The Third International Conference on Bioenvironment, Biodiversity and Renewable Energies

Pollution Control and Sustainability Challenges of Ironmaking and Steelmaking Operations

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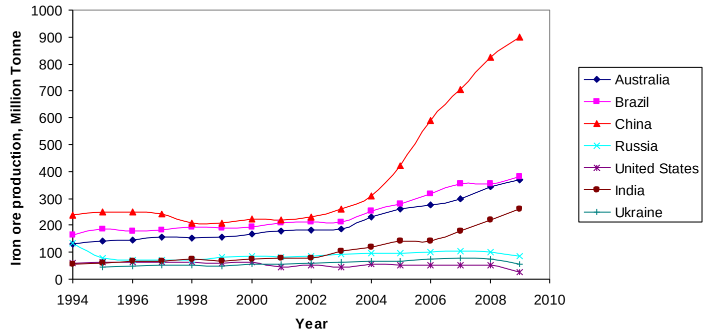
Iron

- Known to men since 1200BC
- Simple to make:

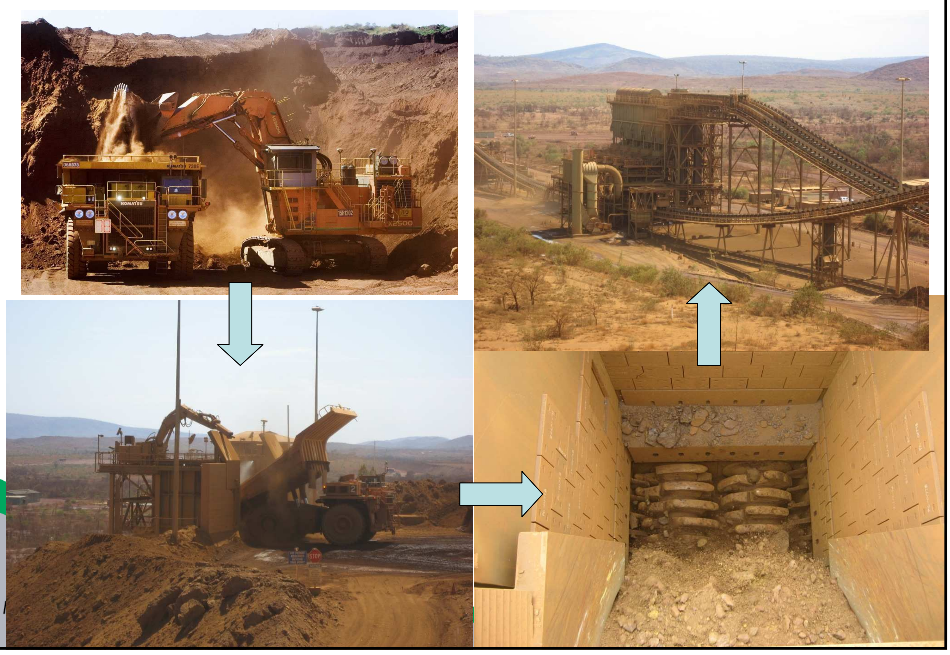
$C + O_2 \rightarrow CO_2$ + heat
$CO_2 + C \rightarrow 2CO$
$3Fe_2O_3 + CO \rightarrow CO_2 + 2\ Fe_3O_4$ (Begins at 450^0)
$Fe_3O_4 + CO \rightarrow CO_2 + 3\ FeO$ (Begins at 600 ^{0}C)
$FeO + CO \rightarrow CO_2 + Fe$
or $FeO + C \rightarrow CO + Fe$ (Begins at 700 ^{0}C)

