The increasing role of direct reduced iron in global steelmaking

by F. Grobler* and R.C.A. Minnitt†

Synopsis

Direct reduced iron (DRI), produced by the reaction between iron ore and reducing gasses, is used as a source of low-residual iron, in addition to ferrous scrap and pig iron, in the production of steel mainly through the electric arc furnace (EAF) route of steelmaking. The main DRI technologies in use are those of Midrex and Hyl, but in recent years a myriad of newer processes emerged based on variations in feedstock, reducing agent and fuel sources.

Since the beginning of the nineties, DRI has increasingly emerged as a cheaper, low-residual iron feedstock for EAFs, which have traditionally relied almost entirely on ferrous scrap feed. The main stimulus behind the interest in DRI has been the increasing popularity of the EAF and the 'mini-mill' set-up as the favoured steelmaking option compared to the traditional and much less flexible blast furnace/ basic oxygen converter. This, however, has been creating a problem with regard to availability of low-residual scrap, resulting in upward pressure on high quality scrap prices and leaving DRI, traditionally the 'expensive alternative', as a much more competitive consideration.

The second main determinant has been the increasing production efficiency of existing steel plants which, in the light of improvements such as continuous casting and near net shape casting, has been constraining the supply of low-residual domestic scrap, traditionally the prime source of EAF feed.

The explosion of current and proposed DRI projects has been accentuating the mounting interest of global role-players in assuring the availability of reliable sources of low-residual iron units for the future, especially in cases where definitive competitive advantages exist with regard to proximity to primary sources of iron ore and fuel (gas or coal).

Introduction

Steelmaking has been around since ancient and medieval times, when steel was produced by heating and manipulating iron ore at temperatures below the melting point of iron, and then going through the laborious ritual of re-heating and manual reworking to eventually end up with a useable piece of steel.

In the more civilized era, the interest in producing iron directly from the ore in a solid state without having to melt it at high temperatures already existed in the early 19th century. The technical and economic problems experienced in those days, however, prevented direct reduction (DR) processes from competing with the blast furnace route of steelmaking (Brown[4]). Consequently, the interest in DR processes began to decrease.

Since the early 1900s, however, the electric arc furnace (EAF) emerged, using steel scrap as the basic charge and having little reliance on iron ore. This steelmaking method, although it had a late start, has become increasingly popular among steelmakers, especially considering its lower capital investment costs and smaller scale when compared with the blast furnace route.

Consequently, due to production efficiencies such as continuous casting and near net shape casting (NNSC), as well as the entrance of the EAF into the arena of large scale, higher quality products, traditionally occupied by the conventional blast furnace/ basic oxygen converter, more and more pressure was being exercised on the available supply of high quality, low-residual scrap, the main source of metallics used in EAF steelmaking.

This has increasingly forced steelmakers to consider other sources of low-residual metallics, and more specifically direct reduced iron (DRI), as potential feedstock of EAF steelplants.

Ferrous scrap

Definition

'Scrap' cannot be 'produced' or 'manufactured' in the strict sense of the word, but can be defined as pieces of ferrous metal which occur

- as a by-product in the steelmaking process (internal or domestic scrap)

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- ➤ or which is produced as a by-product in the manufacture of steel-containing parts or goods (prompt scrap)
- ➤ or which has been discarded after use in the form of consumer goods (obsolete or capital scrap).

Factors influencing scrap supply

Steel technology and productivity improvements such as continuous casting and near net shape casting reduces the amount of internally generated scrap, increasing the demand for purchased scrap. New technologies allow electric arc furnace plants to produce higher quality products with longer lifetimes, which keeps them (the products) out of the scrap cycle for a longer period than before (Scarnati[13]) Increasing demand due to the development of 'mini-mills' has strongly influenced the expansion of the scrap market with concomittant upwards pressure on their prices.

