Raw Materials Improvement Report
# Table of contents

Message from worldsteel Safety, Technology and Environment Director, Henk Reimink......(v)
Message from Project Chairman, Tata Steel Limited Raw Materials and Ironmaking Technology Chief, Ashok Kumar .................................................................(vi)
Executive summary ........................................................................................................(vii)

1. About the World Steel Association ................................................................................ 1
   1.1 Aims and Objectives ................................................................................................. 1
   1.2 History ..................................................................................................................... 1
2. Project background ............................................................................................................. 2
   2.1 Goals and objectives ................................................................................................. 6
   2.2 Scope ....................................................................................................................... 7
   2.3 Objectives ............................................................................................................... 7
   2.4 Methodology of data collection ............................................................................... 7
   2.5 Deliverables ............................................................................................................. 9
   2.6 Working group ....................................................................................................... 9
   2.7 Project timeline and meetings ............................................................................... 10
3. Iron ore scenario ............................................................................................................. 11
   3.1 Worldwide iron ore availability and use ................................................................. 11
   3.2 Regional iron ore availability ................................................................................. 16
   3.3 Survey results in iron ore part ................................................................................ 47
   3.4 Identification of raw material processing technologies ....................................... 48
   3.5 Case studies – China ............................................................................................ 56
4. Coal/coke scenario ........................................................................................................... 61
   4.1 Worldwide coal availability and use ................................................................. 61
   4.2 Regional coal availability ..................................................................................... 64
   4.3 Survey results in metallurgical coal part ............................................................. 65
   4.4 Identification of coal/coke processing technologies ........................................... 68
5. Ironmaking technology scenario .................................................................................... 72
   5.1 Overview of the processes and survey results .................................................. 72
      5.1.1 Blast furnace .................................................................................................... 72
      5.1.2 Sinter .............................................................................................................. 72
      5.1.3 Alternate ironmaking processes ...................................................................... 90
   5.2 Identified good practices ..................................................................................... 101
6. Raw materials efficiency model .................................................................................. 102
7. Conclusions ................................................................................................................ 103
   7.1 Raw material management ............................................................................... 103
   7.2 Technology development .................................................................................... 105
   7.3 Proposals for follow-up .................................................................................... 106
   7.4 Identified good practices .................................................................................... 106
   7.5 Identified problematic areas ............................................................................... 108
   7.6 Concerns over future supply ............................................................................ 109
8. Appendices.................................................................................................................................................. 111
   Appendix A: Resources/reserves definitions ......................................................................................... 111
   Appendix B: Iron ore reserves per country and type .............................................................................. 112
   Appendix C: Raw materials issues in the steel industry ........................................................................ 112
   Appendix D: List of potential technologies in iron and steelmaking ..................................................... 115
   Appendix E: Regional iron ore availability ............................................................................................ 116
   Appendix F: Regional coal availability and trade .................................................................................. 121
   Appendix G: Treatment of waste gas streams ....................................................................................... 121
   Appendix H: References for Section 4 (coal/coke scenario) ................................................................. 125
   Appendix I: Raw material survey questionnaires .................................................................................. 126
   Appendix J: References ......................................................................................................................... 127
   Appendix K: Survey responses .............................................................................................................. 135
   Appendix L: Conversion glossary ............................................................................................................ 146
Message from worldsteel Safety, Technology and Environment Director, Henk Reimink

This report provides high-level insight and analysis for members to acquire quality raw materials appropriate for their specific operation. The initial project team comprised 21 project members from 18 member companies and one association. The project was hopeful that supplying organisations would support this project and be able to identify some of the mining or beneficiation techniques – this was not supported formally, but worldsteel did receive informal information that allowed the team to verify some of their findings or confirm reserves.

The information available in the public arena was also useful for the reserves data on raw materials. The project team set to work in a very enthusiastic manner and managed to bring in expert support from within their companies, who then also became supportive of the work. The visits to the various sites were very useful in gaining a better understanding of what was possible and especially in building confidence that the industries’ ironmaking processes are very flexible in the use of a range of raw materials – the industry has been locked into a supply route in many cases from earlier long-term contracts that at the time suited both suppliers and customers.

This report identifies that the industry has a very wide operating envelope, which it can use to its advantage and the quarterly supply contracts make it even more flexible towards changing supply routes to suit the quality and economic delivery of raw materials. The use of lower grades has a direct and proportional impact on throughput and slag rate as well as energy, material use and consequently emissions. So to maintain ironmaking efficiency, the material can be upgraded to a commonly used level with simple technology and light investment by the raw materials suppliers. The outcome of this project has been successful in removing some of the constraints the industry thought it had and it can now take advantage of the flexibility from the abundant resources that will ensure raw materials will be economically available for centuries.

Henk Reimink
Safety, Technology and Environment Director
World Steel Association
Message from Project Chairman, Tata Steel Limited Raw Materials and Ironmaking Technology Chief, Ashok Kumar

Raw materials have an overwhelming impact on the profitability of the industry. This project was conceived against the backdrop of a perceived shortage of volume as well as decline in quality of available raw materials resources.

The project’s prime purpose was to share and learn through the exchange of information across regions and develop the steel industry’s own view of the raw material resource scene availability and techniques to upgrade as well as practices to use inferior quality materials in steelmaking. The team's composition certainly facilitated this, and we would like to thank the companies of each of our project participants for their support.

We attempted to include iron ore and coal suppliers' views; however, with few notable exceptions, we had limited success. The team members, however, produced a comprehensive view of their respective regions and jointly have managed to provide a fair world view of iron ore and coal resources.

We would like to thank the raw material resource companies that did open their doors and the technology suppliers who shared insights into ways of conditioning the raw materials for use in steelmaking. Assessment of reserves across the world does not indicate any imminent risk of running out of Fe or carbon sources to meet the requirement for steel production. It is true, however, that the rapid increase in demand led by China and other events have caused shifts in prices and new resources.

Without stealing the thunder from the report itself, let it be said that when looked at as an entity across the world, raw materials used for steelmaking have a rather wide range of properties. Where possible, beneficiation of coal and iron ore is carried out extensively to reduce impurity levels and there are instances of higher gangue raw materials being used in steelmaking. The quality of raw materials appears not to be linked to the fortunes of the industry and 'value in use' is very much the operating mantra.

Yet the quality of raw materials does make a difference to the technical performance level of a steel plant, nor to the environmental impact of the production process. Steelmakers are therefore concerned about the longevity of the resource base and technology interventions to counter possible shifts in quality. Use of ‘inferior’ raw materials is a declared initiative in most technology plans. We also spent time debating the role alternative ironmaking technologies play or could play in tackling possible quality shifts in available raw materials. We were impressed with how much variation in approach and accommodation of raw material varieties is possible while remaining within the ambit of the BF-BOF route. Special thanks to the worldsteel technology team and staff for keeping the project team going and their generosity with their support. The report points to a broad existence of practices – worldsteel helped us to create a project that is focused on significant possibilities.

On behalf of the project team,

Ashok Kumar
Raw Materials and Ironmaking Technology Chief
Tata Steel Limited
Executive summary

The World Steel Association’s technical committee members approved this project to explore the use of lower-grade raw materials. The project began in February 2010 with 21 project participants from 17 member companies and one association. The team put together a simple survey on raw material usage and invited the worldsteel membership to participate. The raw materials suppliers were also invited; however, they declined to participate formally. The project also wanted to have an overview of globally available resources and this was a major task for a small group to find the regional resources. However, this has added substantially to understanding the supply options and future opportunities for supply. The main analysis of the work was completed in 2011 with the remainder of the time taken to verify conclusions and present the findings to TECO-03 in May 2012, which were approved, finalising the report by the end of July 2012.

Current and long-term raw materials supply scenarios have a significant impact on raw materials resources, both in the development of new reserves and the level of quality available. Increasing steel demand has gradually diminished easy access to quality raw materials. The economic changes in the supply of ore has changed the focus for the steel industry to seek out a wider supply base for raw material and turn towards blending, beneficiation and agglomeration processes. As well as innovative coke, sinter and ironmaking technologies, which enable the utilisation of lower grade raw materials, increasing steel production via conventional BF-BOF route and utilising lower quality of raw materials proportionally results in higher consumption of coal, coke and iron ore.

This requires additional energy, produces more slag and emissions at a proportionately higher rate and reduces the productivity of the blast furnace process. This project deals with the issues of using lower grade raw materials that have been improved or upgraded in the existing raw materials handling and ironmaking processes (coke making and sintering). There has also been the introduction of processes that have a wider tolerance for lower grade raw materials (eg iron nuggets, sponge iron etc) and the upgrading of raw materials by beneficiation processes (iron ore and coal).

This report also builds a trend and relationship between publicly available information on reserves, material quality aspects and quantity forecast, and identifies the potential impact of delayed or prolonged exploration of reserves. The sharing of operating experiences especially with those that use lower grade material in India, China and Russia as well as those that use traditional sources from Australia and Brazil has identified a very wide operating envelope. For organisations with their own raw materials resources, this report will assist in outlining sound strategies for raw material management, appropriate selection of investment in either mining and beneficiation equipment while maintaining their ironmaking efficiency. By upgrading existing facilities, installing proven technology and creating an appropriate level of beneficiation and agglomeration techniques for both iron ore and coal, most organisations can unlock from a specific supply route for ore and coal.
The information received from 19 companies has shown that there is great flexibility in the ironmaking process (blast furnace) that can take many differently sourced materials and levels of quality. They have an impact of course on the efficiency and hot metal throughput and slag rate. This however can be offset by beneficiating the material to get a consistent input quality level – the material does not have to come from the same place each time. The change in supply contract period from one year plus to quarterly in the ore industry in particular now provides an excellent opportunity to source material from many suppliers.

From the data most are able to provide the level of quality that is standard for the industry at 63 – 65% Fe. The ability to negotiate with many suppliers will create a competitive market that will be to the industry's economic advantage. This means that this level of flexibility allows sites and organisations to create a supply route that is flexible and relevant for the industry, depending on the economic climate. It will reduce the perceived ability for few suppliers to monopolise supply of raw materials.

Member companies located in the regions where availability of good quality of lump iron ore is limited and in the future need to use lower-grade materials will affect their equipment’s productivity and this may breach environmental regulations or license limits or their own operating standards. The project team members originate from major steel companies from across the worldsteel membership; the group includes mining experts, technical and engineering specialists and chief technology representatives from the participating sites.

The project group developed the survey questionnaire to collect the information related to raw materials quality, availability, beneficiation methods, and lower grade materials influence on coke, sinter and ironmaking. The outcome was collected using two quantitative surveys and allowed analysis and conclusions to be drawn from these. The information was verified by the team with their colleagues on their sites to ensure the conclusions and recommendations were achievable and practical as well as obtaining qualitative information from members in the form of case studies. Project meetings and site visits were held in relevant locations, generously hosted by member companies. This allowed project participants to realise the material issues/concerns and infer more robust outcomes.
1. About the World Steel Association

The World Steel Association is the focal point for the steel industry globally. It provides global leadership on significant strategic issues affecting the industry, particularly focusing on safety, technical, environmental issues. Worldsteel develops with its members the methodology and metrics for the industry and allows a sound base to be established using secure and confidential data bases with easy access by member companies. Worldsteel promotes steel as a product and the industry to its customers, within the industry, media, financial markets, international institutions and the general public. Worldsteel assists its members to expand or develop markets for steel, managing major projects in the construction, manufacturing and automobile industry.

1.1 Aims and objectives

Steel is considered as the most important, innovative, recyclable and adaptable material for the 21st century. Worldsteel supports its members to be profitable and thus rewarding shareholders and encouraging investment in new products and processes.

Key objectives include:

• To deliver an injury free, illness free and healthy workplace.
• To minimise the industry environmental footprint and being held accountable for emissions to air, water and soil.
• To free the industry of government involvement, which distorts the market and prevents fair competition.

1.2 History

Table 1 – Important dates

<table>
<thead>
<tr>
<th>Year</th>
<th>Event</th>
</tr>
</thead>
<tbody>
<tr>
<td>1967</td>
<td>International Iron and Steel Institute (IISI) established. One member from nine European countries + Japan and US covering three regions of the world</td>
</tr>
<tr>
<td>1970</td>
<td>Five regions of the world now covered, with companies joining from India, Brazil and Argentina</td>
</tr>
<tr>
<td>1980s/90s</td>
<td>Seven regions of the world now covered, with companies joining from Korea and first Affiliate Member joins from Russia.</td>
</tr>
<tr>
<td>1994</td>
<td>Annual International Management Seminar (IMS) starts</td>
</tr>
<tr>
<td>1997</td>
<td>Joint UNEP/IISI Report on Environmental Issues in steel</td>
</tr>
<tr>
<td>2003</td>
<td>Steeluniversity.org launched</td>
</tr>
<tr>
<td>2004</td>
<td>Formal entry of five-largest Chinese producers into membership (Baosteel, Anshan, Handan, Shougang, Wuhan) + CISA</td>
</tr>
<tr>
<td>2005</td>
<td>First Sustainability Report published</td>
</tr>
<tr>
<td>2006</td>
<td>Beijing office opened and Safety and Health Principles agreed</td>
</tr>
<tr>
<td>2008</td>
<td>IISI changes its name to World Steel Association (worldsteel)</td>
</tr>
</tbody>
</table>
2. Project background

With the increasing demand for steel, requirement of raw material rises proportionally. There are limited sources of high-quality raw materials and increased utilisation of these for steelmaking will deplete them over time.

This forces the industry to use lower-grade material to be able to meet the demand for the building of infrastructure and increased standard of living in developing countries. The use of lower-grade material is affecting the productivity in blast furnaces due to increased processing of non-metallic components, which is turned into by-products (slag).

This report addresses key challenges faced by the steel industry in the medium – to long-term, when high-grade raw materials are more difficult to obtain. This leads to strategic raw material management, utilising lower-grade materials and employing beneficiation techniques to ensure the ironmaking processes remains at the high level of efficiency and create the lowest level of by-products, energy use or emissions.

This has the additional benefit of transporting the minimum amount of raw materials in their improved state.

Figure 1 – Outlook of steel demand and likely impact on raw materials processing technologies

Global crude steel production

Global crude steel production is likely to continue in the future with a growth rate of around 3-4%, as identified by Raw Materials Group, Sweden.
Table 2 – Global crude steel production forecast

<table>
<thead>
<tr>
<th>Region</th>
<th>2007 production</th>
<th>2000-07 growth rate</th>
<th>2010 production</th>
<th>2010-20 growth rate</th>
<th>2020 production</th>
</tr>
</thead>
<tbody>
<tr>
<td>EU-27</td>
<td>210</td>
<td>1.2</td>
<td>175</td>
<td>0.5</td>
<td>184</td>
</tr>
<tr>
<td>CIS</td>
<td>98</td>
<td>4.1</td>
<td>105</td>
<td>2.5</td>
<td>134</td>
</tr>
<tr>
<td>N. AMERICA</td>
<td>131</td>
<td>0.3</td>
<td>110</td>
<td>1</td>
<td>115</td>
</tr>
<tr>
<td>S. AMERICA</td>
<td>50</td>
<td>3</td>
<td>45</td>
<td>2</td>
<td>55</td>
</tr>
<tr>
<td>AFRICA</td>
<td>19</td>
<td>4.5</td>
<td>16</td>
<td>4</td>
<td>24</td>
</tr>
<tr>
<td>CHINA</td>
<td>489</td>
<td>21.2</td>
<td>640</td>
<td>5</td>
<td>1042</td>
</tr>
<tr>
<td>JAPAN</td>
<td>120</td>
<td>1.7</td>
<td>107</td>
<td>0</td>
<td>107</td>
</tr>
<tr>
<td>KOREA</td>
<td>5.1</td>
<td>3.3</td>
<td>55</td>
<td>2</td>
<td>67</td>
</tr>
<tr>
<td>REST OF ASIA</td>
<td>136</td>
<td>7.5</td>
<td>120</td>
<td>6</td>
<td>195</td>
</tr>
<tr>
<td>REST OF WORLD</td>
<td>39</td>
<td>1.7</td>
<td>38</td>
<td>1</td>
<td>42</td>
</tr>
<tr>
<td>TOTAL</td>
<td>1343</td>
<td>6.8</td>
<td>1411</td>
<td>3.4</td>
<td>1965</td>
</tr>
</tbody>
</table>

Based on the above table, the requirement of key raw material will also be growing at a proportional rate.

China’s steel demand growth is expected to continue to absorb the new supply of iron ore, keeping global supply/demand aligned.

Figure 2 – Global iron ore supply/demand outlook (million tonnes)

Quality position – iron ore

Current iron ore quality indicates that, in the near future, the requirement of beneficiation and blending processes has to optimise the use of raw materials, based on the quality and quantity of ore availability from key regions, and develop other sources of material if available.
Long-term beneficiation targets

- Fe upgrading to current levels of use and iron recovery from other sources
- Reduction of gangue phases (SiO2 and Al2O3)
- Reduction of elements with detrimental effects on iron – and steelmaking and product quality, especially P, S, K2O, Na2O, non-ferrous metals
- Optimum preparation for agglomeration and ironmaking processes

Reducing environmental footprints in steel industry

Utilisation of low grade raw material by conventional and widely adopted ironmaking process such as blast furnaces increases the risk of exceeding environmental norms or license limits.

This is also the highest energy emission intensity-step in steelmaking, accountable for more than half of the total energy use in the overall steelmaking process.

Reducing agents such as coal and coke (among others) are used in blast furnaces and impact on efficiency. Thus maintaining a low reducing agent rate (RAR) is the key factor in reducing emission of CO2 intensity.

Graph 1 – Country-wise RAR consumption pattern

The best performing regions are Germany and South Korea, using an RAR of 493 kilogrammes per tonne of hot metal (kg/thm). On average, India uses 760 kg/thm, which is high compared with other countries.

This corresponds with Indian sources (SAIL, 2005) that indicate total energy use for steelmaking is 60% to 75% above comparable plants in OECD countries.

This data reflects the quality of input raw materials, equipment and process efficiency responsible for high RAR.

Table 3 – RAR Reduction Enablers

<table>
<thead>
<tr>
<th>Reduction of RAR</th>
<th>Enablers</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 Increase in shaft efficiency</td>
<td>Improving operation</td>
</tr>
<tr>
<td>2 Decrease in heat loss</td>
<td>Decrease in heat load to BF</td>
</tr>
<tr>
<td>– Heat transfer to BF</td>
<td>Decrease in ash and gangue</td>
</tr>
<tr>
<td>– Heat of slag and metal.</td>
<td></td>
</tr>
<tr>
<td>3 Blast condition</td>
<td>Decrease in blast moisture increase in blast temp</td>
</tr>
<tr>
<td>4 Improve equilibrium</td>
<td>Natural gas, plastic injection</td>
</tr>
<tr>
<td>– Application of H₂</td>
<td>Improve reducibility of raw materials</td>
</tr>
<tr>
<td>– Decrease in TR.</td>
<td></td>
</tr>
<tr>
<td>5 Reduction condition</td>
<td>Use of pre-reduced ore/metal</td>
</tr>
<tr>
<td>Decrease in O/Fe ratio</td>
<td></td>
</tr>
</tbody>
</table>

The above table indicates how raw material condition is important for reduction in RAR and influences directly the level of CO2 emissions into the atmosphere.
Best available technology and technical savings potential

According to a study conducted by the International Energy Agency (IEA), the total potential energy saving on a global basis is around 133 Mtoe (million tonnes of oil equivalent). If achieved, this would result in 421 million tonnes of CO2 being eliminated. In the case of India, the potential energy savings that could be achieved by applying BATs amount to 6.1 Mtoe is approximately 16% of the energy use in Indian iron and steel sector.

Graph 2: Country wise energy-saving potential, Mtoe

Mtoe (million tonne of oil equivalent):
1 toe coal 29.308 GJ 7 Gcal
1 toe oil 41.868 GJ 10 Gcal

2.1 Goals and objectives

The main objective for undertaking *Raw Materials Improvement* is to carry out research from within the worldsteel membership and with some external sources to develop a project report in order to identify the current best and emerging technologies and practices using low-grade iron ore and coal efficiently and share these techniques with the worldsteel participating members.

The goals of the worldsteel project on raw material beneficiation:

1. Clarifying the status of raw materials supply sources, consumption and potential future sources (key areas only of existing sites or large potential sites)
2. Optimal and environmental responsible way to utilise the available raw material sources, whilst taking care of environmental factors i.e. slag, emissions, water, energy consumption
3. Clarification of status of technology for beneficiation of low grade materials (different types of ore using specific type of beneficiation)

This will expand the understanding of worldsteel members of raw material sources, quality levels and technologies using low grade raw materials in an optimal manner and allow pressure to be applied to raw material providers to improve quality of the remaining raw materials and avoid a degradation of the coke, sinter and ironmaking processes.
2.2 Scope

The scope of the project is to provide a status of current and potential raw material supplies among the member companies/potential suppliers, and if known new sources of supply not yet explored but surveyed.

Collect information on technologies for utilisation of low-grade raw materials in the following three categories:

1. Conventional technology for ironmaking process to use low grade materials.
2. New technologies, including those under development, for ironmaking (DRI, SR or similar).
3. Raw Material Improvement technologies.

The scope covers the following material and processes:

- Material
- Iron ore, coking coal
- Processes
- Mining
- Improvement (how, for what type of material and what is practical)
- Agglomeration (sintering, pelletising)
- Coking operation
- Blast furnace operation
- New processes, ironmaking technology under development

2.3 Objectives

1. Understanding raw material sources and qualities levels and technologies using low grade raw materials.
2. Sharing of necessary data and its analysis to:
   - Understand the available techniques for improving iron ore and coal properties for use in ironmaking;
   - Introduce types of management techniques, and;
   - Link these above items with country backgrounds and experiences.

2.4 Methodology of data collection

The project team split into three subgroups, namely iron ore, coal and ironmaking. Individual group members decided to collect the information in two ways, firstly by means of survey data received from member companies and also from a few major raw materials suppliers, secondly from the information available in the public domain. Ore suppliers were contacted, but did not respond fully – the project team received some informal information, but had to rely on equipment suppliers and those members who have their own material resources to determine current techniques.
A. Development of the survey and data collection (Refer Appendix I)

The first phase of the project concentrated on the type and quality of data that needed to be collected in order for the results to be comparable. Instead of using complex software to collect information, efforts were put into the design and development of a survey using MS Excel that simplified the collection of data and allowed participants to submit information easier.

It was a challenge to use a single survey format to collect data from different types of mines and plants. The survey was developed in such a way that all identified processes and sub-processes have their own sections.

The following data requests were made in the survey:

**General information about the company:**

a) Name, address  
b) Annual production

**Specific information:**

a) Mining
   
   • Resource (proved, probable, measured and inferred)  
   • Mining technology  
   • Equipment  
   • Mine type and mine wise stripping ratio

b) Plant
   
   • Feed quality of plant before beneficiation  
   • Product type with production ratio  
   • Improved product quality  
   • Specific power and water consumption  
   • Flow chart  
   • Constraints and challenges and future projects  
   • Best practices and blending technology

**Uncertainties**

The reliability of the survey depends on the robustness of the data. This means that in making a comparison it is necessary to take into account the quality, accuracy and origins of the data in a way that will not lead to any misinterpretations, wrong conclusions or generalisations.

B. Information available in public domain

The project team agreed to collect more information on raw materials from public domain and from other known reliable sources in order to get broader picture for the project. The bibliography identifies the material available.
2.5 Deliverables

Deliverables for the raw material project are: final project report, a dedicated seminar at TECO 03, South Africa and a compact disc containing ‘Raw Material Cost Model’, Survey Data and Presentations.

2.6 Working Group

The project group consists of the following team members:

Table 4 – List of project members

<table>
<thead>
<tr>
<th>Chairman</th>
<th>Ashok Kumar</th>
<th>Tata Steel Limited</th>
</tr>
</thead>
<tbody>
<tr>
<td>Secretariat</td>
<td>Henk Reimink</td>
<td>World Steel Association</td>
</tr>
</tbody>
</table>

Key project members

Atul Bhatnagar       | Tata Steel Limited |
D.P. Chakraborty    | Tata Steel Limited |
Alok Chandra        | Ispat Industries Limited (Now JSW Ispat Steel Ltd) |
Jan Dolfing          | Tata Steel Europe |
Elizabeth L. Fitzpatrick | BlueScope Steel Limited |
Konstantin Golovko  | Metinvest Holding LLC |
Nikolay Avdeyenko    | Metinvest Holding LLC |
Wang Jian            | Anshan Iron & Steel Group Corp. |
Euitae Kim           | POSCO |
Jinbo Kim            | POSCO EU Office |
Sahubji Kuchroo      | Tata Steel Limited |
Darryle Lathlean     | BlueScope Steel Limited |
Jean-Louis Lebonvallet | ArcelorMittal |
Louis W. Lherbier    | United States Steel Corporation |
Dr Rongshan Lin      | Dillinger Hüttenwerke AG |
Dr-Ing. Hans Bodo Lüngen | Stahl Institut VDEh (Steel Institute VDEh) |
Zejun Ma             | Shougang Group |
P.K. Murugan         | JSW Steel Limited |
Roberto Musante      | Ternium Siderar |
Kenichi Nagano       | Nippon Steel Corporation |
P.C. Tibrewal        | Steel Authority of India Ltd. (SAIL) |
Sing-Tsu Tsai        | China Steel Corporation |
Dr Haifa Xu          | Baoshan Iron & Steel Co., Ltd. |
Jialong Yang         | Wuhan Iron and Steel (Group) Corp. (WISCO) |
Jay Parwani          | World Steel Association |
2.7 Project timeline and meetings

Meeting 1: 2–4 February, 2010 – Brussels
Meeting 2: 28 June – 2 July, 2010 – Sweden (Hosted by LKAB Kiruna)
Meeting 3: 25–28 October, 2010 – India (Hosted by Tata Steel)
Meeting 4: 30 May – 1 June, 2011 – Brussels
Meeting 5: 24–26 October, 2011 – Australia (Hosted by Bluescope Steel)
Meeting 6: 17-18 April, 2012 – Brussels

Figure 5 – Project timeline and meetings
3. Iron ore scenario

Project Group Members DP Chakraborty, Sahabji Kuchroo (Tata Steel Limited), Konstantin Golovko (Metinvest Holding LLC), Jian Wang (Anshan Steel), Jay Parwani (worldsteel).

Resources availability, proved reserves and trade scenario are appraised in this section of the report. Information received by means of the surveys from member companies and also from few suppliers has been showcased.

3.1 Worldwide iron ore availability and use

World iron ore resources are estimated to be more than 800 billion tonnes, with possible iron content of 230 billion tonnes. From this, 180 billion tonnes are proven surveyed reserves having iron content of 87 billion tonnes. As indicated in the previous section, global crude steel production is likely to continue in the future with a growth rate of around 3-4%, as reported by the raw material group, Sweden. The growth rate of iron ore reserves estimated as around 7.5% per annum, according to the US geological survey. This ascending growth of crude ore reserves is due to the conversion of some resources into reserves as well as due to exploration of further resources. US Geological survey estimates resources and reserves every year.

Table 5 – US geological survey estimates

<table>
<thead>
<tr>
<th>Year</th>
<th>Mine Production in million tonnes</th>
<th>Crude ore reserves in million tonnes</th>
<th>Addition in reserves%</th>
<th>Iron content in million tonnes</th>
<th>Fe % in ROM</th>
</tr>
</thead>
<tbody>
<tr>
<td>2008</td>
<td>2220</td>
<td>150,000</td>
<td>-----</td>
<td>73,000</td>
<td>48.67</td>
</tr>
<tr>
<td>2009</td>
<td>2240</td>
<td>160,000</td>
<td>8.14</td>
<td>77,000</td>
<td>48.13</td>
</tr>
<tr>
<td>2010</td>
<td>2590</td>
<td>180,000</td>
<td>7.65</td>
<td>87,000</td>
<td>48.33</td>
</tr>
<tr>
<td>2011</td>
<td>2800e</td>
<td>170,000</td>
<td>7.40</td>
<td>80,000</td>
<td>47.06</td>
</tr>
</tbody>
</table>

Graph 3 – Trend of world iron ore reserves and Fe content
The graph reflects the crude ore reserves in the world and their Fe content. As exploration increases, the Fe percentage is expected to decrease and reserves of low Fe percentage will increase. The growth rate of reserves is more than 7.5%. Iron content and Fe percentage varies greatly depending on the types of ore reserves.

Global crude steel production is likely to continue to grow at a rate of around 3-4%, as per the report of raw material group, Sweden. Based on the current reserves and steel production growth figures, steel demand could be fulfilled uninterruptedly for the next 50 years.

**Graph 4 – Country-wise trend of iron ore reserves and Fe content** *(Source: US Geological Survey)*

**Table 6 – List of countries with annual mine production and iron ore reserves**

<table>
<thead>
<tr>
<th>Crude ore reserves</th>
<th>Mine production in million tonnes</th>
<th>Iron Ore Reserve in million tonnes</th>
<th>Iron Content</th>
<th>Fe percentage in ROM</th>
</tr>
</thead>
<tbody>
<tr>
<td>Australia</td>
<td>433</td>
<td>35000</td>
<td>17000</td>
<td>48.6</td>
</tr>
<tr>
<td>Brazil</td>
<td>370</td>
<td>29000</td>
<td>16000</td>
<td>55.2</td>
</tr>
<tr>
<td>Canada</td>
<td>37</td>
<td>6300</td>
<td>2300</td>
<td>36.5</td>
</tr>
<tr>
<td>China</td>
<td>1070</td>
<td>23000</td>
<td>7200</td>
<td>31.3</td>
</tr>
<tr>
<td>India</td>
<td>230</td>
<td>7000</td>
<td>4500</td>
<td>64.3</td>
</tr>
<tr>
<td>Kazakhstan</td>
<td>24</td>
<td>3000</td>
<td>1000</td>
<td>33.3</td>
</tr>
<tr>
<td>Russia</td>
<td>101</td>
<td>25000</td>
<td>14000</td>
<td>56.0</td>
</tr>
<tr>
<td>South Africa</td>
<td>59</td>
<td>1000</td>
<td>650</td>
<td>65.0</td>
</tr>
<tr>
<td>Sweden</td>
<td>25</td>
<td>3500</td>
<td>2200</td>
<td>62.9</td>
</tr>
<tr>
<td>Ukraine</td>
<td>78</td>
<td>6000</td>
<td>2100</td>
<td>35.0</td>
</tr>
<tr>
<td>US</td>
<td>50</td>
<td>6900</td>
<td>2100</td>
<td>30.4</td>
</tr>
<tr>
<td>World total (rounded)</td>
<td>2590</td>
<td>170000</td>
<td>80000</td>
<td>47.1</td>
</tr>
</tbody>
</table>
A significant drop in iron ore with exploration of new reserves with relatively lesser Fe percentages, this may potentially be the likely scenario for rest of the regions.
Graph 8 – Trend of iron ore reserves and Fe content – China

Graph 9 – Trend of iron ore reserves and Fe content – India

Although, India is showing a stable trend of Fe percentage with the exploration of further high quality reserves, but considering the marketable Fe, this may reflect a descending trend.

