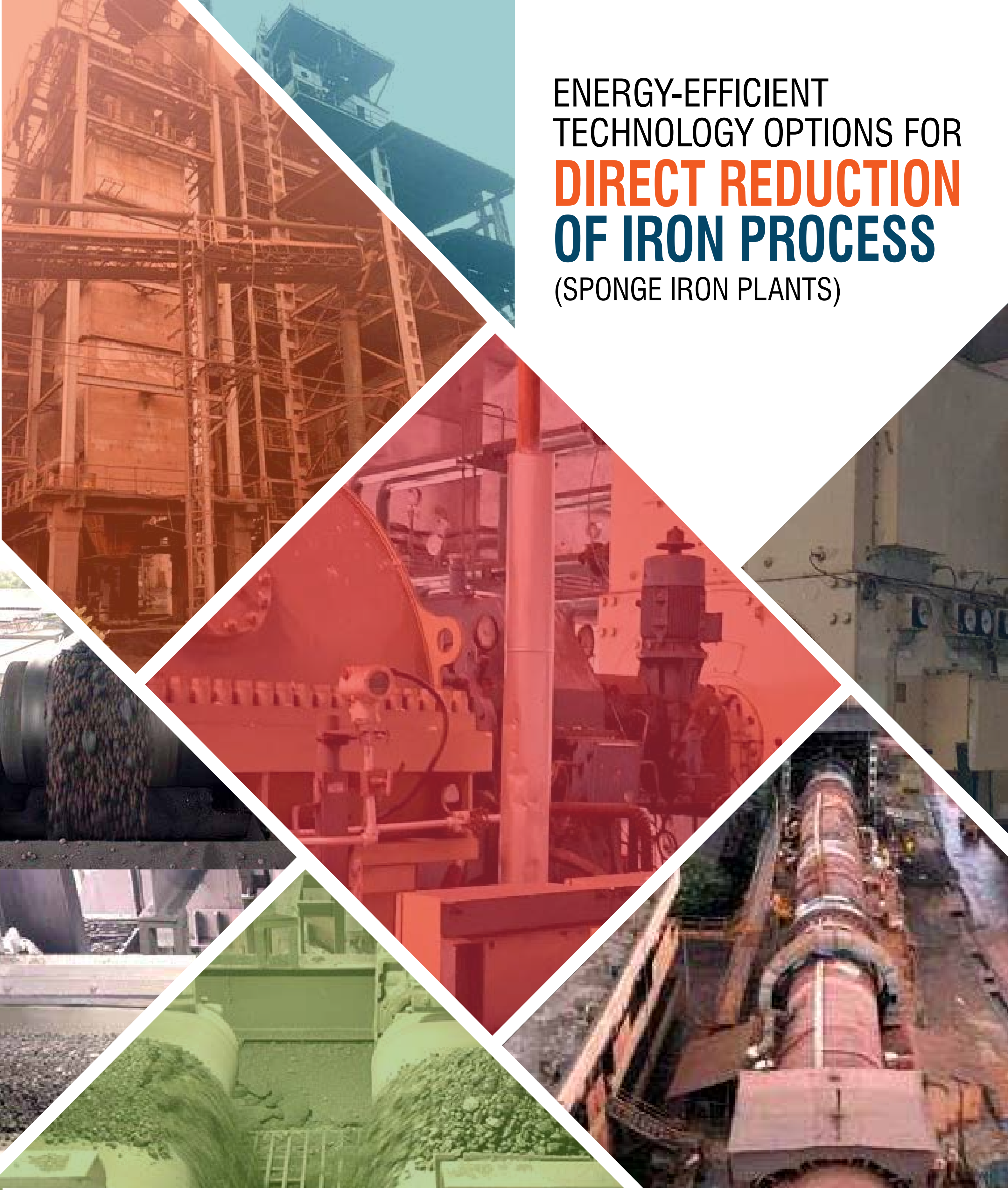
ENERGY-EFFICIENT TECHNOLOGY OPTIONS FOR DIRECT REDUCTION OF IRON PROCESS

(SPONGE IRON PLANTS)



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SIMA

Sponge Iron Manufacturers Association

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FOREWORD

TERI's analysis over the past few years brings to fore the central role of the industry sector in India's long-term low-carbon strategy. In 2019–20, we undertook an in-depth study of the Indian steel sector and brought out a comprehensive report— Towards a Low-carbon Steel Sector: Overview of the Changing Market, Technology and Policy Context for Indian Steel. The report outlines various options to reduce the emissions from a rapidly growing steel sector. The report highlights that hydrogen-based steel production is likely to play a major role in the medium to long term. However, it also emphasizes that there is a lot that can be done in near term to reduce the energy consumption from the steel sector. This holds true not just for integrated steel plants but also in the highly disaggregated sponge iron sector, which is dominated by small-sized coal-based direct reduction of iron (DRI)-based plants.

India is one of the unique countries in the world where coal-based DRI route contributes to nearly 20% of the total steel capacity in the country. The prominence of DRI route in the country is primarily attributed to easier availability of non-coking coal, relatively lower investment costs, and limited access to natural gas, which is the preferred option in many developed countries. As a result, there are close to 300 low-capacity DRI plants (100 tonnes per day or less) that use non-coking coal as a primary fuel and have low levels of energy efficiency. It is in this context that, TERI has now developed a compendium focusing only on the DRI sector. This technology compendium can act as a ready reckoner and provides techno-economic details of appropriate energy-efficient technologies that can be adopted by the coal-based DRI industries in the short term. The adoption of these technological options can help the DRI units improve their energy and environmental performance.