- Key commodity to modern economy

Iron ore production



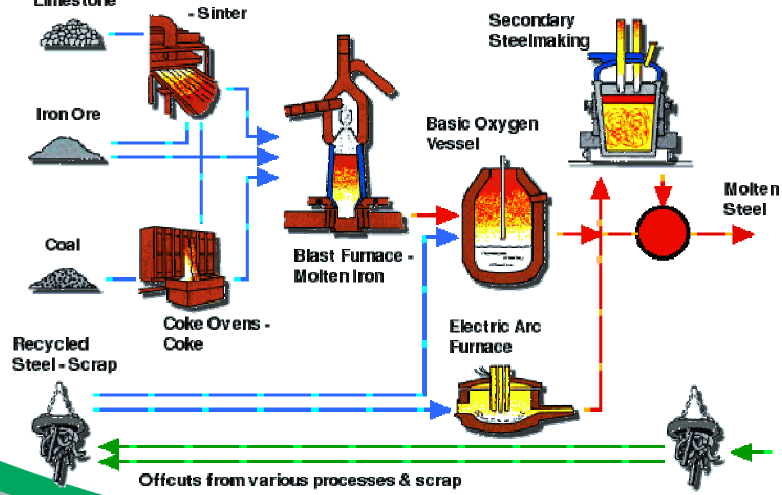
Ore Extraction and Handling

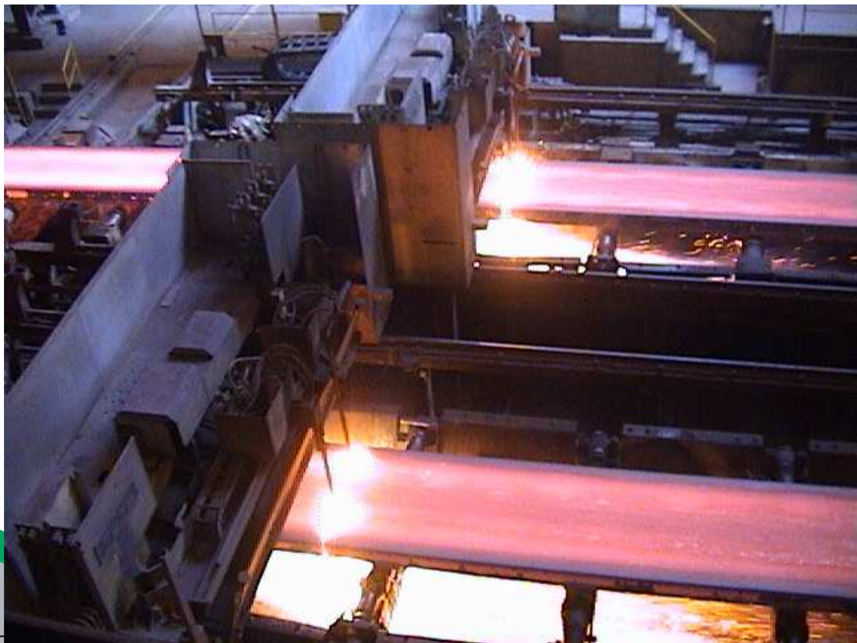


Mine Site Processing Plant

Port and Shipping

1 - Production of Molten Steel

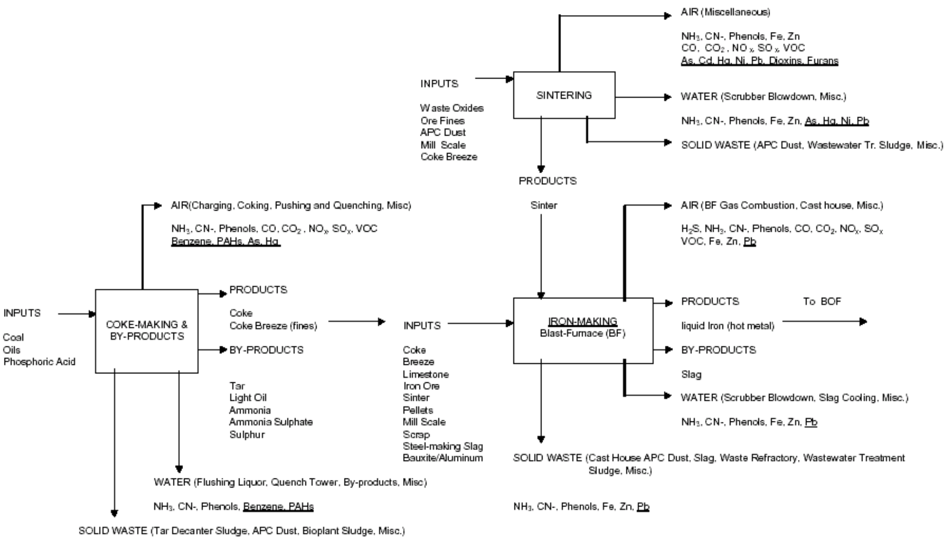




AIR POLLUTION

- ***Priority Pollutants***
  - SO_2, NO_x, CO, Pb, photochemical smog (O_3), particulate matter PM (PM_{10} and $PM_{2.5}$)
- ***Air toxins***
  - **Metals and metal compounds** (As, Cd, Hg, Cr^{6+}, Ni, Pb)
  - **Pesticides**
  - **Polycyclic Aromatic Hydrocarbons** (PAHs) (Benzo(a)pyrene (BaP))
  - **Volatile Organic Compounds** (VOCs) (benzene)
  - **Persistent Organic Pollutants** (POPs) (aldrin, chlordane, DDT, dieldrin, dioxins, furans, endrin, hexachlorobenzene, heptachlor, mirex, polychlorinated biphenyls, toxaphene)
  - **Dioxins and Furans** (TCDD)
  - **Asbestos**
- ***Greenhouse gases***
  - CO_2, CH_4, N_2O, CFCs and HCFs, CF_4, SF_6

Ironmaking Emissions



Note: *CEPA*-toxic substances are underlined

Coke Oven Emissions

Sinter Plant Stack before and after Energy Recovery System

Air Pollution and Health

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Illawarra air pollution breaches up in 2009

NICOLE HASHAM
04 May, 2010 12:50 AM

The Illawarra repeatedly failed to meet national air quality targets last year, prompting health concerns for children, the elderly and those living near industrial areas.