Graph 10 – Trend of iron ore reserves and Fe content - Brazil (Source-CRU)
World iron ore trade scenario

In 2010, 1.7 billion tonnes of iron ore were produced. Almost 80% of this production came from four countries – Australia, China, Brazil and India. For exports, Australia, India and Brazil contribute approximately 80% of total global exports in the industry. On the other hand, China is the world’s largest importer, importing 619 million tonnes in 2010, more than 60% of all global imports, with an average quality level of 62% Fe.

During the period 2005-2010, global iron ore demand rose from 1,489 million tonnes to 1,800 million tonnes, mostly due to demand from China. Annual iron ore demand is expected to continue its growth over the next ten years, with CRU estimating global demand of 2,700 million tonnes by 2021. CRU estimated global seaborne trade of iron ore was 992 million tonnes in 2010. CRU expects the expansion of the seaborne iron ore market will continue and that by 2021, the seaborne iron ore trade will be 1,475 million tonnes.

The demand in China is driving the growth of the industry, with seaborne iron ore imports into China comprising 80% of the increase in global seaborne iron ore imports between 2010 and 2021. In 2011, world trade in iron ore was forecast to increase by 5% to 1.1 billion tonnes. Over the medium term, world iron ore trade is projected to increase at an annual average rate of 5%, reaching 1.4 billion tonnes in 2016.

China’s imports are projected to continue to grow strongly and the major growth in iron ore supply is expected to come from Australian and Brazilian producers.

Outlook for world iron ore trade

Graph 11 – Outlook of iron ore export

China’s reliance on imports to increase

China is the world’s largest importer of iron ore, and will continue to be so over the medium term. In 2011, China’s imports of iron ore increased by 11% to 686 million tonnes. China was expected to import 728 million tonnes of iron ore in 2012.
Over the outlook period, Chinese steel producers are expected to increase their reliance on imported ore for a number of reasons: available domestic reserves are declining in quality and are mostly in remote areas with limited infrastructure to bring it to the ironmaking sites; an increasing number of steel mills are located in coastal regions with easy access to ports; and efforts are being made to produce higher or more complex grades of steel in China, which will underpin increased demand for relatively high-quality iron ore from Australia and Brazil.

Over the period 2011 to 2016, China’s imports are projected to increase at an annual average rate of 5%, reaching 857 million tonnes by 2016. This is projected to account for approximately 62% of domestic iron ore consumption, compared with an estimated 57% in 2010.

Graph 12 – Outlook of iron ore import

3.2 Regional iron ore availability

Project members from Iron ore group proposed areas to report the regional iron ore statistics. The scope for each region covers:

- Resource/reserve/grade
- Production/consumption/export
- Improvement processes adopted
- Policy/regulation
- Key challenges/difficulties

Australia

Resource/Reserve/Grade

Hematite has been the dominant iron ore mined in Australia since the early 1960s. Approximately 96% of Australia’s iron ore exports are high-grade hematite, the majority of which has been mined from deposits in the Hamersley province of Western Australia (WA). The Brockman Iron Formation in Hamersley province is a prime example of high-grade hematite iron ore deposits.
Magnetite mineral contains 72.4% iron, which is higher than hematite. Despite this, the common presence of impurities in magnetite ores makes them lower grade and more costly to produce concentrates used in steel smelters. Magnetite mining is an emerging industry in Australia with large deposits in the Pilbara region (WA) being developed. The largest project is the USD$5.2 billion Sino Iron project being developed by the Chinese company Citic Pacific. To date, the other major magnetite development is the $2.6 billion Karara joint venture project owned by Gindalbie Metals and Chinese steel producer Ansteel.

In previous years, Geoscience Australia has reported estimates of Australia's national resources of iron as tonnes of iron ore because these resources were dominantly hematite ores. However, as a result of ongoing exploration and assessment of magnetite deposits, Australia has now identified substantial reserves and resources in both hematite and magnetite ores. Because of the high average grades (percentage Fe) of hematite ores when compared to the average grades for magnetite ores, it is necessary to report national resources in terms of 'contained Fe'. Accordingly, for 2010, Australia's national resources of iron are reported in two categories:

a) Tonnes of iron ore
b) Tonnes of contained Fe

In 2010, Economic Demonstrated Resources (EDR) of iron ore increased by 23% to 34.5 billion tonnes because of increased resources for some deposits, including in the WA mines Balmoral Central, Marillana, Roy Hill, Robe River, Mount Whaleback, Karara, West Pilbara, Hamersley, Solomon, Mining Area C, Gabanintha and Jack Hills. Resource definition of existing deposits and the inclusion of new magnetite deposits have also contributed to the increase in EDR. Paramarginal Demonstrated Resources (para marginal resources are a mix of hematite, magnetite and goethite within 300 metres of the surface suitable for open pit mining) have increased from 0.3Gt to 0.7Gt Inferred resources increased by 65% to 47.8Gt because of large increases at Hamersley, Balmoral Central, Karara, Mining Area C, and Solomon mines. The inclusion of 19 new deposits also contributed to the high Inferred Resources for 2010. Western Australia has around 98% of the country’s total identified resources of iron ore with the majority of the resources occurring in the Pilbara region. Almost half of the 34.5 billion tonnes EDR is accessible, except for 18 million tonnes (Mt) at ore body, 23 billion tonnes in the Newman District (WA) and 30% of the Windarling resource (WA). Both have been quarantined for environmental reasons. At current rates of mine production, accessible EDR for iron ores is sufficient for approximately 80 years.

The total Joint Ore Reserve Committee (JORC) Code Reserves of iron ore were estimated to be 13.6 billion tonnes representing 39% of accessible EDR. Contained iron is 7.1 billion tonnes or 42% of the EDR of contained Fe. At the current rate of mine production, JORC Code Reserves are sufficient for around 31 years. A total of 19 new deposits, mostly occurring in WA, were added to Australia’s iron ore resource base during 2010. They are Cashmere Downs (Cashmere Iron), Magnetite Range (Accent Resources), Steeple Hill (Fairstar Resources), Extension (Iron Holdings), Mount Forrest (Mindax) Boundary (IOH), Buckland Hills, Fingers, Hawsons, Hercules (Iron Clad), Koodaideri South, Mount Dove, Mount Padbury, North Star, Warrawanda, Yerecoin (Giralia Resources), Weld Range, Spear hole (Dynasty Metals) and Bilberatha Hill (Venus Metals Ltd).
Production/Consumption/Exports

Around 92% of Australia’s annual production is exported to integrated steel markets in Asia. According to a report by the Australian Bureau of Agricultural and Resource Economics and Sciences (ABARES), Australia’s iron ore production in 2010 was 433.5Mt (393.9Mt in 2009) with 97% produced in WA. Exports in 2010 totalled 401.9 million tonnes (362.4 million tonnes in 2009), with a value of $47.166 billion.

Table 7 – Iron ore production in million tonnes

<table>
<thead>
<tr>
<th></th>
<th>2007-08</th>
<th>2008-09</th>
<th>2009-10</th>
<th>% Change</th>
</tr>
</thead>
<tbody>
<tr>
<td>Iron ore (Mt)</td>
<td>324.7</td>
<td>353</td>
<td>423.4</td>
<td>19.9</td>
</tr>
</tbody>
</table>

Figure 6 – Iron ore export from Australia

In 2010, Australia had approximately 18% of world EDR of iron ore and was ranked second after China (37%). In terms of contained iron, Australia has around 19% of the world’s EDR and is ranked first, with Brazil second (18%).

Improvement

High-grade hematite ores are referred to as direct shipping ore (DSO) because they are mined and beneficiated using a relatively simple crushing and screening process before being exported for use in steelmaking. Australia’s hematite DSO from the Hamersley region (WA) averages from 56% to 62% iron (Fe). Magnetite ores require initial crushing and screening the same as hematite ores, but also includes a second stage of processing. This second stage relies on the magnetic properties of the ore and involves large scale magnetic separators being used to separate the magnetite and produce a concentrate. Consequently, the types of magnetite minerals, include coarse and fine grained magnetite, are important economically. Metallurgical tests on both coarse-grained and fine-grained magnetite ores (Accent Resources, 2009) show that the coarse grained magnetite Banded Iron Formation (BIF) (mass concentrate recovery is 45.9% at 69.2% iron content) performed better with regard to mass recovery when compared to fine-grained magnetite (mass concentrate recovery is 29% at 69.6% iron). Size requirements
also differ for both mineral types, so that fine-grained magnetite BIF 80% passing size require 45 microns, while coarse grained magnetite BIF 80% passing size require 75 microns, which results in less grinding energy.

<table>
<thead>
<tr>
<th>Type of Ore</th>
<th>Improvement Process</th>
<th>Mass concentrate recovery (%)</th>
<th>Size requirements</th>
</tr>
</thead>
<tbody>
<tr>
<td>Magnetite – course grained (BIF)</td>
<td>Crushing, screening, magnetic separation</td>
<td>From 45.9 at 69.2 Fe</td>
<td>80% of 75 microns</td>
</tr>
<tr>
<td>Magnetite – fine grained</td>
<td></td>
<td>From 29 at 69.6 Fe</td>
<td>80% of 45 microns</td>
</tr>
</tbody>
</table>

Further processing involves the agglomeration and thermal treatment of the concentrate to produce pellets that can be used directly in blast furnaces or in direct reduction steel-making plants. The pellets contain 65% to 70% iron, being a higher iron grade than hematite DSOs currently being exported from the Hamersley region. Additionally, the magnetite pellets contain lower levels of impurities, particularly phosphorous, sulphur and alumina when compared with hematite DSOs. These pellets are premium products that attract higher prices from steelmakers, offsetting the higher costs of producing magnetite pellets.

**Government policy/regulation**

The general rule is that the Crown (or state government) owns all minerals. This has been implemented by statute; initially by enacting that all future grants of land must contain a reservation to the Crown of all minerals. Now, all new grants of freehold titles in Australia have provided that all minerals are reserved for the Crown. In relation to minerals situated within state boundaries, *prima facie*, the power to legislate for minerals remains with the states in Australia.

However, despite the fact that the Constitution of Australia does not list minerals as an area over which the Federal Parliament has jurisdiction, a number of the Commonwealth Parliament’s powers encompass matters relevant to mining operations and any legislation of the Commonwealth based upon these powers will override any inconsistent state legislation. As to Commonwealth jurisdiction over the territories, the constitutional limitations regarding mining operations conducted within the states have no application in the northern territory, or other Australian territories.

Each of the states and territories has its own legislation regulating the exploration for and production of onshore minerals. The Commonwealth has no onshore mining legislation that is applicable in the states or territories.

As to offshore minerals, the Commonwealth has sovereignty in respect of the territorial sea, and sovereign rights in respect of both the continental shelf and the exclusive economic zone for the purpose of exploration of the natural resources. Thus, the sovereignty over minerals of the states and the Northern territory extends only to the low-water mark and it is the Commonwealth which is entitled under international law to exercise sovereignty over minerals under the territorial sea, within the exclusive economic zone and on the continental shelf.
However, following an agreement negotiated between the Commonwealth government and the states in 1979, the Commonwealth conferred power on the states and the Northern territory to make laws for matters including mining operations in respect of the coastal waters and granted them proprietary rights to the seabed.

Key challenges/difficulties

Australia is a key player on the global resources stage. Australian mines are unique in that these have a substantial amount of resources and are geographically close to key markets – namely China and India, but Australian mines are faced with capacity constraints.

That means Australian export earnings have already and continue to be hampered by port and rail infrastructure, skills shortages and approval complexities. Industry commentary indicates that had Australia maintained its global market share between 2002 and 2007, it is estimated that Australia would have earned an additional AUD$17 billion.

Whilst capacity constraints have been on the national agenda for some time, Australia’s global market share of the resources market has slid backwards and needs increased attention to avoid slipping further. Australia has a situation in which blue- and white-collar skills shortages seen in the 2002 to 2007 boom period are forecast to continue and likely to worsen.

In addition, Australia’s complex regulatory environment means that approval processes can be lengthy, which in turn further deprives Australia of export revenue. Finally, Australia’s rail and port networks have struggled to keep pace with production capacity, let alone predicted growth from the mining and resources sector.

This is further exacerbated by what are effectively different user systems and commercial drivers applied by asset owners/operators. On the eastern seaboard, Australia has a predominantly multi-user rail and port infrastructure system and on the western seaboard a largely single user system (dedicated for specific owners). While there are merits to both, matters of joint user needs, competition policy and interface with government functions present challenges for either model.

Brazil

Resource/reserve/grade

Total Brazilian iron ore reserves reach 29 billion tonnes, with the largest reserves being located within the south-eastern, southern and northern systems and the Algeria Complex. The south-eastern system mines are located in the Iron Quadrangle region of the state of Minas Gerais, where they are divided into three mining sites (Itabira, Minas Centrais and Mariana). The ore reserves in the three mining sites have high ratios of itabirite ore relative to hematite ore.

Itabirite ore has iron grade of 35–60% and requires concentration to achieve shipping grade, which is at least 63.5% Fe average. At the three mining sites, sinter feed, lump ore and pellet feed are produced by standard crushing, classification and concentration steps in the beneficiation plants. The southern system mines are located in the Iron Quadrangle region of the state of Minas Gerais in Brazil.
The system has three major mining complexes: Minas Itabirito (comprising four mines, with two major beneficiation plants and three secondary beneficiation plants), Vargem Grande (comprised of three mines and one major beneficiation plant); and Paraopeba (comprised of four mines and three beneficiation plants). Run-of-mine ore is beneficiated into sinter feed, lump ore and pellet feed.

The northern system mines, located in the Carajas mineral province of the Brazilian state of Para, contain some of the largest iron ore deposits in the world. The reserves are divided into northern, southern and eastern ranges situated 35km apart.

The system has open-pit mines and an ore-processing plant. The mines are located on public lands for which mining concessions are held. Because of the high grade of the Carajas ore (66.7% Fe on average) there is no need to operate a concentration plant in the area. The beneficiation process consists simply of crushing, screening, hydrocycloning and filtration. Output of the beneficiation process consists of ore for sinter feed and pellet feed.

The midwestern system comprises the mines of Urucum and Corumba, located in the state of Mato Grosso do Sul. The Urucum ore reserves contain a high ratio of hematite ore, which has an average grade of 62.2%. The Urucum and Corumba operations have standard crushing and classification steps, producing lumps and fines. Iron ore products from the Urucum and Corumba mines are delivered to customers by barges travelling along the Paraguay and Parana rivers.

In the Alegria Complex ores are friable and compact hematite ore and friable itabirite. The itabirites have several mineral compositions with predominance of one, two or three major minerals: hematite (or specularite martite), goethite and magnetite.

The gangue minerals are mainly quartz and traces of clay minerals (kaolinite) and micas.

**Vale and Samarco iron ore reserves in Brazil**

**Table 8 – Brazil Iron ore deposits, ore type and mining methods**

<table>
<thead>
<tr>
<th>Iron ore deposit</th>
<th>Proven reserves (Mt)</th>
<th>Probable reserves (Mt)</th>
<th>Total reserves (Mt)</th>
<th>Type of ore</th>
<th>Mining method</th>
</tr>
</thead>
<tbody>
<tr>
<td>South-eastern system</td>
<td>2,220</td>
<td>1,279</td>
<td>3,499</td>
<td>Hematite-itabirite (50.6% Fe)</td>
<td>open-pit</td>
</tr>
<tr>
<td>Southern system</td>
<td>1,460</td>
<td>1,811</td>
<td>3,271</td>
<td>(50.3% Fe)</td>
<td>open-pit</td>
</tr>
<tr>
<td>Midwestern system</td>
<td>8</td>
<td>28</td>
<td>35</td>
<td>(62.2% Fe)</td>
<td>open-pit</td>
</tr>
<tr>
<td>Northern system</td>
<td>4,949</td>
<td>2,311</td>
<td>7,260</td>
<td>(66.8% Fe)</td>
<td>open-pit</td>
</tr>
<tr>
<td>Alegria Complex (Samarco)</td>
<td>1,134</td>
<td>935</td>
<td>2,069</td>
<td>Hematite-itabirite (41.2% Fe)</td>
<td>open-pit</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>9,771</strong></td>
<td><strong>6,364</strong></td>
<td><strong>16,135</strong></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Production/consumption/export

Brazil produced 312 Mt of beneficiated iron ore in 2010 compared with 261 Mt in 2009, ranking the second world’s largest producer after Australia with an 18% share of total world production. Of that production, almost 80% was from the leading iron ore producers – Vale, 62.4%; Minerações Brasileiras Reunidas (MBR), 16.4%; and Samarco Mineração, 5.2%. Other producers, such as Companhia Siderúrgica Nacional (CSN), contributed 16%. The leading importers of Brazilian iron ore were China (31%); Japan (11%); Germany (8.5%); France, Italy, and the Republic of Korea (4% each); and others (37.5%).

Graph 13 – Iron ore production trend in Brazil

Brazilian iron ore industry is heavily export-oriented. Domestic consumption in 2010 was estimated at 43Mt, roughly 14% of exports. Brazil’s exports are forecast to increase steadily over the outlook period, growing at an annual average of 6% to reach 436 million tonnes in 2016. A significant proportion of these exports are expected to be sourced from expansions to Vale’s Brazilian operations.

Graph 14 – Trend of iron ore export and domestic consumption – Brazil
Improvement processes

Types of beneficiation in Brazil

A typical beneficiation process at the Brazilian mines for hematite-itabirite ores consists simply of sising operations, including screening, hydrocycloning, crushing, flotation and filtration. Output from the beneficiation process consists of sinter feed and pellet feed.

Figure 7 – Iron ore beneficiation flow chart, Type 1

Mining and processing are subject to extensive regulation, which differs in each jurisdiction of the operations.

The jurisdictions typically have government agencies that are charged with granting mining concessions and monitoring compliance with mining law and regulations. For example, mining activities in Brazil are supervised by the National Mineral Production Department or DNPM, an agency of the federal ministry of mines and energy. This ministry is planning to propose changes to the Brazilian Mining Code, which if adopted may have important implications for mining operations in Brazil or require unexpected capital expenditures. In Brazil, mining companies pay a royalty, known as the CFEM, on the revenues from the sale of minerals which they extract, net of taxes, insurance costs and costs of transportation. The current royalty rates for iron ore are 2%. The Brazilian government is preparing to propose changes in the CFEM regime. Any changes must be incorporated into a final proposal by DNPM, which is then subject to approval by the Brazilian National Congress.

Key challenges/difficulties

Investment in mining requires a substantial amount of funds in order to replenish reserves, expand production capacity, build infrastructure (rail, ports) and preserve or rehabilitate the environment. Both the sensitivity to industrial production and the need for significant capital investments create sources of financial risk for the mining industry in Brazil. Brazilian reserves are gradually depleted in the ordinary course of a given mining operation. As mining progresses, distances to the primary crusher and to waste deposits become longer, pits become steeper and underground operations become deeper. As a result, over time, unit extraction costs could be rise with respect to each mine. Regarding the existing operations, the restrictions
on production can occur from the identification of cavities in mines, which can disrupt their operation. For new designs, the risk is the delay/failure to obtain environmental permits, which may delay the starting of these projects and impact on the volume produced.

South Africa

Resource/reserve/grade

South African iron ore resources, estimated at nearly 5.37 billion tonnes, are ranked 9th largest in the world. If the Bushveld Complex’s lower-grade potential resources are included, the resource base increases by 26.4 billion tonnes, which would then rank South Africa’s iron ore resources as the sixth largest. In terms of export of iron ore, South Africa is ranked number six. The principal deposits of iron ore in South Africa are the superior-type banded iron formations of the Transvaal Supergroup in the Northern Cape Province, which can be traced as a prominent, arcuate range of hills for some 400km from Pomfret in the north to Prieska in the south. The most significant deposits occur in the vicinity of Postmasburg and Sishen, where high-grade hematite concentrations have been preserved in the narrow north-south trending belt of the iron – and manganese-bearing lithologies of the Asbestos Hills Subgroup (around 2.6 million tonnes at Beeshoek Mine, Sishen Mine and Welgevonden deposit – Astrup et al., 1998). An additional 100 million tonnes are estimated to occur as hematite concentrations within the Penge Formation of the Chuniespoort Group (Transvaal Supergroup), which crop out along the northern rim of the Bushveld Complex near Thabazimbi in the Limpopo Province. The Bushveld Igneous Complex also contains approximately 26.4 billion tonnes of iron ore resources in the form of titaniferous magnetite, titanium dioxide and vanadium pentoxide: 50 – 67% Fe; 8 – 22% TiO2; 0 – 2% V2O5 (Astrup et al., 1998).

Other significant magnetite deposits are estimated to contain in the region of 2,600 million tonnes iron ore resources (Astrup et al., 1998). These include the high-grade Palabora and Mapochs Mines (0.3 billion tonnes) as well as the low-grade Zandrivierspoort, Moonlight, Cascade, Delft, De Loskop, Kraaipan Station, Kromdraai and Crocodile River deposits (2,300 million tonnes).

Production/consumption/exports

The four major producers are BHP Billiton, Rio Tinto, Vale and Kumba Resources. South African based Kumba is said to be the fourth largest after the three aforementioned companies. Kumba came into being as a result of the separation of the mining and the steelmaking components of Iscor Ltd in 2001. This separation came at a price for Kumba as the separation agreement requires that Kumba provides Iscor, since globalised and renamed Ispat – Iscor, with iron ore at cost. Its main sources of ore are Thabazimbi mine and the Sishen mine.

Kumba accounts for 80% of SA iron ore exports and Assmang accounts for the bulk of the remaining 20%. Kumba is one of the world’s premier suppliers of high quality lump-iron ore to the international steel industry and owns a large proportion of the known lump-ore reserves in the world. Kumba also sells 4.5 million tonnes per annum to Ispat-Iscor. The group annually produces 24 million tonnes of iron ore from Sishen and some 2.5 million tonnes from Thabazimbi. Eighty per cent of ore from Sishen is exported and the remainder sold locally. The two producers use the Saldanha Bay harbour to export their iron ore. Ore is transported from the Northern Cape by
means of rail on the Orex line. Exports have been limited by lack of capacity on the rail way line as well as the handling facilities at the port. Port infrastructure is being upgraded and is now nearing completion with the installation of additional rail way wagon tippers and increased stockyard capacity. The rail upgrade will consist mainly of the purchase of additional rolling stock.

**Figure 8 – South African iron ore projection and key mine sites**

![Graph 8](image)

*Graph 8: South African iron ore projection and key mine sites.*

**Graph 15 – Iron ore production trend: South Africa**

![Graph 15](image)

*Graph 15: Iron ore production trend: South Africa.*
Improvement

Most iron ore in South Africa is beneficiated through dense medium separation or jigging at the mine site, in order to convert the mined ore into a saleable product and/or to increase its value in use (VIU) to local and international steel producers. The upgrading of ferrous ores by jigging has been a trend in recent years in South Africa. The incorporation of the enhanced technology of a new fines gate has overcome the problem experienced worldwide in the separation of fine ferrous ores. The new jig gate minimises the back mixing of fine concentrate with reject before discharge. All flux separators are used in iron ore beneficiation for classification and simultaneously upgrading.

At least one final product can be obtained typically, while the other two sized products may be processed further. The all flux technology is in use for more than five years in South Africa, the first plant in Australia was commissioned early in 2012. Four more iron ore plants in India are under construction.

Figure 9 – Iron ore beneficiation flow chart Type 2

India

Resource/reserve/grade

Hematite and magnetite are the most important iron ores in India. Around 59% of hematite ore deposits are found in the eastern sector. About 92% magnetite ore deposits occur in Southern Sector, especially in Karnataka. Of these, hematite is considered to be superior because of its high grade. Indian deposits of hematite belong to the pre-Cambrian iron ore series and the ore is within banded iron ore formations occurring as massive, laminated, friable and powdery form.

As per UNFC system, the total provisional resources of hematite in 2010 are estimated at 17.9 billion tonnes of which 8.1 billion tonnes (45%) are under 'reserve' category and the balance 9.8 billion tonnes (55%) are under 'remaining resources' category. By grades, lumps constitute around 56% followed by fines (21%), lumps with fines (13%) and the remaining 10% are black iron ore, others and not known grades. Major resources of hematite are located in:
Iron ore scenario

Odisha – 5,930 million tonnes (33%),
Jharkhand – 4,597 million tonnes (26%),
Chhattisgarh – 3,292 million tonnes (18%)
Karnataka – 2,159 million tonnes (12%) and
Goa – 927 million tonnes (5%).

The balance resources of hematite are spread in Andhra Pradesh, Assam, Bihar, Maharashtra, Madhya Pradesh, Meghalaya, Rajasthan and Uttar Pradesh. Magnetite is another principal iron ore that also occurs in the form of oxide, either in igneous or metamorphosed banded magnetite-silica formation, possibly of sedimentary origin.

As per UNFC system total resources of magnetite in 2010 provisionally are estimated at 10.6 billion tonnes of which 'reserves' constitute 2.2 billion tonnes while 8.4 billion tonnes are placed under 'remaining resources'.

Classification on the basis of grades shows 21% resources of metallurgical grade while 77% resources belong to unclassified, not-known and other grades. India's 97% magnetite resources are located in its four states, namely Karnataka – 7.8 billion tonnes (73%), Andhra Pradesh – 1.5 billion tonnes (14%), Rajasthan – 0.53 billion tonnes and Tamil Nadu – 0.51 billion tonnes (5%). Assam, Bihar, Goa, Jharkhand, Kerala, Maharashtra, Meghalaya and Nagaland together account for the remaining 3% resources.

**Improvement**

Iron ore is upgraded to higher iron content through concentration. The choice of the beneficiation treatment depends on the nature of the gangue material present and its association with the ore structure. Several techniques such as washing, jigging, magnetic separation, advanced gravity separation and flotation are being employed to enhance the quality of the Iron ore. Due to the high density of hematite relative to silicates, beneficiation usually involves a combination of crushing and milling as well as heavy liquid separation.

**Figure 10 – Improvement process flow chart: Opencast mine**
Agglomeration of iron ore

Iron ore fines/blue dust cannot be charged in the blast furnace directly as they reduce the permeability of the burden and prevent the rising of the gasses inside the blast furnace. So they are agglomerated (by igniting at lower temperature causing only superficial fusion) into larger lumpy pieces with/without addition of additives like limestone, dolomite etc.

Two types of agglomerated products are commonly produced/used in the industry, namely sinter and pellet. Accordingly, the processes are known as sintering and pelletising respectively.

a) Sinter: Sinter is a clinker-like aggregate that is normally produced from relatively coarser fine iron ore (normally -3mm) mixed with coke breeze (-3mm), limestone dolomite fines (-3mm) and other metallurgical return wastes from the plant. Sinter is a much preferred input/raw material in blast furnaces. It improves blast furnace operation and productivity and reduces coke consumption in blast furnace. Presently, more than 50% hot metal in India is produced through the sinter and blast furnace route.

b) Pellets: Pellets are normally produced in the form of globules from very fine iron ore (normally -100 mesh) and mostly used for production of sponge iron in gas-based plants, though they are also used in blast furnaces in place of sized iron ore.

Government policy/regulation

Mining and processing are subject to extensive regulation. The Mines and Minerals (Development and Regulation) Act, 1957 (MMDR Act), lays down the legal framework for the regulation of mines and development of all minerals other than petroleum and natural gas. The central government has framed the Mineral Concession Rules, 1960 (MCR) for regulating grant of Reconnaissance Permits (PR), Prospecting Licenses (PL) and Mining Leases (ML) in respect of all minerals other than atomic minerals and minor minerals.

The central government has also framed the Mineral Conservation and Development Rules, 1988 (MCDR), for conservation and systematic development of minerals. These are applicable to all minerals except coal, atomic minerals and minor minerals.

Key challenges

The reserves of high-grade iron ore are limited (less than 20% of total reserve). Therefore, it would be necessary at this stage to ensure conservation of high-grade ore by blending with low-grade ores or beneficiating the lower grade ores.

R&D efforts are needed for developing necessary technologies for utilising more fines in the production of steel as a measure of conservation of iron ores.

Efforts are also necessary to utilise the tailings/waste as well. Investment in mining requires a substantial amount of funds in order to replenish reserves, expand production capacity, build infrastructure and preserve the environment.
Both the sensitivity to industrial production and the need for significant capital investments are important sources of financial risk for the mining industry.

Indian reserves are gradually depleted in the ordinary course of a given mining operation. As mining progresses, distances to the primary crusher and to waste deposits become longer, pits become steeper and underground operations become deeper. As a result, over time, unit extraction costs could increase with respect to each mine.

**European Union**

**Resource/Reserve/Grade**

Sweden is the leading producer of iron ore in the EU. It has substantial iron ore reserves, which have actively been developed. Mining and beneficiation of iron ore continues to be of significant importance to the country’s economy. Luossavaara-Kiirunavaara AB, LKAB (98% government owned) has mines at Kiruna and Malmberget in North Sweden above the Polar Circle.

**Kiruna:** The ore body in Kiruna is a single, enormous slice of magnetite. It is approximately four kilometres long, has an average width of 80 metres and extends to an estimated depth of two kilometres. It is inclined at roughly 60 degrees.

The main level is at a depth of 1045 metres below the surface. Mining of the ore body takes place between the 775 and 1,045-metre levels. Around 26 million tonnes of crude ore is mined each year.

**Malmberget:** The Malmberget mine consists of around 20 ore bodies, of which ten are currently mined. Most of the deposit consists of magnetite ore, but non-magnetic hematite also occurs. The present main level of the Malmberget mine is at a depth of 1000 metres. Around 14 million tonnes of crude ore is extracted from the ore bodies each year.