The compendium also gives a brief account of the potential and futuristic technologies such as coal gasification and hydrogen-based processes, which are either fully commercial or under the development stage globally. Compilation of information on these technologies will help key stakeholders make informed decisions in terms of the routes that they need to follow as they expand their plant capacities to meet the rising steel demand.

I hope that this compendium will help in enhancing the knowledge base of the industry as it charts new pathways for a low-carbon future.

Dr Vibha Dhawan
Director General, TERI

PREFACE

India is the largest producer of direct reduction of iron (DRI), popularly known as sponge iron and accounted for about 39.3% of the global production in 2020. India's growing economy will require an increase in steel production to meet the demands of sectors such as housing and infrastructure, automobile, engineering, etc. This demand cannot be met entirely through conventional Blast Furnace-Basic Oxygen Furnace (BF-BOF) route, given high investment costs and limited availability of coking coal for this route. The DRI industry has, therefore, a critical role to play in augmenting India's future steel production to meet its growing demand.

Like its global compatriots, the steel industry in India is facing the challenges of reducing carbon emissions and improving energy as well as resource efficiency. Both coal- and gas-based DRI plants are operational in India. However, the share of coal-based DRI production is quite substantial and in comparison to gas-based production, this route is energy- and carbon-intensive. To meet the DRI production target of 80 million tonne by 2030–31 as envisaged under the National Steel Policy (2017), whilst improving the industry's energy and environmental impact, adopting energy-efficient and innovative low-carbon technologies will be essential.

The Sponge Iron Manufacturers Association (SIMA) acts as an apex body to promote and protect the growing needs of the industry and plays a vital role in bringing together the DRI industry, the Government of India (GOI), and other regulatory bodies. SIMA has contributed towards the comprehensive survey of the Indian Sponge Iron Industry in 2019–20, which was undertaken by the Joint Plant Committee set up under the aegis of the Ministry of Steel (GOI). The Association provides a platform for knowledge sharing and exchange, giving details on technological developments and innovations in manufacturing, energy, environment, and other related issues to the industry.

This technology compendium prepared jointly by TERI and SIMA will be an important source of information on the techno-economic aspects of suitable energy-efficient technologies that can be adopted by DRI units. SIMA members–major sponge iron producers and regional associations–will gain from the detailed information provided in this compendium. Information on new technologies such as coal gasification and hydrogen-based processes will also provide an insight into global technology developments and prospects and growth possibilities for the industry in India.

The compendium brings together valuable information in an accessible format. I am sure that the stakeholders in the DRI sector will benefit immensely from this publication.

Deependra Kashiva,
Executive Director
Sponge Iron Manufacturers Association (SIMA)

ACKNOWLEDGEMENTS

We would like to extend our sincere thanks to the Sponge Iron Manufacturers Association (SIMA) for encouraging us to bring out this joint publication. Special thanks to Mr Deependra Kashiva, Executive Director, SIMA for contributing to the preparation and review of the report. We are also extremely grateful to Popuri Engineering, especially Mr N Krishna (Director, Technical) and Mr G V Subramanyam (Technical Advisor) for providing useful guidance in shaping the document with relevant energy-efficient-technologies options for the coal-based DRI sector. We would like to extend our sincere thanks to Mr A Kesava Babu, sectoral expert for reviewing and helping us in finalizing the document. We also acknowledge the contribution of our colleagues—Mr Will Hall and Ms Sneha Kashyap—who provided useful information and participated in many internal discussions with regard to this compendium.

We sincerely acknowledge Mr Rakesh Kothari, Director, Kamachi Industries for allowing us to visit their coal-based DRI plant located at Gummidipoondi, Tamil Nadu. We also express our profound gratitude to Mr N Umashankar, General Manager, Operations and Mr G Chandrasekhar, Assistant General Manager, E&I for sharing useful process details and operating parameters along with their experiences in energy-efficiency improvements of their plant. These insights proved invaluable in developing the contents of this document.

The Energy and Resources Institute (TERI) also acknowledges the support provided by Shakti Sustainable Energy Foundation (SSEF). Their support was vital in kick-starting the conversation on a low carbon transition for the Indian iron and steel sector.

ABBREVIATIONS

ABC	After-burning Chamber
AHU	Air-handling Unit
ANN	Artificial Neural Network
APFC	Automatic Power Factor Controller
ATM	Atmosphere (Unit for Pressure Measurement)
BEP	Best Efficiency Point
BF	Blast Furnace
BOF	Basic Oxygen Furnace
CDRI	Cold Direct Reduced Iron
CLO	Calibrated Lump Ore
CO	Carbon Monoxide
COP	Coefficient of Performance
DRC	Davy Reduction Corporation
DRI	Direct Reduction of Iron
EAF	Electric Arc Furnace
EIF	Electric Induction Furnace
ESP	Electrostatic Precipitator
FeO	Ferrous Oxide
Fe_2O_3	Hematite
Fe_3C	Iron Carbide
FRP	Fibre-reinforced Plastic
Gcal	Gigacalorie
H_2	Hydrogen
HBI	Hot-briquetted Iron
HDRI	Hot Direct-reduced Iron
HP	Horsepower

