14,000 lit per unit (US EPA, 1994).

Although according to NGERA - a national framework for the reporting and dissemination of information about greenhouse gas (GHG) emissions - it is mandatory for all the companies (that are a constitutional corporation and meet a reporting threshold) to report on their GHG emissions, energy production, energy consumption as a result of their production activities, not every company is reporting these figures in detail. In most cases the companies choose to report their sustainable indicators on the group scale (or ‘customer sector groups (CSGs)’ aligned with the commodities they extract) rather than on individual mine, regional and or country basis. For example, companies, such as BHP Billiton, Fortescue Metals, etc., do not publish these indicators individually.

Table 8 presents a matrix on sustainable mineral reserves management indicators reporting by major iron ore producers in Australia for the 2009, which clearly exemplifies how different companies report on these indicators.

Table 8: Sustainable mineral reserves management indicators reported by the major iron ore producers in Australia 2009 (SMRMI)

Company	Ore			Waste	Energy		CO2 Emissions		Water		SO2	NOx
	Raw	Saleable	Grade	Rock	Direct	Indirect	Direct	Indirect	Amount	Source		
BHP Billiton	✓	✓	✓	-	-	-	-	-	-	-	-	-
Rio Tinto (Hamersley)	✓	✓	✓	-	✓	✓	✓	-	✓	✓	-	-
Fortescue Metals	✓	-	✓	✓	✓	-	✓	-	-	-	-	-
Cliffs	-	-	-	-	-	-	-	-	-	-	-	-
Mt Gibson	-	-	-	-	-	-	-	-	-	-	-	-
OneSteel	✓	✓	✓	-	✓	✓	✓	-	✓	✓	-	-
Grange Resources	✓	-	✓	-	-	-	-	-	-	-	-	-
Peak Minerals Indicator	**GEO-7**		**GEO-9**	**ENV-1**	**ENV-8**		**ENV-4**		**ENV-2**	**ENV-3**	**ENV-6**	**ENV-5**

Note: tick (✓) means data is reported.

6.2. Iron ore mining industry and Socio-economic issues/sustainability

There are significant opportunities that are available to Australia as a result of abundant mineral resources, coupled with strong global demand and higher world prices for these resources since the early 2000s. However, the perception of benefits and impacts of mineral resource extraction and processing in Australia are changing. For example, the current resources boom, has contributed to high rates of economic growth in some sectors, record low levels of unemployment and increasing incomes for Australians (Table 9 and Figures 13 & 14). It is evident that whilst Australian iron ore industry is expanding since 1991 in terms of number of mines or establishments and the employment (although employment per million tonnes of ore is going down as result of automations and mechanisation in the industry), the steel industry’s number of establishments and the employment is dwindling. This may be due to several important reasons, such as China emerging as a major steel producer in the world and consequently Australia remained as net exporter of iron ore to China rather than producing steel itself.

Table 9: Salient economic statistics of iron ore and iron and steel in Australia

Commodity	Unit	2002/03	2003/04	2004/05	2005/06	2006/07	2007/08	2008/09	2009/10
Iron ore/ concentrate	kt	199,146	222,797	251,935	263,853	287,693	324,693	352,996	393,868
Pig iron	kt	6,111	5,926	5,969	6,318	6,392	6,329	4,352	-
Crude steel	kt	9,399	9,430	7,395	7,866	8,010	8,151	5,568	5,135
Exports of Iron Ore and Iron and Steel from Australia									
Iron ore & pellets	kt	181,478	194,773	228,456	239,380	257,365	294,293	323,451	362,396
Value	$m	5,342	5,277	8,120	12,854	15,512	20,511	34,234	29,960
Iron & steel	kt	3,589	3,818	2,338	2,428	2,648	2,131	1,741	1,518
Value	$m	1,855	2,004	2,031	1,674	1,743	1,562	1,363	851
Scrap	kt	890	955	1,009	1,876	1,328	1,783	1,742	1,875
Value	$m	211	298	402	467	607	833	749	690
Imports of Iron Ore and Iron and Steel by Australia									
Iron ore & pellets	kt	4,667	5,417	4,648	5,026	4,722	4,401	3,599	3,850
Value	$m	114	140	145	222	338	311	269	195
Iron & steel	kt	1,306	1,583	2,116	2,191	2,318	1,848	2,082	1,369
Value	$m	1,226	1,353	2,041	2,075	2,479	2,225	3,192	1,822
Net Trade (Exports – Imports)									
Iron Ore	kt	176,811	189356	223808	234354	252643	289892	319852	358,546
Value	$m	5,228	5137	7975	12632	15174	20200	33965	29,765
Steel	kt	2,283	2235	222	237	330	283	-341	149
Value	$m	629	651	-10	-401	-736	-663	-1829	-971

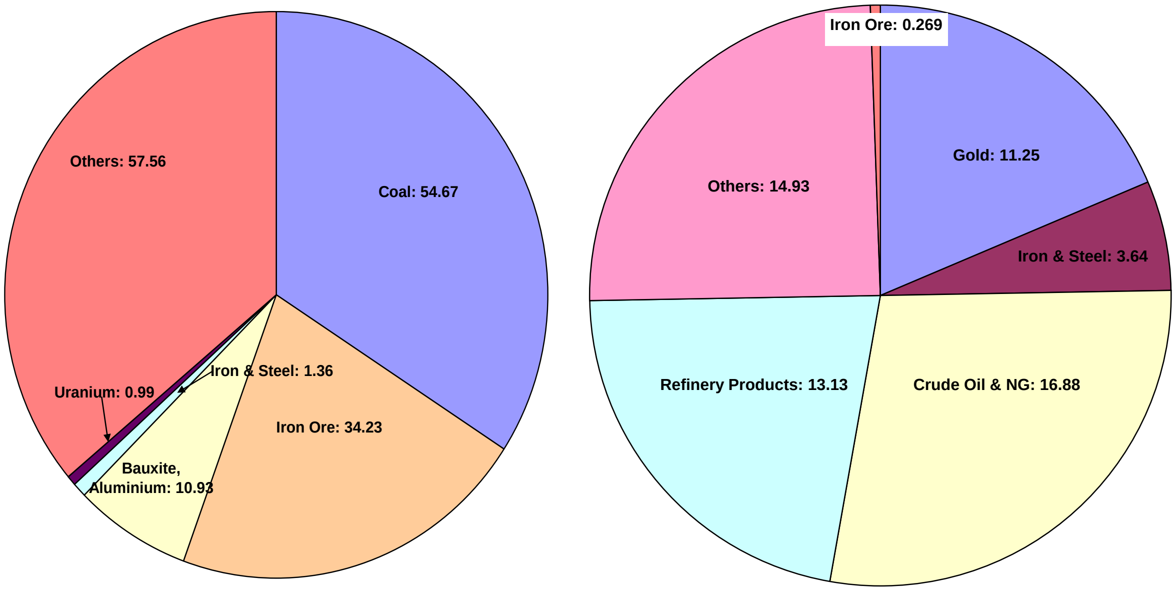


Figure 13: Value of Australian exports (left) and imports (right) of mineral commodities in 2008/09 (billion $)

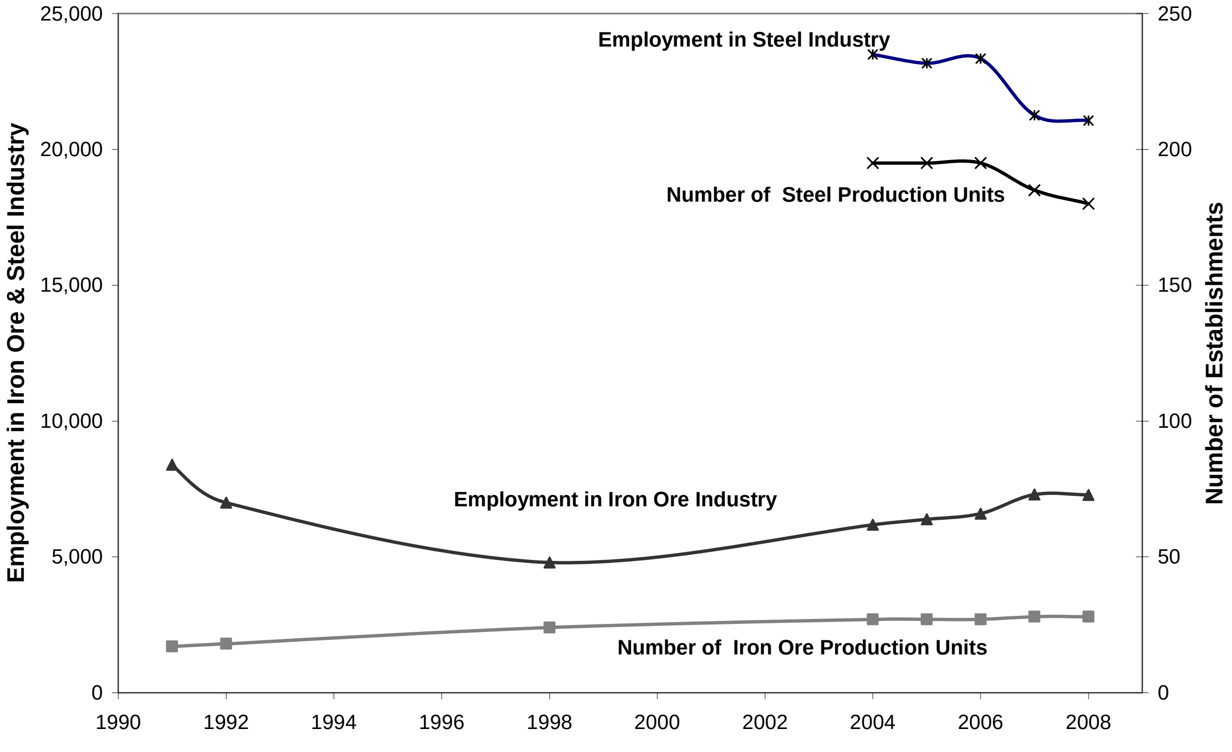


Figure 14: Employment in iron ore and steel industry of Australia

Over the past 5 years (2003-2008), employment has increased by ~18% in the iron ore industry whilst the steel industry has declined by ~10%. However, compared to the early 1990s, the employment iron ore industry has declined by ~13% despite nearly a doubling of iron ore mines.