Availability of various scrap grades

The available scrap supply, which is the primary feedstock for these furnaces, has fallen short of requirements (Barnett and Kopfle[2]). The current situation is as follows:

- ➤ internal (home) scrap (i.e. from iron and steel plants), which has been used as high-quality scrap feed by steelmakers, has decreased in availability because of the improved continuous casting rate and rolling yield
- ➤ prompt scrap (i.e. from the industry processing the steel products) is not increasing much and appears to be more or less proportional to steel production
- ➤ obsolete or capital scrap, (i.e. what is recovered from used or dismantled products) is the only scrap source which is increasing, the accumulation of which increases in direct proportion to the increase in world steel production.

The mounting pressure on the scrap market from mini-mills coming on stream, is forcing scrap users to turn increasingly to the low grade scrap sources, such as obsolete scrap, as source of iron units. The major problem with obsolete scrap, however, is its quality.

Problems with scrap

- ➤ *Residuals' problem*
  Tremendous growth in electric arc steelmaking has led to an unavoidable quicker turnabout of scrap and consequently, to increased contamination of scrap by other elements.
  Steel, in its final form, produced from scrap contains other metals and when such products are scrapped, is difficult, or sometimes impossible, to separate these metals which in turn contaminates the steel produced thereafter. New steel applications have increased the number of additives to steel which must eventually be removed during re-melting. The residuals (Cr, Ni, Mo, Cu, Sn—often ranging from 0,15 to 0,75 per cent depending on the type of scrap) have an adverse effect on the mechanical properties of the steel. That is why the use of EAFs (using scrap only) for the production of deep drawing quality steels as well as low carbon steel products is generally avoided. The nitrogen content of EAF steels is higher than that of OH or BOF steels. As a result, steels produced in arc furnaces usually have poor ageing characteristics which make them practically unsuitable for deep drawing applications.
- ➤ *Price volatility*
  The mounting pressure on the available high quality scrap sources results in increased price volatility (see Figure 3). Obsolete scrap is basically elastic in price, discarding seasonal factors and depends, essentially, on demand. Prices will go up or down in response to demand, within a reasonable price range. Low residual scrap prices, however, are not elastic. While demand continues to increase, prices will rise. The price mechanism of scrap works well to the extent that, during peak steel demand years, collection and processing of scrap that would otherwise be considered uneconomical becomes feasible due to higher prices. As the scrap price rises, at some point it becomes more expensive to produce steel from scrap than from iron ore. The incentive to the integrated producer is then to cut back on purchases of scrap and increase the proportion of hot metal/DRI, if available.

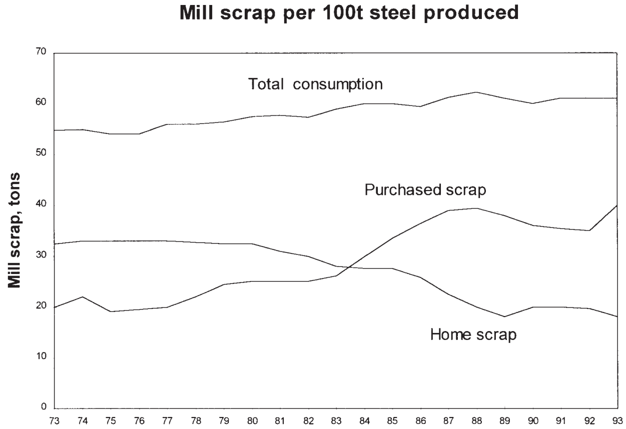

Figure 1—Home scrap vs purchased scrap comparison. (Source: Scarnati[13])

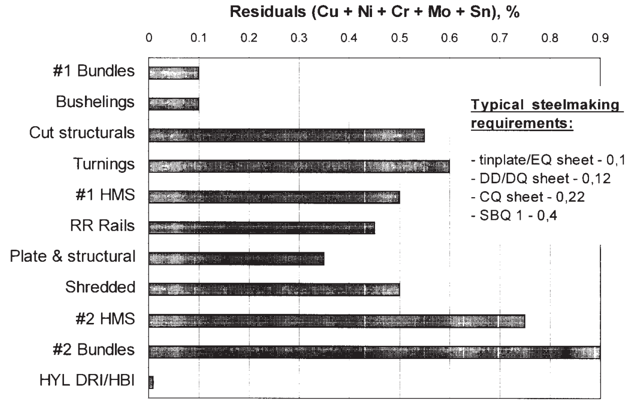

Figure 2—Typical residual content of scrap. (Source: Scarnati[13])