HVAC	Heating, Ventilation, and Air Conditioning
ID	Induced Draft
KPI	Key Performance Indicator
LoI	Loss on Ignition
Mt	Million Tonne
Mtpa	Million Tonne Per Annum
NG	Natural Gas
ODP	Ozone Depletion Potential
OSIL	Orissa Sponge Iron Limited
PAT	Perform, Achieve and Trade
PCC	Post-combustion Chamber
PID	Proportional Integral Derivative
PLC	Programmable Logic Control
RPM	Rotations Per Minute
SEC	Specific Energy Consumption
SIIL	Sponge Iron India Limited
TOE	Tonne of Oil Equivalent
TDR	Tisco Direct Reduction
tpd	Tonne Per Day
tph	Tonne Per Hour
tpy	Tonne Per Year
TR	Tonne of Refrigeration
VAM	Vapour Absorption Machine
VFD	Variable Frequency Drive
WHR	Waste Heat Recovery
WSA	World Steel Association

EXECUTIVE SUMMARY

Direct reduction of iron (DRI) forms an important sub-sector of the Indian steel sector, accounting for about 33% of the total steel production, which is about 34.15 million tonne of steel produced in 2020-21. The substantial growth of DRI sector in India can be mainly attributed to the easy availability of non-coking coal and limited access to natural gas. This has led to the establishment of around 300 low-capacity DRI plants using non-coking coal available in the country with an average capacity utilization of 60%. The coal-based DRI kilns in India suffer from low-energy efficiency (about 37%) due to high-energy losses through off-gases (41%). However, a large number of DRI plants with installed capacity of 200 tonne per day (tpd) or more have mostly installed waste heat recovery (WHR)-based power generation systems. This has not only helped in meeting the internal electricity needs but also led to additional energy credit of about 40%, thereby lowering the overall specific energy consumption in DRI production. Further, the excess power generation from WHR system, which is about 60%, helps in generating additional revenues for the plants.

One of the key performance indicators of coal-based DRI plants is the specific energy consumption (SEC) in DRI production, which is observed to be in the range of 4.10–5.26 gigacalorie (Gcal) per tonne DRI. An analysis of input thermal energy utilization clearly indicates that there is significant scope for energy-efficiency improvements by employing feasible WHR system. The WHR-based power generation, the most attractive among all, is economically viable for plants with capacity of 200 tpd and above. Smaller capacity plants of 100 tpd or less can adopt other WHR options such as iron ore preheating and coal drying for improving their energy performance. Adoption of plant-specific energy-efficiency options, for instance switch over to iron ore pellets, artificial neural network for accretion control, decentralized variable frequency drive (VFD) for shell air fans, would help in reducing the SEC level by as high as 2.3 Gcal/t-DRI.

This technology compendium provides techno-economic details for a range of energy-efficient technologies for rotary kiln-based DRI industries. It will enable DRI industries to select and implement the technologies based on their prioritization. The compendium also discusses the potential of futuristic technologies such as coal gasification and hydrogen-based processes, which are either already commercialized or under development to enable their adoption in the future.

INTRODUCTION

Steel is the most important component for infrastructure development of a country. It facilitates growth of the building sector that drives urbanization, in addition to supplementing machinery and tools, which are inseparable from industrialization. The contribution of steel sector to a country's GDP is well known. It has been observed that no country has achieved high levels of per capita income without substantially raising its per capita steel consumption. India's steel consumption per capita is still very low and during 2019 it was 74 kg, much less than the world average of 224.5 kg (MoS, 2020). This is a clear indication of the large growth in steel consumption required to raise Indian GDP per capita and improve the welfare of its citizens.

With demand for steel expected to grow rapidly in the years to come, various options for modernizing existing capacity and building new capacity require thoughtful consideration. While considering both these options, it is imperative to prioritize the competitiveness of these facilities, not only for today but also in the long term. To achieve this, it is important to ensure that green field steel plants are 'future-proofed' to address tomorrow's challenges as the campaign life in iron and steel sector are exceptionally long.

One of the biggest challenges—over the long term—is to bring down carbon dioxide emissions from the Indian iron and steel sector. Through deploying advanced energy-efficiency measures in the existing steel capacity, carbon dioxide emissions can be significantly reduced. This is especially true in the context of coal-based direct reduction iron-manufacturing plants (sponge iron plants), which provide a significant scope for energy-efficiency improvements. Most coal-based direct reduction plants are relatively smaller in capacities when compared to the larger integrated steel plants.

Whilst energy-efficiency measures are of vital importance in the near term to help reduce costs and the environmental impact of the sector, over the medium to long term, the sector will need to adopt new low-carbon technologies. This will require a shift from using solid coal in rotary kilns, which is dominant today, towards gas-based technologies, which can substantially reduce the environmental impact. In the near term, based on economic considerations, this could include using syngas, produced via coal gasification, or natural gas. The use of both these gases in steel manufacturing is well established in domestic and international markets.

A shift to gas-based technologies can not only reduce environmental impact in the immediate term, but also provide an easier transition towards using hydrogen in the medium to long term, as the costs of green hydrogen is expected to fall in the future. This will ensure that the sponge iron-manufacturing sector remains competitive and continues to be a vital part of the Indian steel sector, even with increased focus on environmental impact and emission reduction measures in the future.

This compendium aims to provide viable options for improving energy efficiency in existing coal-based DRI plants. It also gives an overview of futuristic technologies that highlight the viable options for adoption by DRI industries to decarbonize their operations.

1 BACKGROUND OF IRON AND STEEL INDUSTRY

1.1 Overview of Iron and Steel Industry

Steel is the product of a large and technologically complex industry with strong forward and backward linkages of material flow. India's steel industry has reached sufficient levels of maturity regarding technology absorption, product development, and productivity gains. In terms of both production and consumption, India stands second in the world (WSA, 2020). Indian steel industry exists in different sizes—large, medium, and small—with varying degree of vertical and horizontal integration. It is quite heterogeneous and consists of state-of-the-art plants with wide and varied product basket. Steel manufacturing in the country utilizes different routes such as blast furnace–basic oxygen furnace (BF–BOF), coal-based direct reduction (DR), gas-based DR, electric induction furnace (EIF), and electric arc furnace (EAF).