Part of the long-term decrease can be attributed to businesses gaining productivity through rationalisation of operations; changing work practices as well as the continuing evolution in more powerful and productive machinery (especially haul trucks). However, according to MCA (2000) the use contractors, as a replacement for direct employment, have shifted the employment gains flowing from increased activity and new production. The change in employment associated with automation would also have a number of potential flow on impacts for mining communities (see Box X).

Box 1. ***by Karen McNab, University of Queensland***

The sustainability challenge – the case of automation in iron ore

The University of Queensland's Centre for Social Responsibility in Mining (CSRM) is exploring the social implications of autonomous and remote operation technologies in the Australian mining industry. Much of the development in automation has been in the Pilbara region of Western Australia – Australia's largest iron ore producing region. In identifying the social implications of automation, the project highlights the sometimes uneasy relationship between different sustainability factors.

A number of mining companies have announced plans to implement autonomous haul truck fleets and underground loaders. The most ambitious plan for automation is Rio Tinto's Mine of the Future program which includes a half billion dollar investment in driverless iron ore trains in the Pilbara; new technologies in underground tunnelling and mineral recovery; a remote operations centre in Perth; and a fleet of 150 driverless haul trucks (Rio Tinto, 2012).

Companies cite increased production efficiency and improved mine safety as the main benefits of automation, claiming it contributes to overall mine sustainability. The sustainability of a mine, however, extends beyond production efficiency and workplace safety to encompass all impacts, risks and benefits. As an industry with a strong regional presence, the workforce management practices of the mining sector and how, where and with whom mining companies do business have significant implications for the sustainability of regional communities.

Automation and remote operation centres will redefine the mine workforce and the concept of the 'mining community'. Within a decade, automated mines are expected to have only skeletal on-site workforces. Semi-skilled functions such as truck driving and train driving will be conducted from remote operation centres in capital cities and highly specialist teams will visit mines at scheduled periods to support otherwise remote maintenance and management. It is the social implications of these changes, and the risk they pose to the successful implementation of automation, which CSRM is working to understand.

In the case of iron ore, automation is expected to generate a 50% reduction in operational roles, resulting in a possible 30-40% reduction in the mining workforce. The majority of these jobs are in semi-skilled occupations such as truck driving, which is an important source of regular employment for Indigenous employees approximately 50% of whom occupy semi-skilled positions (Brereton and Parmenter, 2008 in McNab and Garcia-Vasquez, 2011).

CSRM commissioned economic modelling based on the labour force breakdown of an 'example' open cut iron-ore mine and extrapolated to examine Pilbara wide scenarios. All modelled scenarios show a net loss in first, second and third order jobs within a 75km radius of the selected mining town. The scenario with the least impact is based on the existence of a remote operation centre being located in a regional town. Automation is also likely to change a mine site's supply chain activities including maintenance activities and local procurement. Both of these changes will in turn have implications for regional employment, regional business opportunities with implications for economic opportunities, regional populations, population-dependent social services, and regional infrastructure (McNab and Garcia-Vasquez, 2011).

Automation will require the creation of new roles with higher-order skills and specialist tradespeople and professionals (Horberry and Lynas, 2012; Lynas and Horberry 2011). The relocation of mining jobs away from mine sites to urban centres may also change the structure of the workforce potentially reducing barriers for women to work in the industry, for example. These issues also have social implications that are not being flagged in the public discussion about automation.

These potential social implications of automation need to be considered to truly understand the implications of automation for industry sustainability.

Contrary to the theory of the comparative advantage of minerals in national economy, many mineral resource rich countries are often outperformed by resource sparse countries – often known as the 'resource curse' (Auty and Mikesell, 1998). Goodman and Worth (2008) have argued that the negative impacts associated with the resource curse are of political, social, environmental and economic nature. According to Goodman and Worth (2008), a nation suffering from the resource curse realises huge gains from export of minerals, which strengthens the local currency (because other nations must buy its currency to obtain the commodity, forcing the price of the currency up). This also means the country's other exports become more expensive, decreasing the competitiveness of other sectors that produce internationally tradable goods. Furthermore, the stronger currency makes importing foreign goods cheaper, increasing the competition for locally produced goods on the national market (Goodman and Worth, 2008; Palma, 2005).

Box 2. ***by Fiona Haslam-McKenzie, Curtin University***

Social Pressures from Iron Ore mining in the Pilbara

The Western Australian Pilbara iron-ore region has been economically very important but the scale and rapidity of the industry have had significant social impacts which have not been well understood and consequently, not carefully planned for, or the ensuing outcomes properly addressed (Haslam McKenzie and Buckley 2010).

The demand for adequate accommodation for example, has outstripped supply, pushing prices to unprecedented levels and squeezing out other industries and sectors which cannot compete in the highly inflated property market, creating mono-economies. The use of non-residential workforce involving block shifts and long distance commuting is becoming common in the mining industry and associated industries across Australia (see Haslam McKenzie 2011).

A number of commentators have raised concerns regarding regional development and issues around the potential impacts of rapid mining growth on workers, families, mining communities and the provision of infrastructure and services.

7. FUTURE TECHNOLOGICAL DRIVERS AND THEIR IMPLICATION TO WORLD IRON ORE TRADE

In Australia steel production occurs at integrated facilities from iron ore or at secondary facilities, which produce steel mainly from recycled steel scrap. Integrated facilities typically include coke production, blast furnaces, and basic oxygen steelmaking furnaces (BOFs), or, historically at least, in some cases open hearth furnaces (OHFs). Raw steel is produced using a basic oxygen furnace from pig iron produced by the blast furnace and then processed into finished steel products. Secondary steelmaking most often occurs in electric arc furnaces (EAFs). However, the OHF technology for steel production is becoming obsolete, and are also not used in Australia.

7.1. Impurity Rich Iron Ore – Beneficiation Options

7.1.1. Impurities in iron ore and their potential effects on steel making

Impurities in iron ore, such as phosphorous (%P), sulphur (S), silica (%SiO_2) or alumina (%Al_2O_3) are critical to the quality of steel production. The significance of the problem posed by impurities can be gauged from the fact that the small Mount Bundey iron ore mine in the Northern Territory was closed in 1971 due to increasing sulfur (reaching more than 0.108% S), (Ryan, 1975). Impurities are also a primary driver in the uptake and need for beneficiation (especially for magnetite projects).

According to Upadhyay and Venkatesh (2006), substantial amounts of alumina come to the sinter from various sources such as fines (75%) coke-breeze (13%), dolomite (7%), and recycled iron containing fines or scrap (4.5%) and limestone (0.5%). It has been observed that a drop of 1% in Al_2O_3 in the sinter reduces reduction degradation index (RDI) by 6 points (Upadhyay and Venkatesh, 2006). This leads to an improvement in productivity by 0.1 t per m^3 per day, lowers the coke rate by 14 kg/tonne of hot metal and increases sinter productivity by 10–15%, i.e. 800–1000 t per day (Das, 1995; De, 1995).

Phosphorus distribution in the ore is linked to the genesis of iron ore and it becomes associated with the iron during the formation of the banded iron formation. The presence of phosphorous (P) is mainly common in secondary iron oxide minerals, such as limonite, ochre, goethite, secondary hematite and alumina rich minerals such as clay and gibbsite and in apatite/hydroxyappatite in magnetite ores. The acceptable levels of the P in hot metal varies from 0.08 to 0.14%, however the P content of <0.08 wt% is most desirable (Cheg et al., 1999). A typical balance of P and S in furnace is achieved through mixing of raw materials, such as coke (65%), iron ore/sinter (25%) and fluxes/others (10%). The sulfur is acceptable up to maximum level of 0.06%. Lastly, the desired level of silicon in steel is 0.6%, and any increase in silicon content forwards the reaction in blast furnace. This will increase the coke rate, resulting in more silicon addition (Upadhyay and Venkatesh, 2006).

Potential iron ore impurity removal innovations include (Edwards et al., 2011; Murthy and Karadkal, 2011; Somerville, 2010):

- Phosphorus tends to be associated largely with the goethite in Australian iron ores,
- Developing a heat treatment – leach route to remove P,
- Results – reduction in P level to 0.06% P (quite acceptable) by beneficiation

- Reverse flotation for removal of Si and Al
- Bioflotation and bioflocculation

7.1.2. Evaluation of iron ore beneficiation technology

According to the US EPA (1994) , the term ‘beneficiation’ of iron ore means: milling (crushing and grinding); washing; filtration; sorting; sizing; gravity concentration; magnetic separation; flotation; and agglomeration (pelletizing, sintering, briquetting, or nodulizing). In general, run of mine (ROM) iron ore minerals cannot directly be used in iron and steel making processes, due to grade and/or impurities, and therefore needs to be blended with other ores, concentrated and/or beneficiated. While concentration includes all the processes which will increase (upgrade) the iron content of an ore by removing impurities, beneficiation, a slightly broader term, includes these processes as well as those that make an ore more usable by improving its physical properties (e.g. pelletising and sintering). Many of the iron ore mines employ some form of beneficiation to improve the grade and properties of their products (Pelletising: is a treatment process used for very fine or powdery ores; Sintering: is a process used to agglomerate iron ore fines in preparation for blast-furnace smelting).