**Table 9 – Iron ore reserves estimates, ore type and mining method – EU**

<table>
<thead>
<tr>
<th>Company</th>
<th>Proven reserves (Mt)</th>
<th>Probable reserves (Mt)</th>
<th>Total Reserves (Mt)</th>
<th>Type of ore</th>
<th>Mining Method</th>
</tr>
</thead>
<tbody>
<tr>
<td>Kirunavaara</td>
<td>579</td>
<td>79</td>
<td>658</td>
<td>Magnetite (48,7% Fe)</td>
<td>Underground mining</td>
</tr>
<tr>
<td>Malmberget</td>
<td>270</td>
<td>52</td>
<td>322</td>
<td>Magnetite (42,5% Fe)</td>
<td>Underground mining</td>
</tr>
<tr>
<td>Gruvberger</td>
<td>10</td>
<td></td>
<td>10</td>
<td>Magnetite (52,2% Fe)</td>
<td>Open-pit</td>
</tr>
<tr>
<td>Total</td>
<td>859</td>
<td>131</td>
<td>990</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Production/consumption/export

In 2010 LKAB produced 25.3 million tonnes of iron ore products, of which 22.1 million tonnes were pellets and 3.2 million tonnes were fines.

Iron ore production in Sweden

Graph 16 – Iron ore production trend – Sweden
The iron ore products are mainly sold to European steel mills. Other important markets are North Africa, the Middle East and Southeast Asia.

Graph 17 – Iron ore trend of export and domestic consumption: Sweden

improvement processes in Sweden

LKAB's ore has high iron content and consists mainly of magnetite in a deep underground mine.

The main product is iron ore pellets manufactured from magnetite. During pellet manufacture, magnetite oxidises to hematite (Fe₂O₃→Fe₃O₄) - this creates large amounts of energy that can be utilised in the pelletising process. Therefore, the process requires significantly less fossil fuel, such as coal and oil for pelletising.

In the ore-processing plants at surface level, the crude ore is upgraded to pellets and fines. Ore is ground to a fine powder in several stages before undesirable components are removed by separators.
The concentrate is mixed with water to form slurry and pumped to the pelletising plant. The slurry is then dewatered with large filters, and then mixed with binders and additives, depending on the type of pellet to be produced.

**Government policy/regulation**

The government is the major equity owner of the country’s iron ore operations (98%).

**Key challenges/difficulties**

Mining is expected to remain very significant to Sweden’s economy. The global role of Sweden as an iron ore producer will increase as production increases. Within five to ten years, iron ore production is expected to reach 50 Mt/yr. Sweden has substantial iron ore deposits, which are expected to continue to be actively developed.

**Russia**

**Resource/reserve/grade**

Russia boasts the largest iron ore reserves in the world, some 99.4 billion tonnes, of which 55.66 billion are proven reserves. Total resources are 122.8 billion tonnes, which puts Russia among the top five iron ore resource-rich countries. The quality of the iron ores in Russia is lower than in Australia, Brazil and India, but higher than China.

The share of hematite/magnetite high-quality ores (50-60% Fe) account for only 12.6%, while the greater part of iron ore resources has iron content of 16-40% Fe. Two thirds of the iron-ore reserves are found in the European part of Russia, in the Kursk iron ore basin, which accounts for 64.6 billion tonnes of reserves.

A number of large iron-ore deposits such as Mikhailovskoye, Yakovlevskoye, Lebedinskoye, Stoilensky, Stoil-Lebedinskoye and Korobkovsky are located there.

Russia has 198 iron ore deposits in total, of which 79 deposits contain proven reserves.

**Table 10 – Russian iron ore reserves by mine**

<table>
<thead>
<tr>
<th>Iron ore deposit</th>
<th>Proven reserves (Mt)</th>
<th>Probable reserves (Mt)</th>
<th>Total reserves (Mt)</th>
<th>Type of ore</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mikhailovskoye</td>
<td>8,520</td>
<td>4,774</td>
<td>13,294</td>
<td>Hematite-magnetite in the ferruginous quartzites (39.6% Fe)</td>
</tr>
<tr>
<td>Stoilensky</td>
<td>5,414</td>
<td>2,216</td>
<td>7,630</td>
<td>Hematite-magnetite in the ferruginous quartzites (35% Fe)</td>
</tr>
<tr>
<td>Korobkovsky</td>
<td>2,149</td>
<td>1,705</td>
<td>3,854</td>
<td>Magnetite in the ferruginous quartzites (32.9% Fe)</td>
</tr>
<tr>
<td>Lebedinskoye</td>
<td>3,747</td>
<td>1,796</td>
<td>5,543</td>
<td>Magnetite in the ferruginous quartzites (34.6% Fe)</td>
</tr>
<tr>
<td>Iron ore deposit</td>
<td>Proven reserves (Mt)</td>
<td>Probable reserves (Mt)</td>
<td>Total reserves (Mt)</td>
<td>Type of ore</td>
</tr>
<tr>
<td>--------------------</td>
<td>----------------------</td>
<td>------------------------</td>
<td>---------------------</td>
<td>------------------------------------------------------</td>
</tr>
<tr>
<td>Stoi-Lebedinskoye</td>
<td>2,298</td>
<td>109</td>
<td>2,407</td>
<td>Magnetite in the ferruginous quartzites (35% Fe)</td>
</tr>
<tr>
<td>Gostischevskoe</td>
<td>2,595</td>
<td>7,559</td>
<td>10,154</td>
<td>Hematite-siderite-martite (61.6% Fe)</td>
</tr>
<tr>
<td>Prioskolskoe</td>
<td>1,560</td>
<td>678</td>
<td>2,238</td>
<td>Magnetite in the ferruginous quartzites (37.1% Fe)</td>
</tr>
<tr>
<td>Yakovlevskoye</td>
<td>1,866</td>
<td>7,740</td>
<td>9,606</td>
<td>Hematite-siderite-martite (60.5% Fe)</td>
</tr>
<tr>
<td>Kvodor</td>
<td>322</td>
<td>220</td>
<td>542</td>
<td>Apatite-magnetite (26% Fe)</td>
</tr>
<tr>
<td>Kostomuksha</td>
<td>812</td>
<td>88</td>
<td>900</td>
<td>Magnetite in the ferruginous quartzites (32.1% Fe)</td>
</tr>
<tr>
<td>Gusevogorskoie</td>
<td>2,705</td>
<td>2,411</td>
<td>5,116</td>
<td>Vanadium-titanium-magnetite (16.6% Fe)</td>
</tr>
<tr>
<td>Tashtagol</td>
<td>418</td>
<td>297</td>
<td>715</td>
<td>Magnetite (45.5% Fe)</td>
</tr>
<tr>
<td>Sheregeshevskoe</td>
<td>148</td>
<td>14</td>
<td>162</td>
<td>Magnetite (35.7% Fe)</td>
</tr>
<tr>
<td>Abakan</td>
<td>107</td>
<td>9</td>
<td>116</td>
<td>Magnetite (41% Fe)</td>
</tr>
<tr>
<td>Rudnogorsk</td>
<td>230</td>
<td>39</td>
<td>268</td>
<td>Magnetite in the ferruginous quartzites (32.7% Fe)</td>
</tr>
<tr>
<td>Chiney</td>
<td>464</td>
<td>472</td>
<td>936</td>
<td>Titanium-magnetite (33.5% Fe)</td>
</tr>
<tr>
<td>Vislovskoe</td>
<td>1,453</td>
<td>2,500</td>
<td>3,953</td>
<td>Hematite-siderite-martite (60.7% Fe)</td>
</tr>
<tr>
<td>Others</td>
<td>20,852</td>
<td>11,274</td>
<td>32,126</td>
<td>Various</td>
</tr>
<tr>
<td>Total</td>
<td>55,660</td>
<td>43,900</td>
<td>99,560</td>
<td></td>
</tr>
</tbody>
</table>

**Graph 18 – Russia yearly reserves proven – probable**

![Graph showing yearly reserves](image)

**Production/consumption/export**

In 2010, Russia produced 99 million tonnes of ore, which was 10.6% more than in 2009 and almost equal to the level of 2008. Iron ore concentrate is the predominant form of iron ore product, while production of sinter feed ore accounts for around 4.4% of the total production.
Due to the lower quality of Russian iron ore, merchant iron ore production in Russia is one third of the volume of ore mined. As a result, despite the sizeable run-of-mine output, Russia is in fifth place in the world in terms of merchant iron ore production.

Almost 90% of the total production of ore in Russia is consumed domestically, and relatively small volumes, around 11-12 million tonnes per annum, are exported. The main consumers of Russian iron ore are China, Ukraine, Slovakia, Turkey, Poland, Hungary, Czech Republic and South Korea.

In 2008 and 2009, the country reduced iron ore exports to eastern Europe to 4.5 million tonnes from 10.2 million tonnes in previous years. At the same time, exports to China increased. This led to a change in the structure of exports: the share of eastern European countries in total imports from Russia decreased from 47% to 22%, while China's share rose from 25% to 48.5%. It should also be noted that Russia imports a certain volume of iron ore. In both 2009 and 2010 Russia imported more than 6 million tonnes of ore.
Improvement processes

The majority of ore mined in Russia has low Fe content and high content of gangue, with undesirable elements such as silicates and SiO2 and alumina Al2O3. Improvement of ore in order to achieve a higher Fe content is achieved by the process of magnetic separation. The process increases the Fe content from 36% Fe on average to 60-65% Fe. Furthermore, the SiO2 content decreases, on average, from 26.2% to 7.8%, and Al2O3 content is reduced from 4.9% to 1.8%.

Graph 21 – Russian ore composition before beneficiation

Graph 22 – Russian ore composition after beneficiation

The beneficiation process includes the following stages. At first, the low-grade ore (non-oxidised quartzites) undergoes four stages of crushing in cone crushers. Crushed ore is then fed to dry magnetic separation. After the dry magnetic separation, the magnetic part of the ore is conveyed to the first stage of grinding, whereas the non-magnetic part (tailings) goes to the screening section to be separated into break stone and waste fines.
Iron ore scenario

The ground ore is beneficiated during three stages of wet magnetic separation and two stages of de-sliming. De-watering is then performed in disc vacuum filters, where air and excessive moisture are forced through filter cloth. The output concentrate contains around 65% Fe and the residual moisture is 9.5–10%. Magnetite concentrate is either sold as a final product to steelworks, which then use it to produce sinter, or goes to the pellet plant for production of fluxed pellets.

**Government policy/regulation**

The state programme of development of the mining industry in Russia envisages a global reconstruction and modernisation of production facilities to improve the quality of iron ore, as well as construction of new mines and pits in proven reserve fields. More than 70% of the companies in the iron ore mining industry are private firms. As a result, the implementation of the government programmes in iron ore mining now depends heavily on the major mining companies. A small share of financing is allocated by the state. One of the main sources of state funds is the tax on the extraction of iron ore at the rate of 4.8%.

**Key challenges/difficulties**

The main objective of the Russian iron ore industry is not to develop new deposits in order to increase volume but to improve the quality of mined ore, by increasing the Fe content and reduce unwanted impurities.

**Ukraine**

**Resource/reserve/grade**

Ukraine holds almost 28 billion tonnes of iron ore reserves, including 23.4 billion tonnes of proven and 4.4 billion tonnes of probable reserves. Ukraine’s reserves constitute around 15% of total world iron ore reserves. There are five iron ore basins in Ukraine, with nearly two-thirds of resources being concentrated in the Kryvorizky iron ore basin, which is also the main mining area. Majority of the operating mines exploit deposits of ferruginous quartzite, a magnetite type of ore, containing 35% Fe on average, via the open-pit mining method. A number of quartzite deposits also have oxidised quartzite ores, which are currently not mined due to the absence of feasible beneficiation technology. There are rare occasions of rich hematite ores, containing 46–67% Fe, which are mined by the underground method.

The Kremenchutsky iron ore basin is the second largest in Ukraine, containing around 16% of the country's total resources, represented by ferruginous quartzite ore with 35% Fe content on average. There is currently one open pit mine in the area but a new mine is under development. The richest iron ores of hematite-martite nature, containing 60% Fe on average, are found in the Belozersky iron ore basin in Ukraine. However, its resources are the smallest, accounting for 2% of the country's total resources. There is one producer in the area operating underground mines. The other two iron ore areas in Ukraine, including Kerchensky and Pryazovsky basins, are currently not being exploited due to the lower quality of ores. However, the Pryazovsky basin is widely seen as the next prospective mining area in Ukraine, with types of ore similar to the Kryvorizky basin. At present, Ukraine exploits around 60% of its iron ore resources. Assuming production levels of 2010, the average life of resources is estimated at 165 years, with average quality of the ores expected to remain relatively stable.
Table 11 – Ukraine’s iron ore reserves

<table>
<thead>
<tr>
<th>IO basin</th>
<th>Proven reserves (million tonnes)</th>
<th>Probable reserves (million tonnes)</th>
<th>Total reserves (million tonnes)</th>
<th>Type of ore</th>
<th>Mining method</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Ferruginous quartzite (30-45% Fe)</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Rich ores (46-67% Fe)</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Oxidised quartzite brown ores</td>
<td></td>
</tr>
<tr>
<td>Kryvorizky</td>
<td>15,586</td>
<td>3,085</td>
<td>18,671</td>
<td>Open pit</td>
<td></td>
</tr>
<tr>
<td>Kremenchutsky</td>
<td>4,225</td>
<td>181</td>
<td>4,405</td>
<td>Quartzite (27.4-58.5% Fe)</td>
<td>Open pit</td>
</tr>
<tr>
<td>Belozersky</td>
<td>491</td>
<td>146</td>
<td>637</td>
<td>Rich ores (60.6% Fe)</td>
<td>Underground</td>
</tr>
<tr>
<td>Kerchensky</td>
<td>869</td>
<td>313</td>
<td>1,182</td>
<td>Brown ores (28.4% Fe)</td>
<td>N/A (mining discontinued)</td>
</tr>
<tr>
<td>Pryazovsky</td>
<td>2,259</td>
<td>697</td>
<td>2,956</td>
<td>Magnetite quartzite (27.6% Fe) Rich ores</td>
<td>N/A (not yet exploited)</td>
</tr>
<tr>
<td>Total</td>
<td>23,429</td>
<td>4,422</td>
<td>27,851</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Production/consumption/export

Ukraine produced 78 million tonnes of iron ore in 2010. Production had been relatively stable during the previous six years, remaining in the range of 65-75 million tonnes.
The primary form of beneficiated iron ore is concentrate or pellet feed, which is obtained as a result of beneficiation of quartzite ores mined in open-pit mines. Sinter fines account for roughly 20% of production and represent the beneficiated product of underground mines. Output of lump ore is negligible.

Iron ore concentrate is either processed further into pellets at the mines or sold in the market to steel mills, which use it for sinter production. Sinter fines are predominantly sold to the steel mills for sinter production, although some of the mining companies in Ukraine have their own sinter mills and sell sinter to the nearby steel plants.

**Graph 23 – Iron ore production trend in Ukraine, million tonnes**

Even though the main task of the iron ore industry in Ukraine is to support domestic steel production, Ukraine is a significant exporter of iron ore in the world market. Exports reached an all-time high in 2010, at 33 million tonnes, representing 42% of Ukrainian iron-ore production. The main reason for export growth was the favourable conditions in the global iron ore market, which supported full capacity utilisation of the Ukrainian mines against the backdrop of depressed demand from the domestic steel mills. As the Ukrainian steel production recovers from the downturn, the share of iron ore exports is expected to decrease, returning to its normal pre-crisis level of approximately 30%. The main export markets for Ukrainian iron ore are Europe and China. Europe mostly consumes Ukrainian pellets and sinter ore, which China mostly buys in concentrate.
Beneficiation processes

Beneficiation processes used by Ukrainian producers differ depending on the type of ore. A typical beneficiation process for Ukrainian magnetite ores comprises of three to four stages of crushing, three stages of grinding and three to five stages of wet magnetic separation of low (LIMS) or medium (MIMS) intensity magnetic separation.

This process allows increasing the Fe content from 30-35% in the run-of-mine ore to 65-68% in the beneficiated products which comes in the form of concentrate or pellet feed with a grain size of 0.056mm.

Table 12 – Beneficiation methods used by Ukrainian producers

<table>
<thead>
<tr>
<th>Capacity, Mt</th>
<th>Mining method/Ore type</th>
<th>Fe ROM %</th>
<th>Fe percentage beneficiated</th>
<th>Improvement methods</th>
<th>Final product type</th>
</tr>
</thead>
<tbody>
<tr>
<td>65</td>
<td>Open pit/Magnetite</td>
<td>30-35</td>
<td>64-68</td>
<td>3-4 stages of crushing 3 stages of grinding 4-5 stages of magnetic separation (LIMS/MIMS) Floatation</td>
<td>Concentrate/ Pellet feed Pellets Sinter</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>15</td>
<td>Underground/Hematite-martite</td>
<td>50-58</td>
<td>60-61</td>
<td>Crushing Screen sising Dry magnetic separation – high intensity</td>
<td>Sinter feed</td>
</tr>
</tbody>
</table>
This process also allows for the reduction of the amount of gangue, including the reduction of silicon oxide from more than 40% to 5-9% and aluminum oxide from 1-1.7% to 0.1-0.4%. However, the remaining amount of silicon in the concentrate is still high compared with international standards.

In addition, moisture content in the concentrate is also high (9-10%) as a result of the wet magnetic separation process and very fine size of the final product.

Lastly, beneficiation of magnetite ore leads to the accumulation of large amounts of tailings, as around 60-65% of materials is rejected in the process of magnetic separation. This can be deposited back in or near the mine.

Two Ukrainian producers have installed facilities for further upgrading the iron-ore concentrate by means of flotation. As a result of this process, the content of Fe can be increased to 67-68% and the amount of silicon can be reduced to 5-6%. There is a general tendency in Ukraine towards increasing the quality of ore beneficiation and the capacity of flotation units is expected to increase in the future. It is common for Ukrainian magnetite ore producers to upgrade their concentrate to higher value-added products such as pellets and sinter. Pellets are mostly produced by export-oriented miners, while sinter is sometimes produced by the mines, which are located close to domestic steel plants.

Typical Ukrainian pellets contain 62-63% Fe.

Export-oriented producers are currently trying to increase their pellet quality to 65% by relying on higher-quality flotation concentrate.

Pellet production is forecast to increase in Ukraine in the next five years, mostly to support growing demand in the overseas markets. At the same time, sinter is expected to remain the preferred form of iron input for hot metal production by the domestic steel plants in Ukraine.

**Graph 25 – Chemical composition of Ukrainian ores after beneficiation**
Figure 12 - Typical beneficiation process for Ukrainian quartzite magnetite ore

Graph 26 – Chemical composition of Ukrainian ores before beneficiation
**Government policy/regulation**

Government policy in the field of iron ore mining is based on the principles of balanced economic and social development, rational usage of raw materials and energy resources and responsible waste management. There is no state policy in place aimed at speeding up exploration or mining, as Ukraine has enough iron ore capacity to support its domestic steel production.

Minerals can be mined in Ukraine only under license, which is granted by the government for a 20-year period via an auction process. Land allotment can be granted only to the legal entity that holds a license for mineral utilisation. Royalty fees are regulated by the Tax Code of Ukraine and paid annually to the state and regional budgets. No additional mining taxes are applied. Cut-off grades are determined by mine design organisations for each mining project separately and are approved by the state natural resources commission.

The government used to grant tariff concessions for railway transportation of iron ore, especially to those companies that invested in their own railcar fleet. However, these policies are being gradually phased out as railway transportation is becoming increasingly operated by private companies.

As iron ore locations become increasingly deeper, mining processes need to be adapted to work below design depths, namely below 700m for open-pit and 1,500m for underground mines. Underground mines are facing increasing rock pressures and risks of land shifts and failures, while open-pit mines need to cope with increased stripping and waste-rock handling. Poor iron ores are requiring additional beneficiation, while new solutions need to be found for waste thickening and its transportation to its stockpiling locations. As significant amounts of oxidised quartzite ores have been accumulated and sizeable deposits are in the ground, economically feasible technologies need to be developed for beneficiation of such ores.

There is also a general call from the domestic steel industry to increase quality of iron ore products, increase Fe content and reduce gangue, as the steel industry is on the way towards greater efficiency, reduced energy consumption and environmental pressure.

Other challenges facing the iron-ore industry include limitations with land allotment for mine extensions and waste stockpiling on the back of agricultural development in Ukraine and utilisation of highly mineralised mine water in order to minimise the negative environmental impact.

**US and Canada**

**Resource/reserve/grade**

US resources are estimated at around 110 billion tonnes of ore containing 30% Fe. High-grade resources have been depleted and at present US resources are mainly low-grade taconite-type ores from the Lake Superior district that require beneficiation and pelletising prior to commercial use. The finely-divided concentrate is typically difficult to sinter.
There were eight active iron ore mines in the US (as of 2010), utilising total reserves of 1.6 billion tonnes. Major US operations include the Tilden and Empire mines in Michigan (Marquette Range); United Taconite, the North shore Mine, and Hibbing Taconite in Minnesota (Mesabi Range), all managed by Cliffs Natural Resources, Minntac and Keewinaw Taconite (Keetac), owned and operated by US Steel, and Minorca, owned and operated by ArcelorMittal, in Minnesota.

High-grade pellets (<5.5% SiO2 and minimal Al2O3) are produced at each site with a total capacity of 57 million tonnes per year. In Canada, there are four active mines (2010), utilising total reserves of almost 4 billion tonnes, owned by Iron ore of Canada (IOC), where Rio Tinto was a majority shareholder, along with ArcelorMittal and Cliffs Natural Resources.

Canadian iron ore is mainly produced in Quebec and Newfoundland-Labrador. Canadian operations are capable of producing almost 45 million tpy of iron ore products, including 17 million tonnes per year (tpy) of concentrate and 28 million tpy of pellets.

Canadian consumption is relatively flat with the prevailing share of the ore being exported. Canadian exports exceeded 30Mt in 2010. Excluding intra-regional trade, both US and Canada export 30-40% of their total iron ore production.

**Table 13 – Iron ore reserves estimates, ore type and mining method – North America**

<table>
<thead>
<tr>
<th>Country</th>
<th>Company</th>
<th>Total Reserves (Million tonnes)</th>
<th>Type of ore</th>
<th>Mining Method</th>
</tr>
</thead>
<tbody>
<tr>
<td>US</td>
<td>Keetac and Minntac (US Steel)</td>
<td>732</td>
<td>Magnetite-taconite ore</td>
<td>Open pit</td>
</tr>
<tr>
<td></td>
<td>Northshore Mine</td>
<td>316</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Hibbing Taconite</td>
<td>107</td>
<td>Magnetite-taconite ore</td>
<td>Open pit</td>
</tr>
<tr>
<td></td>
<td>Minorca</td>
<td>36</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>United Taconite</td>
<td>136</td>
<td>Magnetite-taconite ore</td>
<td>Open pit</td>
</tr>
<tr>
<td></td>
<td>Empire</td>
<td>10</td>
<td>Magnetite-taconite ore</td>
<td>Open pit</td>
</tr>
<tr>
<td></td>
<td>Tilden</td>
<td>266</td>
<td>Hematite-magnetite-taconite ore</td>
<td>Open pit</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td>1594</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Canada</td>
<td>Iron ore Co, Carol Lake Mine</td>
<td>638</td>
<td>Hematite ore (39% Fe)</td>
<td>Open pit</td>
</tr>
<tr>
<td></td>
<td>ArcelorMittal (QCM) Mont Wright/Lac Fire</td>
<td>2607</td>
<td>Hematite ore (31% Fe)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Cliffs Natural Resources, Labrador, Quebec, Bloom Lake</td>
<td>580</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Cliffs Natural Resources, Labrador, Wabush</td>
<td>71</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td>3896</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Production/Consumption/Export

In 2010, total domestic iron ore production in the US and Canada was 80.2 Mt.

Production has been steady over recent years, except for the dip in 2009. Most US iron-ore production is sold directly to the domestic steel industry, although a large amount of domestic ore is shipped to Canada and small amounts are generally exported to other countries.

Beneficiation processes: US iron ore operations

In the US Mesabi Range, magnetite recovery and beneficiation is mainly accomplished through fine grinding and low intensity magnetic separation (LIMS). There is some variation from mine to mine depending on ore grade. Amine flotation for silica control is employed in some cases. In the Marquette Range, similar beneficiation processes are in place for magnetite-bearing ore. Hematite is upgraded through fine grinding, selective flocculation, and flotation at Cliff’s Tilden operation. A typical beneficiation process at a US magnetite iron ore mine consists of the following stages. The ore entering beneficiation operations typically has a magnetic iron content of 23%. The milling, magnetic separation, and flotation processes (prior to agglomeration) result in a concentrate with a magnetic iron content of 67.5%.

Figure 13 – Beneficiation process for USA magnetite taconite ore

Ore is fed from the rail cars into one of two 60-inch gyratory crushers for primary crushing. These crushing operations are dry processes where bag house collectors are used to control fugitive dust. Collected dust is reintroduced to the crusher system. Ore leaving the short head crushers is -3/4-inch with 1/2 to 1 percent natural moisture. Although this is a dry process, water is used for fugitive dust control. Fine ore is fed from the surge bins to one of 34 grinding mill lines, each of which consists of a rod mill, a ball mill, and several separation and classification stages. In each line, ore is first fed into a rod mill. This ore is then fed, along with additional water, into a two-drum magnetic separator.
Varying quantities of water are used to wash gangue away from the magnetic values. The gangue flows to a tailings thickener and is ultimately disposed of in the facility’s tailings ponds. The ore leaving the ball mill, which is in a slurry of 85-88% solids, flows to a magnetic rougher. The magnetic rougher increases the magnetic iron content of the ore to approximately 40%. The ore slurry leaving the rougher contains between 70-80% solids; water is then added, decreasing the solids content to around 35%. The ore resulting from magnetic separation then enters a hydraulic concentrator that separates magnetic material (product) and gangue by gravity or magnetic properties (no chemicals are added). In the concentrator, magnetic ore material, now 64% iron, settles to the bottom of the tank. Gangue overflows from the tank and is thickened (dewatered) and disposed of in the tailings ponds. The heavier iron ore is drawn off the bottom of the concentrator in each line and sent to one of the facility’s four central flotation lines.

**Magnetation, Inc**

Magnetation, Inc. is a producer of hematite iron ore concentrates and an inventor of an innovative mineral beneficiation technology. The company started reclaiming hematite from abandoned tailings and ore stocks in Northern Minnesota using high-gradient magnetic separator (HGMS) in 2009. In 2010, the firm introduced an advanced version of HGMS, known as the Rev3 Separator™. This separator was a ‘clean sheet of paper’ design by Magnetation engineers specifically for high volume, high availability iron ore applications. The focus of the Rev3™ design was to produce a machine that overcomes the traditional drawbacks of Wet High Intensity Magnetic Separation (WHIMS) including their complex mechanical and electrical systems, high electrical energy consumption, tendency to foul with misplaced particles and debris in the slurry, and the resulting high operating costs and poor equipment uptime. The novelty and simplicity of the Rev3™ design creates significant value in the Technology. The end result is very high equipment availability, throughput, and metallurgical efficiency. The Rev3™ utilises 'off-the-shelf' ferrite permanent magnets, employed in a unique geometry along with a proprietary flux amplifying matrix.

**Table 14 – Size and chemical analysis of MagCon fines and sinter feed**

<table>
<thead>
<tr>
<th>Product</th>
<th>Mesh</th>
<th>Iron</th>
<th>SiO2</th>
<th>Fe++</th>
<th>S</th>
<th>CaO</th>
<th>MgO</th>
<th>MnO</th>
<th>Na2O</th>
<th>K20</th>
<th>Phos</th>
<th>H2O</th>
</tr>
</thead>
<tbody>
<tr>
<td>MagCon Fines</td>
<td>&lt;.5</td>
<td>3</td>
<td>15</td>
<td>49</td>
<td>97</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Mag Con Sinter Feed</td>
<td>50</td>
<td>64.6</td>
<td>5.05</td>
<td>0.48</td>
<td>0.006</td>
<td>0.03</td>
<td>0.02</td>
<td>0.25</td>
<td>0.23</td>
<td>0.02</td>
<td>6</td>
<td></td>
</tr>
<tr>
<td>Product</td>
<td>10 Mesh</td>
<td>100</td>
<td>140</td>
<td>200</td>
<td>325</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>MagCon Fines</td>
<td>70 Mesh</td>
<td>50 Mesh</td>
<td>70 Mesh</td>
<td>100 Mesh</td>
<td>140 Mesh</td>
<td>200 Mesh</td>
<td>325 Mesh</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>MagCon Sinter Feed</td>
<td>&lt;.5</td>
<td>62.3</td>
<td>94.5</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
</tbody>
</table>
Canadian iron ore operations

At ArcelorMittal’s Mount Wright iron ore operations in Canada; specular hematite containing 31% Fe is upgraded by spirals to a concentrate containing 66.1% Fe, 4.9% SiO2, and 0.32% Al2O3. The process flow-sheet is presented below:

Figure 14 – Mount Wright concentrator flow sheet

ArcelorMittal’s Port-Cartier Pellet Plant in Quebec produces DR-grade pellet concentrate (<2% SiO2) using hydraulic classifiers. Wet, high-intensity magnetic separation (WHIMS) may also be in use. The iron ore company of Canada’s Carol Lake operations process hematite and magnetite ore with 39% iron. The flotation circuit was added in 1998 for the production of Direct Reduction (DR)-grade pellet feed (<1.2% SiO2). The process flow-sheet is displayed below:

Figure 15 – Flotation circuit flow chart

The ore resulting from magnetic separation then enters a hydraulic concentrator that separates magnetic material (product) and gangue by gravity or magnetic properties (no chemicals are added). In the concentrator, magnetic ore material, now 64% iron, settles to the bottom of the tank. Gangue overflows from the tank and is thickened (dewatered) and disposed of in the tailings ponds. The heavier iron ore is drawn off the bottom of the concentrator in each line and sent to one of the facility's four central flotation lines. Ore is fed from the rail cars into one of two 60-inch gyratory crushers for primary crushing. These crushing operations are dry.
processes in which bag house collectors are used to control fugitive dust. Collected dust is reintroduced to the crusher system. Ore leaving the short head crushers is -3/4-inch with 1/2 to 1% natural moisture. Although this is a dry process, water is used for fugitive dust control.

Fine ore is fed from the surge bins to one of 34 grinding mill lines, each of which consists of a rod mill, a ball mill, and several separation and classification stages. In each line, ore is first fed into a rod mill. This ore is then fed, along with additional water, into a two-drum magnetic separator.

Varying quantities of water are used to wash gangue away from the magnetic values. The gangue flows to a tailings thickener and is ultimately disposed of in the facility's tailings ponds. The ore leaving the ball mill, which is in a slurry of 85-88% solids, flows to a magnetic rougher.

The magnetic rougher increases the magnetic iron content of the ore to approximately 40%. The ore slurry leaving the rougher contains between 70 and 80% solids; water is then added, decreasing the solids content to around 35%. The ore entering beneficiation operations typically has a magnetic iron content of 23%. The milling, magnetic separation, and flotation processes (prior to agglomeration) result in a concentrate with a magnetic iron content of 67.5%.