Coal-based DR is unique in the Indian steel sector as it caters mainly to localized steel demands. The uniqueness of DRI technology is driven by the availability of domestic coal reserves, and lack of sufficient domestic natural gas supplies and coking coal in the country. As with any industrializing economy, the steel sector is of vital importance to India's economy. It contributes around 2% to the country's GDP and employs around 2.5 million people in the steel and related sectors (MoS, 2019).

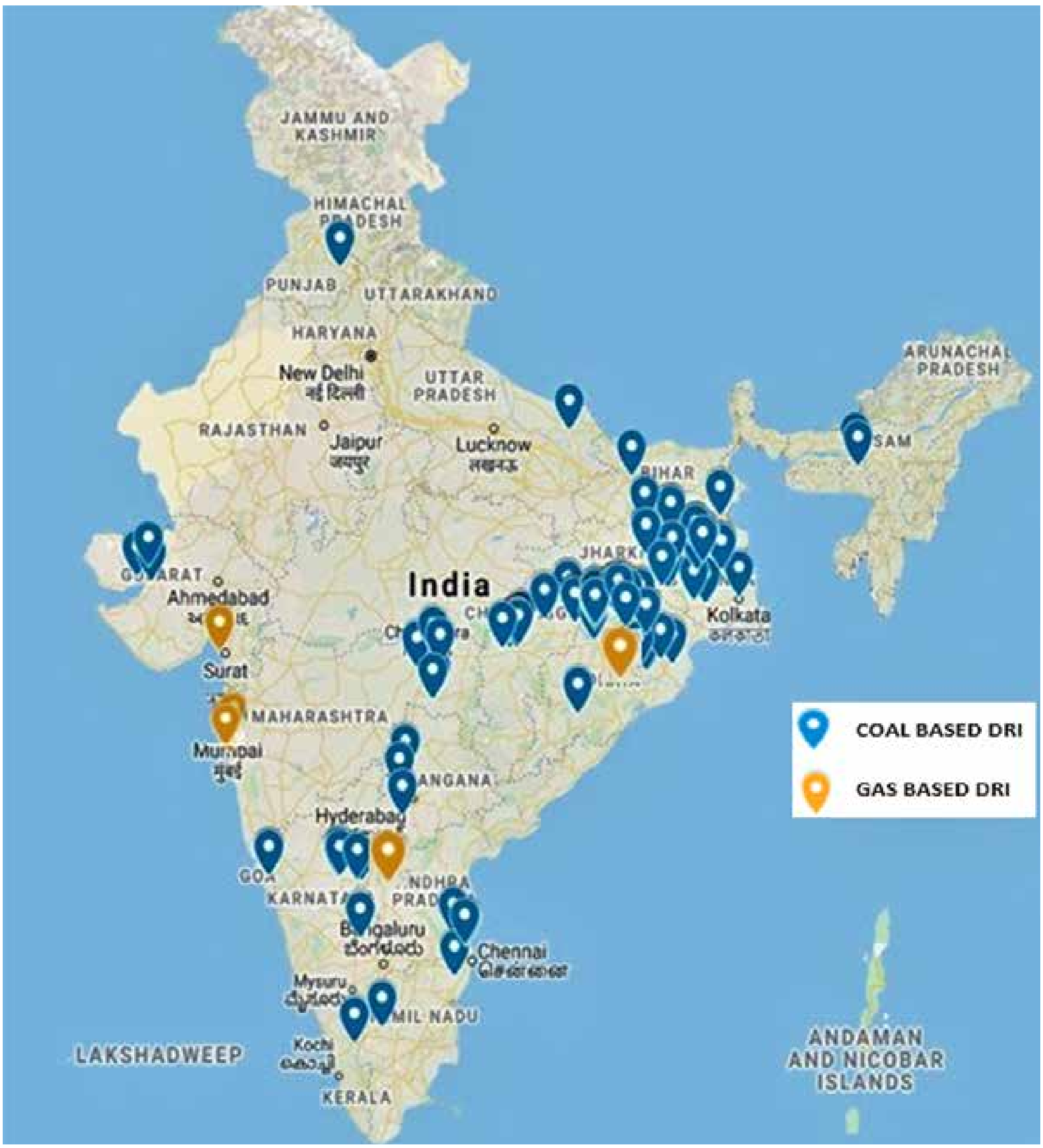
1.2 Details of Direct Reduction of Iron Plants

India's total annual direct reduction of iron (DRI) capacity was 47.85 million tonne (Mt) in 2020-21, with a production of 34.15 Mt. There are 285 DRI plants in India, majority of which use coal-based rotary kilns. The installed capacity of DRI plants varies in the range of 50–500 tonne per day (tpd) with single or multiple kilns. Most of the DRI plants utilize 100 tpd kilns. The total installed capacity of coal-based DRI plants is 36.74 Mt while that of gas-based DRI plants is 11.10 Mt, with two plants using gasification route (Syngas and COREX gas) and three plants using natural gas route supplemented by COREX/coke oven gas.