Iron ore beneficiation methods have evolved over the period and are based on: 1) mineralogy (e.g. hematite, goethite or magnetite); and 2) gangue content of the ores (e.g. Al, Si and P). Either the gravity, magnetic or flotation methods are employed as stand-alone or, most commonly, in combination, for the concentration of iron ores worldwide (Silva et al., 2002). Table 10 below presents a generic approach in choosing the applicability of a specific concentration method that is suitable for different ore mineralogy for pellet feed, sinter feed and lump ore size fractions, respectively.

Like in the other parts of the world, the Australian iron ore deposits consist of several types (Tables 4 and 5), and a very little quantity of it is suitable for direct shipping (to blast furnaces). This calls for beneficiation to concentrate its iron content before being shipped. Although some ores could be beneficiated by washing or screening, their production is declining because of the depletion of reserves. Among ores that require beneficiation are the low-grade fines, which are produced in larger quantities. The major beneficiation process involved with iron ores is sintering, which is a particle enlargement process. However, for most Australian ores, the only beneficiation process involved is sizing.

Table 10: Ore mineralogy and suggested concentration method for iron ores (modified from: Silva et al., 2002

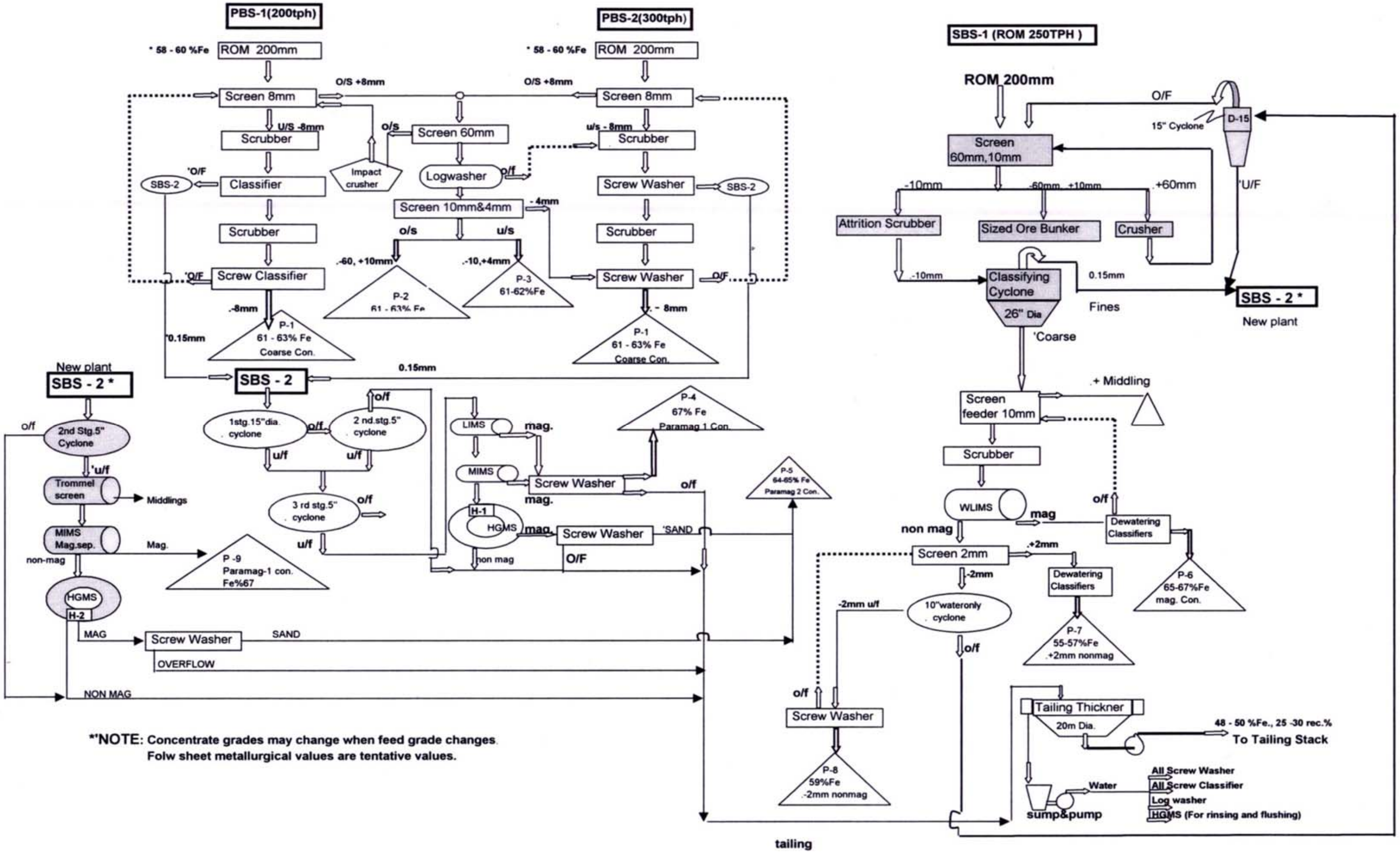
Main Mineralogical Features	Fine Size Range (-1 mm)					Coarse Size Range (+ 1 mm)			
	HGMS	REDMS	Spiralling	Heavy Media	LIMS	HGMS	REDMS	Jigging	Heavy Media
DOM = Hematite DGM = quartz with low amount of Al minerals	R	NR	SR	ISC	NA	R	NR	SR	ISC
DOM = hematite DGM = gibbsite with low-medium amount of quartz	R	R	R	ISC	NA	R	R	R	ISC
DOM = magnetite DGM = quartz	NR	ISC	NR	NR	SR	NR	ISC	ISC	NR
DOM = goethite SOR = hematite DGM = quartz with low amount of Al-bearing minerals	R	NR	ISC	NR	NA	R	NR	R	NR
DOM = hematite SOR = goethite DGM = quartz with low amount of Al-bearing minerals	R	NR	ISC	NR	NA	R	NR	R	ISC
DOM = hematite SOR = hematite + magnetite relicts DGM = gibbsite with low amount of quartz	R	NR	ISC	ISC	NA	R	SR	R	NR
DOM = hematite, compact particles DGM = quartz + waste rock contamination	NA	NA	NA	NA	NA	NR	R	R	SR
DOM = hematite DGM = quartz with the presence of secondary phosphorus bearing minerals (e.g. wavellite)	R	SR	ISC	NR	NA	ISC	R	ISC	NR

Notes: DOM- dominant ore-mineral ; DGM – dominant gangue mineral ; SOR – secondary ore-mineral ; R - recommended ; NR – not recommended ; SR – strongly recommended ; ISC – in some cases; MS – magnetic separation; HG – high gradient; LI – low intensity; RED – rare earth drum.

The criteria for the selection of the most suitable beneficiation method for each application include a series of parameters; the most important among them is related to ore mineralogy. So, the understanding about constituent minerals is the key in evaluating the success of any mineral processing operation. For example, the gravity method is employed for some, such as the separation of the heavier ore minerals from a lighter gangue (or waste) material in a suitably chosen heavy medium. On the other hand, the magnetite ores (magnetic) are beneficiated by low intensity magnetic separators (wet drum), sometimes in combination with flotation and gravity methods. Figure 15 presents a typical iron ore beneficiation flow-charts in respect of hematite ores.

Conventionally, the beneficiation of hematite iron ore involves the use of various combinations of process steps, such as crushing, grinding or milling, concentration or separation by size or weight such as by a screen and/or specific gravity, as by a hydraulic classifier, and concentration with the aid of flotation agents, as in froth flotation, or by means of a magnetic classifier (Figure 15). However, the exact method varies depending upon the iron and gangue content of the ores. High Fe content and low alumina and phosphorous contents in iron ore reduce this proportion. Hence, quality of raw materials plays an important role in deciding which beneficiation process best fits for a particular ore type (Rao et al., 2001). The variability of beneficiation methods from site to site is as a result of heterogeneity mineral deposits exhibit (as they are created by natural processes) and thus there is no single method which could become applicable to every situation.

On the other hand, magnetite mining and value adding is much more intensive than the process required for the more traditionally mined hematite ore. Figure 16 presents the magnetite concentration process flow sheet. In this, once the magnetite ore is extracted it must go through intensive/successive process steps to separate out and crush the magnetite into a concentrate – for direct export or for conversion into pellets. The first step is to feed the ore through a primary crusher, either located within and/or outside the pit. The crushed ore is then transported to a concentrator, which is comprised of a series of mills and other processes (Figure 16). The mills produce a fine ore stream that can be separated by magnetic separators to either concentrate or tailings. The resulting concentrate will be thickened and filtered to reduce moisture. Some part of the concentrates is then shipped directly to China for use in blast furnaces, with the remainder being formed into pellets and fired for hardness.



