HIsmelt® - MEETING THE GLOBAL STEEL INDUSTRY CHALLENGE

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SYNOPSIS

The Global Steel Industry needs an alternative to conventional ironmaking technology that meets the challenge of increasing environmental and cost pressures. Commercial HIsmelt plants will provide an alternative ironmaking route that offers competitive solutions to meet the metallics requirement of the iron and steel industry.

Blast furnaces are inflexible and operate to a tightly defined burden specification that has a significant impact on production costs. Premium prices are paid for lump ores and agglomerated feeds to meet these specifications. The capital intensity of modern blast furnace based plants makes the addition of moderate levels of incremental capacity difficult to justify. Additionally, greenhouse gas, other emissions and waste disposal, are significant issues for blast furnaces with coke ovens and sinter plants.

EAF based mini-mill producers are entering the high quality value-added market, particularly the flat rolled products sector. This requires a supply of consistent high-quality low-residual iron units, ideally at a stable price. The price volatility, variable quality, and availability of raw materials are of constant concern to the EAF steelmaker.

The HIsmelt process has demonstrated its flexibility in using a wide range of ferrous feeds, including steelplant wastes and high phosphorus ore. Coals ranging from coke breeze to a 38% volatile steaming coal have been successfully trialled and their respective process performance parameters quantified. The HIsmelt process has simple and robust engineering and has demonstrated a high level of reliability.

The commercial operation of the HIsmelt technology will address the key issues that are currently confronting steelmakers, including, high capital and operating costs, environmental constraints including plant waste disposal, lack of production flexibility, and metallics supply. The process has been developed to produce high quality pig iron from fine iron ores and non-coking coals. It provides flexibility in operation and a premium grade product that has a high value in use (VIU) to both integrated and electric arc steelmakers.

KEY WORDS

Pig Iron, Blast Furnace, Integrated Steel Mill, Raw Materials, Flexibility, Capital Cost, Environmental, HIsmelt, Direct Smelting.

INTRODUCTION

The world steel industry is currently under considerable pressure. Prices have been at historical lows since the Asian crisis, whilst at the same time, environmental pressures are steadily increasing. Although it is possible to speculate on how these effects will play themselves out over the next few years, one thing is fairly certain: economic, environmental and cost pressures will only intensify. "Business as usual" is no longer an option and many steel producers will need to restructure and re-engineer their business to survive.

Application of a new technology is an option to address these growing pressures. Now, more than ever, the industry needs direct smelting as a means of relieving environmental concerns and lowering the cost base of steel production.

In the context of an integrated steel mill, direct smelting eliminates the need for coke. This allows de-commissioning (or non-replacement) of coke ovens and/or elimination of strategic concerns related to importation of coke. Sinter plants are also no longer needed, eliminating pollutants (including dioxins) and the need for costly corrective measures. In-plant reverts are eliminated as a waste issue, since these can generally be recycled to the direct smelting furnace. In some cases the blast furnaces themselves are sub-optimal (too small) and relines can be difficult to justify. Against this background, direct smelting is expected to deliver hot metal at a total cost less than that of a current blast furnace with largely written-down capital. In effect, direct smelting capital plus operating cost is expected to be less than blast furnace operating cost - not an easy challenge!

Greenfield construction of facilities to produce pig iron in an integrated plant is today almost non-existent. The reasons are obvious with many parts of the integrated industry not even capable of covering cash costs, having to build at very large scale to even be marginally economic, and having the environmental sword of greenhouse gases and pollution as a longer term threat.

The situation for EAF producers is different but no less competitive. Stable supply of high-quality virgin iron units is a major issue, especially for those with plans to penetrate further into flat products. Some years ago DRI was considered the way of the future, with 20-50% or so in the charge mix considered optimal. Now EAF operators tend to regard DRI in a less favourable light [1] and are more interested in 30-50% hot metal as a feed. This gives a significant boost in terms of EAF productivity and operating cost, hence hot metal in the charge mix has a high value-in-use.

A recent article by CP Manning and RJ Freuhan [2] reviews what has happened in the steel industry in the last few decades, where it is now, and what may be the future.

One of the processes highlighted for the future is direct smelting and the authors have encapsulated their ideals for this technology in a box titled Novel Process for Iron Production on page 56.

In summary they characterise the ideal process for iron unit production should include the following:

- Very high efficiency with respect to energy and materials usage.
- Great flexibility in feed materials.
- Reduced capital costs.
- Operation flexibility.
- Capability of producing steel or low carbon iron directly.