Large capacity DRI plants	
Plant	**Capacity (Mtpa)**
Coal-based DRI plants	
Adhunik Metaliks Limited	0.324
Godawari Power and Steel Limited	0.495
Jindal Steel & Power Limited (JSPL), Raigarh	1.370
Lloyds Metals and Energy Limited	0.270
Prakash Industries Limited, Champa	1.000
Rungta Mines	1.390
Sarda Energy and Metals Limited	0.360
Shyam Metallics and Energy Limited, Sambalpur	0.800
Shyam Sel and Power Limited, Jamuria	0.425
Shri Bajrang Power and Ispat Limited	0.360
SMC Power Generation Limited	1.000
Super Smelters Limited–III, Burdwan	0.740
Tata Steel Long Products Limited	1.05
Tata Steel BSL Limited	1.500
Gas-based DRI plants	
Arcelor Mittal Nippon Steel Limited, Hazira	5.500
JSPL, Angul	1.800
JSW Steel Limited, Salav, Raigarh	1.000
JSW Steel Limited, Dolvi, Raigarh	1.600
JSW Steel Limited, Vijayanagar	1.200

1.3 Mapping of Direct Reduction of Iron Units

The coal-based DRI units are mainly located in mineral-rich states such as Chhattisgarh, Odisha, West Bengal, Jharkhand, and Karnataka.



1.4 Production Process

Direct reduction of iron can be defined as a process in which metallic iron is directly produced by reduction of iron ore in solid state at temperature below the melting point of iron. The reduction of iron ore can be achieved using either carbon-bearing material, such as non-coking coal, or a suitable reducing gas in the form of reformed natural gas. The reducing gas in DRI process mainly consists of hydrogen and carbon monoxide. The iron thus produced in solid state is known as direct reduced iron. The DRI resembles a honeycomb structure, which looks spongy in texture when viewed in microscope and hence is also called 'sponge iron'. The DRI plants in India follow one of the practices to obtain reductants as hydrogen or carbon monoxide in the reduction process from solid coal, coal gasification, or natural gas.

1.4.1 Direct Reduction of Iron Production Using Solid Coal

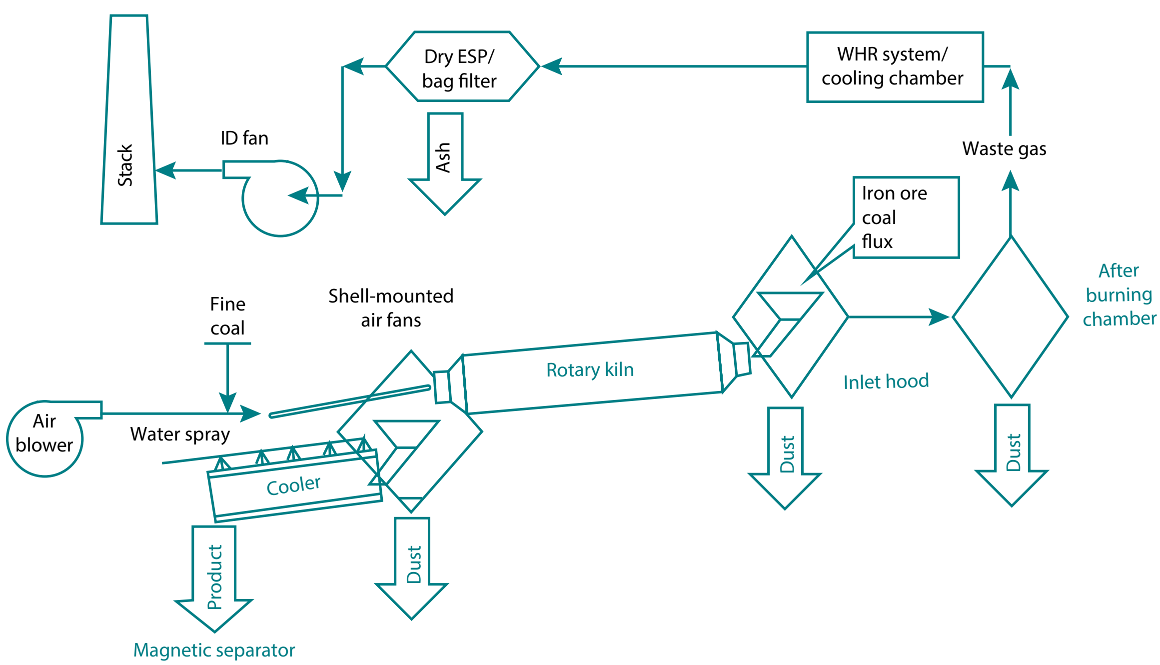
Most of the coal-based DRI production in India has customized plant specifications, using one of the standard DRI processes such as SL/RN, KRUPP-REIN, KRUPP-CODIR, DRC (DAVY Reduction Corporation), ACCAR, DRC, or customized such as TDR (TISCO Direct Reduction), SIIL (Sponge Iron India Limited), JINDAL, OSIL (Orissa Sponge Iron Limited), and Popuri Engineering Limited. The solid coal-based DRI production uses horizontal rotary kiln in production processes. The kiln is provided with an inside refractory lining of 150–200 mm to protect the shell and has a slope of 2.5%–3.0% towards the discharge end. The combustion air requirement for the feed is provided by air blowers along the length of the heating zone. The major raw materials used in sponge iron production include iron ore (hematite or Fe_2O_3), non-coking coal, and limestone/dolomite. Hematite, which is rich in iron content of 65% or more is preferred in sponge iron plants. Iron ore can be used in the form of lumps and pellets. Most of the DRI plants in India employ smaller capacity rotary kilns (100 tpd or less).