DRI as alternative solution

Historical

Direct reduction technologies have been developing since the early 19th century, as an attempt by steelmakers to produce iron directly from iron ore, avoiding high temperatures needed to melt iron. Besides technical problems, direct reduction technologies met with economic and financial difficulties in its development due to the relative unimportance of it in the shadow of ferrous scrap as a feedstock for EAFs.

More recently, the search for better quality iron units in the production of steel in mini-mills, as well as problems with price volatility of scrap has led to a renewed interest in the development of direct reduced iron (DRI), also called sponge iron.

Defining DRI

'Reduced iron' derives its name from the chemical change that iron ore undergoes when it is heated in a furnace at high temperatures in the presence of hydrocarbon-rich gasses. 'Direct reduction' refers to processes which reduce iron oxides to metallic iron below the melting point of iron. The product of such solid state processes are called direct reduced iron (DRI), whereas the product of the blast furnace is referred to as hot metal in the molten state, or pig iron in the solidified form. DRI can be produced either in lump, pellet or fines as a porous product which retains the original size and shape of the pellet and lump feed. Hot briquetted iron (HBI) is the terminology used to refer to DRI which has been mechanically compressed, after reduction and before cooling, into dense (>5g/ml.), pillow-shaped briquettes at more than 650°C. HBI, which is the preferred form for the merchant product, has a lower porosity than DRI, facilitating shipping and storage, and reducing the danger of spontaneous combustion of wetted DRI. Iron carbide or Fe_3C is a stable, finely granular material produced from high grade fine ores with around 6% carbon (McManus[11]). The carbon is added from the reducing gases during reduction, binding with the Fe as Fe_3C. Generally, iron carbide is grouped among other reduced iron products, but technically it is distinct from DRI/HBI because it has very little free metallic iron content, being a stable compound of iron and carbon. A group of newer processes, called direct smelting processes, reduce iron oxide to metallic iron in a molten state directly from iron oxide to give a similar product to that of the blast furnace. These include the Corex process, Hismelt process, Itmk3, AIAI Direct Steelmaking Program (Weston and Thompson[15]), the Japanese Dios project (Furukawa[6]), and the Russian Romelt process (Romenets[12]).

The Direct Reduction process

Direct reduction processes can be divided roughly into two categories, gas-based, and coal-based. In both cases, the objective of the process is to drive off the oxygen contained in various forms of iron ore (sized ore, concentrates, pellets, mill scale, furnace dust etc.), in order to convert the ore, without melting (below 1200°C), to metallic iron. In gas-based processes, this is usually done by 'cracking' or 'reforming' some kind of organic fuel, such as methane (CH_4), into a mixture of reducing gases (carbon monoxide and hydrogen) using carbon dioxide (CO_2) or steam (H_2O). The reforming process takes place in a reformer, and the heated gas from the reformer is passed through the iron ore in the furnace where it reacts with the oxygen in the iron ore. Similarly, in the case of solid fuels such as coal, the carbon (C) acts as the reductant to form reduced iron and CO_x.

This is different from blast furnace practice, where the ore is reduced mainly in the solid state, and carbon saturated iron (in the liquid state) is the product. Silica, which is absorbed in the blast furnace slag, is then removed. In the case of directly reduced iron, however, the quality of reduced iron is not as desirable as blast furnace pig iron, seeing that the remaining oxygen and silica contained in the reduced product, need to be removed in the steel furnace, at some added cost.

The product—physical characteristics of DRI

- Constant size and dimension
- Known and constant composition
- 80 to 88 per cent metallic iron, compared to 95 per cent in blast furnace iron
- Some residual non-metallic impurities such as carbon and gangue
- Some residual oxygen content from unreduced iron oxides.