While the later would be a utopian outcome, it is a possibility that direct smelting may get there.

This paper discusses these ideals in the context of HIsmelt and elaborates in more detail on environmental aspects.

PROPOSED HISMELT KWINANA PLANT

To put this comparison of HIsmelt process and engineering technology into context for comparison with existing integrated pig iron production plants, the proposed HIsmelt Kwinana Plant is used as a base reference.

The simplified flowsheet for this plant is shown in Figure 1.

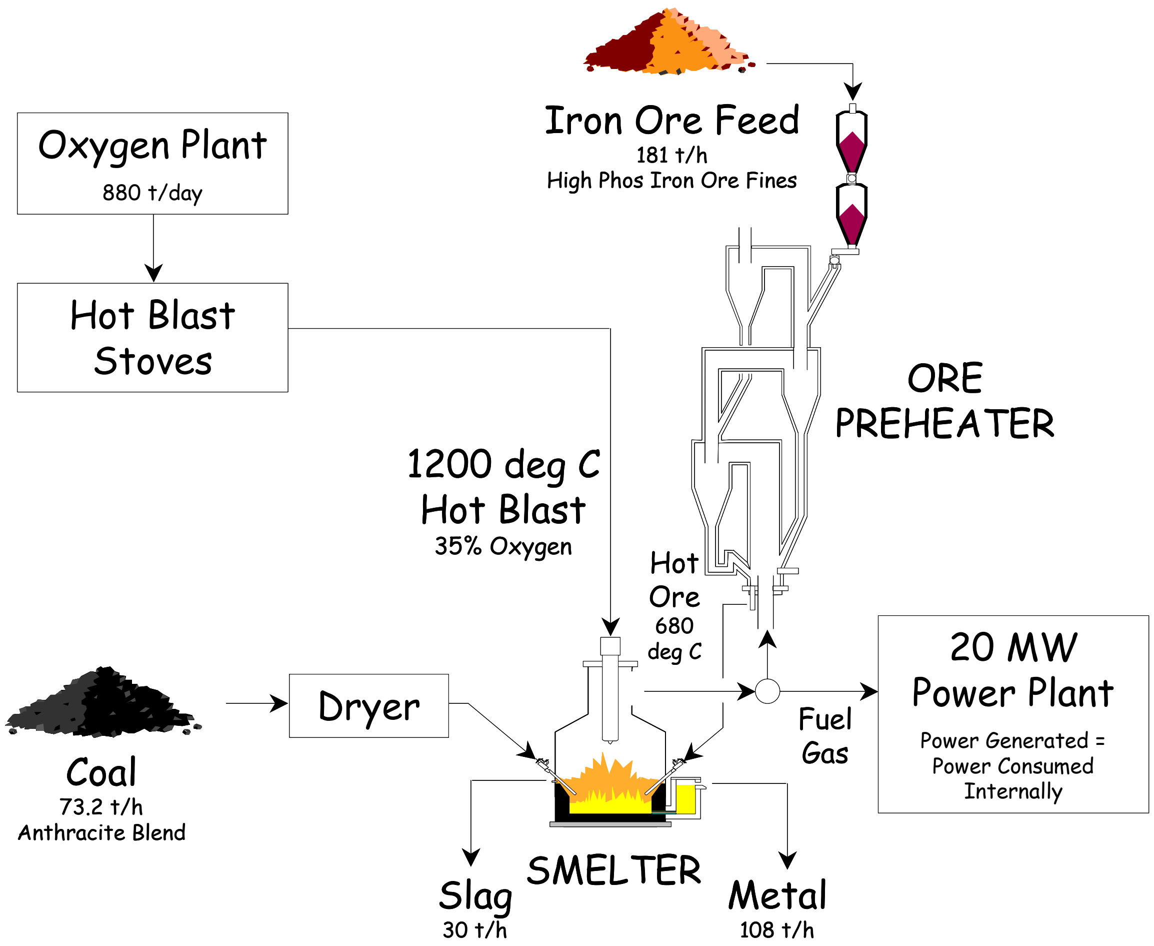

Figure 1 Flowsheet for Proposed HIsmelt Plant

The 820,000 tpa plant has been designed to meet commercial objectives of its owners, to have an energy balance that does not require the purchase or sale of energy of any significance, and to be the platform from which further scale up and development of the process and engineering can be made for plants of capacity greater them 1.5 million tonnes per annum.