**Government policy/regulation**

US government policies and regulation are mostly focused on strict environmental license permits, including federal limits on particulate matter (PM) emissions, potentially tighter limits on NOx and possibly SOx to control haze, concerns regarding trace amounts of mercury emitted from pellet induration furnaces and release of process water or run-off with dissolved solids.

Canada: In general, environmental regulations are favourable at present, but permitting could become more restrictive with continued expansion. Provincial governments are responsible for mining activity within their respective Province. Provincial legislatures make laws concerning matters for which they have jurisdiction, which include exploration, development, production, and conservation and management of most non-renewable natural resources.

**Key challenges/difficulties**

Key challenges of the US iron ore mining industry lie in the area of logistics, including the absence of lake transport in winter due to ice and limited export opportunity because of the cost of navigating small locks between the Great Lakes and deep sea ports on the St. Lawrence Seaway. Another challenge is poor ore quality as a lot of beneficiation is required to exploit ore or tailings. Canada’s iron ore industry is primarily export oriented. Canada’s continuing challenges in the mineral sector include globalisation of the industry, especially competition from developing countries with minerals resources that were less costly to develop. In addition, there are challenges of operating in northern latitudes, high capital investment requirements, which explains why major projects involve large mining or steel companies, infrastructure constraints, as there are only two public deep-sea ports servicing the Labrador Trough and port expansion may be necessary to increase exports. Lastly, with regards to ore quality extensive beneficiation is required for the larger deposits.
Also concentrates made from Labrador Trough ore are high grade, but have smaller particle size than ideal sintering ore. Therefore, pelletising is preferred for agglomeration. Overall, the Canadian iron-ore industry is well positioned to expand based on its resource base and its access to the different markets.

3.3 Survey results in iron ore part

General information

The survey questionnaire was sent to mining and steel companies. The main objective was to prepare the survey questionnaire and clarify the available resources and reserve. Worldsteel received responses from ten companies. These companies own 36 mines, of which 33 are mining open cast and the other three are underground mines. The project database has information around techniques used for all processes and sub processes in the different companies. This covers mining, beneficiation, product upgrading, water and power requirement, waste ratio and various constrain. Examples of good practices are included in section 7.4 of this report.

Identification of beneficiation plants

To keep the result anonymous, participating beneficiation plants were presented with a unique identification code from 1-21. These identification numbers are used throughout the report. Out of 36 mines, 11 deposits have hematite/goethite, 13 deposits have magnetite, 11 deposits have a mixture of hematite and magnetite and there is only one other category. Distributions are shown in the pie charts below.

Ore and mine type

Beneficiation plants are improve iron ore from Fe percentage as low as 25% up to 66%. There has been an attempt to segregate beneficiation plant by the types of ore processing and their Fe percentage ranges. This is shown in graph 28 below.

Beneficiation plant versus feed Fe percent

As low as 25% Fe can also be beneficiated.

Graph 27 – Range of feed Fe percentage for beneficiation Hematite/Hematite + Goethite/
3.4 Identification of raw material processing technologies

Limonite: Hematite as low as 27% can be beneficiated.

Graph 28 – Range of feed Fe percentage for beneficiation – Hematite

![Graph showing the range of feed Fe percentage for beneficiation - Hematite]

Magnetite Beneficiation plant feed Fe percent
All magnetic feed Fe percentage ranges from 30-35% can be beneficiated.

Graph 29 – Range of feed Fe percentage for beneficiation – Magnetite

![Graph showing the range of feed Fe percentage for beneficiation - Magnetite]

Hematite +Magnetite Beneficiation plant feed Fe percent
Fe percentage as low as 24.52 is beneficiated.
Iron ore scenario

Graph 30 – Range of feed Fe percentage for beneficiation – Magnetite + Hematite

The following graphs could be used as a benchmark for individual categories of iron ore processing. Graphs with Fe upgrading and gangue removal in each plant are shown below:

Fe percentage upgrading in beneficiation plants

Average Product Fe percentage > 65, minimum Fe percentage is 62 and maximum Fe percentage is 68:

Graph 31 – Feed vs product Fe percentage
Seventeen companies have provided the data for upgrading the Fe percentage in their beneficiation plants, as shown in the above graph.

Silica reduction in beneficiation plants

Max silica percentage reduction is from 60.5 to 3.6 Seventeen mining companies provided data for silica percentage reduction and 13 companies provided for alumina percentage reduction from the feed mix and same is shown in the graphs here. Above graph shows that silica percentage as high as 65.5 is beneficiated up to 3.6. (Refer company code no. 17 in graph 32).

Alumina reduction in beneficiation plants

The maximum alumina percentage reduction is from 8.0 to 1.6

Similar to silica, alumina percentage reduction is also possible from as high as eight to as low as 1.6. Project team has analyzed yield of each beneficiation plants and same is shown in the graph below. 16 mining companies have provided yield data, which shows that yield% is varying as low as 25 to as high as 92. The same depends on the Fe% upgrading and also the mineralogy of the ore.
Fe Upgrading versus yield percentage

Yield % is varying from as low as 25 to as high as 92

Graph 34 – Trend of yield % variation

While evaluating the data, it became clear that iron ore with high gangue content (low-grade ore) can be beneficiated. The team was also interested to learn the specific power consumption trend, to see the impact in the processing costs. The graph below shows that companies are beneficiating even if the specific power consumption as high as 57 kWh/tonne of ore processed. Power consumption mainly depends on liberation characteristics of ore and product size and their downstream requirements.

Fe upgrading versus specific power consumption

Specific power consumption is as high as 57 kWh/tonne

Graph 35 – Specific power consumption trend
Tables given below are showing the various processing technologies used in the mines for beneficiation processes, using different types of ores.

1. Process Followed in hematite

**Table 16 – Beneficiation of hematite ore, feed versus project Fe%**

<table>
<thead>
<tr>
<th>Mines</th>
<th>Type of ore</th>
<th>Feed Fe</th>
<th>Product Fe</th>
<th>Process</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>Hematite</td>
<td>27.0</td>
<td>64</td>
<td>Mill and spiral</td>
</tr>
<tr>
<td>B</td>
<td>Hematite</td>
<td>37.5</td>
<td>63</td>
<td>Milling, magnetic separation and direct flotation</td>
</tr>
<tr>
<td>C</td>
<td>Hematite</td>
<td>60.0</td>
<td>62</td>
<td>Washing</td>
</tr>
<tr>
<td>D</td>
<td>Hematite</td>
<td>61.0</td>
<td>63</td>
<td>Washing</td>
</tr>
<tr>
<td>E</td>
<td>Hematite</td>
<td>65.0</td>
<td>66</td>
<td>Washing</td>
</tr>
<tr>
<td>F</td>
<td>Hematite</td>
<td>65.6</td>
<td>67</td>
<td>Washing and jigging</td>
</tr>
</tbody>
</table>

2. Process followed in hematite + magnetite/martite

**Table 17 – Beneficiation of Hematite+Magnetite ore, feed versus project Fe**

<table>
<thead>
<tr>
<th>Mines</th>
<th>Type of ore</th>
<th>Feed Fe</th>
<th>Product Fe</th>
<th>Process</th>
</tr>
</thead>
<tbody>
<tr>
<td>G</td>
<td>Hematite + Magnetite</td>
<td>29.3</td>
<td>67</td>
<td>Mill, magnetic and flotation</td>
</tr>
<tr>
<td>H</td>
<td>Hematite + Magnetite</td>
<td>36.1</td>
<td>66</td>
<td>Grinding, low intensity magnetic separation</td>
</tr>
<tr>
<td>I</td>
<td>Hematite + Magnetite</td>
<td>47.0</td>
<td>66</td>
<td>Milling, low intensity magnetic separation, sulphur/phosphorus removal</td>
</tr>
<tr>
<td>J</td>
<td>Hematite + Magnetite</td>
<td>56.0</td>
<td>64</td>
<td>DMS drum, cyclone</td>
</tr>
</tbody>
</table>

3. Process followed in magnetite

**Table 18 – Beneficiation of Hematite ore, feed versus project Fe%**

<table>
<thead>
<tr>
<th>Mines</th>
<th>Type of ore</th>
<th>Feed Fe</th>
<th>Product Fe</th>
<th>Process</th>
</tr>
</thead>
<tbody>
<tr>
<td>K</td>
<td>Magnetite</td>
<td>30.8</td>
<td>67</td>
<td>grinding, low intensity magnetic separation, reverse flotation</td>
</tr>
<tr>
<td>L</td>
<td>Magnetite</td>
<td>31.2</td>
<td>64</td>
<td>grinding, dry magnetic separation, reverse flotation</td>
</tr>
<tr>
<td>M</td>
<td>Magnetite</td>
<td>33.5</td>
<td>68</td>
<td>grinding, low intensity magnetic separation</td>
</tr>
</tbody>
</table>


3.4 Identification of raw material processing technologies

Figure 16 – Treatment of iron ore – Key beneficiation processes

<table>
<thead>
<tr>
<th>Run of mine</th>
<th>Magnetite - Hematite - Limonite</th>
</tr>
</thead>
<tbody>
<tr>
<td>Beneficiation</td>
<td>Crushing Screening</td>
</tr>
<tr>
<td>Low Grade Ore</td>
<td>Grinding Screening Desliming Dewatering</td>
</tr>
<tr>
<td>Products</td>
<td>Grinding Upgrading Dewatering</td>
</tr>
<tr>
<td>Agglomeration</td>
<td>Lump</td>
</tr>
<tr>
<td>Iron Making</td>
<td>Fines</td>
</tr>
<tr>
<td>Sinter</td>
<td>Concentrate</td>
</tr>
<tr>
<td>Pellet</td>
<td>Blast Furnace</td>
</tr>
<tr>
<td>Direct Reduction</td>
<td></td>
</tr>
</tbody>
</table>

Figure 17 – Beneficiation process

<table>
<thead>
<tr>
<th>Mineral bearing phase</th>
<th>Intergrowth</th>
<th>Beneficiation for Fe concentration and reduction of detrimental elements</th>
</tr>
</thead>
<tbody>
<tr>
<td>Magnetite</td>
<td>Very coarse (&lt; 30 mm)</td>
<td>Drum low intensity magnetic separator, dry</td>
</tr>
<tr>
<td>Coarse (3.15 - 0.1 mm)</td>
<td>Low- intensity magnetic separation, wet/dry</td>
<td></td>
</tr>
<tr>
<td>Fine (&lt;0.1 mm)</td>
<td>Low- intensity magnetic separation, wet</td>
<td></td>
</tr>
<tr>
<td>Upstream separation</td>
<td>Flotation</td>
<td></td>
</tr>
<tr>
<td>Hematite</td>
<td>Very coarse (&lt; 30 mm)</td>
<td>Jigging dry/wet, heavy media separation</td>
</tr>
<tr>
<td>Coarse (3.15 - 0.1 mm)</td>
<td>Upstream separation</td>
<td></td>
</tr>
<tr>
<td>Spiral separation (&lt;1.6 mm)</td>
<td>High intensity magnetic separation (&lt;1.6 mm)</td>
<td></td>
</tr>
<tr>
<td>Fine (&lt;0.1 mm)</td>
<td>High intensity magnetic separation</td>
<td></td>
</tr>
<tr>
<td>Flotation</td>
<td>Selective flocculation</td>
<td></td>
</tr>
</tbody>
</table>
### Beneficiation process

<table>
<thead>
<tr>
<th>Mineral bearing phase</th>
<th>Intergrowth</th>
<th>Beneficiation for Fe concentration and reduction of detrimental elements</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mixed magnetite / martite / hematite</td>
<td>Coarse to fine</td>
<td>Drum low intensity magnetic separator, dry Low/medium intensity magnetic separation, Spiral separation High intensity magnetic separation Upstream separation Flotation</td>
</tr>
<tr>
<td>Limonitic hematite</td>
<td>Very coarse (&lt;30 mm)</td>
<td>Jigging dry/wet, heavy media separation</td>
</tr>
<tr>
<td></td>
<td>Coarse (1 - 0.1 mm)</td>
<td>Spiral separation High intensity magnetic separation Desliming</td>
</tr>
<tr>
<td></td>
<td>Fine (&lt;0.1 mm)</td>
<td>High intensity magnetic separation Desliming</td>
</tr>
</tbody>
</table>

**Figure 18**– Typical flowsheet used example 1 – Magnetite (wet)

**Figure 19** – Beneficiation process examples: Magnetite
Figure 20 – Beneficiation process examples: Magnetite

Figure 21 – Flowsheet Example 4 – Hematite
3.5 Case Studies – China

Development of the resource-processing technology of the Hujiamiaozi concentrator at Anshan Steel

In recent years, Anshan has strengthened its development of the processing technology of lean hematite resources and has made great progress.

**Hujiamiaozi concentrator**

The successful construction of Hujiamiao Concentrator represents progress and development of the resource processing technology of the Company.

The designed annual capacity of the concentrator was 8 million tonnes iron ore and annual iron concentrate output was 2.6 million tonnes. Engineering construction investment was RMB 880 million yuan. The project began construction in March 2005 and was completed in August 2006.

The Hujiamiao concentrator was built two years ago, and main technical and economic indexes reach and exceed the design indexes.

### Table 15 – Analysis of Hujiamiaozi concentrator

<table>
<thead>
<tr>
<th>Index</th>
<th>Capacity of run of mine ×10⁴t/year</th>
<th>Output of concentrate ×10⁴t/year</th>
<th>Grade of run of mine %</th>
<th>Grade of concentrate %</th>
<th>Grade of tailing %</th>
<th>Iron recovery %</th>
</tr>
</thead>
<tbody>
<tr>
<td>Design</td>
<td>800</td>
<td>238</td>
<td>27.5</td>
<td>67.50</td>
<td>10.50</td>
<td>73.02</td>
</tr>
<tr>
<td>Production</td>
<td>916</td>
<td>229</td>
<td>24.5</td>
<td>67.63</td>
<td>10.12</td>
<td>69.01</td>
</tr>
<tr>
<td>+116</td>
<td>-9</td>
<td>-3</td>
<td>+0.13</td>
<td>-0.38</td>
<td>-4.01</td>
<td></td>
</tr>
</tbody>
</table>
Characteristics of hematite resources

Ore reserves amount to 8.5 billion tonnes in the Anshan district, of which magnetite and hematite make up around 50% each. Anshan-type hematite is settlement metamorphic ferruginous quartzite. Iron minerals are mainly hematite, martite, magnetite. Gangue mineral is mainly quartz.

<table>
<thead>
<tr>
<th>Lean iron</th>
<th>Fe = 28-32%</th>
</tr>
</thead>
<tbody>
<tr>
<td>High content of silicon</td>
<td>SiO2= 52-54%</td>
</tr>
<tr>
<td>Grinding difficulty level</td>
<td>WI = 15-18kWh/t</td>
</tr>
<tr>
<td>Dressing difficulty level</td>
<td>P80 = 30-50µm</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>TFe</th>
<th>FeO</th>
<th>SiO2</th>
<th>Al2O3</th>
<th>CaO</th>
<th>MgO</th>
<th>MnO</th>
<th>S</th>
<th>P</th>
</tr>
</thead>
<tbody>
<tr>
<td>28.68</td>
<td>5.66</td>
<td>53.77</td>
<td>1.48</td>
<td>0.82</td>
<td>0.95</td>
<td>0.085</td>
<td>0.075</td>
<td>0.033</td>
</tr>
</tbody>
</table>

Technological process

Crushing and screening: Three-stage crushing and one stage screening processes, closed circuit technology is being used. Grinding and dressing: staged grinding and dressing of coarse and fine particles respectively, gravity separation – magnetic separation – anionic reverse flotation process is used.

Waste water from the production of the concentrator is used after treatment and processing. Overflow from thickening operation of various stages flowed by gravity to the water distributing pond through pipes and then treated in the inclined plate clarifying ponds after the reagent is added.

The feed water density was around 8000 mg/litre and overflow density decreased to below 100 mg/litre after treatment.

The overflow returned back to the production water system. The production water treatment process is technology that is developed by Anshan Iron & Steel Group. By using this technology, the concentrator realised zero drainage of sludge. Availability of circulation water reached 94.9% and fresh water consumption per tonne of ROM (run of mine) is 0.705 m³.

Pipe transportation process for tailing with high density

Tailing is thickened to a density of 45% and then pumped to a tailing dam 8.5km away by a slurry pump with two-stage series pump. The tailing pipe uses high molecular composite tube. This tube material has high wear resistance, small friction losses and is self-lubricating. Compared with steel tubes, it saves 20-30% energy.
Analysis:

a. Feed quality of plant before beneficiation

<table>
<thead>
<tr>
<th>(All in%)</th>
<th>Plant 1</th>
<th>Plant 2</th>
</tr>
</thead>
<tbody>
<tr>
<td>T.Fe</td>
<td>29.28</td>
<td>24.52</td>
</tr>
<tr>
<td>SiO2</td>
<td>56.1</td>
<td>60.53</td>
</tr>
<tr>
<td>Al2O3</td>
<td>0.64</td>
<td>0.18</td>
</tr>
<tr>
<td>Na2O+K2O</td>
<td>0.041</td>
<td>0.043</td>
</tr>
<tr>
<td>P</td>
<td>0.016</td>
<td>0.01</td>
</tr>
<tr>
<td>Moisture</td>
<td>2.5</td>
<td>2.5</td>
</tr>
<tr>
<td>Ig-Loss (LOI)</td>
<td>5.365</td>
<td>5.947</td>
</tr>
<tr>
<td>Size &lt;0.15mm</td>
<td>Yes</td>
<td>Yes</td>
</tr>
</tbody>
</table>

b. Product type with size and ratio of production

<table>
<thead>
<tr>
<th></th>
<th>Lump</th>
<th>Size</th>
<th>Sinter fines</th>
<th>Size</th>
<th>Pellet fines</th>
<th>Size</th>
</tr>
</thead>
<tbody>
<tr>
<td>Plant 1</td>
<td>N/A</td>
<td>N/A</td>
<td>43%</td>
<td>-0.074mm</td>
<td>57%</td>
<td>-0.074mm</td>
</tr>
<tr>
<td>Plant 2</td>
<td>N/A</td>
<td>N/A</td>
<td>45%</td>
<td>-0.074mm</td>
<td>55%</td>
<td>-0.074mm</td>
</tr>
</tbody>
</table>

Plant 1 produces lumps of – 40 and +10mm and Sinter fines of – 10mm with 45:55 ratio.

c. Beneficiation product quality

<table>
<thead>
<tr>
<th>(All in%)</th>
<th>Plant 1</th>
<th>Plant 2</th>
</tr>
</thead>
<tbody>
<tr>
<td>T.Fe</td>
<td></td>
<td></td>
</tr>
<tr>
<td>SiO2</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Al2O3</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Na2O+K2O</td>
<td></td>
<td></td>
</tr>
<tr>
<td>P</td>
<td></td>
<td></td>
</tr>
<tr>
<td>S</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Moisture</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Ig-Loss (LOI)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Size &lt;0.15mm</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
d. Yield percentage specific power consumption and specific water consumption

<table>
<thead>
<tr>
<th>Plant</th>
<th>Input</th>
<th>Total</th>
<th>Total reject%</th>
<th>Specific power (kwh/tonnes of processing)</th>
<th>Specific water use (tonnes/tonnes of processing)</th>
<th>Process water used (tonnes/tonnes of processing)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Plant 1</td>
<td>100</td>
<td>33.33</td>
<td>66.67</td>
<td>40.5</td>
<td>1</td>
<td>10.2</td>
</tr>
<tr>
<td>Plant 2</td>
<td>100</td>
<td>32.12</td>
<td>67.88</td>
<td>41</td>
<td>0.95</td>
<td>9.89</td>
</tr>
</tbody>
</table>

e. Process flow chart

The technical characteristics of the process are as follows:

- In the light of characteristics of uneven disseminated particle size of iron mineral, coarse and fine particles were dressed respectively. It achieves dressing of narrow fraction and may achieve better separation effect.
- Using gravity separation to treat coarse fraction may obtain final concentrate and tailing directly. It realised the target of recovering liberated ore and rejecting liberated gangue as early as possible and reduced regrinding feed amount. Thus, it decreased regrind mill quantity, saved grinding energy and expense and decreased concentrate cost.
- Fine fraction was first fed to the magnetic separation operation. In this operation, the tailings were rejected and at the same time the slime effectively removed. It created conditions for the next reverse flotation operation;
- The process that coarse and fine particles were dressed respectively and pre-concentration magnetic separation process were used. It greatly reduced feed amount of the reverse flotation, saved reagent and heat consumption and further decreased concentrate cost.
Conclusions and recommendations

- Since 2000, large-scale technical reconstruction of the Concentrator using advanced processes and equipment occurred with the purpose of increasing product quality, reduce operating costs and increase capacity. It now meets the needs of the iron and steel demand of the company.
- Progress and development of resource-processing technology of the company benefit from increasing of integrated level of the resource processing industry of China. And at the same time, the company actively promotes technical progress of the resource processing industry of China and leads the technical progress of the industry. It provides thoughts and methods for production of top iron charge by using low grade materials.
4. Coal/coke scenario

Project Group Members: Atul Bhatnagar, Jan Dolfing – Tata Steel

Coal provides 25% of world’s primary energy, 40% of world electricity and nearly 70% of world steel. In its most recent study, the German Federal Institute for Geosciences and Natural Resources (BGR) estimates the current proven recoverable global coal reserves at 997.2 billion tonnes. This represents more than 144 years of production at current levels. In contrast, proven oil and gas reserves are equivalent to around 46 to 63 years at current production levels. The information on coal/coke is compiled from the information available in public domain and in addition from research information available from team members, survey questionnaires and reports from world energy institute.

4.1 Worldwide coal availability and use

Coal reserves are available in almost every country worldwide, with recoverable reserves in around 70 countries. The biggest reserves are in the US, Russia, China and India. China’s coal reserve accounts for 12.6% of total reserves in the world.

Figure 23– Worldwide coal availability

After centuries of mineral exploration, the location, size and characteristics of most countries’ coal resources are quite well known. The classification for quantity of coal is as follows:

Resource: The amount of coal that may be present in a deposit or coalfield. This does not take into account the feasibility of mining the coal economically. Not all resources are recoverable using current technology.
**Reserves:** Reserves can be defined as proven (or measured) reserves and probable (or indicated) reserves. Probable reserves have been estimated with a lower degree of confidence than proven reserves.

**Proven Reserves:** Reserves that are not only considered to be recoverable, but can also be recovered economically. This means they take into account what current mining technology can achieve and the economics of recovery. Proven reserves will therefore change according to the price of coal; if the price of coal is low proven reserves will decrease.

Depending upon the carbon content, coal is classified as:

- Anthracite: More than 85% carbon
- Bituminous: 45-85% carbon
- Sub-bituminous: 35-45% carbon
- Lignite: Less than 35% carbon

The coal availability is illustrated on the next page.

**Figure 24 – Coking coal**

- Coking coal is coal that can be used in the production of coke which in turn is used in the blast furnace in the chemical reduction process for producing pig iron.
- Coking coal is a rare resource. It accounts for less than 10% of total hard coal resources in the world.
Coking coal supply and dependency on higher-risk areas

Figure 25 – Demand supply outlook of coking coal

In 2011, world metallurgical coal trade increased by 4% to 264 million tonnes. World metallurgical coal trade is projected to increase at an annual average of 5% likely to reach 341 million tonnes in 2016. Traditional importers such as Japan, the Republic of Korea and the European Union are projected to grow steadily, while India and China are projected to be the largest importers of metallurgical coal. Mongolia’s export of metallurgical coal in 2011 is around 20 million tonnes. Mongolia has significant reserves of high-quality coal and is located in close proximity to Chinese and Russian steel-makers.

Graph 36 – Outlook for world metallurgical coal exports

India’s imports of metallurgical coal are forecast to increase at an annual average of 13% over the outlook period to reach 52 million tonnes in 2016. The projected expansion of India’s steel production capacity will rely on imported metallurgical coal as there are few high-quality domestic coal reserves. Over the outlook period, China is expected to increase its reliance on imports relative to domestically produced coal. China is expected to import 728 million tonnes of iron ore in 2012.
Import demand is expected to grow strongly over the medium term for several reasons: the decreasing quality and increasing cost of domestic coal production; the increasing desire for higher quality coal for the production of higher value steel products; and the increasing number of steel mills located in coastal regions in close proximity to port infrastructure.

**Graph 37 – Outlook for world metallurgical coal imports**

![Graph showing outlook for world metallurgical coal imports](image)

**4.2 Regional coal availability worldwide**

Coal availability: The annual reports of coal mining companies were surveyed and the following information was available:

- Coal requirement approximately 1.0 billion tonnes. RIO Tinto & BHP together have around 21 billion tonnes of coal (measured indicated and inferred).
- Together they can feed the world for 12 years approximately @ 50% yield at the current consumption rate.
- The indicated and inferred resources are increasing every year with increased exploration.
- Good resource areas such as Goonyella, Peaks Down, Saraji, Norwich park will continue for more than 15 years.
- Around 30% of the resources would need to be mined underground in future. It is expected that production costs may go up due to underground mining of coal.
- The proportion of underground mining is significantly less for current measured resources (10% appx.).
Coking coal consumption

World Consumption of coking coal in 2009 has increased by 2.6% to 761.3 million tonnes. In 2009, the People’s Republic of China accounted for 58.5% of global coking coal consumption up from 52.2% in 2008.

The next five major coking coal consumers are: India, Japan, the Russian Federation, Ukraine and South Korea. Together they accounted for another 25.6% of World Annual Coking Coal Consumption

Coals for pulverised coal injection (PCI)

Coal used in this way, as PCI, Provides important economic benefits of a lower reductant price as thermal coal can be used for PCI versus expensive coking coal. It also lowers the quantity of coke required to produce pig-iron. One tonnes of PCI coal replaces around 1.4 tonnes of coking coal and prolonging coke supply.

4.3 Survey results in metallurgical coal part

A survey was conducted to collect information on technologies for utilisation of low-grade raw materials also to get a update on research that has been completed on coal beneficiation.

In addition, the objective was to compile and share the best practices and the concerns of steelmakers. The steelmakers’ availability of coal information is limited as coal is mostly purchased from miners.

Some responses were received from members who have their own mines and have provided beneficiation techniques and process information. The response covers the key areas of Asia, Australia, South America, Africa, and Europe.
Summary of results

Use of beneficiation technology

Most of the plants (65%) work with maximum size of 50mm or less. The beneficiation technology is selected on size of the coal and is standard and depends on the complexity of coal. The top size is lower (<25mm) is mostly in places where the liberation of coal happens at smaller sizes. The Froth flotation process is the most preferred process (93% of plant use this for beneficiating – 0.22mm). This is in line with the efficiency of technology as depicted in the chart below.

Best practices on low quality

Based on the responses as received the steelmakers want to increase the proportion of non-coking coal in their usage as it is available at relatively lower costs. 60% of the respondents feel that by improving their blending systems the use of low grade resources can be enhanced.

Graph 40 – Survey results for coal blending trend and direct non-coking coal usage

While 40% reported that by improving their beneficiation processes low grade materials can be effectively utilised The use of blending techniques is not highly modernised as only 25% of responses have indicated that they use blending techniques. Most of the responses have feed bins for proportioning. However everyone indicated a need for better blending facility to increase use of lower grade coals.
Technical issues

Issue 1: Fine coal Beneficiation

- Fine size (0.25mm)
- 93% of the washeries use froth flotation
- Technology depends on surface characteristics of coal
- New development will affect beneficiation operations

There has been development of technology based on hindered settling of coal; this is being gradually used for beneficiation of coal fines. Increased usage of Teetered Bed Separators (TBS) and new generation reflux classifiers have shown the success of this technology.

Issue 2: Lower top size

- More usage of coals with lower yields will also have an impact on the size.
- The top size will gradually move from 50mm to 25mm range (even lower).
- The moisture in the shipped coal will increase.
- Suppliers may opt for briquette/agglomeration.
- The current proven suppliers may add finer coal if coal prices increase. The other incentive for coal suppliers would be to increase yields by increasing ash content in transported coal.
Issue 3: Increased blending

- Coals with lower quality will be more frequently used
- Increase in usage of non-coking pulverised injection (PCI) and Petroleum (PET) Coke
- Use of blending yards and stocking space at steel companies premises is perceived as an issue in the future.
- Automation/ instrumentation in blending systems is needed to improve consistency.

4.4 Identification of coal/coke processing technologies

Introduction

Coal upgrading technologies cover a wide range of processes that can be applied to improve the quality of coal to meet market requirements. These can include raw coal pre-treatment, crushing and sising, and cleaning or beneficiation. Coal upgrading is used to produce a saleable product and add economic value to run-of-mine (ROM) coal. More recently, it has been recognised that coal upgrading can also bring considerable environmental benefits. These include reduced emissions of carbon dioxide (CO2), sulphur dioxide (SO2) and dust particulates, through the supply of cleaner coal of consistent quality to downstream coal utilisation processes.

Beneficiating coals

The overall benefits of upgrading coal include:

- Lower ash content
- Higher heat value
- Consistent coal quality

Bituminous coals and anthracite, which account for two-thirds of the world’s coal production, can be upgraded. Among the largest producing countries, most coals from the US, Australia and South Africa are already washed and cleaned close to the economic limit. There is potential in the people’s republic of China, India, the Russian Federation and some other countries that process smaller amounts to increase the use of coal treatments. The use of clean coal reduces environmental pollution, with reduced emissions of CO2, sulphur and particulates. Cleaning the feed coal reduces the costs of investing in flue gas cleaning facilities.

Technological developments

Dry separation technologies

Dry coal processing does not require water and no moisture is added to the process. Dry processing is relevant where limited improvement is required. The dry separation of coal can be achieved by a number of means. Methods include separation by the use of friction, magnetic properties, electrostatic separation, microwave separation, pneumatic oscillating tables, air jiggling, air dense medium fluidisation and bed beneficiation. The processes that have been commercialised are pneumatic beneficiatio (oscillating table and air jig) and air dense medium fluidised bed (ADMFB) beneficiation.
Ultra-clean coal processes

A number of developments have occurred in the field of clean coal technology. This section describes two potential technologies for cleaning the coal significantly. Most of the mineral matter (ash) in coal is removed before combustion.

Figure 27 – Two strategies for chemical beneficiation

UCC process

Ultra-clean coals (UCC) are coals with a low ash content. UCC can be produced by a chemical leaching process. This works as a series of steps that converts the mineral into a soluble form and then removes the ash to a point where the total ash content is less than 0.2%.