Advantages of using DRI/HBI

- Absence of tramp elements; increases the quality of the scrap
- Purity, or the absence of non-metallic substances, affects productivity and energy consumption
- Uniform density and shape influences the number of backcharges, productivity, energy consumption and damage to furnace walls and refractories
- Uncomplicated use in the EAF-DRI lump, pellets or briquettes can be dumped cold into a steelmaking furnace along with scrap, using standard bucket charges, especially if it is charged after a hot liquid bath has been made by melting scrap
- Lower cost—lower capital, and operating costs, and lack of reliance on coke as a fuel source
- Less time consuming—Experience shows that a DR-EAF facility can be constructed in less than two years, as compared with 5 to 7 years for a blast furnace/BOF

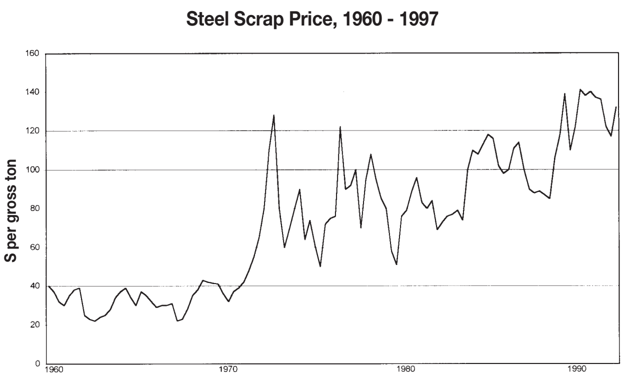

Figure 3—Average scrap price. (Source: IISI, 1997)

facility (Houseman[9]). Several DR plants have been constructed in less than 18 months and have reached design rating within 30 days after start up (Brown[4])

- Availability—unlike low residual scrap supply, which is limited, the supply of DRI can be increased according to the demand
- Associated carbon—DRI has the added benefit, when compared to scrap, that it contains an associated energy value in the form of combined carbon which increases furnace efficiency
- Direct charging—the use of hot DRI directly transported and charged to a furnace, can reduce energy consumption by as much as 16 to 20 per cent by making use of the energy value of the DRI at temperatures greater than 600°C (Scarnati[13])
- The price for DRI is basically open to negotiation with the producer, unlike scrap prices, which are routinely published by grade and market. Generally, DRI prices have been in the range of $100 to $140 per ton over the past decade, and DRI and HBI will typically be at a price equivalent to that of premium low residual scrap grades
- Blending abilities of DRI with scrap allow cheaper, low quality scrap grades to be used
- In the oxygen furnace, DRI acts as a 'coolant', while in the blast furnace it is used as charge material to increase productivity and decrease coke consumption (Bonomo[3])
- More environmentally friendly—avoids problems of hazardous contaminants such as lead or cadmium in EAF dusts.

Disadvantages

- Due to the nature and surface area of untreated DRI, it has the inherent disadvantage to be highly reactive with moisture, leading to re-oxidation and possible exothermic auto-ignition. However, considerable research into various methods of passivation has been done, and the problem has been largely overcome by hot briquetting
- Unlike blast furnace pig iron, which is almost pure metal, DRI contains some siliceous gangue, which needs to be removed in the EAF, increasing the power consumption
- Increased refractory consumption if large amounts of pre-reduced pellets are used instead of scrap.

Current and future capacity

Current capacity

Current global nominal capacity is around 37,5 mt/y. By far the majority (90%) of this is gas-based with the two dominant technologies being Midrex (55%) and HYL (32%) (CRU[5]). Feedstock in most cases are lumpy iron ore and pellets. Exceptions to these are Nucor's iron carbide plant in Trinidad, and the FIOR plant in Venezuela which feeds on iron ore fines. The rest (10%) of the capacity is based on coal and other solid fuels. Contrary to the gas-based units with large output capacities of over 1 million t/y, the coal-based units have traditionally much lower output capacities (200 000–600 000t/y).

Planned and future capacity

Considering all the new DRI projects which came on stream in the past few years, together with those planned in the future to the turn of the century, it is clear that there has been a virtual explosion of new DRI projects world-wide in recent years.