VERY HIGH EFFICIENCY WITH RESPECT TO ENERGY AND MATERIALS USAGE AND FLEXIBILITY OF RAW MATERIALS

Materials usage and flexibility is best looked at relative to the specific inputs to the HIsmelt process and integrated pig iron production with a blast furnace.

Iron Bearing Materials:

Consumption in both integrated iron making plants or HIsmelt is directly related to the iron ore quality and the recovery of iron through the processing steps.

Iron ore falls into two types, those that have a sufficiently high iron content that can be used directly as lump or fines or those that have to be significantly treated by mineral dressing processes to remove gangue minerals and to reach a grade suitable for processing in a blast furnace. The latter, (that require significant mineral dressing) are usually made into pellets e.g. taconites in USA.

Fines from high grade ores may have some mineral dressing upgrade, such as screening and are usually used in sinter plants, although some are also fine ground and processed into pellets. There are also some lump ores that have to be crushed due to of their decrepitation characteristics and can be used either in sinter production or pellets.

There is also another category of iron ore, namely magnetite rather than hematite and because they have less oxygen content require less energy for reduction to iron. There are also many other types of iron ores such as limonites, goethite, titanomagnetites, those with high alkalis, those with undesirable contamination of irremovable gangue minerals such as copper, arsenic, zinc, phosphorus and sulphur that may or may not be useable in the integrated blast furnace route to pig iron.

It is therefore obvious that throughout the world there are many iron ore deposits that, whilst they contain millions of tonnes of iron units, they cannot be commercially exploited because the current technology of producing pig iron from a blast furnace precludes them from being used economically. In some specific cases such as Highveld Steel and Vanadium (South Africa), BHP (New Zealand Steel), Quebec Iron and Titanium, special processes have been developed that allow commercial exploitation. Economics for commercial exploitation are often however unique because of very cheap raw materials or the production of a high value by-product such as vanadium or high titania slag.

Use of the HIsmelt process is not a panacea that provides a solution in all these cases but it does open the window of opportunity to exploit many currently unusable iron ores.

Examples of these opportunities are the use of high phosphorus ores, as typified by high phosphorus West Australian ores that contain about 0.12% phosphorus. When these ores are processed in a HIsmelt plant, the pig iron product phosphorus is typically 0.03 – 0.04%, compared to a blast furnace, which would contain >0.2%. HIsmelt also runs with ores that are -6mm in size, which is the normal sinter plant feed, as well as process materials that are typical pellet feed materials that are 80% finer than 40 microns without any change in the iron yield in the process. By pretreatment in a fluid bed preheater, ores with high loss on ignition can also be treated. HIsmelt has also demonstrated the capability of processing typical steel plant waste products such as mill scale, blast furnace dust catcher dust, scrubber sludges from both blast furnace and basic oxygen steelmaking.

Hence it can be concluded that HIsmelt as a process is far more flexible than the integrated iron making industry when the choice of iron bearing feed materials is considered.

As far as iron yield is concerned, the actual smelter when compared to a blast furnace has a slightly lower yield as the iron oxide in the slag is typically about 4% compared to the blast furnace at 2% and both have approximately the same slag volumes per tonne of pig iron. The blast furnace iron losses in the dust catcher and scrubber sludge are comparable to those from HIsmelt but the real issue is how much of the iron can be recovered, or recycled back to a sinter plant. Obviously there are very large variations in overall iron recovery in different integrated plants depending on the quality of ore used. Against this however, has to be the offset of yield losses of iron units in mineral processing steps prior to making pellets and the yield loss of iron in the sinter plant which cannot be captured and recycled.

On balance, with the extra processing steps and associated handling, on a comparison basis the best of the integrated plants have an iron unit recovery to pig iron comparable to HIsmelt in spite of the different iron oxide content in the slag. HIsmelt as a single plant processor will have a superior iron unit recovery to most integrated plants currently operational, and can recycle its own uprising dust plus dust and millscale from steelmaking, casting and rolling processes.

Flux Additions:

Consumption in an integrated plant is generally slightly less than for a HIsmelt plant because a blast furnace is operated at a lower lime to silica ratio of about 1 whereas HIsmelt has normally been run at 1.2 to 1.3 during the research and development period. When the first commercial plant is fully tested it is probable that a lower flux consumption can be obtained and thereby reduce the slag make per tonne of pig iron.