Hypercoal process

Hypercoal has reduced ash and alkali contents. The raw coal is treated with organic solvent, which is flashed-off and recycled. Insoluble minerals and undissolved coal from a high ash by-product coal, which can be used in conventional pulverised fuel plants. Hyper-coal process can utilise most types of bituminous and sub-bituminous coals.

Research and development of low rank coal

Indonesian Low Ranked Coal (LRC), for example, has comparatively high moisture content, of 25-28%, and relatively low ash content, usually below 7%. The specific energy range is 10-20 MJ/Kg.

Processes in Indonesia

Kobe Steel Ltd has been developing Upgraded Brown Coal (UBC) since 1993. The approach taken is to use slurry dewatering as used in coal liquefaction. This is a five-step process using light oil to remove water from brown coal:
• Pulverisation of the LRC raw material.
• The pulverised coal is mixed with recycled oil, typically petroleum light oil and heavy oil to produce a slurry.
• The slurry is heated in an evaporator
• Oil is recovered by decanting
• The upgraded coal is briquetted for transport

Processes in the US

Western Syncoal LLC, the advanced coal conversion process demonstration (ACCPD) has been described by Couch (2002). The Syncoal process upgrades LRC by a combination of thermal processing and physical cleaning.

Convert Coal Inc (CCI) has developed a novel coal-to-liquid (CTL) pyrolytic process. This converts LRC containing 30-35% volatile matter into two products; syncrude and a low emission coal-char-fuel. In the case of the former product, the (CTL) process produces coal tar oil (CTO) as an intermediate product, which is turn is hydro-treated to produce syncrude. The syncrude product can be used as the raw material in petroleum refining. On the other hand, the low emission coal-char-fuel can be used in power plants.

Cokemaking techniques and their effect on raw materials use
(refer to Appendix H for references)

Introduction

During cokemaking a blend of coals is subject to a time temperature profile (with temperatures around 1200°C) under exclusion of oxygen. The blend of coking coals normally contains the moisture of the coals received (from 8 to 11%) and depending on the local weather conditions this level can be lower or higher.

The conventional way coking process is using high (up to 7-metre so-called slot ovens), narrow (40-60cm) and long (>10m) rectangular shaped ovens. The coal blend is gravity charged from the top and the ovens are heated with hot gas supplied between the individual ovens. The specific gravity of the coal blend with this top charging technique is around 700-750 kg/m³ on a dry basis. The ovens are constructed from refractory material and are built up in a set of a number of ovens which form a so-called battery.

After the heat treatment of around 20 hours the coke is pushed out of the oven and after handling and screening fed to the BF. The released gas during the process is treated in a by-product plant where different useful by-products such as tar, benzene, toluene and xylenes (BTX) and sulphuric acid are recovered. Below several variants of the conventional process are discussed with the assumed/published effect on raw material use. In a conventional coke making process under normal conditions a limited amount of lower quality coals can be used (10-20% so called semi soft coals together with 80-90% so-called hard coking coals, ref 1) in order to produce high quality coke for a high productive blast furnace. These effects of the different processes can be divided into two groups, one related to increasing the specific gravity of the coal blend during the coking process and the other related to drying and heating the coal blend before charging into the oven. Both techniques are reported to lead to better coke quality or can lead to a lower quality coal blend at the same coke quality targets.
1) Stamp charging

This technology is applied by different operators. Instead of charging the blend by gravity from the top of the oven, a compacted cake is prepared by mechanical stamping of the blend in a box outside the oven. After this densification (to levels >1000 kg/m3 db) the resulting cake is moved sideways into the oven, after which the coking process starts. Sources 2), 3) and 4) claim improved coke quality and/or higher level of inferior coals is possible with the same coke quality.

2) Briquetting

With this process, part of the blend is converted into higher density briquettes and later added to the rest of the blend followed by top-charging into the ovens. It is claimed that improved coke quality and/or higher level of inferior coals is possible with the same coke quality, see 5) and 6).

3) CMC (Coal Moisture Control)

With this process, the coal blend is dried from 8-11% total moisture to 5-6% and subsequently charged into the ovens. Developed by Nippon Steel (see 7), this process allows for an increase in dry bulk density. Its claimed advantages are higher productivity and better coal quality/lower blend costs, see 8) and 9).

4) DAPS (Drying and partial briquetting)

This process combines briquetting of the fines and removes the moisture from the coal blend and therefore the claimed advantages are considered more substantial compared with the individual techniques, see 10).

5) SCOPE 21

This projects maximises the use of drying/heating and densification of the coal blend by heating the blend to 300 °C before charging into the oven. Also, thin refractory is used to increase the plant’s productivity. It is claimed that lower quality coals can be used and lower energy consumption can be reached, along with higher productivity. The development of technologies for preliminary treatment of coal, temperature control and blending enables the use ratio of the non-coking coal and slightly caking coal to increase up to 50%, see 11).

6) Heat recovery process

Coke is made by heating a horizontal cake of coal blend (instead of the conventional vertical cake) and the energy to heat the cake results from burning the volatiles directly above/below the cake. Excess energy is converted into steam/electricity and no by-products are recovered. See 12).

7) Carbonyx

Carbonyx is a company that is developing carbon alloy structures and the processes to produce them with the help of additives and a continuous process. It claims to be able to use abundant inexpensive raw materials to produce a coke-like product named Cokonyx. See 14).
5. Ironmaking technology scenario

Project Group Members: Elizabeth Fitzpatrick (BlueScope Steel), Rongshan Lin (Dillinger Huttenwerke AG), Yang Jialong (Wuhan), Xu Haifa (Baosteel), Jean-Louis Lebonvalet (ArcelorMittal), Roberto Musante (Ternium), Pedro Etchevarne (Ternium), Louis L Herbier (U. S. Steel).

Sintering iron ore for feed into blast furnaces are the most widely adopted process routes throughout the world, accounting for nearly 70% of the steel production globally - operating parameters are highly dependent upon the quality and cost effectiveness of the two key raw materials, iron ore and coke. Adoption of alternate ironmaking technologies depends upon various aspects, such as the quality of raw materials, process efficiency and the environmental footprint. Subsequent sections of the report will describe the ironmaking processes and survey results obtained from the project members in detail.

5.1 Overview of the processes and survey results

5.1.1 Blast furnace

The blast furnace worldwide is the most important facility to produce iron or hot metal. The size of blast furnaces can vary from less than 500m³ to more than 5,500m³. The development trend has been towards building larger sized blast furnaces to improve efficiency. The blast furnace can be very efficient and flexible regarding energy consumption and hot metal production and the use of raw materials. However, the overall performance of the blast furnace is directly influenced by the quality of raw materials used. In order to obtain an overview of the current situation of the worldsteel member plants and to recognise the future trend, a questionnaire was organised both to collect the technical data and to gather experiences of the blast-furnace operators.

The focus was predominantly targeted on the quality of the raw materials used and the influence on the blast furnace performance. Altogether, 16 steel companies participated in the first questionnaire. After the evaluation of the first questionnaire, a second questionnaire was conducted to clarify some points. In the following section the results from the questionnaire and its evaluation are divided into two parts, corresponding the questionnaire structure.

First phase of survey of raw materials used in the blast furnace

The ferrous materials used in the blast furnace are sinter, pellets and lump ore. Some blast furnaces recycle also directly certain amount of scrap or briquettes which contain internal reverts such as BF/BOF dust and sludge.

5.1.2 Sinter

Table 19 shows the original questionnaire results on sinter quality, the corresponding results are summarised in a table. The chemical composition of the sinter was quite clearly given by the participants and could be well summarised in the categories min, max, and average value. As shown in the table, the Fe content varies in the range between 45.8% and 59.1%, the average value is 55.6% Fe.
The silica content is from 3.7% up to 10%, a quite large range between the different blast furnaces, while the alumina content ranges from 0.7% to 2.8%. The sinter is normal dry and has a moisture content of around 1% H2O, because it is directly cooled in a cooler by air. The sinter size range is between 5mm and 50mm. The oversize and undersize amount quoted are somehow confused, as they are not consistently defined in the questionnaire or in the practical application in plants. The tumbler index is also given in a large range of 56.5% and 92%. Of course, the values are additionally dependent on the sampling point where the sinter is stabilised or not. The average value of the reduction degradation index (RDI) is around 27%, but the lowest value of 6.9% appears outside the normal distribution and not feasible.

Table 19 – Lump ore quality

<table>
<thead>
<tr>
<th>Source (mine, country)</th>
<th>BF burden (%)</th>
<th>Lump ore (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Ave</td>
<td>min</td>
</tr>
<tr>
<td>T. Fe</td>
<td>36.6</td>
<td>30.0</td>
</tr>
<tr>
<td>SiO2</td>
<td>3.5</td>
<td>1.6</td>
</tr>
<tr>
<td>Al2O3</td>
<td>1.7</td>
<td>0.2</td>
</tr>
<tr>
<td>Na2O+K2O</td>
<td>0.04</td>
<td>0.001</td>
</tr>
<tr>
<td>P</td>
<td>0.06</td>
<td>0.02</td>
</tr>
<tr>
<td>S</td>
<td>0.05</td>
<td>0.00</td>
</tr>
<tr>
<td>Moisture</td>
<td>4.1</td>
<td>0.8</td>
</tr>
<tr>
<td>Ig Loss</td>
<td>3.2</td>
<td>0.5</td>
</tr>
<tr>
<td>Size range (mm)</td>
<td>20.7</td>
<td>4.8</td>
</tr>
<tr>
<td>% oversize</td>
<td>8.0</td>
<td>0.0</td>
</tr>
<tr>
<td>% undersize</td>
<td>5.9</td>
<td>0.7</td>
</tr>
<tr>
<td>Tumbler index</td>
<td>97.8</td>
<td>95.0</td>
</tr>
</tbody>
</table>

Blast furnace survey responses graphical approach

Fifteen survey responses were received for the blast furnace. Within these responses, 45 were individual burden components.

- Blast furnace burdens consisted of lump, sinter, pellet and one plant charging BOF slag.
- One respondent charged 100% pellet of two types.
- One respondent is charged 100% sinter of two types.
- One respondent is charged two types of lump ore to their burden.
Sinter is the dominant burden feed. Burden flexibility is achieved in all plants through the use of two burden materials. Of the respondents who are charging Lump ore the minimum is 7% and the maximum burden amount of lump is 35%. Of the respondents who are charging sinter but not at 100% of burden, the burden composition of sinter is within the range of 15-79%. Of the respondents who are charging pellet but not at 100% of burden the burden composition of pellets is within the range of 15% to 85%.

Coke

The information around the coke quality is given in table 20. Most steel companies have their own coke plants supplying their blast furnaces with coke. However, the capacity of the own coke plant does not always fully cover demand. Thus, external coke from different sources has to be purchased. Correspondingly, the coke quality used in a BF coke can vary considerably. The average values do not reflect these variations in the amount and quality. The information from the questionnaire is limited to provide the minimum and maximum range. The minimum coke consumption is only 300 kg/tHM, whilst the maximal consumption reaches more than double 750 kg/tHM. Of course, it depends on the amount of PCI or oil injection rate, but the ash content of the coke plays also an important role. As shown in the table, the maximum ash content can be as high as 18.6%.

Table 20 Coke quality

<table>
<thead>
<tr>
<th>Site</th>
<th>Coke quality and consumption</th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Coke name</td>
<td>CO</td>
<td>Min.</td>
<td>Max.</td>
</tr>
<tr>
<td>Consumption kg/tHM</td>
<td></td>
<td>300</td>
<td>750</td>
<td></td>
</tr>
<tr>
<td>Coal proportion (%)</td>
<td></td>
<td>0</td>
<td>200</td>
<td></td>
</tr>
<tr>
<td>Quality %</td>
<td>T.C</td>
<td>0.1</td>
<td>89.5</td>
<td></td>
</tr>
<tr>
<td></td>
<td>F.C</td>
<td>0.6</td>
<td>1.4</td>
<td></td>
</tr>
<tr>
<td></td>
<td>VM</td>
<td>0.1</td>
<td>1.8</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Ash</td>
<td>2</td>
<td>18.7</td>
<td></td>
</tr>
<tr>
<td></td>
<td>S</td>
<td>0.5</td>
<td>1.9</td>
<td></td>
</tr>
<tr>
<td></td>
<td>P</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Na2O+H2O</td>
<td>0.2</td>
<td>0.9</td>
<td></td>
</tr>
</tbody>
</table>
Not every blast furnace plant uses pulverised coal injection (PCI) to replace coke, some blast furnaces inject oil or natural gas. The information around the PCI quality used in the plants is given in table 21.

Again, due to the variation of the quality and amount, only minimal and maximal ranges are summarised in the table. The type of coal as PCI can be classified as typical PCI coal and thermal/power coal. The difference of these both types is the low caloric value (LCV) of the coal.

At a similar injection rate, PCI coal with high LCV can replace more coke than thermal coals with lower LCV. Consequently, the use of thermal coals is limited in the blast furnace.

The ash content of coals influences the total reducing agent consumption, in the same way as the coke. From the volatile matter point of view, a large range of coals can be used as PCI, from anthracite (10%VM) to HV coals (35%VM). The choice is quite flexible.

Table 21 – PCI quality

<table>
<thead>
<tr>
<th>Site</th>
<th>Min</th>
<th>Max</th>
</tr>
</thead>
<tbody>
<tr>
<td>Type of coal</td>
<td></td>
<td></td>
</tr>
<tr>
<td>PCI consumption kg/\text{HM}</td>
<td>0</td>
<td>230</td>
</tr>
<tr>
<td>Source (mine, country)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>C.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>F.C</td>
<td>53</td>
<td>77</td>
</tr>
<tr>
<td>VM</td>
<td>10</td>
<td>30</td>
</tr>
<tr>
<td>Ash</td>
<td>6</td>
<td>20</td>
</tr>
<tr>
<td>S</td>
<td>0.5</td>
<td>4</td>
</tr>
<tr>
<td>P</td>
<td>0.02</td>
<td>0.04</td>
</tr>
<tr>
<td>\text{Na}_2\text{O}+\text{H}_2\text{O}</td>
<td>0.02</td>
<td>0.2</td>
</tr>
<tr>
<td>GCV kcal/\text{kg}</td>
<td>6070</td>
<td>7300</td>
</tr>
<tr>
<td>LCV kcal/\text{kg}</td>
<td>7100</td>
<td>7500</td>
</tr>
</tbody>
</table>

Second phase of survey of raw materials used in the blast furnace

Following evaluation of the initial questionnaire on raw materials, some parameters for the blast furnace construction and operation were missing. A second questionnaire was requested to provide the missing information. Five steel companies delivered the requested information. As shown in table 22, a large range of the blast furnace size and operation performance is considered and summarised.

Table 22 – Burden feed mix

<table>
<thead>
<tr>
<th>Burden Material</th>
<th>Min%</th>
<th>Max%</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lump ore</td>
<td>7</td>
<td>35</td>
</tr>
<tr>
<td>Pellet</td>
<td>15</td>
<td>85</td>
</tr>
<tr>
<td>Sinter</td>
<td>15</td>
<td>79</td>
</tr>
</tbody>
</table>

Respondents were asked to submit the minimum, maximum and average chemical properties of their burden charge. (These graphs are an average of the burden types given in survey).
These responses show that for lump, some operations i.e. (1, 16, and 22) have a wider range of Fe content than the others who appear to have a tighter range on their lump Fe content charged. The wider range of accepted Fe content could be linked to inconsistent or a blended iron ore supply.

**Graph 44 – Fe percentage in lump ore charge**

For pellets the range of Fe content is higher across all plant which is expected for manufactured feed product. The pellets Fe content is the highest of the three potential burden materials.

**Graph 45 – Fe percentage in pellet ore charge**

For sinter there are two categories of operating philosophies, those with wide ranges and those with tighter limits. Plant 7 is charging 2 sinter types and the Fe content of those two are represented here as a minimum and maximum Fe content. Those with wider ranges again could represent a more flexible operation with the ability to respond to market availability of fines.

**Graph 46 – Sinter Fe percentage in burden charge**
Summary of experiences from blast furnace operators

In addition to the above facts, the blast furnace operators were also asked about their experiences and opinions concerning raw-materials issues. Some relevant questions were sent to the steel companies. Their answers were collected and evaluated. In order to reflect the real situation prevailing in the plants, it was attempted to present the answers in a logical structure, but the original text of the answers was not changed. In the following, the questions and answers are summarised. Sintering, a complex dynamic metallurgical process, is carried out as a countercurrent gas-solid contact process. The sinter process involves raising the temperature of the micro-pelletised sinter mix to achieve partial fusion and produce molten material which, on cooling, crystallises or solidifies into various mineral phases that bond the structure together. The process heat is supplied by combustion of coke breeze (fine material), one of the components of the granulated mix. The heat profile generated during the sintering reaction has a significant effect on the type of sinter produced and on its physical properties. Monitoring a sintering operation to ensure completion of sintering reactions, reducing the transient periods to gain stable operations and obtaining and maintaining the target quality are important factors in the production of sinter for blast furnace needs.

Sintering process description

A mixture of iron ores consisting of various mineral phases such as haematite, magnetite, calcium ferrites and calcium silicates, together with additives and solid fuel (coal) are laid down on a grate as a bed of uniform thickness. The grate moves in a horizontal direction, and suction is applied beneath it. Once levelled, the bed passes under an ignition hood, where the top of the bed is first ignited and hot gases are drawn into it, rapidly raising the temperature of the top layer. Normally, ignition burners are set in a brick-lined hood which covers a length of the strand. By the time ignition has been completed, the solid fuel at the top layer has reached its ignition temperature. From this point onwards, the air is sucked down through the bed. The air is first pre-heated by its passage through the upper layers of the bed, then sustains combustion of the hot carbon, and finally is rapidly cooled by evaporating the water from the bed immediately below the combustion zone. The combustion zone moves downwards through the bed as sintering proceeds and the pellets move toward the end of the strand. At the conclusion, all of the fuel has been burnt and each level in the bed has been heated to sintering temperature. The sinter is then tipped off the strand, and the undersize material is screened out (return fines), and returned and re-fed with the raw materials. The oversize sinter is cooled and goes to the blast furnace. (It may contain SFCA or silico-ferrite of calcium and aluminium).

Figure 28 – Sintering process description
Survey results of sinter

Operational constraints are similar among the worldsteel member respondents. Highlighting well acknowledged operational constrains including:

- Consistency of ore, chemistry and sising.
- Moisture content of the ore.
- Ability to utilise concentrates to high percent in the raw mix.
- Maintaining sinter productivity

Graph 47 – % of ore type in standard Fe mix

Graph 48: Fe percentage and hematite ore percentage in sinter blend (left)
Graph 49: Percentage of ore type in sinter blend (right)
Plant One predominately uses hematite in both fine and concentrate form across all its sinter blend of Fe mixes. The minor constituents in the standard blend include fine limonite and taconite in concentrate form. The low Fe Mix has a lower Fe content hematite (64.5%) with limonite fines and concentrates of taconite and Hematite. The high Fe Mix has the highest hematite Fe content of 66.8% with limonite and a concentrate of an undisclosed ore type closing out their blend.

Graph 50 – Ore type percentage in sinter blend (left)
Graph 51 – Ore type percentage and Fe feed (right)

Graph 52 – Ore type % and Fe feed
Graph 53 – Ore type % in sinter blend
Plant Two’s sinter blend includes sinter feed and concentrates of hematite fines and a magnetite concentrate.

The low Fe mix has the highest hematite proportion in the sinter blend though it is of a low Fe content (60%) with the balance being magnetite concentrate of 63.4 Fe content. The high Fe mix is comprised of a magnetite concentrate of Fe content 65.5% and a hematite sinter feed of undisclosed Fe content.

Plant 4 has a standard mix that is predominately marra mamba and limonite sinter feed, with the balance of hematite, 3% being at 62% Fe and 18% at 66.3% Fe.

The low Fe mix includes a magnetite concentrate of 67.01% Fe with marra mamba (60.5% Fe) and limonite (56.5% Fe) sinter feeds, with a marra mamba concentrate being a minor constituent (65.8% Fe).

The high Fe sinter blend includes major constituents of sinter feed-sized material across limonite (57% Fe), hematite (62.05% Fe) and marra mamba (66.3% Fe) ore types, it also consists of concentrates of hematite (Fe percentage not given) and magnetite (67.01% Fe).

Graph 54 – Ore type % and Fe feed in sinter blend (left)
Graph 55 – Ore type % in sinter blend (right)

Plant 14 sinter blend is a mix of sinter feed and dust. When looking at the Fe content of these mixes, there is very little distinguishable change.

The sinter blend chemistry analysis provided from Plant 14 allows us to see potentially why sinter blends are split in this manner.
Table 23 – Sinter blend chemistry analysis

<table>
<thead>
<tr>
<th>Property</th>
<th>Standard</th>
<th>High</th>
<th>Low</th>
</tr>
</thead>
<tbody>
<tr>
<td>T.Fe</td>
<td>63.403</td>
<td>62.160</td>
<td>62.510</td>
</tr>
<tr>
<td>SiO2</td>
<td>8.944</td>
<td>6.842</td>
<td>10.000</td>
</tr>
<tr>
<td>Al2O3</td>
<td>1.255</td>
<td>1.616</td>
<td>1.266</td>
</tr>
<tr>
<td>P</td>
<td>0.036</td>
<td>0.043</td>
<td>0.035</td>
</tr>
<tr>
<td>S</td>
<td>0.080</td>
<td>0.070</td>
<td>0.074</td>
</tr>
<tr>
<td>Moisture</td>
<td>8.465</td>
<td>9.780</td>
<td>7.878</td>
</tr>
</tbody>
</table>

Observations on ore type

While hematite is the predominant Fe oxide making up the sinter blends the Fe content of the hematite is of a broad range 56 to 66.3% Fe content averaging being 63.33%. Plants that have more than two ores feeding into their sinter blend represent a flexible operation.

Conversely, the single ore type could represent local/owned ore mine. Sinter feed is the predominate feed to the blast furnace, with sising of material to the sinter machine being a key component. Concentrates were in use at 4 plants and were of magnetite, hematite, taconite, Marra Mamba and undisclosed Ore type.

Sinter blend chemistry

Ore chemistry of standard sinter feeds:

- Range of Fe was 56.7-66% with the average being 63.4%
- Plant 12 is running with the lowest Fe. This plant has relatively high H2O and LOI compared to other respondents.

It has low sulphur and a mid-range phosporus. SiO2 and Al2O3 are high when compared to other respondents. This plant didn’t disclose their ore type but their feed sising is sinter feed (assumed here to be ore fines).

- Plant 5 is running with the 2nd lowest Fe. This plant has high LOI, no H2O results was given. The plant has high P and S with high SiO2 and Al2O3 and is running 100% Haematite of sinter feed sising (assumed there are ore fines produced).

Five respondents detailed their high and low sinter blend chemistries. Comparisons of these results show that Fe content is also seen in a converse behavior in all of the other major chemical components.
Table 24 – Sinter blend chemistry analysis

<table>
<thead>
<tr>
<th>Property</th>
<th>Standard Min</th>
<th>Standard Max</th>
<th>Standard Average</th>
<th>High Fe Average</th>
<th>Low Fe Average</th>
</tr>
</thead>
<tbody>
<tr>
<td>T.Fe</td>
<td>56.741</td>
<td>65.960</td>
<td>63.331</td>
<td>64.253</td>
<td>63.037</td>
</tr>
<tr>
<td>SiO2</td>
<td>1.750</td>
<td>8.944</td>
<td>4.262</td>
<td>5.247</td>
<td>7.067</td>
</tr>
<tr>
<td>Al2O3</td>
<td>0.700</td>
<td>3.090</td>
<td>1.455</td>
<td>1.089</td>
<td>1.005</td>
</tr>
<tr>
<td>Na2O + K2O</td>
<td>0.022</td>
<td>0.184</td>
<td>0.066</td>
<td>0.065</td>
<td>0.065</td>
</tr>
<tr>
<td>P</td>
<td>0.030</td>
<td>0.094</td>
<td>0.059</td>
<td>0.034</td>
<td>0.038</td>
</tr>
<tr>
<td>S</td>
<td>0.005</td>
<td>0.080</td>
<td>0.035</td>
<td>4.200</td>
<td>0.051</td>
</tr>
<tr>
<td>Moisture</td>
<td>2.349</td>
<td>8.465</td>
<td>6.714</td>
<td>8.393</td>
<td>7.426</td>
</tr>
<tr>
<td>size &lt; 0.15mm</td>
<td>10.000</td>
<td>32.300</td>
<td>21.256</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Graph 56 – Chemical analysis of sinter feed – alumina and silica

Graph 57 – Chemical analysis of sinter feed – phosphorous and sulphur
Sinter blend’s component chemistry

In the survey respondents were asked to provide sinter blend ore types and chemistries.

Of the 16 respondents, there were 41 ore components provided representing a broad range of ore types and ore chemistries. Only one company has a concentrate feed, all others use sinter feed (assumed to the ore fines) or undisclosed sizing.

37 of the 41 detailed ore components given have included some ore chemistry detail. The results of this table have been calculated on supplied data blend component chemistries only.

- 37 responses included the Fe content. The range of Fe was 52.1 to 72.07 with the average being 63.3%.
- 35 responses noted SiO2 content. Giving a span of 16.62 percent points is seen with an average of 4.39%.
- 35 responses noted Al2O3 giving a range of 5.3 percent points with an average of 1.65%
- The percentage (Na2O+K2O) was included in chemistries of 22 of the 37 disclosed chemistries with a broad range of 0.43% between results which has reflected a high average of 0.09.
- The percentage of phosphorus had 30 data points of the 37 with range from 0.002 to 0.186, giving a range of 0.18 which has returned an average of 0.055.
- The percentage of sulphur had 25 responses with a range of 0.005 to 0.17, giving a range of 0.18 which has returned an average of 0.044%.
- Moisture has 29 responses with a range of 1.7 to 10.9, giving an average of 7.12%.
- LOI only had 22 responses with a broad range from 0.71 to 11. Reflecting an average of 3.93.
Table 25 – Chemical analysis of sinter blend ore type

<table>
<thead>
<tr>
<th></th>
<th>Min</th>
<th>Max</th>
<th>Avg</th>
<th>Range</th>
<th>Data point</th>
</tr>
</thead>
<tbody>
<tr>
<td>T.Fe</td>
<td>52.1</td>
<td>72.073</td>
<td>63.317</td>
<td>19.97% Fe</td>
<td>37</td>
</tr>
<tr>
<td>SiO2</td>
<td>1.08</td>
<td>17.70</td>
<td>4.39</td>
<td>16.62% SiO2</td>
<td>35</td>
</tr>
<tr>
<td>Al2O3</td>
<td>0.36</td>
<td>5.66</td>
<td>1.65</td>
<td>5.30% Al2O3</td>
<td>35</td>
</tr>
<tr>
<td>Na2O+K2O</td>
<td>0.02</td>
<td>0.44</td>
<td>0.09</td>
<td>0.43% Na2O+K2O</td>
<td>22</td>
</tr>
<tr>
<td>P</td>
<td>0.002</td>
<td>0.186</td>
<td>0.055</td>
<td>0.18% P</td>
<td>30</td>
</tr>
<tr>
<td>S</td>
<td>0.005</td>
<td>0.170</td>
<td>0.044</td>
<td>0.17% S</td>
<td>25</td>
</tr>
<tr>
<td>Moisture</td>
<td>1.700</td>
<td>10.900</td>
<td>7.121</td>
<td>9.20% H2O</td>
<td>29</td>
</tr>
<tr>
<td>Ig-Loss</td>
<td>0.71</td>
<td>11</td>
<td>3.93</td>
<td>10.29% LOI</td>
<td>22</td>
</tr>
</tbody>
</table>

Graph 59 – Sinter blend ore type and Fe percent

Graphical representation of the Fe content of the ore types used in a plant sinter blend shows that individual plant are using a wide range of Fe content feeds within their operation.
The AI2O3 content of the ore is generally varied with in individual plant there are no outliers in this data set that would be influencing the previously stated ranges.

SiO2 in the component ores has a very wide range over 16.6 percent points. Excluding the values of 11 and 17.7, the results range from 1.083-9.62 with an average SiO2 content of 3.78%.
The S content of the ore appears to be balanced for an individual plant. Plants having a stable Sulphur content of their input or a balance of high and low Sulphur. Plant 2, 4, 13, 14 have a range of S content within their individual sinter blend.

In the phosphorous content of the sinter blend component the same trends are seen with individual plants. Plant 14 is the only plant that has a tight range on their phosphorous input.
LOI (Loss on Ignition) content of the sinter blend constituents generally follows the ore type, goethite, limonites and marra mamba have relatively high LOIs. Plant 15 has not disclosed any ore types but they are running high LOI feeds. Plant 16 is running hematite and an undisclosed ore type, one of the hematites making up the sinter blend is particularly high LOI which is balanced out with other normal range LOI products.

Moisture content of the sinter blend constituents varies across ore types and individual sinter blends.
The NaO₂+K₂O average values presented are being biased by the high results presented by Plant 13. If plant 13’s data is excluded from the analysis the range of NaO₂+K₂O becomes 0.015% to 0.15% with an average of 0.047%.

**Sinter blend components details by ore type and country of origin**

The survey responses on sinter blend ore country of origin had 67 responses over the 16 respondents. If returns and undisclosed ore types are excluded from the analysis then there are 47 data points available for analysis.

The first graph shows that the hematites that are being sourced from South America are the highest in Fe. Indian and Australian Hematite’s being the next most frequently used with an overlapping range of Fe contents. Hematite is also being sourced from Russia and the Ukraine.
Graph 67 – Sinter blend components details, ore type/country of origin

This graph is of hematite only and is presented in increasing Fe content of the ore type from left to right. The other ore types being sourced are: Magnetites (China and Russia), Marra Mamba (South America and Australia), itabirites (South America), blend ore, goethites, pisolites and limonites from Australia.

Graph 68 – Country wise Fe trend in different types of ores

This graph is presented in increasing Fe content of the ore type from left to right. For synopses of the responses received from sinter plants, please refer to Appendix K for details.
5.1.3 Alternate ironmaking processes

1. Corex

Development of the Corex process commenced in the late 1970s and a joint research and development programme was signed in 1979 between VOESTALPINE Industrieanlagenbau (VAI) and Deutsche VOESTALPINE Industrieanlagenbau (DVAI). This led to the construction of a 200 tonnes per day pilot plant at Kehl, Germany, where campaigns comprising more than 6000 operating hours were carried out during the 1980s. This was in order to develop the process to industrial maturity.