Figures from the Department of Environment, Climate Change and Water show the Illawarra exceeded accepted levels of pollution particles on 16 days in 2009.

National standards allow for five breaches each year, which lowers the region's official number to 11.

- EDITORIAL: Air pollution still a major health risk

The particles, known as PM10, are the result of vehicle and factory emissions and wood-burning heaters as well as smoke from bushfires and dust storms.

Of the region's three monitoring stations, Kembla Grange recorded the most breaches (14) followed by Albion Park (9) and Wollongong (6).

All three recorded up to 500 times the usual pollution level on September 23 last year, when a red dust storm blanketed the region.

Small-particle pollution has been known to cause cardiovascular and respiratory problems and can lead to premature death.

The Illawarra has recorded a higher number of particle pollution breaches than Sydney every year since 2006.

Greens MP Lee Rhiannon said Illawarra residents bore the brunt of systemic government failures to reduce air pollution to acceptable levels.

"The Illawarra is shouldering the burden of poor air quality created by its heavy industry base and being located downwind from a very polluted Sydney," Ms Rhiannon said.

University of Wollongong atmospheric chemistry expert Stephen Wilson confirmed much of the Illawarra's air pollution blew in from the north, but said recent breaches were not cause for concern until a long-term trend emerged.

Breaches in 2008 did not exceed the five allowed, and in 2007 there was two beyond

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News → Local News → News → General → Lung cancer concerns to be investigated

Lung cancer concerns to be investigated

SEEMA SHARMA
07 Dec, 2007 06:25 AM

Concerns have been raised on a recent Department of Health report that revealed that 32 more cases of lung cancer were recorded in Whyalla between 1999 and 2004 than would be expected compared to industrial communities of a similar size.

While health officials could not confirm that red dust and other emissions from OneSteel had caused the increase, Mayor Jim Pollock has called for more studies and a detailed report.

OneSteel Whyalla Steelworks executive general manager Mark Parry said the report was inconclusive and the company had extensive health regulations with workers undergoing medical tests annually.

He said some workers have been with the company for more than 10 years and no single employee has been diagnosed with lung cancer or any other form of disease.

Mr Parry said the company was also interested in the report and if there was any indication that OneSteel was causing health threats in Whyalla necessary action would be taken.

Mr Pollock said the health report was alarming and worrying.

"A detailed report is needed and to find out what is causing the increase because the figures are worrying and the cause must be identified and dealt with," Mr Pollock said.

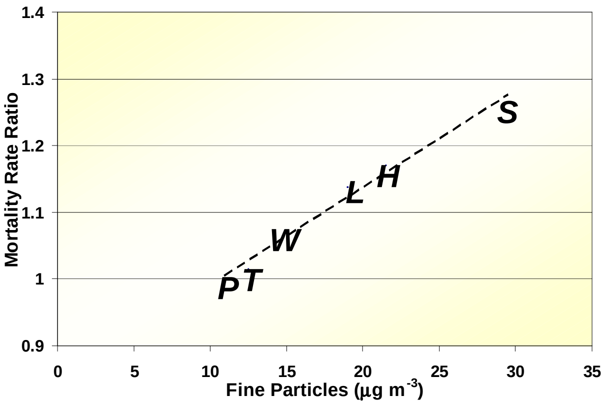
"There is definitely a dirt problem in Whyalla and work is being done with OneSteel which is a major employer in the city to address it.

"Every community faces some health problems and unless something concrete is available to point towards a cause nothing much can be done apart from leading a healthy lifestyle."

Director of Public Health SA Doctor Kevin Bueckett was in Whyalla on Monday to attend the mining conference.

Daily mortality and fine particles

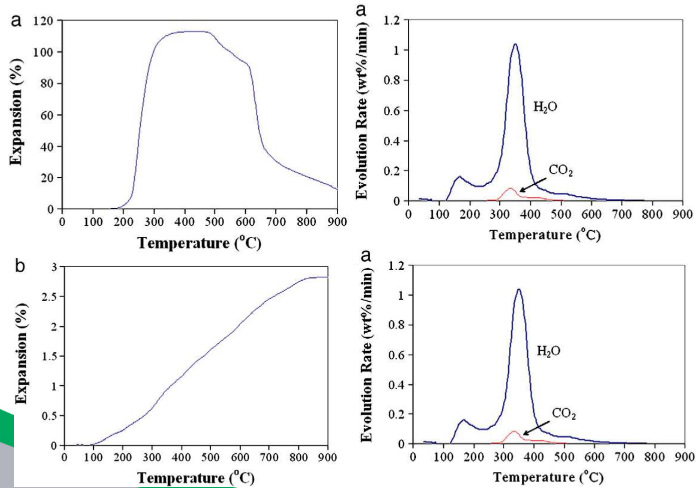
- Fine ($PM_{2.5}$) and coarse (PM_{10} - $PM_{2.5}$) measured
  - 6 eastern US cities for 8 years
  - aerosol acidity for 1 year
- Daily mortality
- Weather measurements
- $PM_{2.5}$, PM_{10} and SO_4^{2-} associated with mortality
- TSP (coarse particles), aerosol acidity not associated
- 10 µg/m³ in $PM_{2.5}$ gave a 1.5% increase in daily mortality
- $PM_{2.5}$ are, in general, combustion-derived