Integrated plants using pellets do however have to melt the extra gangue from the binders used in pellets and similarly if flux is added to make good sinter. Because there is so much variation in individual integrated plant practices and in the various qualities of ores used, apart from the obvious difference of lime silica ratio in the slag, both processes produce approximately the same slag quantity for a similar ore input. Smaller and less efficient integrated plants are at a further disadvantage to the larger most efficient plants because the combination of ash from the coke and pulverised coal injection, which is normally siliceous, requires even more lime, to meet the required lime, silica ratio.

Reductant:

Integrated plants producing pig iron typically use coke as the primary reductant and have reduced consumption of coke by supplementing fuel additions of pulverised coal injection, fuel oil, natural gas and even injection of some plastics.

HIsmelt uses coal directly and while it has a preference for low volatile bituminous and anthracite type coals, it can use a wide range of different coals without problems. Details on how coal is utilised and the types tested can be found in a paper by A Campbell et al titled Coal and the Versatile HIsmelt Process [3].

In considering the role of the reductant and the flexibility and efficiency of its usage for this paper it is appropriate to extend the discussion to look more broadly at environmental impacts of HIsmelt when compared to the typical current integrated pig iron production. This is being done because another key characterisation not mentioned by Manning and Freuhan, is the move to become more environmentally friendly.

POTENTIAL ENVIRONMENTAL IMPACT OF HISMELT

The environmental impact of the widespread adoption of HIsmelt technology will be considerable. By reducing the demand for coke, sinter and pellets and improving the energy efficiency of the iron making process, it will significantly reduce emissions of greenhouse gases and other damaging environmental pollutants such as SO_x and dioxins.

Independent of economic decisions to install a HIsmelt plant as a cost effective option in developing countries, for those areas where environmental problems are most acute, HIsmelt offers a solution that allows steelmaking and downstream processing infrastructure to be sustained by replacement of existing iron making infrastructure.

GREENHOUSE GASES (CO_2)

The bulk of carbon dioxide emissions that are attributable to iron and steel production originate in the energy intensive iron making stage for an integrated plant (greater than 70%).

Integrated Case:

These gases arise from the induration of pellets (when installed) manufacture of coke in coke ovens and the subsequent combustion of coke oven gas, from the manufacture of sinter (where installed) and from the combustion of blast furnace offgas.

Globally the energy intensity required to produce pig iron is highly variable depending on the age and size of plants, the use of best available technology, and the quality of the raw material inputs.

HIsmelt Case:

Internal studies done by HIsmelt indicate that when compared to the most energy efficient, i.e. lowest energy intensity integrated plants, then HIsmelt (as proposed for Kwinana) is about equal. These plants are the most efficient in Japan, Europe, and South East Asia. At the other end of the spectrum the least efficient as found in China, Eastern Europe and CIS for example can be more than 50% less efficient than either. HIsmelt's opinion is that for the current global iron making industry that the HIsmelt technology will reduce CO_2 emissions by at least 20%. Base data for this claim comes from the European Commission Study dated March 2000 [4] and a range of internal studies where HIsmelt has had access to specific detailed integrated plant information.

We take as a estimated global average	2.35 t CO_2/t pig iron
Less: compared to planned Kwinana Plant	$\underline{1.88}$ t CO_2/t pig iron
Which yield a reduction in CO_2	0.47 t CO_2/t pig iron

Note that the 2.35 t CO_2 /t pig iron is less than the 2.6 t CO_2/t pig iron shown in Table (1) for 1995. The lower number accounts for changes in the last 5-6 years, such as closures of old plants and improvements.

HIsmelt technology will by further scale up to larger plants, benefit from the use of technologies still being developed such as Circofer™ (Lurgi) as a front end, and the usual continuous improvement anticipated with new technologies have the potential to get close to 1.3 t CO_2/t pig iron over the next two decades.

Current pig iron production, as reported by the IISI, was 576 million tonnes in 2000 and this translates to 1,350 million tonnes of CO_2 using 2.35 t CO_2/ t pig iron. Growth in pig iron production is assumed to continue at its current trend rate of about 1.3% per annum, and reach somewhere between 800 and 900 million tonnes by 2030. We assume that HIsmelt (and potential direct smelting competitors) will capture, by 2030, about 36% of this total market. To put this penetration into perspective between 1955 and 1975 the basic oxygen steelmaking process penetrated 50% of the global market. With further assumptions of direct smelting achieving an average of about 1.4 t CO_2/t pig iron and some improvement in the average integrated industry to about 2.1 t CO_2 / t pig iron, there will be a global annual reduction in CO_2 emissions of about 200 million tonnes.