***NOTE**: Concentrate grades may change when feed grade changes.
Folw sheet metallurgical values are tentative values.

Figure 15: A typical iron ore beneficiation flow chart for haematitic fines from Goa (India) (Sociadade-De-Fomento Ind Pty Ltd) (Reddy, 1998)

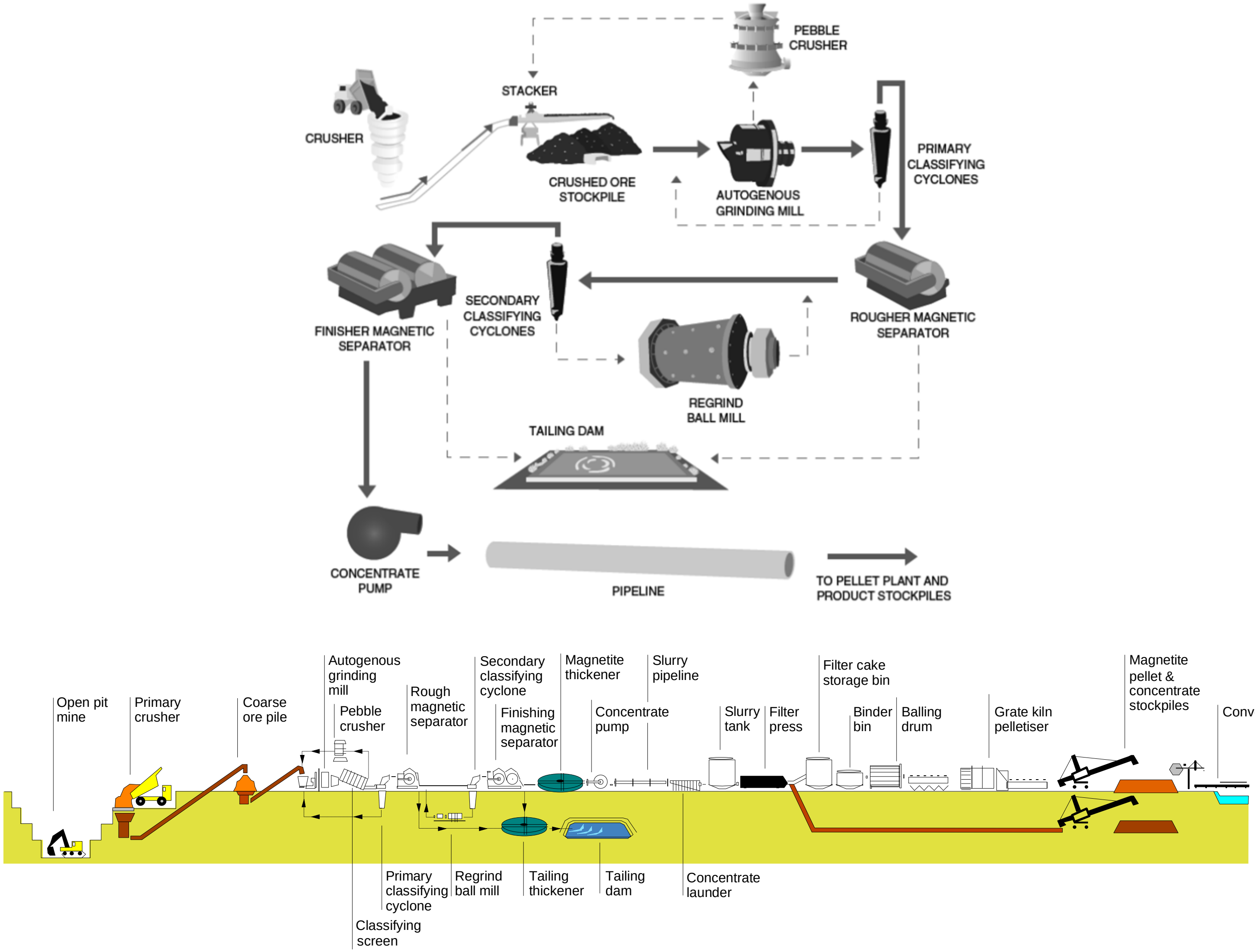


Figure 16: Typical magnetite ore beneficiation flow charts for Australia (Citic Pacific Mining, 2010)

7.2. Steel manufacturing technologies used in Australia – a review

Steel production can occur at an integrated facility, including a mine and smelter complex, or at a secondary facility, which produce steel mainly from recycled steel scrap. An integrated facility typically includes a nearby iron ore mine, coke production, blast furnaces, and basic oxygen steelmaking furnaces (BOFs), or in some cases opens hearth furnaces (OHFs). Raw steel is produced using a basic oxygen furnace from pig iron produced by the blast furnace and then processed into finished steel products. Secondary steelmaking most often occurs in electric arc furnaces (EAFs). Brief descriptions about each of the steel manufacturing technologies being practised in Australia are presented below.

7.2.1. Basic oxygen furnace technology

Steel production in a BOF begins by charging the vessel with 70-90% molten iron and 10-30% steel scrap. Industrial oxygen then combines with the carbon in the iron generating CO_2 in an exothermic reaction that melts the charge while lowering the carbon content. The charge is already melted as the pig iron is coming from the blast furnace. Scrap is added to reduce the temperature. A schematic representation of BOF steel making process and associated process inputs and environmental emission is shown in Figure 17.

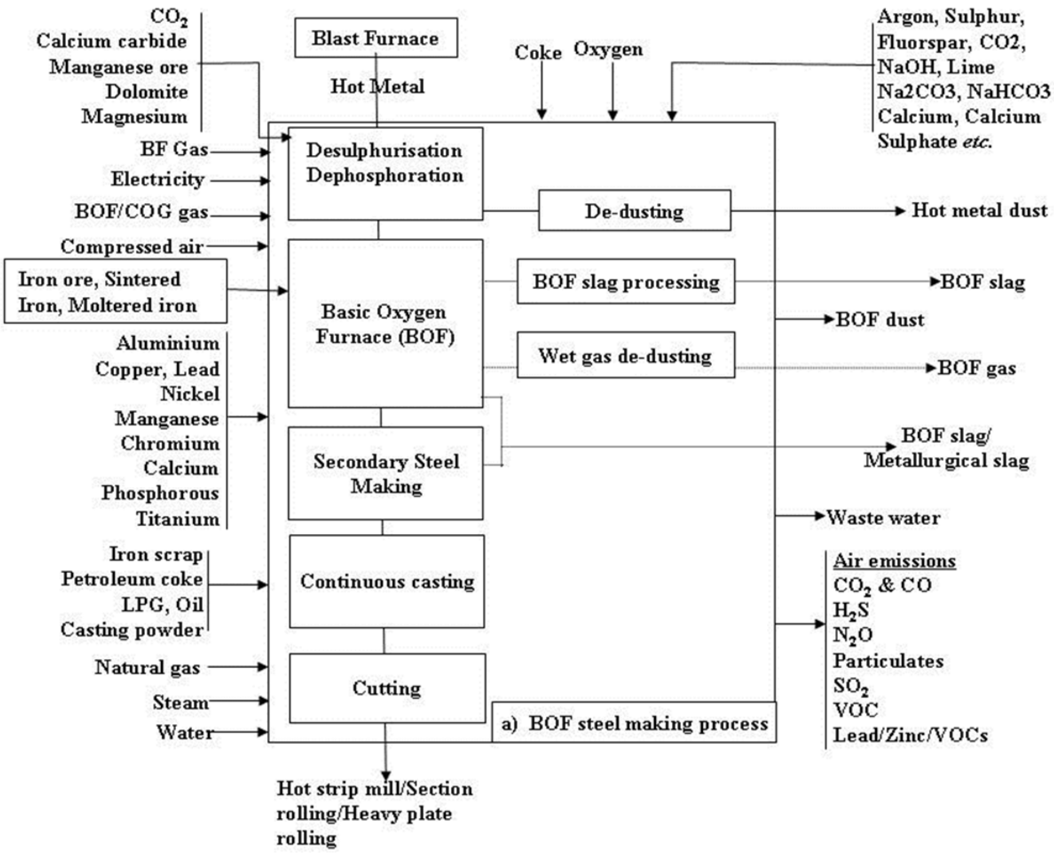


Figure 17: Schematic of steel BOF steel making technology and it's relevant environmental input/output indicators (modified from WSA, 2010c)

7.2.2. Electric arc furnace technology

Steel production in an EAF typically occurs by charging 100% recycled steel scrap, which is melted using electrical energy imparted to the charge through carbon electrodes and then refined and alloyed to produce the desired grade of steel. Although EAFs may be located in integrated plants, typically they are stand-alone operations because of their fundamental reliance on scrap and not iron ore as a raw material. Since the EAF process is mainly one of melting scrap and not reducing oxides, carbon's role is not as dominant as it is in the blast furnace-OHF/BOF processes. In a majority of scrap-charged EAF, CO_2 emissions are mainly associated with consumption of the carbon electrodes besides the CO_2 associated with electricity generation. A schematic representation of EAF steel making process and associated process inputs and environmental emission is shown in Figure 18.

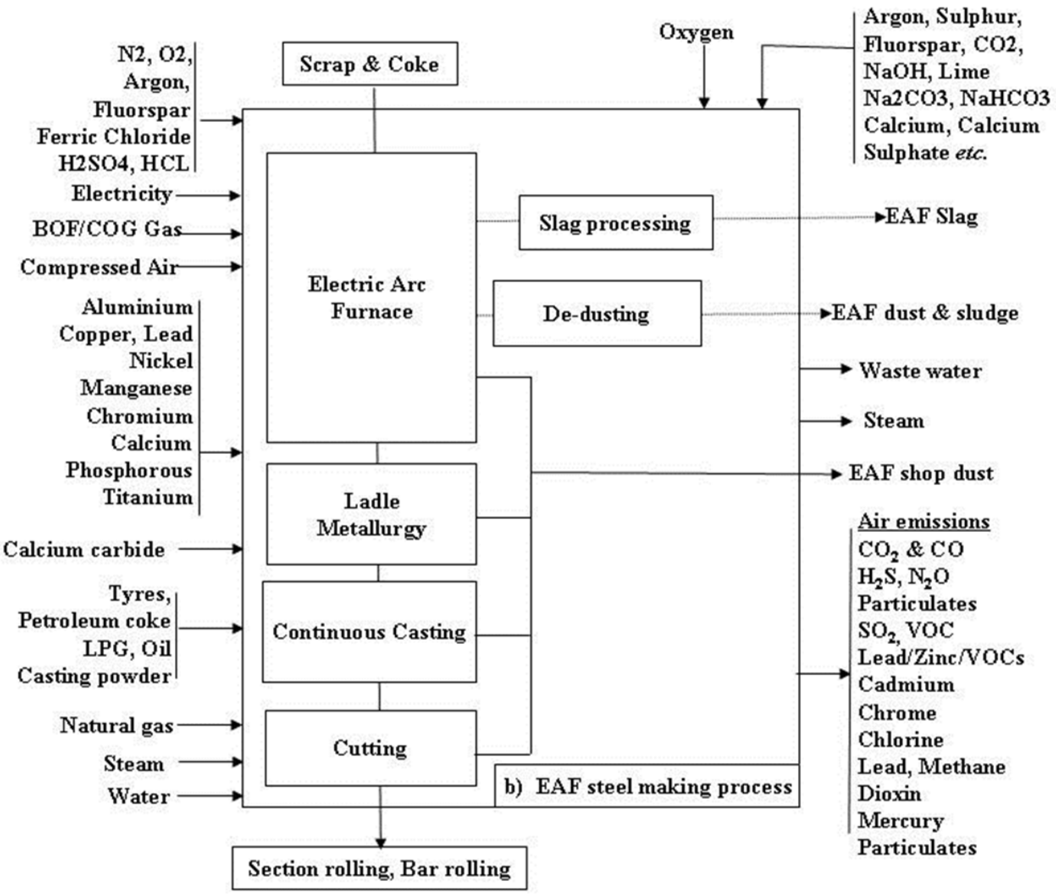


Figure 18: Schematic of steel EAF steel making processes and it's relevant environmental input/output indicators (modified from WSA, 2010c)