Source: Dockery et al., NEJM, 329, 1753, 1993

Particle Formation Mechanism during Ironmaking

Volumetric Expansion and Volatile Evolution of Iron Ores during Heating

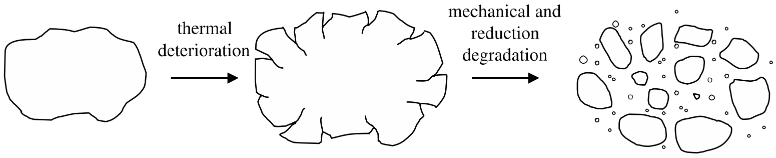


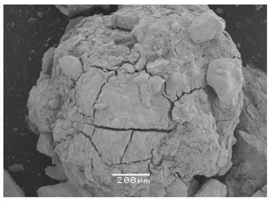
A goethite FeOOH

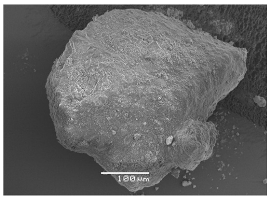
B hematite Fe_2O_3

Source: Strezov et al., Int. J. Mineral Processing, 100 (2011) 27

Particle Formation during Thermal Processing of Iron Ores



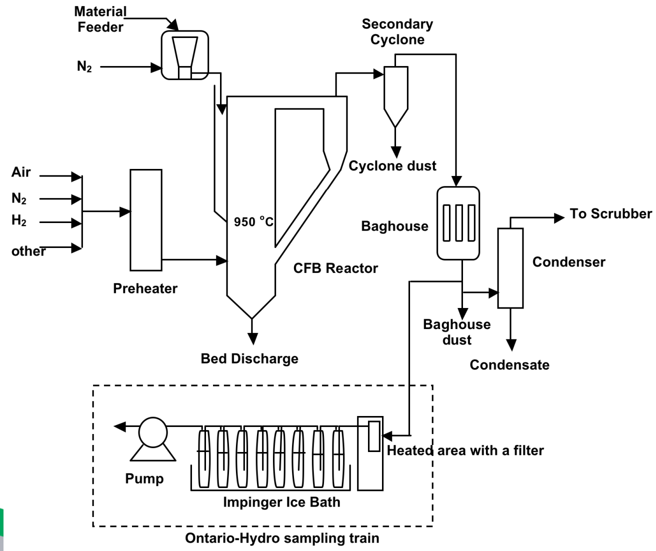




Source: Strezov et al., Int. J. Mineral Processing, 100 (2011) 27

Emissions from Direct Ironmaking Process

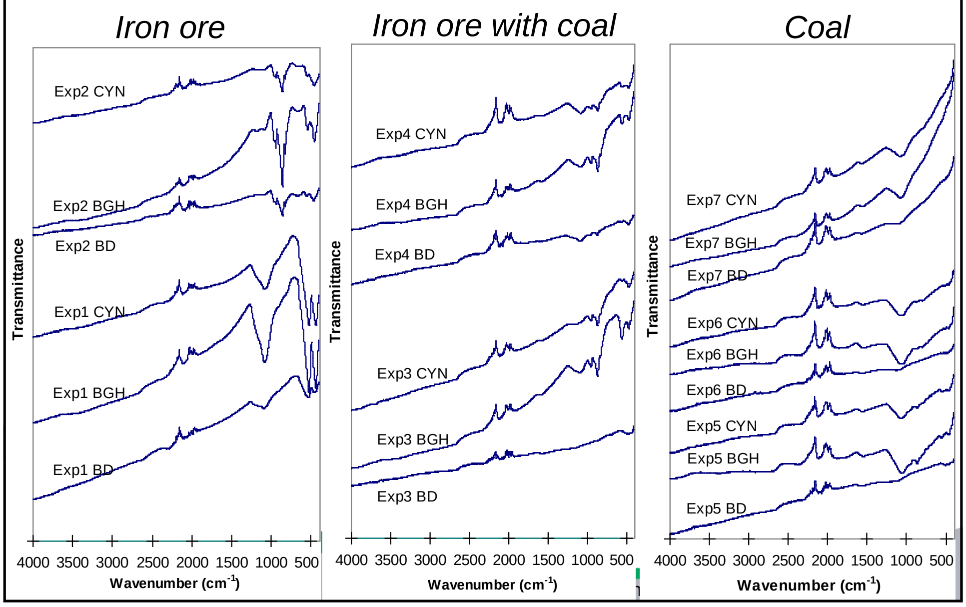
Emissions from Direct Ironmaking



Operating Parameters

Experiment	Feed materials	Mass fed (kg)		Fluidising gas	Fluidising Gas rates (L/min)	Other Gas Flows (N_2) (L/min)
		Coal	Iron Ore			
1	Iron Ore	0	4	N_2	60	40
2	Iron Ore	0	4	H_2/N_2	30/40	40
3	Iron Ore + Coal	2	2	N_2	60	40
4	Iron Ore + Coal	2	2	H_2/N_2	30/40	20
5	Coal	4	0	CO_2/N_2	20/40	20
6	Coal	4	0	Air/$\mathbf{N_2}$	5/55	40
7	Coal	4	0	**Air**/N_2	20/40	40

FTIR Spectra of Particles Collected from the Fluidised Bed Reactor



Trace Element Analysis

Experiments		Raw Samples		Iron Ore under N_2			Iron Ore under H_2/N_2			Iron Ore + coal under N_2	
				Experiment 1			Experiment 2			Experim 3	