Another recent publication that specifically looks at greenhouse gas emission from iron and steel production is the International Energy Agency Greenhouse Gas Reduction Programme in Report No. PH3/30 September 2000 [5].

In this report regional and world emission factors for t CO_2/t pig iron are given on page 108. Data for 1990 and 1995 are shown in Table 1.

Table 1 CO_2 Emission Factors t CO_2/t of Pig Iron

	1990	1995
EU & NAFTA	2.3	2.3
FSU & EET	3.0	2.8
China	3.4	3.4
REMCO	2.2	2.4
World	2.6	2.6

EU = European Union
FSU = Former Soviet Union
EET = East European Economies in Transition
REMCO = Remaining Countries
NAFTA = North American Free Trade Association

These emissions are derived numbers that are simply statistical calculations from dividing the sum of CO_2 emissions from the iron and steel industry in each region by the regional output of pig iron.

Another way of looking at this same issue is to look at specific energy consumption of a typical integrated plant and compare that with HIsmelt.

The specific primary energy consumption for an integrated route to produce pig iron which involves pelletising, sinter plants, coke ovens and a blast furnace, is given as 19-40GJ/t pig iron [5]. The wide variation reflects the relative mix of sinter, pellets, lump ore, energy saving measures adopted, size of equipment, yields, thermal efficiency, and electric power consumption.

On a specific energy consumption basis, the best of the blast furnace operations in Japan and Europe, are in the range of 19-20 GJ / t pig iron, and this is the same range as the proposed Kwinana plant.

HIsmelt would contend that these very efficient integrated plants are very large (3-4 millions tpa) and have fully optimised coke production, sinter production, use of lump ore, and the optimum use of coke oven and blast furnace gas. HIsmelt plants with further scale up from the proposed Kwinana plant and further optimisation that comes from process and engineering development will achieve by 2020 specific energy consumptions about 13GJ/ t pig iron, while the current integrated route as a mature technology, has a diminishing returns problem to fundamentally contend with.

It is interesting that when the best existing available technology for integrated pig iron production (this does not include examples where direct reduced iron, some scrap etc are used as blast furnace feed) is compared to future HIsmelt direct smelting, there is a >30% improvement in specific energy consumption.

Current best available technology	19 GJ / t pig iron
HIsmelt by 2020	13 GJ / t pig iron
Difference	6 GJ / t pig iron
Improvement 6/19 = 31.5%	

This tends to support HIsmelt's assertion that progressive replacement of existing integrated old plants and capture of new pig iron capacity installed over the next three decades, will lead to a significant decrease in annual global carbon dioxide emissions from the steel industry.

Hot Metal Feed To Arc Furnace Case:

Arc furnace steel production, which is steadily increasing its market share, (about 50% in USA) has traditionally been scrap based. Depending on the quality of its end use products it has used the following iron unit sources to meet the specifications of low residual grades.

- High quality auto bundles or equivalent scrap
- Direct reduced iron (DRI)
- Hot briquetted iron (HBI)
- Pig iron.

HIsmelt obviously can provide cold pig iron, the same as a blast furnace, but a great opportunity exists to use hot metal as a direct feed to the arc furnace, thereby reducing electrical consumption by capturing the thermal and chemical energy in the pig iron. There is also a reduction in electrode consumption and simultaneous increase in productivity by the reduction in tap to tap time. Molten pig iron will contain about 3GJ / t pig iron (chemical and thermal energy). DRI and HBI actually increase power consumption because they contain gangue which has to be melted and slagged off.

Several plants already use this technique with success and the important point to note is that where steel plants need to use high quality iron units to meet residual specifications, molten pig iron is by far the best feed material compared to DRI or HBI in order to reduce carbon dioxide emission. Plants with similar capacity to the proposed Kwinana plant are a perfect fit for this type of application.

SULPHUR DIOXIDE (SO_2)

The proposed plant for Kwinana is to be situated on in an industrial strip of land that is governed by an environmental protection policy that has fairly strict controls on emissions of SO_2 into the air shed. For this reason a decision was made at the start of the detailed feasibility cost study to install flue gas desulphurisation of all the combusted gas.

For the proposed plant at Kwinana there is an additional synergy where fine calcined limestone is readily available, locally and after conversion to gypsum in the desulphurisation process it can be recycled back into the cement industry.

The flue gas desulphurisation is designed to emit less than 200g/t pig iron of SO_2.