A DRI plant

Reduction of Iron Ore to Sponge Iron

The iron ore and non-coking coal are reduced to the required size in crushers. Iron ore, coal, and dolomite of required proportion are fed into the kiln continuously from feed end using weigh feeders. The raw materials move along the length of the kiln with the preset rotation. Secondary air is blown into the kiln through air pipes located along the kiln length. Initial heating of the kiln refractory is carried out above the ignition temperature of coal using oil-fired system at the discharge end of the kiln. The temperatures of different heating zones are measured and controlled using thermocouples mounted on the kiln. Fine coal is injected at the discharge end of the kiln to meet additional carbon requirements for the reactions.

As the charge moves along the kiln length, it gradually picks up heat from the hot gases flowing in the opposite direction of the charge. The preheating zone accounts for about 30% of the kiln length, wherein both moisture and volatile matter present in feed mixture are removed. The heat required in preheating zone is provided by combustion of part of coal.



DRI production in a rotary kiln

Source: *Details available at http://www.iipinetwork.org/wp-content/Ietd/content/direct-reduced-iron.html*

The section of rotary kiln after preheating zone is called 'reduction zone'. Here, the oxygen present in the iron ore dissociates and oxidizes, reducing carbon element in non-coking coal to form carbon monoxide, leaving the metallic iron. The rotation of the kiln and its slope ensures better mixing and movement of charge towards discharge end of the kiln at the required rate.

Reactions in coal-based DRI process

$C + O_2$	$= CO_2$
$CO_2 + C$	$= 2CO$
$3Fe_2O_3 + CO$	$= 2Fe_3O_4 + CO_2$
$Fe_3O_4 + CO$	$= 3FeO + CO_2$
$FeO + CO$	$= Fe$ (product) $+ CO_2$

A temperature of about 900–1050°C is maintained in the reduction zone. The higher the temperature, the faster would be the oxygen removal from hematite. The reduction of iron ore occurs in solid state with the critical factor being 'controlled combustion of coal' towards formation of carbon monoxide (Boudouard reaction which is endo-thermic). The residence time for iron ore inside the kiln is about 8–10 hours to form metallic iron. The quality of sponge iron is measured in terms of metallization, which is the ratio of metallic iron to total iron present in sponge iron.

Heat of reactions

$Fe_2O_3 + CO = 2FeO + CO_2$ - 2.05656 GJ/kmol

$FeO + CO = Fe + CO_2$ - 0.25738 GJ/kmol

$CO_2 + C = 2CO$ + 75.0 GJ/kmol

$2CO + O_2 = 2CO_2$ - 135.71417 GJ/kmol

$C + O_2 = CO_2$ - 97.994248 GJ/kmol

$2C + O_2 = 2CO$ - 3.439722 GJ/kmol

$2H_2 + O_2 = 2H_2O$ - 29.8268 GJ/kmol

Cooling of Sponge Iron

The sponge iron and solid waste discharge (comprising char, spent limestone/ dolomite) are transferred to water-cooled rotary cooler. The rotary cooler is sloped at about 2.5%–3%. Water is sprayed on outer shell of rotary cooler to indirectly reduce the temperature of kiln discharge to about 100–120°C. This helps in avoiding re-oxidation of sponge iron on exposure to atmosphere as it is quite unstable at high temperatures.

Electro-magnetic Separation and Screening

The discharge material from the rotary cooler is transferred through conveyors for screening of fines and coarse materials. The discharge material of grain size less than 3 mm is separated out and passed through an electro-magnetic separator, wherein sponge iron is separated from char and other impurities. The sponge iron is screened in size fraction to separate lumps and fines.

The off-gases generated from the rotary kiln flow in counter current direction to input charge leave from feed input end of the rotary kiln and pass through a gravitational dust settling chamber. It then passes through a post-combustion chamber (PCC) or after-burning chamber (ABC) wherein the remaining carbon monoxide in off-gases is converted into carbon dioxide. The off-gases are either passed through a wet scrubber or combination of gas-conditioning tower in order to reduce off-gases' temperature to below 150°C. The cooled off-gases are then passed through an electrostatic precipitator (ESP) before being expelled through chimney.

1.4.2 Gas-based Direct Reduction of Iron Production

Gas-based DRI manufacturing process involves: (i) generation and cleaning of the reducing gases such as hydrogen and carbon monoxide using gasification or reforming route as applicable and (ii) iron ore reduction in a vertical shaft furnace. The vertical shaft furnace is the heart of a gas-based DRI process and consists of a cylindrical, refractory-lined vessel. It uses reducing gases from natural gas, syngas from coal, coke oven gas, or exhaust gas from the COREX process.

Reactions in a gas-based DRI process

Reactions with H_2	Reactions with CO
$3Fe_2O_3 + H_2 = 2Fe_3O_4 + H_2O$	$3Fe_2O_3 + CO = 2Fe_3O_4 + CO_2$
$Fe_3O_4 + H_2 = 3FeO + H_2O$	$Fe_3O_4 + CO = 3FeO + CO_2$
$FeO + H_2 = Fe + H_2O$	$FeO + CO = Fe + CO_2$

The shaft furnace works on the principle of counter flow system, wherein the iron ore (burden) moves downwards by gravity and gets reduced by the upward-flowing reducing gases. The iron burden is fed from the top of the kiln and the sponge iron is taken out from the furnace bottom. The syngas is treated to enrich hydrogen and carbon monoxide content after which it is preheated and used in the shaft furnace. The reducing gas is passed through the ore bed, and the spent gas is recirculated after heating and reforming to a mixture of hydrogen and carbon monoxide in a reformer, wherein it is heated to about 950°C to ensure adequate reduction reaction rates.