Trace Elements	Units	Iron ore	Coal	BD	BGH	CYN	BD	BGH	CYN	BD	BGH
Antimony (Sb)	mg/kg	< 0.5	< 0.5	< 0.5	0.61	1.2	0.58	0.51	2.6	< 0.5	< 0.5
Arsenic (As)	mg/kg	3.2	< 0.5	2	5.9	24	2.3	4.6	53	1.3	4.4
Berylium (Be)	mg/kg	0.5	2.5	0.57	0.83	1.4	0.91	1.5	3.8	0.82	1.1
Boron (B)	mg/kg	0.93	1.6	2.3	4.3	6.8	4.4	9.8	25	2.7	5.1
Cadmium (Cd)	mg/kg	< 0.5	< 0.5	< 0.5	0.77	3.3	< 0.5	0.86	9.3	< 0.5	< 0.5
Chromium (Cr)	mg/kg	11	7.8	8.9	14	34	12	17	36	8.2	20
Cobalt (Co)	mg/kg	2.6	11	2.7	3.3	6.7	3.6	3.2	5.2	3.4	5.2
Copper (Cu)	mg/kg	6	5.4	7.1	25	49	11	13	30	4.8	15
Lead (Pb)	mg/kg	14	8.9	2.1	4.6	22	0.54	16	63	1.1	13
Manganese (Mn)	mg/kg	750	1.7	1260	940	1370	1380	1200	2090	55	930
Nickel (Ni)	mg/kg	5.2	23	17	46	200	14	23	53	8.4	82
Selenium (Se)	mg/kg	< 0.5	0.59	< 0.5	< 0.5	1.7	< 0.5	< 0.5	4	< 0.5	0.71
Thorium (Th)	mg/kg	1.1	2.6	1	1.5	3.4	1.3	1.6	3.5	1.4	1.5
Uranium (U)	mg/kg	0.64	0.54	0.5	0.73	1.3	0.75	0.86	1.6	0.5	0.69
Zinc (Zn)	mg/kg	8.4	54	9.8	30	190	6.5	74	180	14	82
Total Solids	%	99.6	80.4								

Mercury Analysis

Exp.	Total Mercury	Elemental Mercury Hg(0)		Oxidised Mercury Hg(II)		Particle Bound Mercury Hg(P)	
	μg/Nm^3	μg/Nm^3	%	μg/Nm^3	%	μg/Nm^3	%
1	3.25	3.2	98.7	0	0	0.04	1.3
2	2.3	1.9	82.2	0	0	0.4	17.8
3	0.45	0.3	71.5	0.1	26.2	0.01	2.3
4	4.21	4.1	97.3	0.01	0.4	0.1	2.3
5	3.3	2.4	72.7	0	0	0.9	27.3
6	7.40	7.3	98.1	0	0	0.1	1.9