This is significantly lower than the levels reported from the European Commission Study [4] where the average European SO_2 emissions are about 1700g/t pig iron. There is a very large variation among different plants depending on the production facilities (eg sinter plants or no sinter plant, flue gas desulphurisation installed or not).

A useful cross check that this is a reasonable number to use can be obtained from Metal Bulletin's report on the 14th January 2002 [6] where they reported that Sidmar was delaying the planned Sidcomet plant because of environmental issues that had to be addressed, such as 7000t of SO_2 emissions in 2000. If the calculation is made based on their output of 4.1 million tonnes per year of pig iron then the 1700 g/t pig iron number is confirmed.

While it is recognised that by the installation of best available technology on coke ovens and sinter plants, that the 1700 g/t pig iron can be reduced significantly the real issue is why spend further capital to meet lower emissions rather than invest capital into best available technology to produce pig iron.

NITROGEN OXIDES (NO_X)

Nitrogen oxide emissions have various sensitivities in different parts of the world because of their impact on photochemical smog and ozone. The average emissions from European integrated plants is 1000g/t pig iron and the proposed HIsmelt plant will have emissions of 600 g/t pig iron which is a 40% reduction.

HIsmelt has significant combustion sites at the hot blast stoves, the waste heat recovery boiler and the smelting reaction vessel. For an integrated site the same three significant sites of hot blast stoves, waste heat recovery combustion of blast furnace gas and the combustion in the blast furnace are similar, however additional significant combustion sites also exist at sinter plants, coke ovens and pellet plants.

DIOXINS AND FURANS

Dioxins and furans are members of a group of chemicals known as persistent organic pollutants (POPs).

The hazards from POP's are due to their ability to bio-accumulate in the food chain with the consequence that the higher in the food chain one goes, the higher is the concentration.

Their impact on humans can be significant health risks. In the integrated production of pig iron the sinter plant has been identified at many sites in Europe as a major source of POP's [4].

The term Dioxin is used to denote the family of compounds known chemically as polychlorinated dibenzo-dioxins (PCDD) and Furans to a family of compounds know chemically as polychlorinated dibenzo-furans (PCDF). Collectively there are 210 compounds within these two families and compounds with chlorine present at the 2,3,7,8 positions within the molecule have the greatest potential toxicity.

Other compounds in these families have an internationally agreed scale of toxicity relative to 2,3,7,8 dibenzo-dioxin and combinations are usually reported as a toxic equivalent (I-TEQ).

There are two mechanisms, which are not mutually exclusive, called De-novo synthesis and the Precursor route under which PCDD and PCDF can be formed.

For either of the mechanisms there must be available:

- Solid particles containing carbon.
- Organic or inorganic chlorine.
- Metallic ions – usually iron, copper, zinc or manganese.
- An oxidising atmosphere.
- A temperature window of 250 – 450°C.

To ensure that it is impossible to form any PCDD or PCDF compounds in a HIsmelt plant, the waste gas system after cooling in a radiation cooler to 1000°C, then quenches the gas in a wet venturi scrubber.

This process will remove chlorine from the gas and prevent condensation of metals on the surface of any carbon. It also removes into the scrubber water the vast majority of entrained solids.

The gas prior to quench in the venturi scrubber is also reducing due to the presence of carbon monoxide and hydrogen, so is not an oxidising atmosphere and cannot form PCDD or PCDF compounds.

After cleaning, the gas is then combusted in a waste heat recovery stage where the carbon monoxide and hydrogen are converted to carbon dioxide and water. At this step it is not possible to form PCCD or PCDF as the chlorine has been removed along with virtually all the metallic ions and carbon to the scrubber sludge.

RECYCLE OF STEEL PLANT WASTES

In the integrated pig iron process route, some steel plant wastes such as millscale are recycled back to the sinter plant, but this recycle in turn creates a problem with the formation of PCDD's and PCDF's as the conditions to form these compounds are present.

Other materials not suitable for use in the Blast Furnace such as coke fines are recycled to the sinter plant where it is gainfully used as a fuel, but again, is a potential carbon source for the formation of PCDD's and PCDF's.

Similarly dust from the blast furnace dust catcher can be recycled to the sinter plant, but this also contains carbon and iron.

The more difficult materials to dispose of, in spite of containing valuable iron units, are wastes arising from the blast furnace scrubber and oxygen steelmaking furnaces where contaminants make them difficult to reprocess. Contaminates that make reprocessing undesirable in a blast furnace are the alkalis such as sodium and potassium, halides such as chlorine and metal oxides such as zinc, lead, cadmium and tin.