7.2.3. Energy and emissions intensity issues in steel making

The iron and steel industry is a major consumer of energy, mainly in the form of coking coal. Thus, it is liable to cause environmental impacts, mainly due to greenhouse gas emissions. With the Kyoto Protocol entering into force, an international agreement linked to the United Nations Framework Convention on climate change, the greenhouse gas emissions and climate change continue to be significant environmental issues for the steel industry (IISI, 2005). The major feature of the Kyoto Protocol is that it sets binding targets for 37 industrialized countries and the

European community for reducing greenhouse gas (GHG) emissions .These amount to an average of five per cent against 1990 levels over the five-year period 2008-2012. More than 80% per cent of this consumption is unavoidable because it is required for the basic chemical reaction in a blast furnace converting iron ore into iron. Figure 19 below compares steel production technologies and associated energy intensities in GJ per tonne of crude steel produced (WSA, 2009).

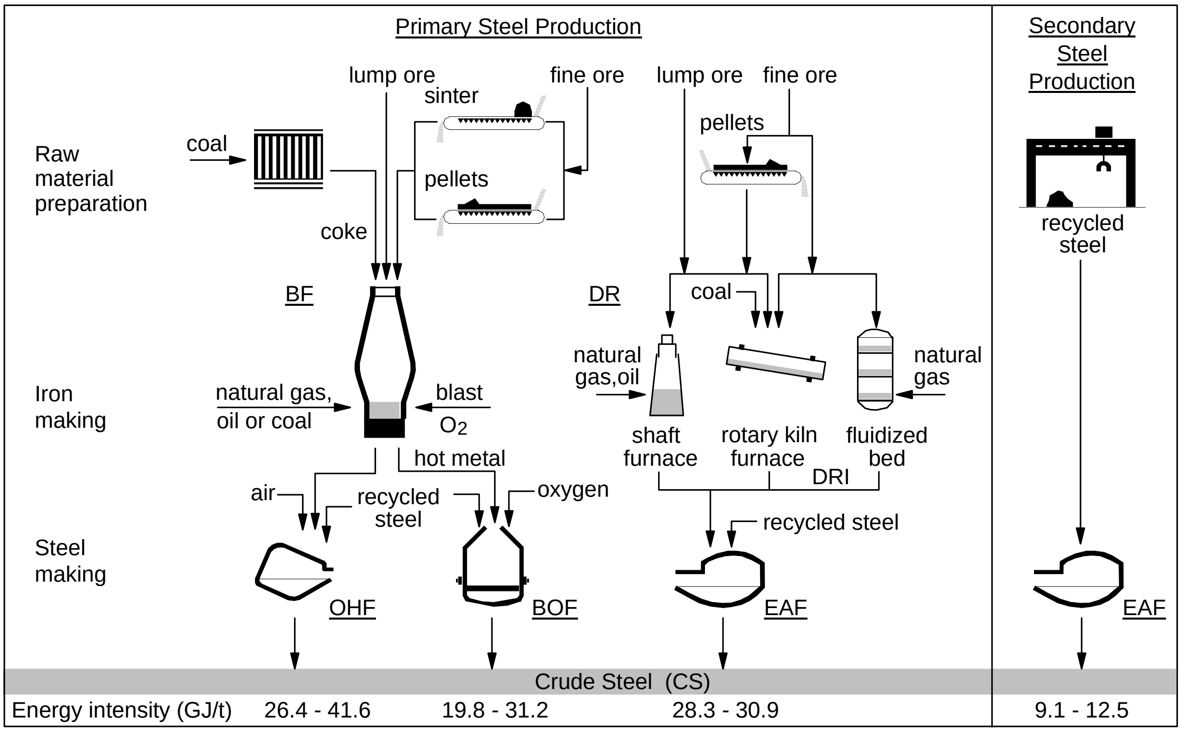


Figure 19: Steel production routes and energy intensities (modified from WSA, 2009)

Iron and steel making consumes large quantities of energy, mainly in the form of coal. The Australian steel industry of has taken enormous strides over the past five decades to reduce its specific energy consumption (SEC) (energy use per ton of crude steel (tcs) produced) between 1996 and 2010 (Figure 20). The SEC for steel production was derived from the annual reports of BlueScope (BlueScope Steel, 2010).

Despite this reliance on coal, the Australian steel industry is continuously seeking ways to reduce its energy intensity through improved operational practices and a range of energy efficiency projects, such as Efficiency Opportunities (EEO) program of Australian federal government. This program involves detailed assessments of energy use and the identification of potential savings. During1996-2006, the energy intensity in Australian steel industry has gone down by approximately 1.5% percent/annum. However, in 2009, with lower production rates and an associated reduction in economies of scale, the energy intensity was higher than historical levels (Figure 20).

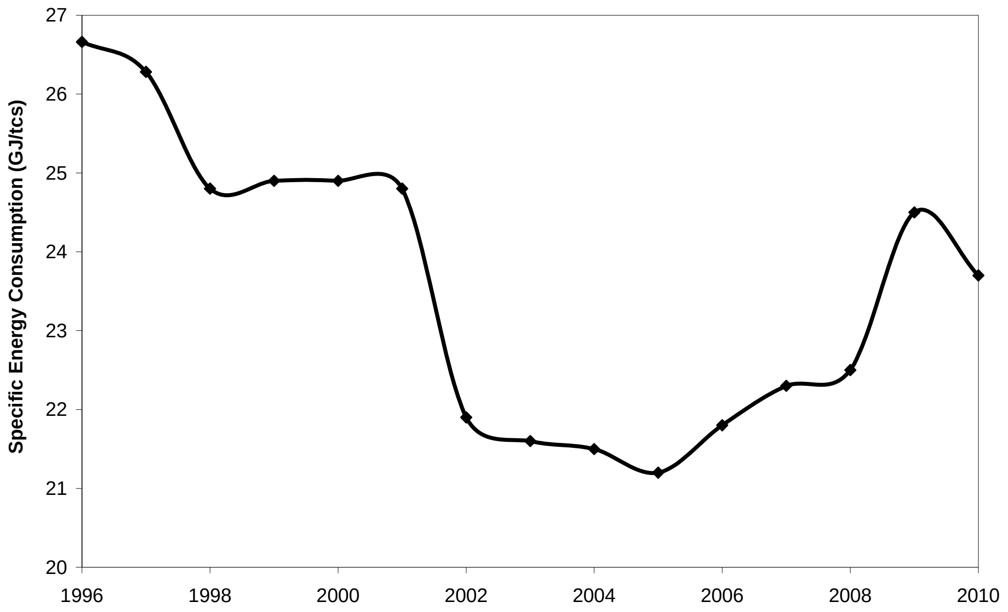


Figure 20: Specific energy consumption in the steel industry (Australia) (tcs - tonnes of crude steel)

Table 11 (below) shows the comparative performance of both BOF and EAF steel-making processes. These methods have been compared based on their environmental resource and energy uses and the associated emissions to air and water and solid waste generation. Further, according to the World Steel Association (2010c), in the 1970s and 1980s, a modern steel plant needed an average of 144 kg of raw material to produce 100 kg of steel. However, with investments in research and technology improvements the steel industry today uses only 115 kg of inputs to make 100 kg of steel – a 21% reduction. This demonstrates the fact that modern steel making technology has embraced cleaner production technology options in their day-to-day activities, contributing to process stewardship (although arguably for economic reasons as much as for environmental reasons).