Figure 29 – Milestones on the road of development

<table>
<thead>
<tr>
<th>Year</th>
<th>Company</th>
<th>Event</th>
</tr>
</thead>
<tbody>
<tr>
<td>2011</td>
<td>BAOSTEEL</td>
<td>Start-up of the Corex® Plant C-3000 N° 2</td>
</tr>
<tr>
<td>2007</td>
<td>BAOSTEEL</td>
<td>Start-up of the Corex® Plant C-3000 N° 1</td>
</tr>
<tr>
<td>2000</td>
<td>JINDAL</td>
<td>Start-up of the Corex® Plant C-2000 N° 2</td>
</tr>
<tr>
<td>2000</td>
<td>SALDANHA</td>
<td>FAT for the Corex® Plant C-2000</td>
</tr>
<tr>
<td>1999</td>
<td>JINDAL</td>
<td>FAT for the Corex® Plant C-2000 N° 1</td>
</tr>
<tr>
<td>1999</td>
<td>SALDANHA</td>
<td>Start-up of Corex® Gas-based DR Plant</td>
</tr>
<tr>
<td>1999</td>
<td>JINDAL</td>
<td>Start-up of Corex® Module N° 1</td>
</tr>
<tr>
<td>1998</td>
<td>SALDANHA</td>
<td>Start-up of Corex® Plant C-2000</td>
</tr>
<tr>
<td>1997</td>
<td>POSCO</td>
<td>FAT for the Corex® Plant C-2000</td>
</tr>
<tr>
<td>1997</td>
<td>JINDAL</td>
<td>Contract for Corex® Plant C-2000 N° 2</td>
</tr>
<tr>
<td>1996</td>
<td>SALDANHA</td>
<td>Contract for Corex® Plant C-2000 and Corex® Gas-based DR Plant</td>
</tr>
<tr>
<td>1995</td>
<td>POSCO</td>
<td>Start-up of the Corex® Plant C-2000</td>
</tr>
<tr>
<td>1995</td>
<td>JINDAL</td>
<td>Contract for Corex® Plant C-2000 N° 1</td>
</tr>
<tr>
<td>1989</td>
<td>ISCOR</td>
<td>Start-up of the Corex® Plant C-1000</td>
</tr>
<tr>
<td>1981</td>
<td></td>
<td>Pilot Plant at Kehl, Germany</td>
</tr>
<tr>
<td>1981</td>
<td></td>
<td>Start of Corex® Development</td>
</tr>
</tbody>
</table>

Figure 30 – Flow sheet of Corex process

Survey of raw materials used in the Corex

Ferrous materials

The ferrous materials used in the Corex are pellets and lump ores. In addition, a small quantity of ore (pellet fine and lump fine) is directly charged into melter gasifier only when the furnace condition permits. The sinter also can be used in Corex theoretically; however, South Africa and China both have not yet adopted this operating practice. No paper has been published on Corex using sinter feed. The S-VAI gives the specification of COREX Ferrous Materials.
Table 26 – Specification of COREX ferrous materials

<table>
<thead>
<tr>
<th></th>
<th>Tolerable</th>
<th>Preferred</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Lump ore:</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Fe&lt;sub&gt;tot&lt;/sub&gt;</td>
<td>55% min</td>
<td>80% min</td>
</tr>
<tr>
<td>Grain size</td>
<td>6-32mm</td>
<td>10-25mm</td>
</tr>
<tr>
<td><strong>Pellets:</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Fe&lt;sub&gt;tot&lt;/sub&gt;</td>
<td>55% min</td>
<td>60% min</td>
</tr>
<tr>
<td>Grain size</td>
<td>6-20mm</td>
<td>8-16mm</td>
</tr>
<tr>
<td><strong>Sinter:</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Fe&lt;sub&gt;tot&lt;/sub&gt;</td>
<td>45% min</td>
<td>50% min</td>
</tr>
<tr>
<td>Grain size</td>
<td>6-50mm</td>
<td>10-32mm</td>
</tr>
</tbody>
</table>

In fact, more strict specification is required in practical Corex production. The lump ores and pellets with no less than 64% (TFe) can be used in Corex plants. The following table is from a respondent around the pellets and lump ores used in their Corex plants.

Table 27 – Iron ore feed to COREX

<table>
<thead>
<tr>
<th></th>
<th>Pellet ave</th>
<th>Pellet min</th>
<th>Pellet max</th>
<th>Lump ore ave</th>
<th>Lump ore min</th>
<th>Lump ore max</th>
</tr>
</thead>
<tbody>
<tr>
<td>T.Fe</td>
<td>64.7</td>
<td>66.40</td>
<td></td>
<td>62.31</td>
<td>67.4</td>
<td></td>
</tr>
<tr>
<td>SiO2</td>
<td>1.95</td>
<td>3.03</td>
<td></td>
<td>2.12</td>
<td>3.84</td>
<td></td>
</tr>
<tr>
<td>Al2O3</td>
<td>0.052</td>
<td>1.71</td>
<td></td>
<td>0.74</td>
<td>1.74</td>
<td></td>
</tr>
<tr>
<td>P</td>
<td>0.039</td>
<td>0.056</td>
<td></td>
<td>0.028</td>
<td>0.068</td>
<td></td>
</tr>
<tr>
<td>S</td>
<td>0.006</td>
<td>0.014</td>
<td></td>
<td>0.007</td>
<td>0.036</td>
<td></td>
</tr>
<tr>
<td>Moisture</td>
<td>0.4</td>
<td>4.8</td>
<td></td>
<td>0.7</td>
<td>3.5</td>
<td></td>
</tr>
<tr>
<td>Ig-Loss</td>
<td>0.53</td>
<td>4.33</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Na20+K20</td>
<td>0.042</td>
<td>0.053</td>
<td></td>
<td>0.038</td>
<td>0.211</td>
<td></td>
</tr>
<tr>
<td>Size range (mm)</td>
<td>8</td>
<td>20</td>
<td></td>
<td>8</td>
<td>25</td>
<td></td>
</tr>
<tr>
<td>% oversize</td>
<td>0.73</td>
<td>5</td>
<td></td>
<td>4</td>
<td>32</td>
<td></td>
</tr>
<tr>
<td>% undersize</td>
<td>0.6</td>
<td>14</td>
<td></td>
<td>0.8</td>
<td>20.6</td>
<td></td>
</tr>
<tr>
<td>Feed mix (%) excl. fluxes, reverts, fuels</td>
<td>60</td>
<td>100</td>
<td>0</td>
<td>40</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Reductant characteristics

Coke and lump coal are both used in Corex. Similar performance requirements as those for blast furnace coke exist for Corex feed, only the size requirements (8-40mm) are different. Based on the operation experience, if the coke dosage is high, the quality requirements of the lump coal can be reduced. In addition, coal fines (from lump coal and coke) are also used in Corex process after being briquetted. The following table is the specification of Corex coal.

Table 28 – Coal feed to Corex

<table>
<thead>
<tr>
<th></th>
<th>Coals for Blending</th>
<th>Coal or Coal Blends</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Tolerable</td>
<td>Preferred</td>
</tr>
<tr>
<td>Moisture before dryer</td>
<td>max. 15%</td>
<td>max. 12%</td>
</tr>
<tr>
<td></td>
<td>max. 5%</td>
<td>&lt;8%</td>
</tr>
<tr>
<td></td>
<td>after dryer</td>
<td>max. 5%</td>
</tr>
<tr>
<td></td>
<td></td>
<td>&lt;5%</td>
</tr>
<tr>
<td>Proximate Analysis [dry]</td>
<td>min. 50%</td>
<td>min. 55%</td>
</tr>
<tr>
<td>Fixed Carbon</td>
<td>max. 40%</td>
<td>55 - 65%</td>
</tr>
<tr>
<td></td>
<td>max. 30%</td>
<td>25 - 35%</td>
</tr>
<tr>
<td>Volatiles</td>
<td>min. 25%</td>
<td>5 - 12%</td>
</tr>
<tr>
<td>Ash</td>
<td>min. 3</td>
<td>&gt; 5</td>
</tr>
<tr>
<td>Fixed Carbon/Ash</td>
<td>—</td>
<td>—</td>
</tr>
<tr>
<td>Sulfur [dry]</td>
<td>—</td>
<td>—</td>
</tr>
<tr>
<td>Grain Size</td>
<td>0 - 50 mm</td>
<td>0 - 50 mm</td>
</tr>
<tr>
<td></td>
<td>&gt; 50% + 15 mm</td>
<td>8 - 40 mm</td>
</tr>
<tr>
<td></td>
<td>&lt; 10% - 2 mm</td>
<td></td>
</tr>
<tr>
<td></td>
<td>&lt; 5% - 1 mm</td>
<td></td>
</tr>
</tbody>
</table>

Table 29 – Coke and coal feed to Corex

<table>
<thead>
<tr>
<th></th>
<th>Min,%</th>
<th>Max,%</th>
</tr>
</thead>
<tbody>
<tr>
<td>Corex burden</td>
<td>50</td>
<td>90</td>
</tr>
<tr>
<td>Ash</td>
<td>9</td>
<td>17</td>
</tr>
<tr>
<td>Volatiles</td>
<td>22</td>
<td>34</td>
</tr>
<tr>
<td>Cfix [dry]</td>
<td>55</td>
<td>69</td>
</tr>
<tr>
<td>Stotal</td>
<td>0.3</td>
<td>0.9</td>
</tr>
<tr>
<td>P</td>
<td>0.04</td>
<td>0.13</td>
</tr>
</tbody>
</table>

Respondents supplied information on ore and reductant

Positive aspects and negative aspects of Corex

Positive aspects

- Can make liquid iron with no / small amount of coke
- The off gas is almost nitrogen free, being based on oxygen rather than air blowing, is therefore more amenable to CO2 sequestration. Nitrogen used to adjust tuyere conditions (protection) carries advantages of the BF on desulphurisation potential and use of slag as input for cement making is concerned.
- It has been realised at a commercial scale for many years after first Corex started in South Africa (Victoria) 1989 C1000. Already there are several operating units.
• Usage of lump and pellet as feed streams  
• Injection of fine ore or dust is possible 20-80kg/tHM  
• Can avoid coking coal and sintering ores  
• Low environmental impact. Due to no coke oven or sinter plant required. Dust, SOx, NOx generation/control can be managed easier. With fewer process reactors, it is simpler to control environmental emissions.

Table 30—Corex operating units worldwide

<table>
<thead>
<tr>
<th>Country</th>
<th>Company</th>
<th>Units</th>
<th>Type</th>
</tr>
</thead>
<tbody>
<tr>
<td>India</td>
<td>JSW Steel Ltd</td>
<td>2</td>
<td>C2000</td>
</tr>
<tr>
<td>India</td>
<td>Essar Steel</td>
<td>2</td>
<td>C2000</td>
</tr>
<tr>
<td>South Africa</td>
<td>ArcelorMittal</td>
<td>1</td>
<td>C2000</td>
</tr>
<tr>
<td>China</td>
<td>Baosteel</td>
<td>2</td>
<td>C3000</td>
</tr>
</tbody>
</table>

Negative aspects

• Use of agglomerates, meaning limited direct use of fine ore  
• Need for coal in lump or briquette form (high strength required)  
• Relatively high coal consumption and export gas energy – making the economics very sensitive to on energy credit. Sinter usage is unknown at present  
• Can be run with no coke but productivity is impacted and fuel rate.

2. Finex

The FINEX process, a smelting-reduction technology based on the direct use of coal and fine ore was jointly developed by POSCO and VAI. The direct use of fine ore for the production of hot metal and DRI will be one of the driving forces behind future developments. In May 2003 the FINEX demonstration plant with an annual nominal capacity of 600,000t hot metal commenced operations. Based on the successful results, the design of the first industrial FINEX 1.5M plant an annual capacity of 1,500,000 tonnes of hot metal was started up in 2007. The following figure is the Finex milestones on the road of development.

Figure 32—Milestones on the road of development (ii)
Survey of raw materials used in the Finex: Ferrous materials

The sinter feed iron ore (~8mm) plus is used directly in Finex. The following picture gives the ore flexibility of Finex. Different types of ore have different size requirements for Finex.

Figure 34 – Physical and chemical analysis for finex iron ore feed
Reductant characteristics

Similar to the Corex, small amount of coke and lump coal are used in Finex. Coal fines are also used in Finex after being briquetted. The following figure gives the coal material flexibility. In additional, pulverised coal fine is under normal usage directly injected at Tuyere.

Figure 35 – Coal requirement for Finex versus BF

<table>
<thead>
<tr>
<th>Indices</th>
<th>VM (%)</th>
<th>Ash (%)</th>
<th>PFSI</th>
<th>BF</th>
<th>FINEX&lt;sup&gt;®&lt;/sup&gt;</th>
</tr>
</thead>
<tbody>
<tr>
<td>Thermal Coal</td>
<td>30~38</td>
<td>&lt; 17</td>
<td>0~2</td>
<td>20%</td>
<td>10%</td>
</tr>
<tr>
<td>Semi-Soft</td>
<td>20~34</td>
<td>&lt; 10</td>
<td>1~6</td>
<td>40%</td>
<td>80%</td>
</tr>
<tr>
<td>Coke Coal</td>
<td>10~25</td>
<td>&lt; 10</td>
<td>0~9</td>
<td>60%</td>
<td>40%</td>
</tr>
<tr>
<td>Semi-Anthracite</td>
<td>10~15</td>
<td>&lt; 15</td>
<td>0~2</td>
<td>100%</td>
<td>0%</td>
</tr>
</tbody>
</table>

Further efforts will be made to increase the use of low grade coal

Positive aspects and negative aspects of the Finex

Positive aspects

1. Direct processing of fine ore (sintering size) to liquid iron means no agglomeration.
2. Can make liquid iron with no/small amount of coke.
3. Use of various ore brands (high Al2O3, low-grade ore).
4. Use of low grade coal
5. The off gas, being based on oxygen rather than air blowing, is more amenable to CO2 sequestration
6. Carries advantages of the BF on desulphurisation potential and use of slag as input for cement making is concerned
7. Has been realised at commercial scale at Posco.
8. Environmental impact is reduced. Due to reduced number of production units. (no sintering or coke making)
9. Up to one-third of the fuel rate can be PCI.

Negative aspects

1. Need for coal in lump or briquette form. Strength needs to be high to obtain high performance. Semi coking coal required to make strong briquette with special binder.
2. While iron ore does not need to be agglomerated, the reduced ore (DRI) needs to be 'hot compacted' – necessitating specialised plant and equipment installation.
3. High coal consumption and export gas energy – making the economics very sensitive to energy credit.
4. Pellet feed cannot be used.
5. Production volume per unit is limited compared to large BF.
3. ITmk3

ITmk3 is pronounced 'Eye-Tee Mark Three' and stands for 'Iron Making Technology Mark Three'. It is a unique technology developed and owned by Kobe Steel Limited, Japan for smelting iron ore fines using non-coking coal to produce a premium grade iron in the form of nuggets.

Unlike traditional technologies of ironmaking, ITmk3 represents a revolutionary change in the way iron is made as also the product quality. In effect, it may be considered as a new source of iron particularly, for electric steelmaking.

The process

The heart of the ITmk3 process is the Rotary Hearth Furnace (RHF) where iron ore fines is reduces and smelted using pulverised coal. The process flow sheet below depicts various units and sub-units used in the ITmk3 process.

![Figure 36 – ITmk3 process flow chart](image)

The steps of iron ore reduction and smelting in the ITmk3 process are given below:

a. Iron ore fines, Flux and pulverised coal are mixed in a mixer.
b. Mixed inputs are converted into carbon composite green pellets in a pelletiser.
c. Pellets are dried at a temperature of around 180 deg. C using preheated air which is heated by exhaust gas of the furnace.
d. In the RHF, the carbon bearing composite pellets are gradually heated up using natural gas. The smelting reduction process involving reduction and smelting takes place in stages. In the last zone, the temperature is raised to 1350-1450 degrees celsius, thereby melting the iron and its easy separation from the gangue in the form of slag.
The following reactions take place when the carbon composites pellets are heated to the reaction temperature:

\[
\begin{align*}
F_{ex}O_y + y CO &= x Fe + y CO_2 \\
CO_2 + C &= 2CO \\
C(s) &= C\{carburised\} \\
Fe(s) &= Fe\{molten\}
\end{align*}
\]

The series of reactions are completed in around ten minutes. To begin with (after approximately three minutes), pellets are converted into DRI with unreacted core which later (after five minutes) convert into a dense metallic iron shell containing molten slag and large void space

Immediately thereafter, the metallic iron melts and starts separating out from slag and by around nine minutes, there is complete separation of iron and slag.

In the last two minutes of the process of the RHF, the molten iron and slag are cooled which further cooling in the cooler follows. The solidified iron nuggets are separated from the slag with the help of a magnetic separator. The sensible heat of the off gas from the RHF is substantially recovered by a recuperator thereby heating the air for combustion of natural gas used in the process. The hot air is also utilised for drying the green pellets.

**Raw material and other inputs**

The three main inputs are iron ore fines, coal and fluxes. Generally, pellet feed grade iron ore fines are used as it is and sinter feed ores is ground to the pellet feed grade.

Coal is ground to minus 200 mesh over 80%. Coal is the reductant for conversion of iron ore into iron and also serves as the main source of heat. The quality and quantity of flux is determined based on the nature of iron ore and coal. Besides coal, natural gas is another heat source, which is burnt in the RHF to heat up the pellets. In place of natural gas, furnace oil could also be used in the process.

**Table 31 – Required grade of iron ore and coal for ITmk3 (Source: Midrex)**

<table>
<thead>
<tr>
<th></th>
<th>Applicable</th>
<th>Preferable</th>
</tr>
</thead>
<tbody>
<tr>
<td>Iron ore</td>
<td>TFe&gt;56%</td>
<td>TFe&gt;60%</td>
</tr>
<tr>
<td>(Wi.%)</td>
<td>SiO₂&lt;6%</td>
<td>SiO₂&lt;5%</td>
</tr>
<tr>
<td>Coal</td>
<td>FC&gt;50%</td>
<td>VM&lt;30%</td>
</tr>
<tr>
<td>(Dry-base Wi.%)</td>
<td>VM&lt;45%</td>
<td>S/FC&lt;0.9%</td>
</tr>
<tr>
<td></td>
<td>Ash/FC&lt;25%</td>
<td></td>
</tr>
</tbody>
</table>

**Product characteristics**

The quality of Iron nuggets depends on the quality of iron ore and coal used in the process. However, typically, iron nuggets are highly metalised product containing over 97% metallic iron with very low phosphorous.

A typical composition of nuggets is given in the table on the next page.
Table 32 – Iron nugget chemical analysis

<table>
<thead>
<tr>
<th>Element</th>
<th>Percentage composition</th>
</tr>
</thead>
<tbody>
<tr>
<td>Metallic Iron(Fe)</td>
<td>+97</td>
</tr>
<tr>
<td>Carbon(C)</td>
<td>2-2.5</td>
</tr>
<tr>
<td>Sulphur(S)</td>
<td>0.07-0.10</td>
</tr>
<tr>
<td>Phosphorus(P)</td>
<td>0.01-0.02</td>
</tr>
</tbody>
</table>

Unlike blast furnace where phosphorous removal is minimal; in ITmk3 process, phosphorous removal is substantial leading to a very low content of phosphorous in iron nuggets. This is mainly because of shorter reaction time, essentially around 6 minutes, and iron and slag are separated after 2 minutes cooling time. In other words, the operation does not reach equilibrium to allow phosphorous to transfer to the metal. It has in fact been established in one of the experimental study of the ITmk3 demonstration plant that if iron and slag are allowed to stay together longer, phosphorous content of metal was much higher.

References
3. Evolution of Ironmaking Technology: by Takuya Negami, Director (Engg) & Advisor, Kobe Steel Ltd, Japan.

Positive aspects
- Use of fine ore and non-coking coal for the basic process.
- Is able to free the product of gangue through partial melting in the process.
- Can handle recyclable streams.
- Product sizes (nuggets) are of a size that can be stored and transported.
- Nugget can be used directly into BOF or EAF.
- Reduces charging time.
- Increases steelmaking or meltshop productivity.
- Reduces energy consumption.
- Option of hot charging if EAF is on site.

Negative aspects
- Need for energy source (fuel gas) to fire the furnace.
- Productivity related issues, while successfully achieving accurate temperature control, to be sorted out at commercial scale.
- 'Desulphurisation' performance expected to be inferior – with sulphur of raw materials likely to separate into slag only partially.
- Disposal of solid slag no identified market/use.
- Smaller scale compared to established processes (~0.5 mtpa scale being commercialised now (from January 2010 onwards).
- Energy intensive. (0.5 t-coal/t-nugget, 1.5 t-ore/t-nugget, 0.5 GJ/t-nugget)
4. DRI

DRI is divided into coal-based and gas-based – gas-based DRI is more mature than coal-based DRI. 50mtpa gas based DRI.

Data from the five plants below:
1. Natural gas based DR processes – Midrex and HYL
2. Coal based DRI, Rotary kiln
3. Coal based both Hot Metal and DRI in one complex, combination of Corex-Midrex
4. HyL ZR (zero reformer) direct reduction plants, identified as 3M%ZR (92.7 THRD/hr) and 4M (115.2 THRD/hr)
5. Conventional HyL with reformer direct reduction plants, identified as 2P5 (116 THRD/hr)

Iron ore charged to DRI process

Gas-based DRI

Pellet

• The average 66% pellet charged into the Midrex from the five DRI plants. The maximum reaches 100%, the minimum is 0.

Lump ore

• Only two plant used the lump ore. One charged 100% lump ore, the other charged 70%. So for the five plants, the average lump ore ratio is 34%, and the minimum is 0.

Sinter

• No sinter used in the five DRI plants.
• The following table is the iron ore used in DRI.

Table 33 – Pellet and lump ore use in DRI process

<table>
<thead>
<tr>
<th>DRI process</th>
<th>Pellet ave</th>
<th>Pellet min</th>
<th>Pellet max</th>
<th>Lump ore ave</th>
<th>Lump pre min</th>
<th>Lump ore max</th>
</tr>
</thead>
<tbody>
<tr>
<td>T.Fe</td>
<td>66.87</td>
<td>66.00</td>
<td>68.50</td>
<td>67.00</td>
<td>63.00</td>
<td>69.30</td>
</tr>
<tr>
<td>SiO2</td>
<td>2.18</td>
<td>1.10</td>
<td>3.50</td>
<td>2.50</td>
<td>1.10</td>
<td>4.30</td>
</tr>
<tr>
<td>Al2O3</td>
<td>0.73</td>
<td>0.30</td>
<td>1.50</td>
<td>0.50</td>
<td>0.25</td>
<td>1.40</td>
</tr>
<tr>
<td>Na2O+K2O</td>
<td>0.20</td>
<td>0.19</td>
<td>0.24</td>
<td>0.13</td>
<td>0.07</td>
<td>0.32</td>
</tr>
<tr>
<td>P</td>
<td>0.03</td>
<td>0.01</td>
<td>0.17</td>
<td>0.05</td>
<td>0.02</td>
<td>0.08</td>
</tr>
<tr>
<td>S</td>
<td>0.00</td>
<td>0.00</td>
<td>0.01</td>
<td>0.01</td>
<td>0.00</td>
<td>0.01</td>
</tr>
<tr>
<td>Moisture</td>
<td>1.08</td>
<td>0.30</td>
<td>3.50</td>
<td>0.80</td>
<td>0.27</td>
<td>1.30</td>
</tr>
</tbody>
</table>
Positive aspects and negative aspects of the gas-based DRI

Positives

• Gas based DRI is more mature than the coal based DRI. 50mtpa gas based DRI.
• CO₂ is less because based on natural gas
• Total productivity of 2mtpa has been achieved
• Hot DRI can be charged hot to the EAF (600-700°C). Hot connection. Energy saving. Can save as much as 150 units.

Negatives

• Restricted to natural gas regions. (Coal gas project under construction, India)
• High quality ferrous. Gangue content has to be low to avoid excessive electrical costs in steelmaking.
• Can not use ore fine directly
• Product is difficult to handle/transport. Oxidising during storage.

Coal usage and coal type

• Only the coal based process used the coal. For the coal, the coal quality is as indicated in the following table.

Table 34 – Chemical analysis of coal

<table>
<thead>
<tr>
<th>Source (mine, country)</th>
<th>Ave</th>
<th>Min</th>
<th>Max</th>
</tr>
</thead>
<tbody>
<tr>
<td>T.C</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>F.C</td>
<td>56.25</td>
<td>51</td>
<td>60</td>
</tr>
<tr>
<td>VM</td>
<td>23.25</td>
<td>18</td>
<td>27</td>
</tr>
<tr>
<td>Ash</td>
<td>14.5</td>
<td>12</td>
<td>17</td>
</tr>
<tr>
<td>S</td>
<td>0.8</td>
<td>0.6</td>
<td>1.1</td>
</tr>
<tr>
<td>P</td>
<td>0.14</td>
<td>0.04</td>
<td>0.25</td>
</tr>
<tr>
<td>Na₂O+K₂O</td>
<td>6380</td>
<td>6100</td>
<td>6640</td>
</tr>
<tr>
<td>GCV kcal/kg</td>
<td>6380</td>
<td>6100</td>
<td>6640</td>
</tr>
</tbody>
</table>
Other energy sources and consumption

- Coke-oven gas, marginal
- Coke – 15% of total coal+coke mix; LPG – 15 kg/tDRI
- We use natural gas as reductants (H2 and CO source) source and also as fuel for energy(heat) supply. Also Electric power is consumed.
- Positive aspects and negative aspects of the coal based DRI
- From Coal based DRI. (Rotary kiln) 15mtpa in India.

Positives

1. Demonstrated with high ash non coking coal (25% ash)
2. Gangue of coal doesn’t end up in the final product but separate as Char
3. Possible on a small scale (0.15mtpa) with Simple equipment

Negatives

1. Possible only at small scale. Productivity not high
2. Coal consumption is high
3. Gas energy needs to be recovered as power the make process economic

5.2 Identified good practices

Responses received from the members indicate rising concern over environment regulations imposed by the government authorities for the existing levels of emissions. The ability of the sintering process to handle very fine iron ore particles. The type of emission incudes both the gaseous and solid emission, to deal with both kind of emissions, different plants have identified various processes, some of them have been showcased in this section, waste gas treatment plant for gases emission and hybrid pelletised sinter (HPS) for solid emission. Sintering of very fine ores will be an increasing issue for future operations. One identified good practice is sintering of very fine ore at low productivity.

Productivity impact is only constraints, significant recovery of the same could be achieved by using the best practices as describe in the report. See Appendix G for more information and references.
6. Raw material efficiency model

Jean Louis Lebonvallet – ArcelorMittal

The expert group realised that in order to make an informed decision on what raw materials to use or purchase they needed to know the impact on the ironmaking process. To do this effectively an economic impact model was developed to show the impact per % of Fe decrease per tonnes of hot metal produced and per percentage of ash content increase per tonne of hot metal for coal.

This is an approximation model and serves only to make the distinction in materials and should not be used to determine the operating costs of ironmaking. The idea for this model is to show the impact of lower grade material used (both iron ore and coal) on their ironmaking process by having to use more coal, creating more slag and reducing output.

The provided ‘Integrated Raw Material Efficiency Model’ is available on the CD accompanying this report. This model can be used by the technical experts who deal with the raw materials technical and commercial issues. It allows the plant based managers to identify the benefits or increased cost to the organisation in using the lower grade materials. This will then form the basis for discussion with the raw material procurement staff to determine the best option for the next shipment of iron ore or coal.

The level of flexibility shown that the industry is capable of will be of tremendous benefit for the procurement strategy as many more options taken as a supply route are open to the business. The decisions can be informed and related to existing operations to predict the likely impact of the material.

This model is built on the information received from this project and has given this project team and anyone using this report the confidence that raw materials sourced are usable in their process and the outcome is predictable. Also that demanding a practical level of beneficiation up to 63 – 66% Fe is reasonable. This can be accommodated in most cases with simple technical solutions and low investment on the supplier’s part or at the company’s own mine sites. The logic in the model has been drawn from the information gathered for this report and the relationship of materials types and make up and related efficiencies experienced. The process uses BF – BOF route as this related predominantly for iron ore in the industry. The alternative routes of Corex and Finex have not been able to be analysed in sufficient detail to include them as a model stream. Those organisations using these processes can utilise the model setup to create their own for their processes and apply the same logic and details from their own knowledge.
7. Conclusions

7.1 Raw materials management

- Global reserves of iron ore and coal are plentiful. The easiest and higher quality material is being mined now and will reduce in quality as the reserves deplete. There is however a great abundance of material available to last a century or more. Lack of access or infrastructure to new mines or locations is naturally a hindrance to transport the goods and needs to be provided for as part of development.
- Global availability of iron ore and coking coal is balanced with the market demand as expected.
- The quality of iron ore in ‘run of mine’ is decreasing. And installed beneficiation processes do not compensate this change entirely as yet.
- Fe content is decreasing, silica and alumina are increasing and well as other elements.
- Particle size is getting finer, and moisture content is increasing after beneficiation process.
- Beneficiation processes for iron ore and coal are available currently and have not changed significantly over the past years, the control techniques and tailored designs for each material type or mine configuration makes it possible to build an efficient process to suit.
- Members see a risk if development of new mining project is delayed both for economic or political reasons, which may drive the quality, associated efficiency down and increase operational costs for the steel industry.
- Quality of metallurgical coal is decreasing; especially the increase of ash and moisture content, and the material particle size is decreasing requiring different improvement techniques that are already available.
- The blast furnace is a very flexible process in utilising wide range of raw material qualities, however this has a large impact on productivity of ironmaking and volumes of coal, fluxes, and iron ore needed and on overall efficiency of operation.
- The project team has found that the variability in material is significantly wider than initially expected giving the industry's confidence that it can use lower grade material; demand it is upgraded and delivered at a consistent quality and adapt the ironmaking accordingly. This allows for a flexible source of supply and with the control and measurement systems in place, the process can be adapted to deal with many supply routes.

Graph 69 – Blast furnace productivity related slag rate
Coke strength after reaction (CSR) has an impact on the volume of coke volume needed.

Increasing trend of using low grade raw material will lead to higher slag rate, lower productivity, and higher Reaction Agent Rate (RAR) consumption.

Depending on the cost of low grade raw material, investment should be either in beneficiation process at the mine site or in steel plant to increase the production capacity. The beneficiation processes being more effective as capital investment is significantly lower per unit of production.

For local raw material near an ironmaking plant investment in ironmaking plant capacity can be optimised for the entire supply chain, beneficiation of the raw material is most efficient from a capital investment point of view.