Mercury in Fish

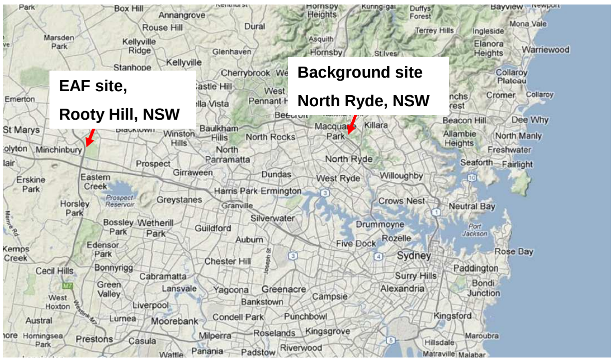
NUMBER OF SERVES OF DIFFERENT TYPES OF FISH THAT CAN BE SAFELY CONSUMED

Pregnant women and women planning pregnancy 1 serve equals 150 grams#	Children (up to 6 years) 1 serve equals 75 grams#	Rest of the population 1 serve equals 150 grams#
2 – 3 serves per week of any fish and seafood not listed in the column below		2 – 3 serves per week of any fish and seafood not listed in the column below
OR		OR
1 serve per week of Orange Roughy (Deep Sea Perch) or Catfish and no other fish that week		1 serve per week of Shark (Flake) or Billfish (Swordfish/Broadbill, and Marlin) and no other fish that week
OR		OR
1 serve per fortnight of Shark (Flake) or Billfish (Swordfish/Broadbill, and Marlin) and no other fish that fortnight		

FOOD STANDARDS Australia New Zealand

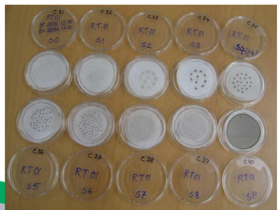
Atmospheric Particle Sampling

Sampling details



Sampling locations

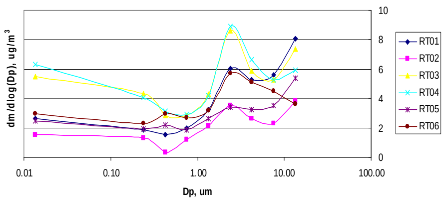
Eight staged MOUDI sampler

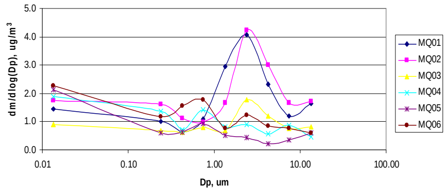


Air particulates on Teflon filter

Air particulates distribution

	EAF site			Background site		
	Min	Max	Mean	Min	Max	Mean
TSP, ug/m³	19.1	50.8	37.1	8.3	17.8	12.4
PM_{10}, ug/m³	15.3	44.9	31.4	7.7	16.0	11.5
$PM_{2.5}$, ug/m³	7.5	26.4	17.5	5.0	9.3	7.5
PM_1, ug/m³	4.7	19.8	12.8	3.8	8.3	5.8





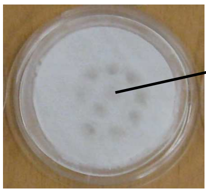
Elemental concentration, ng/m3

TSP

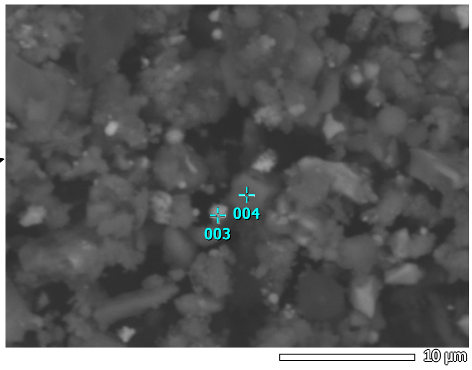
	EAF site			Background site		
	Min	Max	Mean	Min	Max	Mean
Na	nd	nd	--	nd	4774.3	832.1
Al	507.8	1353.8	859.2	34.4	182.0	121.0
Si	1989.5	5445.2	3412.1	329.5	843.3	607.4
P	nd	nd	--	nd	nd	--
S	125.3	737.5	409.7	136.7	1130.4	529.7
Cl	122.7	1921.2	759.9	86.3	4945.7	2170.6
K	112.9	517.3	296.3	89.6	222.9	144.2
Ca	3531.7	7418.4	5727.0	75.7	414.2	183.9
Ti	57.4	222.8	127.2	3.3	24.9	12.7
V	nd	nd	--	nd	nd	--
Cr	10.5	96.2	53.4	nd	nd	--
Mn	231.5	647.5	477.7	2.5	19.9	7.3
Fe	4169.6	24415.2	11791.3	251.4	586.7	400.2
Co	nd	nd	--	nd	nd	--
Ni	0.0	290.3	107.1	0.0	193.0	73.4
Cu	21.2	239.5	94.4	3.9	11.9	8.6
Zn	698.7	3685.5	1438.0	4.8	33.5	20.4
Br	nd	nd	--	nd	nd	--
Sr	nd	nd	--	nd	nd	--