Table 11: Environmental input/output indicators for BOF and EAF steel making

Input				Output			
	Units	BOF	EAF		Units	BOF	EAF
Raw materials				**Products**			
Iron ore	kg/t LS*	0.02-19.4	nil	Liquid steel	Kg	1000	1000
Pig iron	kg/t LS	788-931	0-18.8	**Emissions**			
scrap	kg/t LS	101-297	1009-1499	CO_2	kg/t LS	22.6-174	82.4-180.7
Metallic input	kg/t LS	0-60	1027-1502	CO	kg/t LS	393-7200	0.05-5.5
Coke	kg/t LS	0-0.36	15.4-19.4	NO_x	g/t LS	8.2-55	10-600
Lime	kg/t LS	30-67	25-140	Dust	g/t LS	10-143	4-500
Dolomite	kg/t LS	0-28.4	0-24.5	Cr	g/t LS	0.01-0.08	0.003-4.3
Alloys	kg/t LS	1.3-33	14.4-25.9	Fe	g/t LS	45.15	nil
Coal/anthracite	kg/t LS	nil	0.9-91	Pb	g/t LS	0.17-0.98	0.075-2.85
Graphite electrodes	kg/t LS	nil	2-6	SO_x	g/t LS	nil	3.2-252
Refractory lining	kg/t LS	nil	3-38	PAH	mg/t LS	10	9-970
Energy				**Energy**			
Electricity	MJ/t LS	35-216	1584-2693	BOF gas	MJ/t LS	350-700	nil
Natural gas	MJ/t LS	44-730	50-1500	Steam	MJ/t LS	124-335	nil
Coke oven gas	MJ/t LS	0-58	nil	**Solid wastes/By-products**			
Steam	MJ/t LS	13-150	33-251	All types of slag	kg/t LS	101-206	70-343
BF gas	m^3/t LS	0.55-5.26	nil	Dusts	kg/t LS	0.75-24	10-30
Compressed air	Nm^3/t LS	8-26.0	nil	Spittings	kg/t LS	2.8-15	nil
Gases				Rubble	kg/t LS	0.05-6.4	nil
Oxygen	m^3/t LS	49.5-54.5	5-65	Mill scale	kg/t LS	2.3-7.7	nil
Nitrogen	m^3/t LS	0.55-1.1	5.9-12	Waste refractories	kg/t LS	nil	1.6-22.8
Argon	m^3/t LS	2.3-18.2	0.79-1.45	Ferrous sludge	kg/t LS	nil	4.3
Water	m^3/t LS	0.8-41.7	3.75-42.8	**Waste water**	m^3/t LS	0.3-6	nil

*LS – Liquid steel

7.3. Can Recycling Replace Primary Steel?

The production, consumption and exports of minerals in Australia are rather strange. When we observe the trends iron ore and steel production in Australia shown in Figure 20. Although Australia has very large quantities of iron ore and coking coal, much of which is exported to Asia and Europe, it does not process this to steel itself. On the one hand, in 2009, Australia exported a total of approximately 1.875 Mt of steel scrap, which is nearly 18% of its total steel use (assuming that approximately 1.1 tonnes of steel scrap is needed to produce one tonne of steel). On the other hand, in 2009 Australia's EAF share of total steel was just about 19%. Assuming that all the exported scarp of Australia was utilised within its economy, the EAF share would have been 37% of Australia's total steel production (considering that all the steel scrap will go into EAF steel making). Therefore, it is more logical for Australia and Brazil to produce and export primary steel and in other countries, such as India and China with high population and relatively moderate mineral resources, it is logical to service its own economy by comprehensive recycling of steel scrap and topping up demand with primary steel Figure 21. By all means, it is a bit strange proposition, whether environmentally or economically, for Australia and Brazil to import iron ore, SFFS and steel scrap.

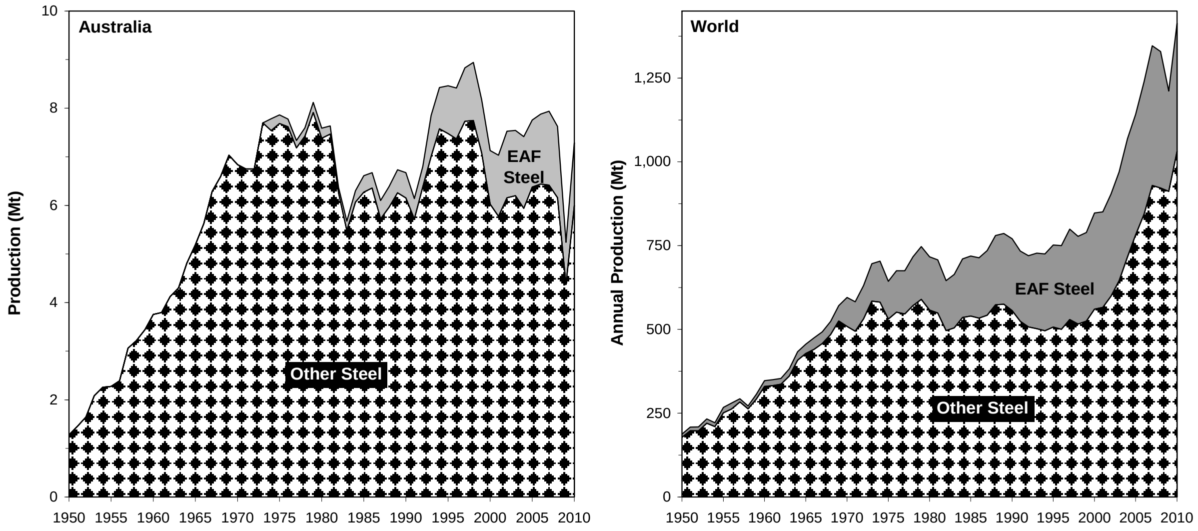


Figure 21: Steel production trends in Australia and the world (Total and EAF routes)

7.4. How does Australia compare with rest of the world in steel recycling?

The idea coined by Jacobs (1969) “the cities of today are the mines of tomorrow” assumes greater importance, particularly in the context of metals’ recycling. The proposition of the author has profound practical implications for our modern times, particularly in the context of the perceived mineral resources shortage. The world steel industry has taken enormous strides over the past five decades to reduce its ecological footprint through maximising the recycling rate (RR) of old steel (end-of-life steel products), which is defined as the consumption of old scrap plus the consumption of new scrap divided by apparent supply, measured in weight and expressed as a percentage.

Almost all steel-producing countries are striving hard to improve their recycling performance, which has resulted in improved recycling rates in the recent past. Figure 22 presents the case of steel can recycling in selected countries in the world. The example of steel can recycling can therefore be used to gauge our ability in scrap collection and recycling (overall steel recycling rates). This also illustrates Australia’s performance in steel recycling in comparison with rest of countries in the world. It underpins the important fact that Australia lags behind many other countries in the world in recycling.

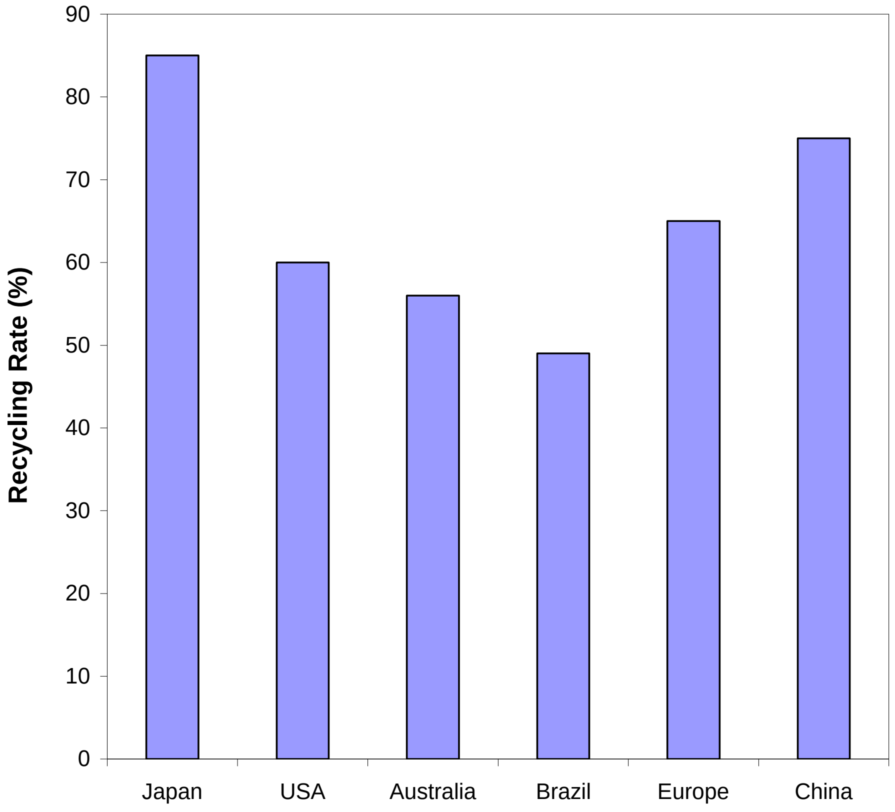


Figure 22: Steel can recycle rates in the world in 2007 (defined as proportion of cans captured and recycled) (Yellishetty et al., 2011)

Although RR is not the best metric to judge our ability to recover materials from anthropogenic engines before they become dissipated into the lithosphere, it could be used to gauge our ability to recover the scrap from different sources and put back into new steel. Although RR represents only the extent to which scrap was used in producing a particular consumer good, it does not indicate the efficiency of recovery of available scrap material. In fact, recycling efficiency (RE) is the appropriate metric to judge our ability to harvest (the potential of recovery) of material before its dissipation to the lithosphere (through losses such as corrosion and wear and tear). RE can be defined as the ratio between the amount of old scrap recovered and reused relative to the amount of scrap actually available to be recovered and reused. Although RE is a better metric, no data that exist on RE worldwide. It is therefore imperative that the steel industry embarks on the task of using the information to achieve material stewardship.

7.5. Iron ore and steel substance flows and sustainability issues

Table 12 and Figure 23 presents mass flows of iron ore and steel (includes crude, finished and semi-finished products) into and out of the Australia and different countries. These flows of iron ore and steel clearly indicate that the weak end of steel industry’s trade is the sea-borne transport, which is also a major environmental challenge for today’s steel industry (Yellishetty et al., 2010). Even as the seaborne transport became very convenient and economic alternative for the intercontinental mass movement of goods at very marginal added costs-making it financially sustainable-the real issue is of its environmental sustainability in longer term. This is of greater concern particularly in the context of present challenges posed to our global climate and its anticipated vicious effects.