For ironmaking plant not near to raw material resources investment in beneficiation in mine is preferred for the whole supply chain.
7.2 Technology Development

Development can be pursued in two ways:

1. Upgrade the existing facility.
2. Adopt the new/alternative process.

1. Upgrade the existing ironmaking facility:

   - To enhance the usage of low grade raw material.
   - Some of the examples are as follows:

Coke making

Drying, pre-heating, quenching and densification, for examples: CDQ (Coke Dry Quenching), stamp charging, CMC (coal moisture control)

Sintering

Hot press sintering (HPS), intensive mixture, upgrade the capacity by extension of grate width or increase of vacuum or suction pressure, improvement of feeding system.

2. Adopt the new/alternative process

   - Some developers of the process claimed that it is possible to use significantly more low grade quality raw material, however members’ opinion is that a proportion of high grade material still needs to be used.

Cokemaking

Heat recovery from coke ovens (gas is already used and some heat recovery is used mainly to in the cokeoven itself).

Carbonyx (coke making using other materials to provide a higher strength coke equivalent), Scope-21 (coke making batteries using best available technologies but no major breakthrough change).

Ironmaking

The blast furnace/basic oxygen furnace is still the most efficient steelmaking route for iron ore feed. It has been refined and now with computer models is controllable and manageable in a flexible way.

Alternative ironmaking processes (Corex, Finex, Midrex, Hismelt, Direct Reduced Iron (gas and coal), Rotary Hearth Furnace (used still mainly for reducing sludges and fine materials), ITmk3 (DRI using rotary hearth style furnace), have been built and are at commercial size however have not yet seen the extension in productivity that the BF-BOF route has to date.
7.3 Proposals for follow-up

• Every member considered the effect of deteriorating raw material quality and suggests considering the associated investments.
• Project team proposed to develop an annual benchmarking survey for all worldsteel members, in order to evaluate the trends. This should include the development of major mining projects.
• Seeing the large impact of raw material in long term perspective, project member proposed to stimulate the mining company’s investment in beneficiation facilities.
• Follow-up of new processes especially in terms of using low grade raw material, to realise the maturity level of process such as ITmk3.

7.3.1 Iron ore scenario

Scope is not limited to steel site, but also incorporates mining business.

7.3.2 Coal/coke scenario

Scope is not limited to steel site, but also incorporates mining business.

7.3.3 Ironmaking technology scenario

Scope is not defined for Ironmaking, propose to maintain expert groups for BF-BOF routes, DRI suppliers, EAF technologies and maintaining an interest in the alternative processes.

7.4 Identified good practices

Based on the survey responses received from the member companies, the following recommendations have been made by project team with specific examples of good practices for sustainable raw material management.

Utilisation of low grade raw material

• Blast furnaces with large capacity would provide the better flexibility in terms of raw material usages.
• Blast furnace of plant ‘a’ achieved a record of world’s first plant to produce 5 million tonnes hot metal per annum by a single BF with relined capacity (3,800 to 5,500 square metres). Daily production capacity: 14,000 tonnes /annual production capacity: 5 million tonnes
• In order to reduce the cost of raw materials, utilisation of low-quality raw material resource is increased gradually. The successful use of various types of low-quality resources would make great economic benefits. Usual practice to have 1 week of blending pile capacity to have the flexibility to use low grade material. A dedicated stock yard to store different grades of raw materials.
• Extensive use of low quality fines in sintering: Australia fines are poor quality ore, with their SiO2 content of more than 7%. In plant ‘b’, these fines were sintered with their content of 20%, the index has not showed significant deterioration, and was acceptable.
• Plant ‘c’ adopted best practice to blend coal in order to control low oven wall pressure, and coke quality. Reduce deviation in coking time through better maintenance.
• Use of low grade coal optimised by proper blending. For example: Use of pet coke and semisoft coking coal. Plant ‘d’ adopted steady coal blend and the low oven wall pressure coals in use since 1966. Reduced variation in coking time through better maintenance and pushing scheduling since 2001.

• In low business case situation, low grade material could be used by compromise with sinter and blast furnace productivity.

• Excessive and improper utilisation of low grade ore in the blast furnace increases the RAR consumption and hence decreases the overall productivity and adversely impact the operational cost. Hence when utilising low grade raw material the overall cost of operation needs to be considered.

Blending and material handling

It is recommended by the project team to have a blending model and blending facility. This is in order to maximise the recycling of reverts, achieving fine tuning and having better consistency.

• Plant ‘e’ is having a dedicated secondary blending yards (300,000t capacity x2) reclaimed by a full width barrel reclaimer.

• Example: In order to prevent dumping or external treatment of plant reverts and to minimise the input of fresh materials as much as possible, the plant reverts are recycled as much as possible through the sinter and pelletising plant. Main value adding components of the plant reverts are iron, carbon, calcium and magnesium which reduce the amounts of fresh iron ore, coke breeze/anthracite, limestone and olivine respectively. In plant ‘f’ the sinter blend consists for around 20% of recycled plant reverts.

Beneficiation of raw material

• In order to deal with the beneficiation processes and its impact, right options of the technology should be consider beforehand.

• Beneficiation process cost should be limited by market price of equivalent iron ore.

• Example of 5 steps beneficiation plant implemented at plant ‘g’.

• Iron-ore magnetite sinter concentrates after magnetic-flotation refining.

• Example of high grade ore usage in plant ‘g’.

• Iron content in sinter made up to 60% while SiO2 content was 7%. The experiment resulted in increased iron content in sinter and decreased lime consumption for sinter production. Coke consumption was decreased and productivity was increased in blast furnace shop. The experiment was performed during two weeks.

Environment issues

• Technologies to treat the sinter plant waste gases such as ‘activated char packed bed filter’ or ‘bag filter’ are associated with high capital expenditure and operational expenditure requirement, but can fulfill environment requirements of local authorities.

• Activated char packed bed filter implemented by plant ‘h’ that cleans all sinter plant waste gas. Eliminating dioxins and chloride related plumes.

• Beneficiation step has strong impact on local environment due to process, tailing storage, water contamination. Choice of the process has to be done carefully as per the local conditions.
7.5 Identified problematic areas

The project team identified the major areas of concern for the steel companies as follows:

Raw materials handling

Logistics and transportation are very important factors and could impact the usage of low grade raw material. For example of plant ‘i’ – the depth of their harbour in conjunction with the ages of their unloading equipment place has limited their berth capabilities. They are currently having 3 ship un-loaders. These serve 2 bulk discharge berths. One of the berths and only one of the un-loaders can discharge cape size ships. These restrictions are becoming an increasing issue in relation to current shipping industry trends and new raw materials requirements. Lack of selective crushing and homogenisation poses issues with plant ‘j’.

Although they have a stable blend feeding into their batteries, these coal have very different and high inert loads. The handling and preparation sequence uses very old hammer mills and lacks homogenisation equipment.

- Ferrous: The capacity of the primary yards is only around 0.8 million tonnes per annum with a further 0.3 million tonnes of blended fines. This combined with few and dual purpose machine (stacker/reclaimer) places significant limitations.
- Coal: PCI plant has a small stocking area, only capable of holding one week of supply. Therefore PCI logistics is a tight situation between small stocking area, rail deliveries and competing for track availability. PCI grinding plant is relatively remote from the furnaces, 0.6 and 0.9km conveying distances.
- Logistics issues during high business condition, flooding etc.

Iron ore quality issues

The quality trend of iron ore goes downward; meanwhile the supply portion of high quality ore like Hematite is decreasing. Plant ‘k’ is expanding the use of economical iron ore in preparation for the trend in order to mitigate the adverse influences

- Demand in iron ore especially from China is steeply surging while supply increase is not enough to balance.
- It represents a huge investment in mining development and the entry barrier for the industry is too high so plant ‘l’ assumes the tight market will go on for the time being.
- In the last years content of fines <0.15mm increased from 5% to 18% making it very difficult to handle mainly in rain season
- Silica content increases in iron ore from 3.5% to 7.5% maximum over a one-year period. There is increasing trend of increase of alumina and phosphorus as well.
- New mines have limonitic ores less productive at sinter plant.
- With increased reliance on Brazilian iron ores, handling of wet ores an increasing problem. Cargoes often arrive as virtual slurry causing material to slop off belts and occasionally causing stock pile slumping. Low residence times of ore at port a particular problem.
- With increased use of reverts, alkali and lead + zinc loadings have increased to the blast furnaces require strategies to be reviewed regarding their efficient removal from the blast furnace.
• In plant ‘m’ sinter plant is distressed. Quality of sinter produced by this sinter plant doesn’t comply with actual concepts requiring its quality according to consistency in chemical and grain size composition. Construction of new up-to-date sinter plant is required.
• Researches performed with regard to plant ‘n’ pellets show that their quality is significantly lower than that of similar products. Measures on improving their quality – especially in grain size composition – are required. Allowable 0-5mm size content in these pellets reaches 9%, which is not accepted.

Coking coal quality issues

High coal moisture

• The impact of having a coal washing plant located onsite, only gives one week of dewatering before it is elevated to the battery feed bins. This washed supplies ~ 25% of the batteries coal blends. The remaining 75% is also sourced from nearby washing plant.

Moisture level averages 9-10% with negative impact on coke density.

Shortage of hard coking coals

• Fewer straight coals and more blend coals including dangerous coals.
• Decrease in availability for hard coking coals
• Quality of coke used at plant ‘o’ is one of worst ones in that region. Low coke quality has negative impact on consistency in cast iron production technology, cast iron quality, and technical state of BF’s lining.

7.6 Concerns over future supply

Based on the factual information, project team outlined the concerns of the future supply of key raw material for the steel industry.

Change in raw material quality

• The increased demand for low Phosphorus steel products. The increased market demand for the tier one products that plant ‘p’ is currently producing increases their sensitivity to current and future increases of P content in iron ores.
• The gangue components the raw material feed into the sinter plant and BF. These pose increased unit costs, and present obstacles for capability expansion.
• Increasing content of Silica and fines
Supply and market situation

- Uncertainty over quality and short term availability of raw materials and of consequent product cost competitiveness.
- Rising iron ore prices have made many Chinese steel companies for not affordable. The current iron ore prices caused by a monopoly, not the normal supply and demand basis.
- With the iron ore mining, resources, poor quality is inevitable. The name of iron ore is not changed, but its chemical composition; grain size tendency became more obviously deteriorated, give a big problem in production.
- Brazilian ore supply strongly managed by a single company.
- Due to volatility in the market contracts are short term based

Environment issues

- Most ferrous by products are being recycled to the sinter plant. This may not prove to be a viable solution overtime, when the sintering process is not applicable.
- All materials that are used within the various processes result in an increased RAR. This coupled with the impending carbon tax world is a cause of concern for us. Carbon tax implementation is an issue if an international scheme was adopted which would assure a consistent application of carbon tax then this concern would be reduced.
8. Appendices

Appendix A

Resource/reserves definitions

**Resource**: A concentration of naturally occurring solid, liquid, or gaseous material in or on the Earth’s crust in such form and amount that economic extraction of a commodity from the concentration is currently or potentially feasible. Original resource: The amount of a resource before production. Identified resources: Resources whose location, grade, quality, and quantity are known or estimated from specific geologic evidence. Identified resources include economic, marginally economic, and sub-economic components. To reflect varying degrees of geologic certainty, these economic divisions can be subdivided into measured, indicated, and inferred. Reserves: That part of the reserve base which could be economically extracted or produced at the time of determination. The term reserves need not signify that extraction facilities are in place and operative. Reserves include only recoverable materials.

**Reserve base**: That part of an identified resource that meets specified minimum physical and chemical criteria related to current mining and production practices, including those for grade, quality, thickness, and depth. The reserve base is the in place demonstrated (measured plus indicated) resource from which reserves are estimated. It may encompass those parts of the resources that have a reasonable potential for becoming economically available within planning horizons beyond those that assume proven technology and current economics. The reserve base includes those resources that are currently economic (reserves), marginally economic (marginal reserves), and some of those that are currently sub-economic (sub-economic resources).
Appendix B

<table>
<thead>
<tr>
<th>Mine Production in million tonnes</th>
<th>Iron Ore Reserve in million tonnes</th>
<th>Iron Content</th>
<th>Fe% in ROM</th>
<th>Type of Iron Ore</th>
</tr>
</thead>
<tbody>
<tr>
<td>Australia</td>
<td>438</td>
<td>35000</td>
<td>17000</td>
<td>Hematite-ilmenite (50,6% Fe)</td>
</tr>
<tr>
<td>Brazil</td>
<td>370</td>
<td>29000</td>
<td>16000</td>
<td>Hematite-ilmenite (44,1% Fe)</td>
</tr>
<tr>
<td>Canada</td>
<td>37</td>
<td>6300</td>
<td>2300</td>
<td>Hematite ore (39% Fe)</td>
</tr>
<tr>
<td>China</td>
<td>1070</td>
<td>23000</td>
<td>7200</td>
<td>Hematite ore (31% Fe)</td>
</tr>
<tr>
<td>India</td>
<td>230</td>
<td>7000</td>
<td>4500</td>
<td>Hematite-magnetite</td>
</tr>
<tr>
<td>Kazakhstan</td>
<td>24</td>
<td>3000</td>
<td>1000</td>
<td>Hematite-magnetite in the ferruginous quartzites (39,6% Fe)</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Hematite-magnetite in the ferruginous quartzites (35% Fe)</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Magnetite in the ferruginous quartzites (32,9% Fe)</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Magnetite in the ferruginous quartzites (34,6% Fe)</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Magnetite in the ferruginous quartzites (35% Fe)</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Hematite-siderite-martite (51,6% Fe)</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Magnetite in the ferruginous quartzites (37,1% Fe)</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Hematite-siderite-martite (60,5% Fe)</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Apatite-magnetite (26% Fe)</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Vanadium-titanium-magnetite (15,6% Fe)</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Magnetite (45,5% Fe)</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Magnetite (25,7% Fe)</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Magnetite (31% Fe)</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Magnetite in the ferruginous quartzites (32,7% Fe)</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Titanium-magnetite (33,5% Fe)</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Hematite-siderite-martite (60,7% Fe)</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Crude Ore Reserves - World total (rounded)</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>2590</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>170000</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>80000</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>47.06</td>
</tr>
</tbody>
</table>

Table 35 – Iron ore reserves per country and per type

Appendix C

Raw material issues in the steel industry

China

Lump ore can be used directly for blast furnaces and does not require sintering. However the availability of such ore is limited. The type of ore matters, for example, in China, half of the ore deposit is low-reducibility magnetite and 20% is hematite fine ore. The iron content of both ore types is as low as 30%. The ash content of the coal and the iron content of the ore determine the amount of slag that is generated per tonne of blast furnace gas. The more slag is generated; the more coal and coke will be needed.
Australia

The product types produced over the past 45 years have changed from being predominantly a premium Brockman mix to one that now includes Brockman, other hematites, marra mamba and channel iron deposits. The proportion of Premium Brockman, Brockman and Other Hematites will continue to fall with magnetites becoming an increasing proportion of the product types. Marra mamba and channel iron deposits will continue to be an important part of Australia’s product types. Australian Iron ore industry is looking at some beneficiation techniques, to remove impurities such as alumina, silica and mainly phosphorus from the ore.

Figure 36 – Share of different type of ores in Australia

Brazil and Latin America

With combined, measured and indicated reserves of iron ore standing at 26 billion tonnes, Brazil has the fifth-largest iron ore resource globally. Brazil’s iron ore is of the highest quality, on a par with that found in Australia’s Pilbara region. Hematite found in the state of Para averages a 60% grade, while Itamirite found in Minas Gerais state averages 50%. With production standing at 420 million tonnes in 2010, Brazil ranks as the second largest global producer of iron ore behind China.

Figure 37 – Esperança mine, Brazil
Southeast Asia

Very limited iron ore, some natural gas, some metallurgical coal, some scrap and rising scrap generation in certain economies – relatively balanced decision to EAF, DRI-EAF or BF/BOF. CIS: Large iron ore reserves (relatively poor quality), large and low cost metallurgical coal, and large (but declining) scrap reserve. Advantageous for EAF at this time, but longer term may tilt towards BF/BOF. Middle East: No iron ore reserves, no coal reserves, limited scrap generation, but large resources of natural gas – likely to be DRI-EAF based on natural gas reduction of imported ore. It is our view therefore that the current 30% share of global steel output produced by EAF will increase out to 2015, although it is unlikely to exceed 35%. There will be some EAF replacement of BF/BOF capacity in North America and Europe and rising development of DRI/EAF in the Middle East, Africa, parts of SE Asia and the CIS.

Table 36 – Top ten iron ore companies in the world (2009)
(Source: Source: Raw Materials Group, Stockholm 2011.) * Estimate

<table>
<thead>
<tr>
<th>Rank</th>
<th>Company name</th>
<th>Country</th>
<th>Prod Mt</th>
<th>Area</th>
<th>Metal</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Vale</td>
<td>Brazil</td>
<td>255</td>
<td>Brazil</td>
<td>Div.</td>
</tr>
<tr>
<td>2</td>
<td>Rio Tinto</td>
<td>UK</td>
<td>172</td>
<td>Australia, Canada</td>
<td>Div.</td>
</tr>
<tr>
<td>3</td>
<td>BHP Billiton</td>
<td>Australia</td>
<td>137</td>
<td>Australia, Brazil</td>
<td>Div.</td>
</tr>
<tr>
<td>4</td>
<td>SAIL/NMDC (State of India)</td>
<td>India</td>
<td>55*</td>
<td>India</td>
<td>Iron ore</td>
</tr>
<tr>
<td>5</td>
<td>Anglo American</td>
<td>UK</td>
<td>43.8</td>
<td>South Africa, Brazil</td>
<td>Div.</td>
</tr>
<tr>
<td>6</td>
<td>ArcelorMittal</td>
<td>Luxembourg</td>
<td>37.7</td>
<td>Global</td>
<td>Iron ore/coal</td>
</tr>
<tr>
<td>7</td>
<td>Metalloinvest</td>
<td>Russia</td>
<td>35.5</td>
<td>Russia</td>
<td>Div.</td>
</tr>
<tr>
<td>8</td>
<td>Fortescue Metal Group</td>
<td>Australia</td>
<td>34.9</td>
<td>Australia</td>
<td>Iron ore</td>
</tr>
<tr>
<td>9</td>
<td>system Capital Management</td>
<td>Ukraine</td>
<td>27</td>
<td>Ukraine</td>
<td>Iron ore/coal</td>
</tr>
<tr>
<td>10</td>
<td>Cliffs Natural Resources</td>
<td>USA</td>
<td>24.9</td>
<td>USA, Australia, Brazil</td>
<td>iron ore</td>
</tr>
</tbody>
</table>
Appendix D

Table 37 – List of potential technologies in iron and steelmaking

<table>
<thead>
<tr>
<th>A. Iron-ore area</th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Installations of high efficiency crushers</td>
<td>Decreases size fluctuation of iron ore lump, lowers energy consumption in sising operation</td>
</tr>
<tr>
<td>2</td>
<td>Fine ore beneficiation using magnetic separation</td>
<td>Beneficiation of slime: mineral conservation and ecological preservation.</td>
</tr>
<tr>
<td>3</td>
<td>Floatex density separator</td>
<td>Beneficiation of fines/ slime fluctuation in feed rate and grain size: do not affect quality of output, applicable in coal washing also.</td>
</tr>
<tr>
<td>4</td>
<td>Lamella thickeners and clarifiers</td>
<td>Beneficiation of fines including slimes, lowers capital and space requirement easy maintenance.</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>B. Technologies in Coke Oven and By-Products area</th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Stamp charging</td>
<td>Substitutes prime coking coal: improve coke quality and BF productivity: lower pollution.</td>
</tr>
<tr>
<td>2</td>
<td>High capacity coke oven</td>
<td>Lowers number of units and manpower : better coke quality: lowers pollution.</td>
</tr>
<tr>
<td>3</td>
<td>Improved design and construction features of coke oven machine and other equipment</td>
<td>Better performance: less manpower and improved pollution control.</td>
</tr>
<tr>
<td>4</td>
<td>Computerised heating control and automation.</td>
<td>Accurate positioning of oven machines increased battery life, improved coke quality, lowers requirement of pollution control measures, etc.</td>
</tr>
<tr>
<td>5</td>
<td>Improved coke quenching system.</td>
<td>Better efficiency: lowers water consumption: long life of wharf and coke conveyors, etc.</td>
</tr>
<tr>
<td>6</td>
<td>Coke dry cooling</td>
<td>Better coke quality: lowers environmental pollution: possibility of power generation and heat recovery.</td>
</tr>
<tr>
<td>7</td>
<td>Pollution control technologies in coke ovens.</td>
<td>Improves emission control: coke quality and efficiency of coke ovens.</td>
</tr>
<tr>
<td>8</td>
<td>Regeneration of acid from acid sludge</td>
<td>Eliminates disposal problems of hazardous acid sludge: regenerated acid can be used in ammonium sulphate plant</td>
</tr>
<tr>
<td>9</td>
<td>Laser based spotting /positioning system for coke oven service machines</td>
<td>Increases productivity due to rapid and accurate alignment of servicing machine</td>
</tr>
<tr>
<td>10</td>
<td>Use of Mg silicate in sinter mix</td>
<td>Yield sulphur of extremely good quality.</td>
</tr>
<tr>
<td>11</td>
<td>Improvement in sinter feeding system</td>
<td>Increases bed permeability; yield and productivity</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>C. Sintering</th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Processes to use super fines in sinter-mix like (HPS) process, vibration, granulation equipment, high agitating mixture, etc.</td>
<td>Decreases Al2 O3 content, fuel rate; improves granulometry; improves productivity of machine</td>
</tr>
<tr>
<td>2</td>
<td>Extension of grate width</td>
<td>Increases productivity/production.</td>
</tr>
<tr>
<td>3</td>
<td>Waste heat recovery from sinter cooler</td>
<td>Energy recovery; reduces cost of production.</td>
</tr>
<tr>
<td>4</td>
<td>Pollution control measures, like, EOS, AIRFINE, Sulfix process, etc</td>
<td>Lowers pollution level; reduces fuel consumption, etc</td>
</tr>
<tr>
<td>5</td>
<td>Use of Mg silicate in sinter mix</td>
<td>Decreases alkali loading in BF; improves sinter reducibility</td>
</tr>
<tr>
<td>6</td>
<td>Improvement in sinter feeding system</td>
<td>Increases bed permeability; yield and productivity</td>
</tr>
</tbody>
</table>
High pressure sintering process
Can use high amount of super fines: improves sinter quality: improves productivity, etc

Increase in bed height and suction in sinter machine
Improvement in productivity and sinter quality

Appendix E

Regional iron ore availability – India
Though the reserves of hematite ore seem large, recoverable high-grade lump is 18% of total.

Table 38 – Reserves type

<table>
<thead>
<tr>
<th>Grade</th>
<th>Fe %</th>
<th>Approx % share of recoverable reserve</th>
</tr>
</thead>
<tbody>
<tr>
<td>High Grade</td>
<td>Fe + 65</td>
<td>18.6</td>
</tr>
<tr>
<td>Medium Grade</td>
<td>Fe 62-65</td>
<td>50.6</td>
</tr>
<tr>
<td>Low Grade</td>
<td>Fe – 62</td>
<td>28.4</td>
</tr>
<tr>
<td>Others</td>
<td></td>
<td>2.4</td>
</tr>
</tbody>
</table>

Table 39 – Iron ore zones in India

| Zone A: (Eastern Zone) Jharkhand & Orissa | Haematite Ore: Singibhum District in Jharkhand and Keonjhar and Sundergarh in Orissa. About 60% of the ore is concentrated in this sector |
| Zone B: (Central Zone) Chattisgarh, M.P. and Maharasta | Haematite ore: Covers Dalli-Rajhara deposit of Durg district, Rowghat – Bailadila of Baster District and Surajgarh Deposit in Maharasta |
| Zone C: (Southern Zone) | Haematite ore: Bellary-Hospet Sector covering iron ore deposits in Sandur Range in Bellary district and includes Kumarswamy and Ramandurg Deposits and magnetite ore, metamorphosed banded iron formation along West coast, Karnataka, Kerala, etc. About 80% of known reserves of Magnetite Ore are concentrated in Karnataka |
| Zone D (Western Zone) | Goa-Redi covering iron ore deposits of Goa and Redi in Maharashtra |
Figure 39 – India metallic minerals map

China

Graph 72– Trend of Chinese iron ore, production, demand
Iron ore availability in Greenland

A. Current versus future stance: Iron ore sources

- Strategic resources of iron are very important in current fickle market conditions. In the current scenario, Brazil and Australia are only the sole major producer of high-quality grade iron ore and controller of price volatility.
- With steel demand growing and iron ore fields in Brazil and Australia locked up by mining’s Big Three (Brazil’s Vale (VALE) and Australia’s Rio Tinto Group (RTP) and BHP Billiton (BHP)), Greenland could become the next mining frontier and a strategic resource for iron ore.
- Strategic sources of good-quality iron ore material will provide flexibility and ease to abate the monopoly and will consider as a great opportunity in terms of expanding businesses with potential entrants.

B. Iron ore potential in Greenland

- The potential for iron resources of the BIF type in Greenland is promising, taking into consideration that a number of deposits are large and that they are located in accessible tracts.
- Recent exploration has demonstrated increased interest in iron ore deposits in Greenland. The recent finding of the huge magmatic iron ore deposits at Isortoq in South Greenland underpins that Greenland are highly underexplored and that there still is a potential of finding undiscovered huge iron ore deposits in Greenland.

Figure 40 – Map of iron ore occurrence in Greenland
C. Major iron ore projects in Greenland

Some of the important mining projects in Greenland are as given below:

I). The Itilliarsuk iron ore, West Greenland (Avannaa Resources)

- Northern segment high grade iron ore deposit containing least 147 Mt @ 45 % Fe2O3 over a strike length of 3500m.
- Southern segment iron ore deposit containing up to 91 Mt @ 34 % Fe2O3. Strike length 2500m.

Both deposits are amenable to open pit mining segment potentially contains smaller high grade zones which in turn could produce lump ore for direct shipping.

II). ISUA Iron Project (London Mining Greenland)

- Isua is located 150 km Northeast of Nuuk and 100 km from a proposed deep seawater port. Isua will produce a premium quality 70% Fe pellet feed concentrate with low impurities and benefits from its position in the warmer south-west corner of Greenland which allows for year round shipping.
- Isua iron ore Deposit is an open pit deposit in Greenland. It mainly contains iron ore. It is controlled/owned by London Mining plc.
- London Mining Plc. has reported an estimated deposit with 951 million tonnes averaging 36.48% Fe. Recently London Mining has confirmed that the Isua ore can produce a concentrate with a specification of 70.2% Fe, 1.9% SiO2, 0.05% Al2O3 and 0.12 % S. This product has potential for application as a premium blast furnace pellet feed for sale to the European and Chinese steel markets.

Table 40 – Chemical specification of concentrate of Isua iron ore deposit

<table>
<thead>
<tr>
<th></th>
<th>%</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Fe (total)</td>
<td>70.2</td>
<td></td>
</tr>
<tr>
<td>FeO</td>
<td>29.8</td>
<td></td>
</tr>
<tr>
<td>S</td>
<td>0.12+/--0.06</td>
<td></td>
</tr>
<tr>
<td>P</td>
<td>0.09</td>
<td></td>
</tr>
<tr>
<td>SiO2</td>
<td>1.9</td>
<td></td>
</tr>
<tr>
<td>Al2O3</td>
<td>0.05</td>
<td></td>
</tr>
<tr>
<td>MgO</td>
<td>0.2</td>
<td></td>
</tr>
<tr>
<td>CaO</td>
<td>0.16</td>
<td></td>
</tr>
<tr>
<td>TiO2</td>
<td>0.01</td>
<td></td>
</tr>
<tr>
<td>K2O</td>
<td>0.005</td>
<td></td>
</tr>
<tr>
<td>D80</td>
<td>um</td>
<td>0.006</td>
</tr>
<tr>
<td>Blaine value</td>
<td>cm²/g</td>
<td>28.5</td>
</tr>
<tr>
<td>Filter cake moisture</td>
<td>%</td>
<td>1,650</td>
</tr>
</tbody>
</table>
The value of the Isua Project is significantly increased if the Isua concentrate is sold into Europe rather than China, based on a significant freight differential of around USD 25/MT.

<table>
<thead>
<tr>
<th></th>
<th>100% of product sold in China</th>
<th>100% of product sold in Europe</th>
</tr>
</thead>
<tbody>
<tr>
<td>NPV8 (USD billion)</td>
<td>2.5</td>
<td>4.5</td>
</tr>
<tr>
<td>IRR (%)</td>
<td>23</td>
<td>33</td>
</tr>
<tr>
<td>Payback period (months)</td>
<td>36</td>
<td>25</td>
</tr>
<tr>
<td>Average freight (USD/wmt)</td>
<td>33</td>
<td>8</td>
</tr>
<tr>
<td>Average netback (odmtu)</td>
<td>120</td>
<td>159</td>
</tr>
</tbody>
</table>

D. References

http://www.londonmining.co.uk/greenland.aspx
http://www.bulk-solids-handling.com/management/projects_contracts/articles/304655/
http://mth.com/Services/Mining.aspx

Figure 41 – Australian iron ore resources
Appendix F
Regional coal availability and trade

Figure 42 – Metallurgical coal exports

Appendix G

1. Treatment of waste gas streams

Chlorine compounds can enter into the sinter process by means of the additive coke slack or dust also by the ore’s from natural chloride contents. Furthermore, returned materials such as certain filter particles, scale and sludges from waste water treatment, which are added to the materials to be sintered, which can also increase the chlorine content of the substances used. This is reflected in the waste gases from sinter installations which contain inorganic gaseous chlorine compounds. Possible ways to treat these chlorine compounds is via waste gas treatment process. Potential processing methods include Activated Char or Semi Dry Scrubber systems.

Figure 43 – Waste gas cleaning plant
2. Introduction

The Waste Gas Cleaning Plant (WGCP) utilise by BlueScope Steel Ltd is a dry treatment process for the waste gas emitted from No.3 Sinter Machine. This process uses a granular type of Activated Char (AC) as an adsorbent, filter or catalyst to remove toxic and hazardous materials contained in the waste gas. The activated char recirculates within the moving bed system, alternating between adsorption and regeneration.

The WGCP consists of the following parts:

1. Adsorbers
2. Regenerator
3. Activated char handling
4. Sulphur-rich gas
5. Ammonia system
6. Dust Collection system
7. Waste Gas Handling
8. Water Treatment Plant
9. Services

A general operating outline for absorbers and regenerators will be provided.

3. Description of process flow through WGCP

Waste gas from the sinter machine is partially cleaned in the existing dry electrostatic precipitators (ESP) and is exhausted through the main fans into the waste gas main.