Since there is no contamination with non-magnetic materials, the gas-based DRI does not require magnetic separation. The gas-based processes are flexible and the final yield can be produced in three different product forms, depending on the specific requirements that include cold DRI, hot-briquetted iron (HBI), or hot DRI. There are mainly three types of gas-based processes that can be utilized in a DRI production: (1) HYL or Energiron process, (2) MIDREX process, and (3) PERED process.

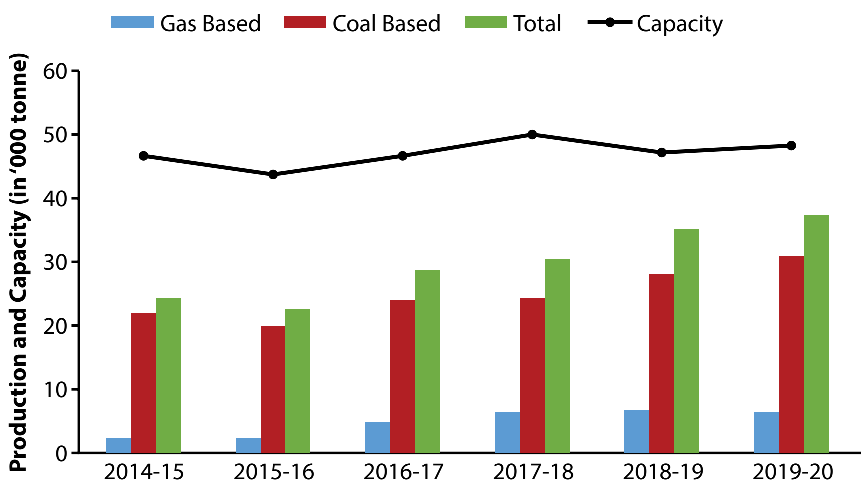
Majority of DRI plants in India utilize solid coal-based route. In light of this fact, this technology compendium mainly focuses on energy-efficient technologies and practices pertaining to rotary kiln-based DRI process using solid coal.

2 KEY PERFORMANCE INDICATORS OF DIRECT REDUCTION OF IRON PROCESS

A key performance indicator (KPI) is a measurable parameter that indicates the effectiveness or efficiency of a system. The KPIs specify the potential for performance improvements with respect to the design or best performance values. The KPIs of a direct reduction of iron (DRI) process include capacity utilization, yield, specific energy consumption (SEC), material balance, and energy balance. This section provides the KPIs with respect to the production of direct reduction iron or sponge iron using solid coal in the process.

2.1 Capacity Utilization

Performance of the DRI sector largely relies on overall utilization of the installed capacity. It is the ratio of the production to the total installed capacity of DRI. The average capacity utilization of DRI plants from 2014–15 to 2019–20 was 62% (varying from 52% to 74.5%).



Capacity utilization of DRI plants

Source: *SIMA (2021)*

The capacity utilization of DRI plants can be calculated using the following formula:

$$\textit{Capacity utilization}\ (\%) = \frac{\textit{Production (tonne/year)}}{\textit{Installed capacity (tonne/year)}} \times 100$$

2.2 Yield

Yield of sponge iron is dependent on factors such as tumbler index, abrasion index, and thermal degradation. Level of metallization of iron ore and loss of iron in the process are also determining factors of the yield. The loss of iron can occur through many ways, such as carryover in off-gases, level of accrertion, magnetic separation, inseparable iron loss in char, which depend on the level of fines present in the feed iron ore.

The yield of rotary kiln is the ratio of total sponge iron production to the iron ore fed. It is dependent on iron content, thermal degradation of iron ore, and operating practices. The optimum yield is equal to iron content provided majority of iron ore properties are met to optimum level. Any deviation in yield can be related to loss on ignition and operating practices. Higher the ratio of the sponge iron formed, the higher will be the yield of the process and vice versa for a given feed.

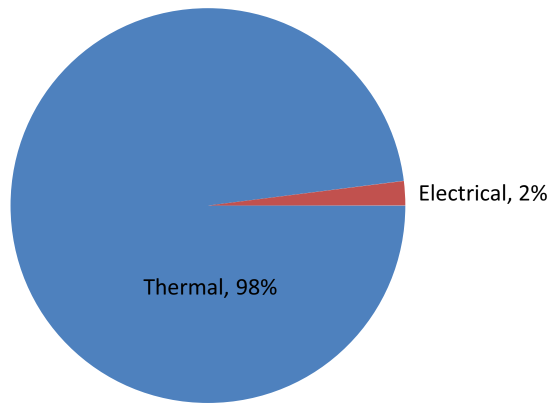
$$\textit{Yield}\ (\%) = \frac{\textit{Sponge iron production (tonne)}}{\textit{Input iron ore (tonne)}} \times 100$$

The maximum yield in a DRI process will be equal to the percentage of iron content in the ore if there are no losses in the process. As an illustration of the best case scenario, about 1.55 tonne of iron ore, with 64% iron content, will produce a maximum of 1 tonne of sponge iron.

2.3 Specific Energy Consumption

Coal is the principal fuel used in rotary kilns. A share of energy consumption of a coal-based DRI plant shows that about 98% of energy is used as coal for heating and reduction process, while electricity accounts for only 2% of the total energy consumption.

The SEC of a coal-based DRI rotary kiln is defined as the ratio of total energy consumption to the corresponding total production. The SEC is an important KPI that helps evaluate how effectively the DRI plant is performing in terms of energy consumption.