Table 12: Imports and exports of Australian iron ore and steel products in the year 2010

Iron Ore				Steel							
Imports		Exports		Imports				Exports			
From Country	**kt**	**To Country**	**kt**	**From Country**	**kt**	**From Country**	**kt**	**To Country**	**kt**	**To Country**	**kt**
N. Caledonia	2,300	China	273,767	Confidential	807.8	Israel	3.2	USA	456.9	France	0.4
Brazil	1,192	Japan	75,585	China	204.3	Australia	3.0	R of Korea	210.8	Philippines	0.4
Philippines	943	R of Korea	38,558	Japan	196.6	France	2.8	Thailand	188.2	Ghana	0.2
Indonesia	845	Taiwan	12,031	Taiwan	122.8	Viet Nam	2.5	Brazil	148.5	Kuwait	0.2
Canada	150	Netherlands	1,452	Singapore	121.2	Poland	1.6	Italy	143.5	N. Caledonia	0.2
South Africa	58	France	296	R. of Korea	90.0	Hong Kong	1.3	UAE	126.7	Colombia	0.2
		India	152	New Zealand	79.4	Czech R.	1.1	Viet Nam	94.3	Saudi Arabia	0.2
		USA	0.1	India	62.0	Denmark	1.1	New Zealand	55.0	Egypt	0.2
				Malaysia	60.0	Austria	1.0	Malaysia	36.4	Hong Kong	0.2
				Spain	37.7	Brazil	0.9	Indonesia	31.4	Fiji	0.1
				Sweden	28.6	UAE	0.7	Taiwan	20.8	Spain	0.1
				South Africa	24.1	Russia	0.5	Chile	16.1	Solomon Islands	0.1
				UK	22.0	Romania	0.4	Pakistan	11.5	Sudan	0.1
				USA	17.3	Saudi Arabia	0.3	Japan	11.3	Iraq	0.1
				Indonesia	15.8	Switzerland	0.3	Canada	9.7	Senegal	0.1
				Mexico	14.7	Ukraine	0.3	Belgium	9.3	Turkey	0.1
				Germany	12.5	Peru	0.2	PNG	7.2	Qatar	0.1
				Thailand	11.6	Norway	0.2	China	6.0	Mauritania	0.1
				Belgium	11.1	Portugal	0.1	Singapore	2.5		
				Finland	10.3	R of Slovak	0.1	India	2.0		
				Italy	7.5	Virgin Islands	0.1	Israel	1.1		
				Turkey	4.9	Moldova	0.1	Bangladesh	0.8		
				Netherlands	4.0			South Africa	0.6		
				Canada	3.9			East Timor	0.5		
Grand Total	**5,488**		**401,840**		**1,970**		**21.8**		**1591**		**3.1**

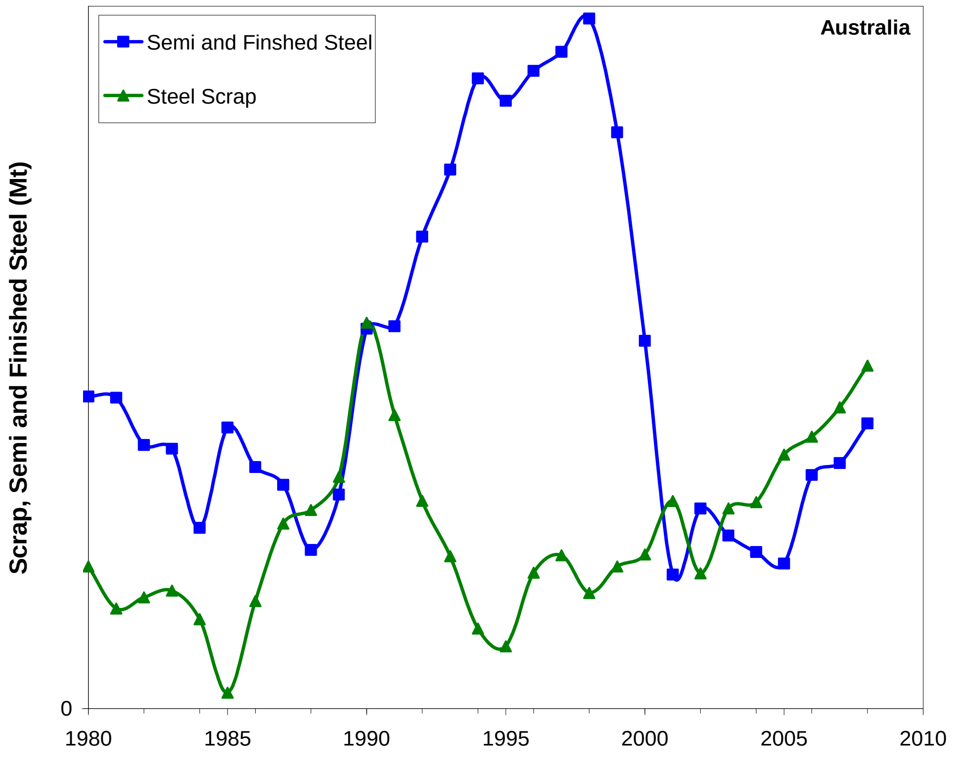


Figure 23: Exports of steel substances from Australia (expressed in crude steel equivalents)

Box 3. ***Reproduced from Steel Stewardship Website***
Steel Stewardship Forum: pioneering responsible steel

The Steel Stewardship Forum (SSF) is a body formed to develop steel stewardship in Australia and a stewardship scheme across the entire steel supply chain and for this to be a template to be presented by Australia at the APEC Mining Ministers Forum as a 'best practice' model for the region.

The concept of the Forum is to bring together all major sectors of the steel product life cycle – from mining through to steel manufacturing, processing, product fabrication, use and re-use, and recycling – in the shared responsibility of working together to optimise the steel product life cycle using sustainability principles including minimising the impact on society and the environment. The SSF believe that collectively we can continue to add value to and improve the performance of the steel industry across the whole product life cycle – thereby reducing negative commercial, social and environmental impacts.

The Steel Stewardship Forum is seeking to develop a credible and independently verifiable steel certification scheme, to be known as Responsible Steel, that seeks to minimise impact and improve performance throughout the steel value chain, recognised by the industry and external stakeholders.

For more information see http://steelstewardship.com

7.6. New Technologies for Steel

Iron and steel making consumes large quantities of energy, mainly in the form of coal. In a recent Australian study by Somerville (2010) estimated that in 2007-08 a total of 14 Mt of CO_2 emissions resulted from nearly 8 Mt of steel production. This mainly was contributed by fossil carbon in the form of coal and coke as fuels and reductants. With the likely introduction of a greenhouse gas emissions trading scheme, the cost of non-renewable carbon will increase and therefore the steel industry will financially benefit from reducing e the use of such fuels.

A joint research consortium of BlueScope Steel, OneSteel and CSIRO was initiated in 2006 aimed at identifying, evaluating and demonstrating application of renewable carbon in iron and steel making. This project forms part of the major initiative by the WorldSteel Association's CO_2 breakthrough programme. According to Somerville (2010), this scheme has been structured around following three main objectives:

1. Identifying and quantifying available sustainable biomass resources
2. Processing biomass to form various types of charcoal through a pyrolysis process,
3. Use of charcoals iron and steel making, such as in sintering, coke making, pulverised fuel injection into the blast furnace and steel recarburisation and slag formation.

Box 2. ***by Daniel Franks, University of Queensland***
The use of charcoal in steelmaking: a sustainable alternative?

CSIRO are currently exploring the use of charcoal (made from biomass) as a sustainable alternative fuel and reductant replacing metallurgical coal in ironmaking and steelmaking. Life Cycle Assessment on biomass alternatives, conducted by CSIRO, indicates the potential for marked reductions in greenhouse gas emissions in various steel making routes (see Norgate and Langberg, 2009).

The Centre for Social Responsibility in Mining (CSRM), as part of the Mineral Futures Collaboration Cluster, has worked with CSIRO to conduct a Social Life Cycle Assessment to further assess the social sustainability of biomass production via the use of social impact indicators (see Weldegiorgis and Franks, 2012).

The social performance of two biomass alternatives, Radiata pine plantation forestry and Mallee revegetation on agricultural land, were assessed against metallurgical coal and each other. Social performance was assessed using land-use, employment and workplace health and safety as impact indicators. A qualitative analysis of identified stakeholder issues was also undertaken.

Findings

No unique solution exists for optimising the social performance of the technology alternatives across all of the indicators.

Biomass alternatives, both Radiata and Mallee, were found to be significant generators of direct employment at the regional level (2.96 x 10-3 per tonne of steel for charcoal produced from pine biomass compared to 1.35 x 10-3 for metallurgical coal and coke production). However, they were also identified as having concomitantly higher rates of workplace injuries (6.26 x 10-5 per tonne of steel for pine compared to 1.24 x 10-5 per tonne of steel for coal). The scale effects of a shift to biomass technologies on land-use are significant. When compared to metallurgical coal biomass alternatives represent a 197 fold increase in land-use (1.97 x 10-1 hectares per tonne of steel compared to 1 x 10-3 for coal).

Sustainability issues: land use cost and conflict

Production of pine plantation forestry in Australia would be required to increase by 67% to accommodate the full substitution of coal (an additional 1.35 million hectares under plantation forestry).

Land-use conflicts have been associated with plantation forestry expansion, with even revegetation projects undertaken for conservation generating local level dissatisfaction and competition with other land-use in some cases. On the other hand, local level conflicts have also manifest from the community health and amenity impacts, and subsidence effects associated with metallurgical coal mining, despite the relatively small area of land impacted (1 x 10-3 hectares per tonne of steel).

Charcoal produced from Mallee biomass planted as a conservation measure on farmland has the benefit of representing a shared land-use that in turn supports farm employment through an additional revenue stream and the management of dryland salinity.

8. POLICY DRIVERS

Australia's natural resources have been an integral part of its economic development for the past several decades. Australia's mineral endowment is providing a basis for higher living standards and also acting as a driver for economic and social change for several decades now (Mercer, 2000).