Two booster fans then push the waste gas through the activated char beds into the adsorbers. An air intake damper allows for waste gas temperature and pressure control. The waste gas is cleaned in the adsorber beds in the following ways:

- Dust is filtered by the slowly descending activated char beds.
- Sulphur oxides (mostly sulphur dioxide (SO2) with some sulphur trioxide (SO3), known collectively as SOx) are adsorbed onto the surface of the activated char.
- Organic compounds such as dioxin are adsorbed onto the surface of the activated char.
- Nitrogen oxides (NOx) react in the presence of the activated char with some injected ammonia gas (NH3) to form nitrogen (N2) and water (H2O).
4. Adsorbers

Figure 44 – Waste gas cleaning adsorbers

- Adsorption occurs when one substance is held inside another by physical bonds
- Absorption occurs when a substance is chemically integrated into another
- Desorption is the reverse of adsorption

The fully cleaned waste gas is then discharged through a 100m high stack.

From the adsorbers, the activated char is transported via a bucket conveyor to the regenerator for cleaning, or 'regeneration'. The regenerator is a two-stage indirect heat exchanger with the activated char descending through tubes filled with inert nitrogen gas.

In the upper stage hot gas from a burner surrounds the tubes and heats the char to 400oC. This desorbs the SOx into the nitrogen carrier gas which then becomes sulphur rich gas (SRG) and is piped away for treatment.

The heat and inert atmosphere within the tubes also results in the destruction of the dioxins. In the lower stage of the regenerator, cooling water surrounds the tubes to cool the now reactivated char prior to exposing it to air, thereby preventing any chance of the char burning.

Screening out the filtered dust and any degraded char particles completes regeneration. This waste dust and char is collected in a bin for disposal. Another bucket conveyor recycles the activated char back to the adsorbers.
5. Design conditions

1) Waste gas conditions (Limit value for performance guarantee)

a. Maximum condition
b. Flow rate: 1,552,000 Nm3 /h (wet)
c. Gas temperature: 100 – 145°C
d. Air intake condition
e. Waste gas: 1,441,200 Nm3/h (wet) at 160°C
f. Air: 175,000 Nm3/h (wet) at 22°C
2) Waste gas composition

Table 42 – Waste gas composition

<table>
<thead>
<tr>
<th>Inlet</th>
<th>Design condition</th>
<th>Normal operation</th>
<th>Abnormal operation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dust</td>
<td>100 mg/Nm3</td>
<td>100 mg/Nm3</td>
<td>400 mg/Nm3</td>
</tr>
<tr>
<td>NOx</td>
<td>300 mg/Nm3</td>
<td>(224 ppm)</td>
<td>248 mg/Nm3 (185 ppm)</td>
</tr>
<tr>
<td>SOx</td>
<td>500 mg/Nm3</td>
<td>(175 ppm)</td>
<td>300-400 mg/Nm3</td>
</tr>
<tr>
<td>(105-140 ppm)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>O2</td>
<td>15.6 %</td>
<td>14 – 17.5 %</td>
<td>During cold start-up &gt; 18%</td>
</tr>
<tr>
<td>CO</td>
<td>1.2 %</td>
<td>0.8 – 1.3 %</td>
<td></td>
</tr>
<tr>
<td>CO2</td>
<td>7 %</td>
<td>4.6 – 8.2 %</td>
<td></td>
</tr>
<tr>
<td>Moisture</td>
<td>10 %</td>
<td>6 – 14 %</td>
<td></td>
</tr>
<tr>
<td>HCl</td>
<td>100 mg/Nm3</td>
<td>50 mg/Nm3</td>
<td></td>
</tr>
<tr>
<td>HF</td>
<td>5 mg/Nm3</td>
<td>3 mg/Nm3</td>
<td></td>
</tr>
<tr>
<td>DXN</td>
<td>3 ngTEQ/Nm33</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

3) Removal performance

a. DeSOx and a DeNOx efficiency (expected)
b. DeSOx efficiency 95% (except during abnormal operation)
c. DeNOx efficiency 10% (except during abnormal operation)
d. Outlet Dust (guaranteed) less than 20 mg/Nm3 (including 4 Adsorber-operation)*
e. Outlet DXN (guaranteed) less than 0.3 ngTEQ/Nm3 (including 4 Adsorber operation)*

Hybrid pelletised sinter (HPS)

HPS is characterised by micro pellets with high mechanical strength, measuring between 2mm and 8mm. HPS feed consists of iron ore pellet feed fines (PFF), return fines and iron and steel work remnants, filter dust, additives and binders like limestone, dolomite, bentonite and coal dust. These micro pellets are fed into a sinter machine to produce sinter cake, which is then broken down and smelted in a blast furnace.

Appendix H

References for Section 4 (coal/coke scenario)

2. LODDO, ESPOSITO, PIVOT (2011) *A modern design approach in the new stamp charging coke oven batteries in Dillingen*. ECIC.
6. Art from Asia on briquetting to be included.
15. www.carbonyx.com

Appendix I

Raw material survey questionnaires were prepared by the project team. Brief details of survey sections are shown below:

1. Introduction
2. Basic Information: Contact details, company information etc.
3. Iron ore as mined: Questions are related to the iron ore as mined, before beneficiation process. Survey asks around ore type (Lump, fines, blue dust, hematite, magnetite, BHJ, BHQ, BIF etc. annual production, quality of end product, life of mine, blending techniques, blending indexes, future techniques for blending, waste/ ROM ratio, method of disposal etc.
4. Iron ore Beneficiation: Number of steps for beneficiation of lumps, sinter fine and pellet fines-Washing, jiggling, spiral, other processes. Input material quality – high grade, low grade, any other. Flow chart of the process. Quality before beneficiation, beneficiation yield, quality of beneficiated product, mode of transportation from mine and beneficiation site, constraints, best practices, lowest quality input, blending technique etc.
5. Pelletising: Quality of iron ore for pelletising, constraints, best practices for low quality materials, blending techniques etc.
6. Sintering: Quality of iron ore for sintering, impact of quality mix on productivity, solid fuel rate and sinter quality, best practices, lowest quality input, blending techniques, use of preparation mix such as disk, segregation control system etc.
7. Coal mine: Mine type, annual production, life of mine, quality of extracted coal, blending techniques, waste management, method of disposal etc.
8. Coal Beneficiation: Beneficiation processes used – Dense media bath, jigs, dense media cyclone, TBS/Flotex/Hydrosizers/Reflux, Spiral, flotation. Throughput capacity, plant life, constraints, best practices, lowest quality used, product mix nomenclature, product quality, mode of transportation, blending etc.
9. Coking: Quality of coal, operation constraints, best practices, lowest quality used, blending techniques, blending indexes, future need etc.
10. Blast Furnace: Burden %, quality mass %, source, size range, % over or undersize, tumbler index, Reduction Degradation index etc. Constraints, best practices, lowest quality used, perception for new technologies i.e. corex, finex, etc. Coal usage and type – quality mass %, blending techniques etc.
11. Other ironmaking plants such as DRI: iron ore quality, ore type, size range, process description – gas based/coal based, reason of choosing technology, operational constraints, best practices, lowest quality used. Coal usage and type, blending etc.
12. Good practices
13. Problems
14. Concern for future supply

Appendix J

Reference lists


Increasing proportion of natural lump ores in blast furnace


**Requirement on iron ores qualities for Corex**


Requirement on iron ores qualities for Finex


An update on Finex technology development


New Developments in Iron and Steel Technology – Paper 1, S. 1-16


Requirement on iron ores qualities for Midrex


Appendices


Requirement on iron ores qualities for HYL III


Beneficiation plants and processes for low grade iron ores


Beneficiation plants and processes for coaking coals

Appendix K

Project members were requested to submit the detailed survey questionnaire. Responses received from the members have been attached in this appendix for readers’ reference and in-depth study.

Blast furnace

**Question 1: Do you have any constraints on your operation?**

- High productivity practice requires high quality raw materials.
- The raw material qualities are the bottleneck to improve BF performances.
- BF operators and production engineers are limited in selecting suppliers of iron ore raw materials and coke especially.
- Limited supply of desired materials force to use several different materials as spot supply.
**Coke quality**
- Low availability in hard coking coal decreases coke quality, the impact is an increase in fuel rate and decrease in productivity.
- The coke is made from local coal with limited quantity of hard coking coals.
- High ash in coke is an important constraint.

**Sinter quality**
- The Fe content is limited even when utilising high percent of concentrates at sinter plant.
- High Alumina content in ore decreases sinter hot strength and BF productivity.
- Concerning chemical composition, the Al2O3 content should not be too high.
- Poor quality of input materials like sinter with high alumina (> 4 %).
- High alumina in ferrous burden.

**Pellets handling**
- BF operation is based on local pellet production with very stable properties.
- Main differences of quality come from pellet supplier.
- There is no winter transportation, so pellet are stored.
- Issues on pellets come from fines content.
- The problem is increased by high coke moisture and frozen pellet utilisation in the winter.

**Input limitation of some harmful elements**
- Higher content in phosphorus or sulphur has a negative impact on steelmaking costs.
- The sulphur input has to be limited.
- Zn load to BF should be less than 0.2kg/thm and K2O load is controlled to 2kg/thm.
- Zn input : <0.14~0.17kg/tHM; Alkali input : <2.0kg/tHM.

**Slag amount**
- Slag Volume gives limitations for high productivity and high PCI level.
- Higher slag rate operation in BF is problematic.

**Injectant**
- BF practice to have high natural gas injection combined with oxygen use is limited by top gas temperature

**Others**
- Slab making capacity limits the blast furnace productivity.

**Question 2: What is your best practice for 'low' quality?**

**Blending raw materials:**
- First practice is to blend the raw materials in order to limit the poor quality ores or coke at low rate the impact can be managed.
- Control the mixing ratio of low grade ore in blending pile, and sequencing pile.

**Selective use of raw material**
- Lower quality ores are used as secondary materials at high productivity.
- For low quality of sinter (with high alumina percent) quartzite is being used to increase slag volume and to restrict slag alumina.
- Low quality material is limited to max 200 kg/t HM.
**Adaptation of BF operation**
- When raw material quality cannot be avoided by mixing, the best practice is to decrease BF productivity, to adapt blowing parameters so that BF stability is recovered.
- Productivity reduction to minimise impacts on cost and life time.
- Usually optimum fuel rate cannot be recovered.

**Use of sophisticated technology**
- Use of 56% captive coal yet maintaining good quality of coke with stamp charging technology. with higher ash coke still maintaining reasonably low levels of [Si] in hot-metal.

**Optimisation of the total cost of hot metal**
- Practices are to optimise the total cost of hot metal: this is a compromise between raw material price and yield. This policy is enhanced when using internal raw materials.

**Others**
- Skip coke consumption – 570,6 kg/t, iron consumption 1011,8 kg/t, natural gas consumption – 77m3/t. Daily production 6138 t/day, cast iron output from 1m3 – 1,541 t m3.

**Question 3: What is the lowest quality that is currently used practically?**

**Iron ore type**
- Yandi fines used in sintering blend at approx. 50%
- High and medium combined water contained ore, such as pisolite and marra mamba

**Sinter quality**
- Sinter with above 4.5 % alumina and coke ash with 17-18%.
- High alumina sintering fines resulting higher sinter alumina

**Coke quality**
- Lowest quality has to be considered in relation to targeted BF productivity: for 60 t/m2/d slag volume is 300 kg/tHM maximum, coke CSR >60. During crisis period productivity was decreased at 50 t/m2/D with 350 t/m2/D.
- CSR 55 ( spot practice)
- Coke CSR 45-55
- Coke: Ash – up to 12%, sulphur up to 1,6%,
- CSR = 60

**Lump ore quality**
- Lump oremmx 7% SiO2 is around to be used.

**Slag ratio**
- Slag volume 450-550 kg/tHM
- Slag rate 300 kg/tHM

**Recycling materials**
- Recycled materials/sludge processed through the sinter plant at 3%.
Input of harmful elements
- Alkali content up to 10 kg/tHM, Ph 0.8 %

Others
- Running bigger blast furnaces with relatively poor coke quality not sufficient enough for bigger blast furnaces.
- Low cost coals, low cost iron ores.

Question 4: How do you assess new technology such as DRI/COREX/FINEX for low grade material?
- We have no practical knowledge of the effectiveness of these processes. no experience.
- No natural gas is available in WE for standard DRI production.
- Today BF route is available and shows flexibility in raw material condition for medium term: no clear interest for Corex at short term.
- Corex and Finex utilisation could be developed in such raw material context but performances have to be assessed by pilot tests.
- The costs are too high; the technology is not mature yet.
- We think the new technology has a long way to go but it’s definitely being evolved faster than we expected.
- CO2 context has also to be considered in the development of new process.
- New technology, such as COREX and FINEX, indicates the flexibility using low grade fine ore and coal directly, which is not hard to BF. On the other hand, BF is still superior to productivity and energy consumption, so both technology will go together but different field for a while, e.g. discriminated by production level. However, new technology is gradually separating initial concept, such as usage of raw material type. We would like to keep an eye on new technology.

Question 5: Blending technique

Question 5.1: What kind of blending techniques do you use?
- No blending.
- Sized iron ore: Chevron stacking method.
- Single chevron stacking for ore and coking coal beds.
- Bedding yard, chevron method.
- Feed bins blend coals directly to the coal bunkers.
- Iron ore reclaimed with barrel reclaimer, coking coal double bucket wheel bridge reclaimer.
- We operate dedicated yards with no bin blending facilities. PCI blended via hopper prior to elevation to raw coal storage bins.
- Various lump ore is blended in the dedicated blending yard. The chevron procedure, which is typical method, is applied to control the mixing ratio through the pile.

Question 5.2: Do you have any special blending techniques for improving the usability of lower quality materials?
- Recycled dusts and sludge initially recycled through cold bonded briquette process, it has been since replaced with recycling through the sintering process. Small fraction of flux dusts cold pelletised and added to sinter blended bed.
- Mixing with high grade material on the bedding.
Question 5.3: Are there any indexes or factors you need to consider for blending?
• VM content and ash composition are the main KPI.
• Standard deviation.
• Consideration given to the various components of dense, porous and fine materials in the bed. Total volume of recyclates and ultrafine material also considered. Full run control during bed building. Chemical considerations for BF and steelmaking also made (Al2O3, SiO2, P).
• We have investigated the variation of chemical composition (TFe, SiO2, Al2O3) in the blending pile. We have not done for a while, because there is no issue regarding the fluctuation of quality.

Question 5.4: What will be needed for the future?
• Some plants can mix 3 types of coal according to logistics issues, we target general use of mixing equipment
• Actually injection is natural gas or oil. For the future PCI will be needed.
• Use of pellets in BF as charge materials.
• Improve blending particle size control.
• Ability to manage increasing levels of Al2O3, SiO2 and P in the iron ore supply.
• Increased ability to manage recycled materials.
• Higher Zn bearing materials from ironmaking and potentially steelmaking operations.
• Volatiles: max 25 %, high calorific value, low ash content, low trace elements.

Sinter

Question 1: Do you have any constraints on your operation?
• Winter transportation and frost, water content of concentrates, low Fe content of concentrates and ores.
• Sinter plant productivity limited during rainy season because of problems in handling of Carajás. The problem is caused by % of super fines and high porosity of the material. The problem began during 2009 and is not experienced with other fines.
• Fluctuation in incoming fines with respect to chemical and physical properties.
• The constraints are as follows: High fuel rate operation, lower sinter yield (high sinter return fines from blast furnace)
• Ore purchasing in FY10. The sinter machine has been uprated (OPUP) by 20% to 6.6Mtpa capacity in 2009. Since then bed permeability has been limiting production. Pre OPUP, the activated carbon bed waste gas cleaning plant was limiting production. Removal of chloride rich feed has resolved this issue.
• Suction pressure of SP2 is 100 mbar
• Higher amounts of concentrates and pellet feeds were used for sintering due to insufficient sinter feed availability. The experience shows, that shares of up to 80% of concentrate and pellet feed at the sinter raw mixture is possible. From 305 share on the return fines increase and the sinter plant productivity decreases. Tumbler strength, RDI index and reducibility of sinter are not affected.
• Permeability of bed, cooler of sinter product, homogenisation of mix.
"Yes. In company ‘A’ Production engineers are limited in selecting main sinter ore for sinter production. Suppliers are directly selected in SRPD."
• No special constraint exists and our sinter operation is stable.
• For productivity of sinter plant: Size, combined water content, SiO2, Al2O3 content.
• For environmental regulation: S, N, Cl, Oil content
• For quality control for steel product: P, V, Cr, Cu content"
Question 2: What is the impact of quality of mix on productivity, solid fuel rate and sinter quality?

- High percent of concentrate ore decreases the sinter productivity, which can practically be mitigated by the use of burnt lime.
- Magnetite decreases solid fuel rate.
- Due to the higher content of Silica and Alumina in Pantanal fines tumbler index decreases when increasing its participation in the mix (Pantanal / Carajas mix). Average particle size and RDI are affected as well.
- Sinter quality deteriorates whenever there is fluctuation of solid fuel rate in sinter mix.
- We have produced a sinter with a high content of SiO2. This causes high slag rate at blast furnaces.
- The quality of mix is favourable in terms of strand productivity (Gross Productivity > 40t m2/d), however solid fuel rate is very high in comparison to world standards. In terms of sinter quality, the strength-Tumbler Index and Shatter Index is lower compared to world standards. Availability of lime fines (<1mm) dictates the granulation phenomena effecting better permeability of bed. This facilitates to enhance machine speed and better productivity along with better sinter quality.
- Insufficient hematite ore can reduce permeability and productivity. Higher Goethite levels requires more fuel.
- The distribution size of mix have a strong impact on productivity, IB2 and %Fe in mix have a influence on flux a flue rate.
- When increasing sinter ore rate, sinter machines' productivity and consumption of solid fuel increase, iron content in sinter decreases, its grain size composition improves.
- "The quality of mix has a positive correlation with productivity and sinter quality while a negative correlation exists between the quality of mix and fuel ratio.”
- Low Fe (High Impurities) ore increases slag volume, which adversely affects productivity.
- Fine ratio and the amount of combined water in sinter mix decrease the productivity. Also the increase of the combined water amount requires higher breeze ratio because the endothermic reaction increases.

Question 3: What is your best practice of sintering for 'low' quality mix?

- Preheating the ore mix by waste energy
- There is no mix considered as low quality
- Since we have our captive mines, we have not explored ore mix of any other quality.
- We consider all our ores to be high quality ores, including Yandi. On occasions we have used very low grade local hematite (<50% Fe). At this time we control usage rates to <5% of ore blend.
- Only one standard mix with different components is used
- Increase of permeability of with tools, productivity. Decrease of rate flux for below %Fe
- "Best parameters on uniformity of sinter's chemical and grain size composition were achieved when operating based on sinter's basicity of 1.3. Iron content in sinter was approximately 56–56.5%. Quality of main iron ore raw materials is relative stable in all the periods."
- For the productivity drop by the usage of low grade ore, such as pisolite, the increase of of pellets, and introduction of strand sintering method. For fine and the water absorbing ore, such as MarraMamba, high speed mixing was introduced to improve granulation.
Question 4: What is the lowest quality that is currently used practically?
- See low Fe mix composition.
- Total Fe content in iron ore fines is as low as 60% level in sinter mix with higher percentage of gangue content.
- Current Usage: Ores from Joda Mines and Noamundi mines both have Fe (T) > 65%.
- Yandi.
- Productivity = 32 Ton/m²/day; %Fe = 56.5%
- "Sinter with basicity 1.8. Iron content – on 52% level. Sinter ore: iron content – 56%, silica content – 20%. Concentrate – iron content 66.5%.”
- Please refer to the above Robe brand specifications indicated in C. Pisolite ore

Question 5: What kind of blending techniques do you use for blending of ore mix?
- Usually we have hoppers per ore quality and proportioning facilities. As winter is severe homogenisation pile are not used.
- No blending
- Chevron Stacking method
- We use a Chevron system, where we mix the iron ore, the reverts and part of the limestone in one pile which is used during around five days in the sinter plant.
- Blending by Pile preparation using Chevron technique. This is a composite Pile mix where all the fluxes and fuels are being added layer-wise.
- Due to limited primary yard capacity and stacker reclaimer capacity, ~50% of ores are discharged direct from ship to secondary yards. Primary Yards use 5 base windrow stacking. Secondary yards use single chevron stacking. Approximately 20% of the fine ore (Yandi) is stored in a separate area using Cone stacking.
- Bedding yards with chevron method
- Use of fine ore bedding yards for iron ores, fluxes, solid fuels and recycled residues.
- Stock piles= chevron and maquina=mixer.
- When blending, sinter ore consumption is defined as 200 kg/t, taking into account its low quality. Concentrate consumption mainly depends on secondary materials’ rate in sinter burden and lime consumption (depending on required basicity).
- Each ore material was fed by CFW at specified mixing ratio from ore bin toward belt conveyor, then blends in drum mixer.

Question 6: Do you use any preparation of mix such as intensive mixer, disk, and segregation control system?
- No special device, large surface sinter strand are available to be adapted to low productivity operation.
- No, we have a drum mixer and conventional system of charge in the sinter machine.
- The present method of homogenisation and granulation encompasses water and lime addition in mixing nodulising drum. The distribution of green mix in sinter strand is ensured through charging by using segregation plate. The angle adjusted to get best size distribution of raw mix in sinter strand to get optimum bed permeability and fuel segregation.
- No additional processes.
- Use of Eirich Mixer.
- No, as sinter plant is distressed.
- Currently, we don’t have any preparation facility but a granulisation process is scheduled to install from year 2010 and will continue to be expanded.
• For granulation, high speed mixer was introduced for fine and high water absorbing ore, such as Marra Mamba. For segregation control, slit bar type equipment is adopted.

Question 7: Are there any indexes or factors you need to consider for blending?
• Blending efficiency and standard deviation.
• The indices that are being monitored are Pile size and number of layers in Pile. The degree of homogeneity is monitored through standard deviation of target sinter chemistry.
• We blend to a target chemistry using a mass balance updated daily. Targets are set based on raw materials supplied. No other factors are used in planning and monitoring blending.
• Intensive mixer and segregation control system
• When blending, the following is taken into account: required quantity and quality of sinter for BF shop demand in planned period.
• Technical capabilities of sinter plant (unsatisfactory technical state), available production wastes and their creation.
• We have our own criteria and indexes for blending based on the cumulative reliable data for the past many years.
• By checking granular index of blended ore sample at the outlet of drum mixer, the status of granulator can be judged.

Question 8: What will be needed for the future?
• Up-date and improvements to sinter technology.
• Quality of fines is expected to be lower. Higher amount of super fines is expected. Improvements must be done to be able to handle during unloading, transportation and charging to the sinter plant mainly during rainy season.
• Base mix bed with higher capacity
• Emission optimising sintering process will lead to sinter-making more environments friendly.
• We currently have 3 ship un-loaders. These serve 2 bulk discharge berths. One of the berths and only one of the un-loaders can discharge Cape size ships. To address current shipping industry trends and new raw materials requirements, we may need to install a fourth ship un-loader.
• Depending on the availability of ores, more concentrates need more intensive preparation
• Increase of productivity (permeability of bed) for 1.75 million tonnes per annum
• First priority task is new sinter plant construction as existing plant is distressed. Also we need to revise main raw material basis as quality of raw materials used is lower than even average international standards.
• The quality trend of iron ore goes downward meanwhile, the supply portion of high quality ore like Hematite is decreasing.
• In the situation, steelmakers should find a way to increase consumption of low quality one for survival.
• Nothing special to mention at this moment.
Survey responses for COREX

**Question 1: Please describe your process (e.g. Gas based DRI, coal based DRI, etc).**
- Coal based both Hot Metal and DRI in one complex, combination of Corex-Midrex.

**Question 2: Please provide the reason for choosing this technology?**
- Coal and lump ore availability and relatively low cost in South Africa.
- Environmental protection considerations motivated Baosteel to adopt COREX production method.
- Indian (JSW) prospective – minimal established infrastructure in the region therefore gas production was highly valued to the region for power generation.

**Question 3: Do you have any constraints on your operation?**
- High fines generation during reduction of Sishen lump ore.
- High strength of the lump ore and lump coal. Lump coal of high strength is expensive and difficult to procure.

**Question 4: What is your best practice for “low” quality? What is low quality for COREX?**
- Never use low strength or high fines content of lump or pellet.
- Coal quality can be utilise. Low quality in relation to COREX process incorporates – Low strength of lump or coal, fines content. Strength measure – pellet compression strength 250 0N/pellet, low temperature break down LTB
- Pellet RDI aim – 3.15mm: 13-30 (15% hydrogen + 35% CO in reduction gas, gas flow 800 l hr) more severe test.
- Lump RDI aim unsure of values
Question 5: What kind of blending techniques do you use?  
N/A

Question 6: Do you have any special blending techniques for improving the usability of lower quality materials?  
• Nut coke (8-25mm) mixed with burden into reduction shaft to reduce sticking. Usage of coke allow for high lump ore usage.

Question 7: Are there any indexes or factors you need to consider for blending?  
N/A

Question 8: What will be needed for the future?  
• Optimisation of the gas utilisation and briquetting technology will need to be developed to replace lump coal.

Survey responses for FINEX

Question 1: Please provide the reason for choosing this technology?  
• Corex process can only use lump or pellet. The motive behind the development of FINEX was to use the ore fines. CO2 captured is recirculated to the process

Question 2: Do you have any constraints on your operation?  
• Sinter feed used only. Can only use limited to no pellets. Grain size important. Semi coking coal. 10% hard coking coal.

Question 3: What is your best practice for 'low' quality?  
N/A

Question 4: What kind of blending techniques are use?  
• Coal blending is important. Binder choice is key to success.

Question 5: Are there any indexes or factors you need to consider for blending?  
N/A

Question 6: What will be needed for the future?  
• Improved briquetting technology.

Survey responses for coal-based DRI

Blending

Question 1: What kind of blending techniques do you use?  
• Separate piling and reclaiming followed by blending using silos, feeders and conveyors.  
• We use in band blending.
**Question 2: Do you have any special blending techniques for improving the usability of lower quality materials?**
- We use cement coating on 4M plant pellet feed for avoiding clustering inside the Direct reduction reactor. In 3M5ZR plant MgO is used for this purpose.
- We use cement coating on 2P5 plant pellet feed for avoiding clustering inside the Direct reduction reactor.

**Question 3: Are there any indexes or factors you need to consider for blending?**
- The plant ‘b’ direct reduction plants feed a mix made of 40% Peña colorada and 60% of Las Encinas.
- The 2P5 Direct reduction plants feed a mix made of 20% Peña colorada and 80% of Las Encinas.

**Question 4: What will be needed for the future?**
- As coking coal and natural gas sources decline and cost increases, coal-based HM, solid iron and DRI technologies
- Development of recycling techniques for solid wastes, such as dolo-char, ESP dust, etc.
- We will increase consumption of this iron ore pellets.

**Survey Responses for gas-based DRI**

**Question 1: Your reason for choosing the technology?**
- Most productive and economically feasible DRI technologies at locations where NG is available for reasonable price (Natural gas based DR processes – Midrex and HYL)
- Coal and lump ore availability at relatively low cost in South Africa (Coal based DRI, Rotary kiln)
- Coal and lump ore availability and relatively low cost in South Africa (Coal based both Hot Metal and DRI in one complex, combination of Corex-Midrex)
- This technology was developed internally by TERNIUM-HYLSA.(Guerrero plant has 2 HyL ZR (zero reformer) direct reduction plants, identified as 3M%ZR (92.7 THRD/hr) and 4M (115.2 THRD/Hr))
- This technology was developed internally by TERNIUM-HYLSA.(Puebla has 1 conventional HyL with reformer direct reduction plants, identified as 2P5 (116 THRD/hr)
- Manage without coal and sinter plant. Green technology.

**Question 2: What are the your constraints on operation?**
- Pellet sticking/clustering during reduction at relatively low temperature 800oC(for Midrex and HYL).
- High fines generation during reduction of Sishen lump ore.(for COREX-MIDREX).
- Every ten weeks each Direct reduction plant have to be stopped for 32 hours for decarburisation of the inferior surface of the heater’s radiant zone.(for Guerrero plant HYL ZR).

**Question 3: Best practice for 'low' quality**
- Screening out the – 6.3mm.
- Never used the low quality raw material. Haven’t trialed lower quality material.
Appendix L

Conversion glossary

Mass
1 kg = 2.205 lb
1 lb = 453.6 g = 16oz
1 metric tonne = 1,000kg = 2,205lb
1 US short tonne= 907kg = 2,000lb
1 UK long tonne = 1,016kg = 2,239lb

Volume
1 L = 0.264 gal = 1000 cm3 (ml)
1 m3 = 1000 L = 35.3 ft3 = 264 gal
1 gal = 3.785 L = 4 qt = 16 c = 128 oz
1 ft3 = cf = 28.32 L = 7.482 gal

Energy
1 J = 1 Nm = 1 kgm2/s2 = 0.239 cal = 0.74 ft-lb
1 Cal = 1 kcal = 1000 cal = 4.187 KJ = 3.968 Btu
1 KJ = 0.239 Cal = 0.947817 Btu = 0.95 Btu
1 Btu = 1,055.056 J = 0.252 kcal
1 kWh = 3.6 MJ = 3,412 Btu; (1MWh = 3.6 GJ = 3.412mmBtu)
1mmBtu = 1.055 GJ = 1 decatherm
1 mcf nat. gas (LHV) = 10.27 therm = 1.027mmBtu = 1.082 GJ
1 toe = 41.868 GJ = 39.683mmBtu = 11.63 MWh = 7.33bbl
1 tce = 29.308 GJ = 27.778mmBtu = 8.141 MWh

Power
1 W = 1 J/s = 3.6 kJ/hour = 31.5 MJ/year
1 kW = 1.341 hp = 738ft-lb/s

Rule of Thumb
1 Btu = 1,055 J
1 kWh = 3.6 MJ = 3,412 Btu
1 hp = 746 W
1 million barrel oil per day (mbd) =486 gal/sec = 2.2TJ/yr = 4232 metric ton C/yr
Natural gas: 1 mscf = 0.2832 Nm3 = 1.027mmBtu = 10.27 therm
3.667 (44/12) ton CO2

Source: International Energy Agency (IEA) Energy Statistics Unit Converter
http://www.iea.org/Textbase/stats/unit.asp
World Steel Association

Rue Colonel Bourg 120
B-1140 Brussels
Belgium

T: +32 2 702 8900
F: +32 2 702 8899
E: steel@worldsteel.org

C413 Office Building
Beijing Lufthansa Center
50 Liangmaqiao Road
Chaoyang District
Beijing 100125
China

T: +86 10 6464 6733
F: +86 10 6464 6744
E: china@worldsteel.org

worldsteel.org