Currently, there is nearly 20 mt/y additional capacity under construction, with at least 48 mt/y being under consideration. Including the phenomenon of capacity creep, a total of 115 mt/y of capacity could be added by the year 2005 (CRU[5]).

Merchant markets

Compared to only 10% merchant capacity of existing plants, 50% of capacity under construction and 80% of that under consideration will be targeted at the merchant market. These merchant DRI producers are not restricted to poor countries, as was the case with the captive plants, but rather the determinants, in consideration of a suitable location, are the availability of low-cost iron ore, gas and proximity to consumer markets.

Economic and financial considerations

Location—a strategic consideration

Probably the most important strategic factor determining the feasibility of a DRI project is its location. It should be kept in mind that any kind of transportation adds an additional cost to the final selling price of the DRI product, whether it be transporting of the raw materials to the DRI plant, or the

Table I

Current world DRI capacity

Region	Existing capacity (mt/y)
North America and Mexico	5.1
South America and Trinidad	8.2
Asia	10
Middle East	8.2
Africa	4.0
Europe and CIS	2.0

Source: (CRU[5])

Table II

Planned world DRI capacity

Region	Planned capacity (mt/y)
North America and Mexico	4.0
South America and Trinidad	6.2
Asia	1.6
Middle East	4.0
Africa	1.7d
Europe and CIS	1.0
India	0.9
Australia	7.3

Source: (CRU[5])

DRI/HBI product to the consumer market. This refers to:

- Proximity to consumer market
- Proximity/availability of iron ore
- Proximity/availability of cheap and abundant natural gas or coal sources
- Favourable local socio-political situation.

Capital costs

The capital cost involved in building a DRI plant is high; around US$200/t to US$300/t. If this is compared with a complete scrap-based mini-mill, it is in the same order of magnitude (Ullah and Yepez[14]). In addition to the DRI production units, in many cases a large part of the investment is made in the building of other infrastructure and transport facilities such as railroads, ports and harbours. In the consideration of an ideal location for a DRI plant, the existence of these facilities would contribute favourably to the viability of such a project.

The apparatus associated with the raw materials contribute the highest cost to the plant. With natural gas, the cost of a reforming unit is an important part of total capital costs. In cases where coal-based technologies are used, costs increase due to handling and preparation, as well as cleaning of DRI to discard ashes (Astier[1]).

Capital costs for altering an older (brownfield) plant are minor relative to the cost of building a new plant (greenfield). Capacity creep also helps to reduce the capital costs of a new plant. (Griscom[7]).

Selling price

The future for merchant DRI shipments depends largely on the ferrous scrap market situation, in terms of availability, price and quality. In the past, the ample supply and low price of scrap has been a dampening factor on the growth of merchant DRI shipments. Therefore, in the past, it was seldom economically viable to give preference to DRI. The situation has, however, changed since the increasing scarcity of good quality scrap, which resulted in increasing scrap prices to levels between $120 and $140 after 1994.

Operating costs

- Cost of iron ore—in all cases it will be cheaper to produce metallics near the mine at FOB prices rather than in the importing countries at CIF prices; DR plants using fines-based technologies, have the added advantage of a lower cost input (natural fines or pellet feed) compared to the more expensive lump and pellets used by solid fuel-based processes
- Cost of coal; but the price variations world-wide are usually not very large
- Cost of natural gas, where variation from one place where gas is abundant, to the usual conditions of industrialized areas, is very large
- Briquetting adds an additional cost, but is essential in the passivation of the unstable DRI.

Cost-efficient options for the future

Favourable location—DRI/HBI producers planning to compete on the international merchant market would have to choose the location for their plants very strategicly. Proximity to cheap sources of gas or coal, as well as a ready supply of good quality iron units are a prerequisite. Furthermore, the potential market should not be too distant.

Fines-based feed—Technologies implementing low grade iron ore fines, rather than the traditionally used high grade lumpy and other higher grades, seems to be becoming increasingly popular. This is due to the cost-saving lower priced fines feedstock. Compared to the unsure nature of future iron ore lump and pellet supplies, abundant fines will be available.