HIsmelt as part of its research and development processed over 1000 tons of a typical steel plant mix of wastes without having to agglomerate any of the fine materials from the scrubber sludges, with high iron recoveries.

The metal oxides concentrate into the offgas of the HIsmelt process and into the sludge. By recycling this sludge to the HIsmelt vessel, concentrations suitable for further processing in an Imperial Smelting Furnace (ISF) can be achieved or alternatively by using the Primus™ technology developed by Paul Wurth, such metal oxides can be recovered directly.

ENVIRONMENTAL SUMMARY

The HIsmelt process offers significant environmental advantages compared to existing integrated technology which will push its proliferation.

Table 2 summarises the information above and also includes some other second order environmental data that clearly demonstrate HIsmelt's advantage.

Table 2

Summary of Environmental Advantages

Item	Unit	European or Global Emission	HIsmelt
Greenhouse Gas CO_2	t CO_2/t pig iron	2.35	1.88 (1.3 future)
Sulphur Dioxide SO_2	g SO_2/t pig iron	1700	<200
Nitrous Oxides NO_x	g NO_X/t pig iron	1000	600
Dioxins, Furans	ng ITEQ/t pig iron	3-5	Nil
Volatile Organic Compounds (VOC)	g /t pig iron	110	Nil
Polyarometic Hydrocarbons (PAA)	µg/t pig iron	550	Nil
Carbon Monoxide CO	g/t coke	5000	Nil
Benzene	g/t coke	25	Nil
Water	m^3/t pig iron	5.8 (*)	<4.0
Dust in Stack Emissions	g/t pig iron	280	20

* This is for water quench of coke. Dry coke quench reduces the amount.

REDUCED CAPITAL COSTS

A detailed capital cost comparison of the blast furnace and HIsmelt route was done for several USA sites in a paper by Bates and Muir [7] where scope of work for each study had the same battery limits defined. Since this work was done two more very detailed cost studies have been done for an Australian site at Kwinana and another site in USA. These are shown in the following table 3 as HIsmelt 5 and HIsmelt 6 respectively.

Table 3: Capital Cost Assumptions for Generic HIsmelt and Blast Furnace

	Production (Mtpa)	**Capital Cost ($US/ta)**	**Capital Cost ($USM)**
Blast Furnace 1	1.09	326	355
Blast Furnace 2	2.36	373	880
Blast Furnace 3	1.09	356	388
Blast Furnace 4	2.43	448	1088
HIsmelt 1	0.50	310	155
HIsmelt 2	0.58	259	150
HIsmelt 3	0.63	286	180
HIsmelt 4	1.50	191	286
HIsmelt 5	0.82	215	177
HIsmelt 6	1.10	181	200

When these numbers are studied it is clear that there is a reasonably wide distribution for the blast furnace route depending on the inclusion of sinter plants, coke oven capacity, flue gas desulphurisation, size of waste heat recovery plant and for all cases the supply of oxygen is assumed to be across the fence. HIsmelt plants 3,4,and 5 assume flue gas desulphurisation. HIsmelt plants fall in the range of 180 – 280 USD per annual tonne and the integrated plants 320 – 450 USD per annual tonne.

With the more detailed engineering that has now been done for a HIsmelt plant it is believed that in most cases for capacity in the range of 800,000 upwards HIsmelt will be about 150 – 200 USD/tonne cheaper than an integrated.

The significant difference is due to HIsmelt not requiring coke ovens, or sinter plants, raw material handling is about the same, pulverised coal injection is comparable to HIsmelt raw material injection and both use hot blast stoves. HIsmelt is slightly more expensive in the waste gas handling due to the high offgas temperatures leaving the furnace, with the associated cooling system and flue gas desulphurisation.

OPERATIONAL FLEXIBILITY

The modern integrated plant to produce pig iron is a very finely tuned supply chain to keep the feed raw materials going into a blast furnace with the minimum chemical and physical variations because of the implications on blast furnace performance.

Considerable efforts are made in the selection of the correct blends of coals into the coke ovens to ensure that coke quality is consistent because even small variations in physical properties can have a significant impact on the porosity of the burden, in a blast furnace. Similarly when sinter is made, each plant uses a particular blend of iron ore fines that again are aimed at giving consistent physical and chemical properties, and can include fluxes. Pellets are also manufactured in a range of qualities, where they may contain fluxes for the slag make that also function as a binder, or they may be just high grade ore with the minimum amount of binder.