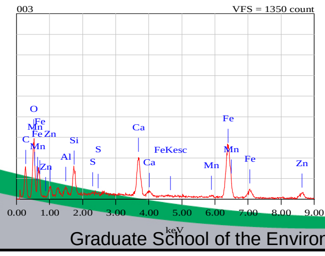
SEM-EDS analysis

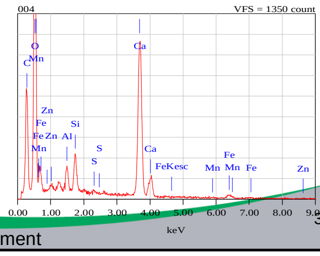
EAF site: RT02



Stage 2

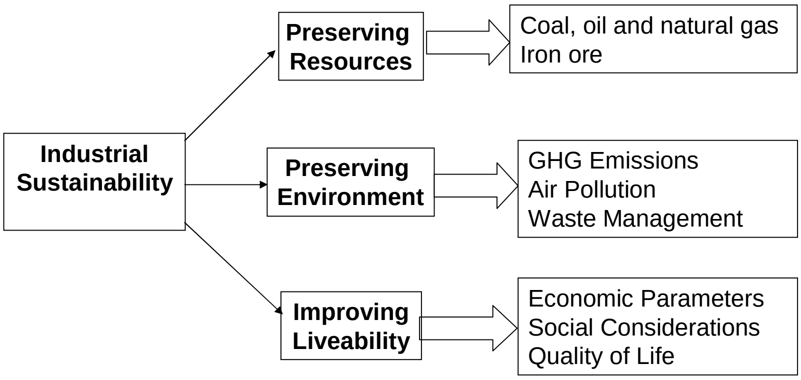






Sustainability of Iron and Steelmaking Operations

Sustainability of Industrial Operations



Sustainability of Ironmaking

- Case studies selected as examples:
  - BF/BOF – Wollongong, Australia
  - EAF – Rooty Hill, Australia
  - DRI – MIDREX plant in Contrecoeur, Canada
- Consumption parameters used:
  - Energy consumption, water consumption and land use
- Emission parameters:
  - Greenhouse gas emissions
  - Priority pollutants (NO_x, SO_2, CO, Pb, PM_{10} and $PM_{2.5}$)
  - Priority metals (Pb, As, Cr^{6+}, Hg, Ni, Cd)
- Pollutant inventory databases used for emission estimates:
  - Australian National Pollutant Inventory
  - Canadian National Release Pollutant Inventory

Sustainability parameters, expressed in metric tonne of steel (BF/BOF and EAF) or iron (DRI)

	BF/BOF	EAF	DRI
Energy consumption (GJ/t)	22	5.8	10
CO_{2e} emissions (tCO_{2e}/t)	2.1	0.7	0.4
Water consumption (m^3/t)	2.6	0.6	0.8
Land use (m^2/t)	1.7	0.5	0.4
Emissions to air (kg/t)			
NO_x	1	0.04	0.2
SO_2	1	7.4×10^{-4}	
CO	56	9.8	
PM_{10}	0.15	0.14	0.13
$PM_{2.5}$	1.4×10^{-2}	0.3×10^{-2}	7.7×10^{-2}
Pb	2.6×10^{-4}	1.4×10^{-4}	
Hg	9.8×10^{-6}	0.1×10^{-6}	
As	6.2×10^{-6}	6.6×10^{-6}	
Cr^{6+}	4.5×10^{-6}		
Ni	3.5×10^{-5}	1.6×10^{-5}	
Cd	8.1×10^{-6}	0.5×10^{-6}	

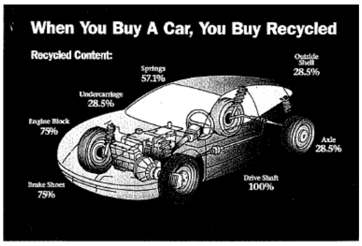
Sustainability parameters expressed in product $ value

	Ironmaking and Steelmaking			Coal fired Electricity Production	Wheat Production
	BF/BOF	EAF	DRI		
5 year increase in global production rate	20.6%	3.9%	24.1%	12.9%	15.3%
Product value ($/t or $/MWh)	715	650	510	265	276
Energy consumption (MJ/$)	31	9	20	14	9
CO_{2e} emissions ($kgCO_{2e}/\$$)	3	1.1	0.8	3.5	1.1
Water consumption (l/$)	3.6	0.9	1.7	290	5400
Land use ($m^2/\$$)	2.4×10^{-3}	0.7×10^{-3}	0.7×10^{-3}	1.8×10^{-3}	5×10^{-6}
Emissions to air (g/$)					
NO_x	1.3	0.06	0.45	2695	
SO_2	1.4	0.001		3930	
CO	80	15		93	
PM_{10}	0.2	0.2	0.25	23	
$PM_{2.5}$	0.02	0.004	0.15	11	
Pb	4×10^{-4}	2×10^{-4}		45×10^{-4}	
Hg	1×10^{-5}	0.01×10^{-5}		33×10^{-3}	
As	0.9×10^{-5}	1×10^{-5}		67×10^{-5}	
Cr^{6+}	0.6×10^{-5}			22×10^{-5}	
Ni	5×10^{-5}	2.5×10^{-5}		719×10^{-5}	
Cd	1×10^{-5}	0.08×10^{-5}		562×10^{-5}	