Fines vs. pellets—Processes using iron ore fines rather than pellets or sized lump ore can save as much as $25 for 30 t of iron produced. High iron yield can be achieved by recycling fines and dust generated during the reduction process.

Fines and low-cost pulverised coal—The Fastmet process, which utilizes iron ore fines and pulverised coal in a rotary hearth furnace, could be developing into potentially the most economical method of producing DRI in North America (Lepinski and Griscom[10]). There seems to be an increasing interest in reserving natural gas for higher value-added products (i.e., petrochemicals) which makes the use of DRI processes using readily available non-coking coals even more attractive.

Direct hot charging—Hot charging of Fastmet iron directly into the melting vessel can lead to substantial savings in energy, electrodes and refractory costs. Capital costs for a Fastmet plant is minimized because all the high temperature processes are achieved in one single piece of equipment, the rotary hearth furnace, making the use of gas reformers, gas cleaning, and gas pumping unnecessary. Midrex estimates the capital cost of a 450 000t/y turnkey plant supplied to a US Gulf Coast location at around $65 to 75m (Griscom and Lyles[8]).

Top gas recycling—Although the original Hyl (batch) process did not recycle top gas, the newer HyL—(continuous) process does so to reduce energy consumption. The other gas-based processes, Midrex and FIOR, also recycle all or part of their available top gas (Ullah and Yepez[14]).

Conclusions

In the midst of increasing growth in global demand for steel, the manufacture of steel via the electric arc furnace (EAF) route is becoming more and more popular compared to other more traditional production methods due to reasons such as efficiency, size, simplicity, etc. This has led to the popularizing of the 'mini-mill'.

High quality, low-residual scrap, which had traditionally been used in EAFs to produce good quality steel is becoming increasingly scarce due to efficiencies at the steel factories and manufacturing plants which were 'producing' it, resulting in escalating prices. Consequently, EAF operators are increasingly forced to consider the use of DRI and other forms of 'scrap substitutes' to blend with lower quality scrap sources, which is relatively more abundant, and in that way to increase the iron units and decrease the residuals to produce a higher quality steel. DRI, which has traditionally been 'the more expensive alternative' is thus becoming increasingly viable.

The 'explosion' of new DRI projects all over the world shows the interest and the opportunity which have been shown by steel producers and iron ore suppliers alike. However, the economic viability of a DRI project depends, not just on the urgent need for good, low-residual iron units, but on strategic economic determinants. The most important strategic factor is the location of DRI plants, as this translates into all the other important inputs. The positioning should be made in such a way that advantage can be taken of the proximity of good quality, low cost iron ore, as well as natural gas (or coal). Additionally, the plant should not be too far from the market or point of off-set as the transport cost can easily absorb the competitive advantage or profit made by such a project.

Some of the newer developing technologies based on low-cost fines and/or cheaper non-coking coal gives an additional cost saving which could make such technologies ideal for the future. Other cost-saving strategies such as hot metal transfer and top-gas recycling also reduces costs significantly to give it a competitive edge.

DRI plant operators and steelmakers should make use of the current opportunity to benefit from increasing scrap prices, as well as the real demand for low-residual iron units. This unique scenario will not last forever, seeing that competition between different DRI technologies, each with its own competitive advantages, will set in place, driving down operating costs. This will lead to lower DRI prices and, consequently, eroding of the competitive margin.

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AusIMM President elected*

The Australasian Institute of Mining and Metallurgy, which represents the individual technical professionals working in the minerals industry, has elected Michael Lawrence as its 1999 President.

Mr Lawrence is Chairman and Chief Valuer of MINVAL Associates Pty Limited, a leading national mineral and coal consultancy founded in 1991, that specializes in technical audits/due diligence and resource asset valuations particularly for capital raising and merger/takeover documentation.

He is a geologist who has served on AusIMM's Council since 1991 and he has been a Vice President since 1994. There have been only 3 geologists and 4 consultants elected as President in the past 20 years of AusIMM's 105 year-long history. ◆

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