The rise of economic prosperity in China and India coupled with countries like Brazil and Russia (so called 'BRIC' countries), indicates that their relatively strong economic growth and consequent demand for resources could well continue into the next few decades, means it is reasonable to expect that there will be a relatively slow unwinding of historically high non-rural commodity prices. It is therefore important to harness the potential strength of this resource endowment and use it to the countries' strategic advantage.

It was also observed by Yellishetty et al. (2011) that there is periodic volatility for all metals, related mainly to fluctuating economic conditions and mining boom/bust cycles (Figure 24). It is this market volatility that is detrimental to many mineral dependent economies, which rely more on foreign exchange earnings for planning their developmental activities (Davies and Tilton, 2005. Davies and Tilton note that that many of these countries have commodity stabilization funds, which they contribute to when prices are high and withdraw from when prices are low (2005).

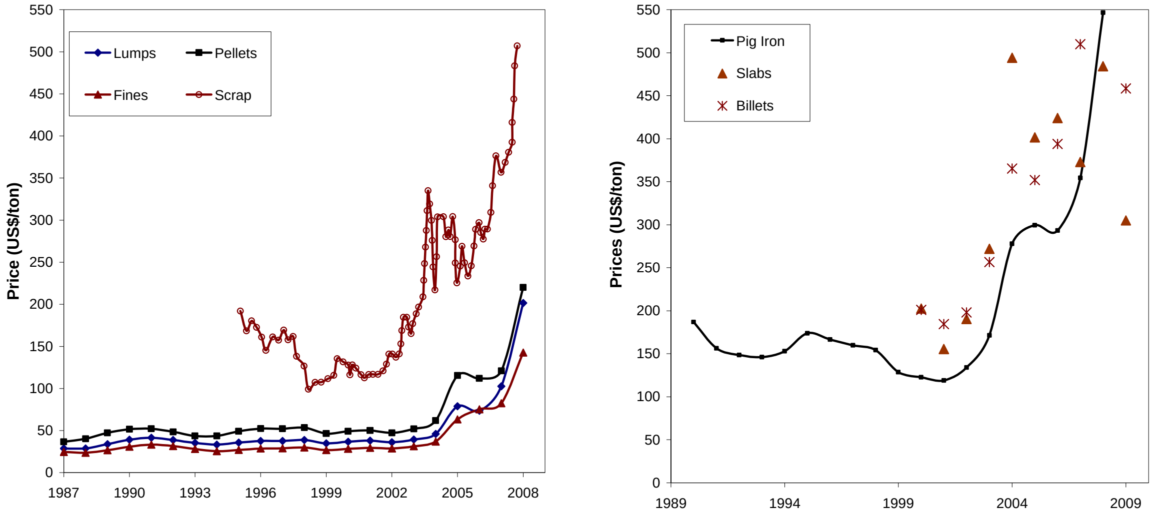


Figure 24: prices of iron ore and scrap (left); pig-iron, billets and slabs in the world (right) (nominal US$)

Although the direct effect of higher commodity prices is to increase Australia's national income through contributing to GDP, natural mineral wealth may not always convert into higher sustained growth or wellbeing overall. According to the Budget Strategy and Outlook (2010), not all resource-rich countries have been able to translate resource wealth into sustained economic performance, and there may be some costs associated with natural resource wealth. But while many resource-rich countries have at times lagged behind in economic performance, others such as Australia have done relatively well (Yellishetty et al., 2011).

Furthermore, Budget Strategy and Outlook (2010) argues that on the other hand, previous experience in Australia and worldwide points to the risk that marked increases in natural resource wealth can undermine economic reform and sound fiscal policy - reducing the gains to national income and skewing their distribution.

The negative impacts associated with the resource curse are of political, social, environmental and economic nature (Goodman and Worth, 2008). A nation suffering from the resource curse realises huge gains from exporting minerals, which strengthens the local currency (because other nations must buy its currency to obtain the commodity, forcing the price of the currency up). This also means the country’s other exports become more expensive, decreasing the competitiveness of other sectors that produce internationally tradable goods. Furthermore, the stronger currency makes importing foreign goods cheaper, increasing the competition for locally produced goods on the national market (Goodman and Worth, 2008; Palma, 2005). While struggling with maintaining its national and international market share, the already weakened non-mining sectors face additional challenges competing with the high salaries paid by the booming resource sector. Ultimately, the point is reached when the sector can no longer attract the workforce required to remain competitive or viable. This effect is worse in countries that are close to full employment and have difficulty supplementing the workforce through migration (Papyrakis and Gerlagh, 2003; Stevens and Dietsche, 2008).

Therefore, it may be important to ensure that the role of policy must ensure building on the strong starting point and to ensure that the Australian community shares in the benefits of Australia’s mineral resources. Therefore it is envisaged that any policy should build the economy’s capacity whilst being flexible, promote investment in a diversified economy, and enhance community wellbeing. Thus, the role of government could become paramount in bringing reformist mineral policies that can take full advantage of this abundant natural capital. The role of a mineral policy must be ensuring that the benefits as a result of minerals and their exports percolate down to the community.

9. CONCLUSIONS

This iron ore case study is prepared as part of the Minerals Futures Collaboration Cluster between CSIRO, Monash university and other partners. In this report, a detailed review of iron ore has been undertaken, which has focussed on key questions such as currently reported mineral resources, ore processing configurations, and issues and trends affecting iron ore.

This report presented a comprehensive account of Australian iron ore resources by major projects, ore types and grades. The study also presented an analysis of production trends and compared that with other major iron ore producers in the world.

Through this study it was observed that the Australia's iron ore production is increasing exponentially whereas domestic steel production has remained steady for quite some time. We have also presented analysed the energy consumption in both iron ore and the steel industry in Australia. The specific energy consumption in the industry steel industry showed a decreasing trend in SEC.

The findings reported in this paper indicate that there is a complex interrelationship between production technologies, consumption patterns and the domestic and global infrastructure of the steel sector.

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Appendix 1: Sustainable mineral reserves management indicators reporting (SMRMI) matrix for Australia 2009 (Mason et al)

Questions	**Resource Data**	**Indicator**
What do we have?	Inventories (a) (1)	GEO-1
What difficulties does it present in terms of its composition as an ore?	Mineralogical formations	GEO-2
What difficulties does it present in terms of how a workforce would be deployed?	Is it FIFO or does it take its workforce from an existing local community?	GEO-3
What difficulties does it present in terms of access to infrastructure to mine, mill, refine and transport the ore?	How remote from processing and transport is a particular deposit or operation?	GEO-4
Do we have more or less than other nations?	Australian AEDR as % of Global EDR	GEO-5
How much of the mineral is mineable now?	JORC code reserves (% of Australian AEDR)	GEO-6
How fast are we currently extracting the mineral?	Production rate (tonnes and % growth pa)	GEO-7
How long will this resource last, if produced at the current rate of extraction?	Life of resource at current production rate (years)	GEO-8
Is the quality of the minerals being mined and processed declining?	Grade decline rate (% mineral)	GEO-9
Economic impacts	**Economic Data**	
What is the contribution of mining and processing to national wealth (GDP)?	Income from sales of goods and services (a) (1)	ECO-1
How does this compare to other sectors of the economy?	Income from sales of goods and services (a) (1)	ECO-2
What are the mining companies making in terms of profit?	Company profits before income tax (b) (1)	ECO-3
What are mining companies spending on equipment or infrastructure?	Private new capital expenditure (a) (2)	ECO-4
What are the mining companies spending on exploration activities?	Mineral exploration expenditure (4)	ECO-5
How much money is the relevant state government receiving in royalties?	Dollars associated with Tonnes minerals exported	ECO-6
How much money is the federal government receiving in company tax?	Company income tax minus relevant exceptions	ECO-7
Environmental impacts	**Environmental data**	
What are the land disturbance impacts of mining and mineral processing?	Overburden tonnage	ENV-1
How efficient is the water usage of mining and mineral processing?	Water used per unit of metal	ENV-2
To what extent is mining and mineral processing activity likely to impact on other water users?	Water sourced from recycled waste waters.	ENV-3
How much does it contribute to Australian GHG emissions?	GHG – per unit of metal	ENV-4
How much does it contribute to local or regional toxin levels?	NO_X, SO_2, per unit of metal	ENV-5
How much does it contribute to local or regional air quality issues?	Total Suspended Particulates per unit of metal? Proportion of PM_{10} and $PM_{2.5}$	ENV-6

How much does it contribute ozone-destroying chemicals in the environment?	How much per unit of metal?	ENV-7
What proportion of stationary energy utilized in all processes is renewable?	How much energy (MW) per unit of metal?	ENV-8
What proportion of stationary energy utilized in all processes is fossil fuel based?	How much energy (MW) per unit of metal?	ENV-9
What proportion of transport energy is fossil fuel based?	How many liters of diesel or other fossil fuels are used per unit of metal?	ENV-10
Social impacts	**Employment data**	
Contribution to income?	What is the lowest, highest and average wage?	SOC-1
Contribution to Employment: Duration	What are the shortest, longest and average periods of employment?	SOC-2
Contribution to Employment: Skills	Proportion of workforce with nationally recognized vocational training?	SOC-3
Contribution to Employment: Persons directly employed	How many people are employed?	SOC-4
Technology Data	**Innovation & R&D**	
What role is technology currently playing in making Australian mining and mineral processing viable?	Technologies being used in Australian mining and mineral processing operations	TEC-1
What role is technology currently playing in making other nations' mining and mineral processing viable?	Technologies are being used in mining and mineral processing operations elsewhere	TEC-2
What are the opportunities for technology to continue making Australian mining and mineral processing viable?	Technologies being pursued to current or anticipated problems.	TEC-3
At what rate are new technologies being taken up?	To what extent are innovative technologies being put in place at sites?	TEC-4