Normalised sustainability index and technology ranking

	Ironmaking and Steelmaking			Coal fired Electricity Production	Wheat Production
	BF/BOF	EAF	DRI Midrex		
Normalised overall sustainability index	0.25	0.85	0.8	0.08	1
Technology ranking	4	2	3	5	1

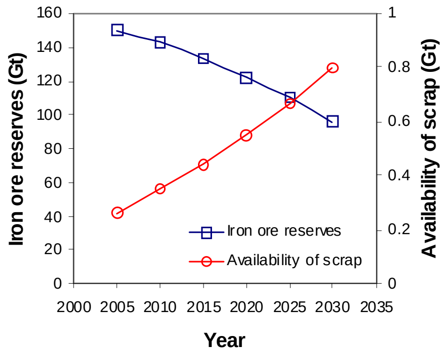
Recycling Steel



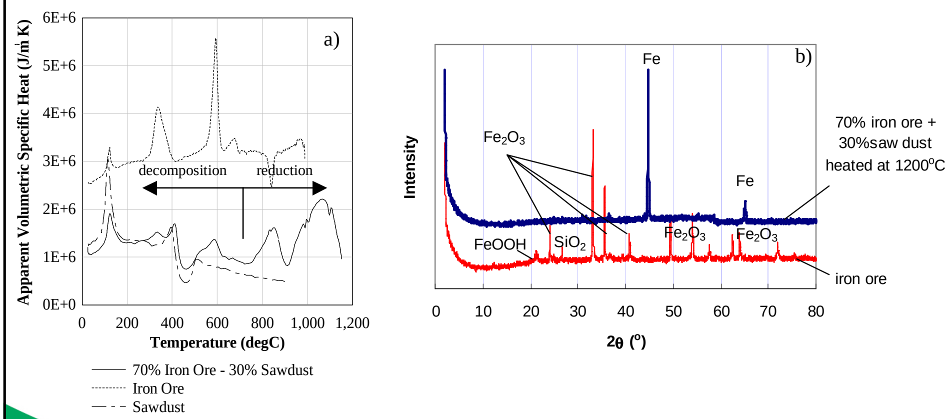
Source: Szekely, ISIJ Int, 1996

- High demand for scrap steel
- Developed market
- 50-67% recycling rate
- GHG reduction

Iron ore reserves and availability of scrap steel for recycling

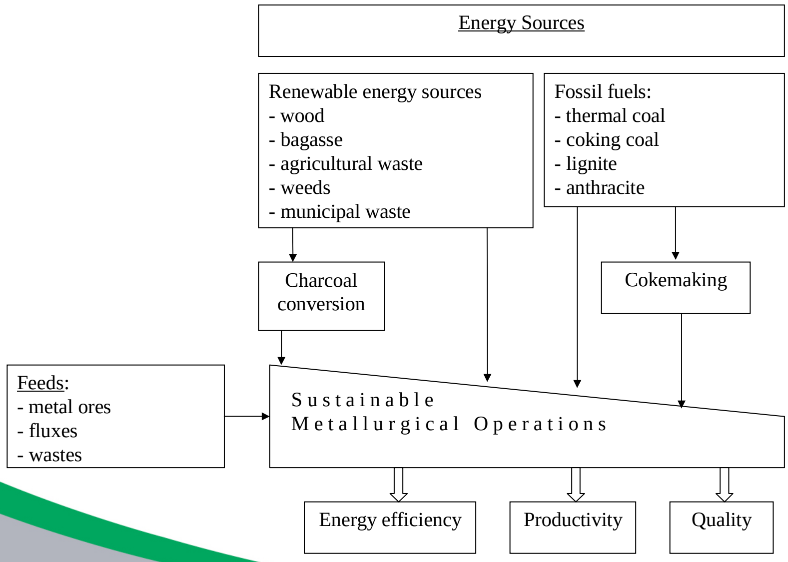


Iron Ore Reduction with Biomass



Strezov, *Renewable Energy*, 31, 1892-1905, 2006

Towards Sustainable Metallurgy



Strezov, *Renewable Energy*, 31, 1892-1905, 2006

Acknowledgement

- Dr Tim Evans, Rio Tinto
- Prof Peter Nelson, Macquarie University
- Dr Artur Ziolkowski
- Dr Pushan Shah
- Mr Kazi Mohiuddin, Macquarie University