Each integrated iron making plant working back from the blast furnace endeavours to optimise its charge burden materials and mix of coke, sinter, pellets, lump ore and flux to maximise productivity at a minimum cost. This is an ongoing process as raw material prices, specifications and availabilities change over time.

Steelmaking technology changes can also have an impact and there is an interesting example here in Japan [8] where NKK have developed a slag free tapping practice that allows them to use cheaper higher phosphorus ores because they dephosphorise the pig iron.

Blast furnaces also are not capable of much turn down (able to run at lower than optimum design capacity) because of rapidly increasing coke consumption, that increases operating costs.

Inherently the response time of a blast furnace to what is fed in at the top, to product as pig iron takes several hours and the pig iron product needs very close monitoring for its chemistry, along with many other variable controls, such as temperatures, to detect trends and then take appropriate action to keep steady state operations. Extensive computer models based around silicon levels in the pig iron and temperature measurements are needed as essential tools on large modern facilities. It is this slow response, inherently poor turndown capability that makes blast furnaces inherently inflexible. This precludes them from being able to quickly react to delays or problems in the steel plant when they have to plate or pig the iron, and also being able to respond to downturns in a market that may be of relatively short (several months) duration without having to be banked and effectively shutdown.

Conversely HIsmelt has reactions that take place in fractions of a second and can be instantaneously stopped, simply by turning off the hot air blast. Restarting after delays is simply a case of injecting some coal and reheating the bath to operating temperature and then start smelting.

With changes in the market demand tonnage output can be flexed by, for example, reducing the oxygen content of the hot air blast, or by using a cheaper higher volatile coal, or a cheap coal with higher ash content. None of these changes are without some cost implications but they are in many cases partially self compensating, so cash costs of operation do not significantly change.

Changes in raw materials specifications do have some impact on HIsmelt economic performance but these can very easily be costed and suitable adjustments made in purchase prices. This is similar to existing contracts for coal and iron ore where prices change relative to ash content in coals, phosphorus and gangue content in iron ores, as examples. HIsmelt has also the large inherent advantage that it can take as a feed material iron ore that is –6mm, that already sells at a discount to premium lump, and fine coal –6mm. It can also process fine ground concentrates without the added costs of pelletising and use a wide range of coals that are currently not suitable for the blast furnace.

CAPABILITY OF PRODUCING STEEL OR LOW CARBON IRON DIRECTLY

As a utopian vision for the future it is desirable to set lofty objectives and progress in technology has only been made when this has been the case. Specifically in the Iron and Steel Industry it has been those with the belief in continuous casting that has seen the development of first billet casters, then slab casters, thin slab casters and today the potential commercialisation of strip casters and this has all happened in the last forty years since Rossi started work at Barrow in the UK.

Issues that have to be resolved in direct smelting processes to reach this vision are, for example:

- Operation at higher metal temperatures.
- Consequence of high iron oxide slags.
- Removal of phosphorus and sulphur.
- Process controls.

The facts from the R&D phase of HIsmelt's development are that it has been possible to operate under controlled conditions at carbon levels of less than 3%. By changing from the normal operation that runs with high phosphorus removal to the slag, to a more highly reducing condition and higher temperatures it is possible to move, very rapidly, sulphur from the metal to the slag. Accidentally during some test periods the bath has also been decarburised and a semi steel has been made but not as yet in a controllable manner.

HIsmelt, because it is tapping pig iron continuously through a forehearth, and then desulphurising the already low phosphorus pig iron, only needs to decarburise to produce a semi steel. While nobody has yet developed commercially in a launder a continuous decarburisation step it is not impossible to contemplate with future technological development in refractories, control and measurement systems that this may be possible.

What has already been commercialised is the Consteel Process [9]. By continuous charging of hot metal and preheated scrap into a EAF the objective is almost realised, and further development may lead to virtually continuous steelmaking.

CONCLUSION

When considering the topic of this paper about Meeting the Global Steel Industry Challenge and considering this challenge as depicted by Manning and Freuhen [2] it can be concluded, that direct smelting using the HIsmelt process and engineering technology satisfies most of the criteria. It is the author's opinion that a further criteria of "environmental friendliness", some of which is captured by the concepts of energy efficiency and flexibility in feed materials, needs to be included and again HIsmelt satisfies this criteria.

The final vision of a future of steel production directly is not yet completely answered, but the goal is significantly closer and may be achievable with development of the HIsmelt process.

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