Share of energy consumption

The SEC of a coal-based DRI rotary kiln is defined as the ratio of total energy consumption to the corresponding total production. The SEC is an important KPI that helps evaluate how effectively the DRI plant is performing in terms of energy consumption.

$$SEC\ (Gcal/tonne) = \frac{\text{Total energy consumption (Gcal/year)}}{\text{Total DRI production (tonne/year)}}$$

Significant variations in SEC level can be observed in coal-based DRI production. The SEC of coal-based DRI production using rotary kiln varies from 4.10 to 5.26 Gcal/t-DRI (average: 4.51 Gcal/t-DRI). SEC levels are plant specific and their variations may be attributed to factors such as iron content in iron ore, fixed carbon and volatile matter in coal, temperature profile of kiln, and operating practices. The on-line measurements and control of key operating parameters are vital in optimizing SEC levels in DRI plants.

Illustration of SEC evaluation of rotary kiln

Parameter	Unit	Value
Sponge iron production	tpd	110
Coal consumption	tpd	110
Calorific value of coal	kcal/kg	5200
Electricity consumption*	kWh/t	70
SEC	Gcal/t DRI	5.26

** Source of electricity (WHR/captive power plant/grid is ignored in SEC assessment).*

Source: *Plant data*

The plant-level SEC may get reduced under two conditions: (i) if sensible heat in off-gases is recovered, reutilized, or recycled in meeting the energy demands of the plant, and (ii) if dolochar (by-product from rotary kiln) is reused at the plant level. In modern coal-based DRI plants, the off-gases are used for power generation and dolochar is used for additional steam generation, resulting in improved SEC levels. In a 400-tpd DRI plant, heat recovery from off-gases and recovery of coalchar would reduce the SEC levels from 5.20 to 3.19 Gcal/t-DRI production.

Illustration of SEC evaluation of DRI plant

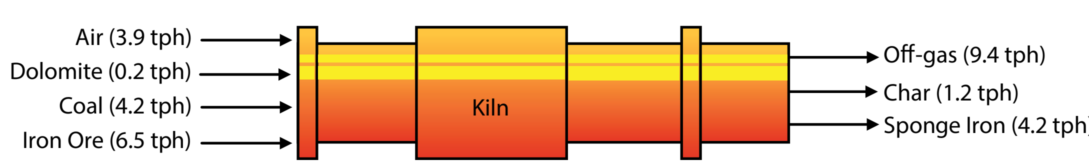
Parameter	Unit	Value
SEC: before heat recovery	Gcal/t	5.20
Heat recovery from off-gases and coal char	Gcal/t	2.01
SEC: after heat recovery	Gcal/t	3.19

Source: Plant data

It may be noted that a more realistic approach for SEC evaluation would be based on the iron content in sponge iron. For example, the SEC works out to be 5.54 Gcal/t of iron, considering 89% of iron content in sponge iron, calorific value of coal as 5200 kcal/ kg, and coal to iron ratio of 0.95.

2.4 Material Balance

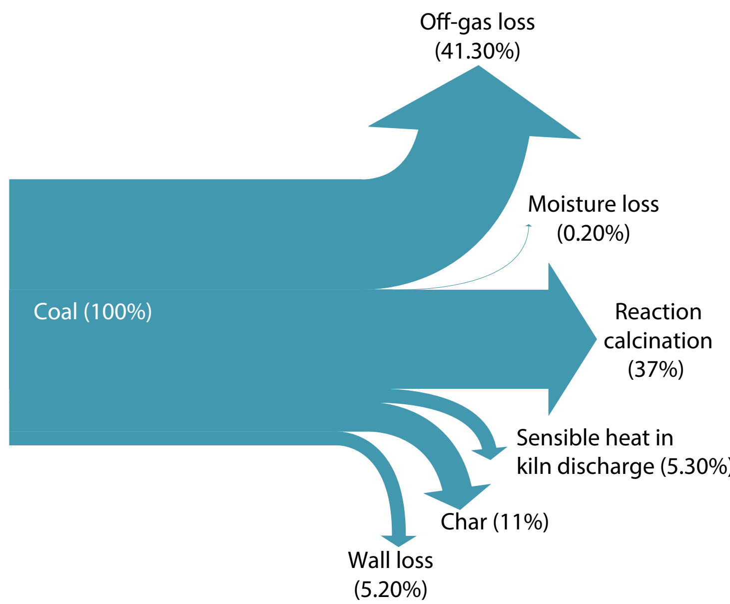
The input materials to rotary kiln include iron ore, dolomite, and coal. Air is supplied for combustion of coal and to maintain the set temperature along the entire length of the rotary kiln for sustaining reduction reactions towards formation of iron. The output from rotary kiln consists of sponge iron, solid waste discharge, and off-gases. The off-gases formed are passed through after-combustion chamber and transferred to either waste heat recovery (WHR) system, or vented out through chimney as applicable. The typical mass balance is based on 64% yield.



Mass balance of a coal-based rotary kiln

2.5 Energy Balance

The energy balance considers total energy as input into the process and reveals useful quantity heat (that is, efficiency) and energy losses as output for a specific time period under steady state conditions. The energy consumption is dependent on a few factors, notably quality of raw materials, design of kiln, and operating practices. The assessment of energy balance is based on measurements and analysis of key operating parameters.



Typical energy balance of a coal-based rotary kiln

Instruments used for performance evaluation	
Instrument type	**Measurement scope**
Pitot tube	Off-gas velocity
Pyrometer	Temperature of furnace and openings
Infrared thermometer	Surface temperature
Power analyser	Power (active, reactive, apparent), power factor, current, voltage, harmonics

The energy balance of a coal-based rotary kiln indicates that useful heat, that is, heat required for reduction and calcination is about 37%. A major share of heat input is lost in off-gases (41%), which include sensible heat in off-gases and chemical heat due to formation of unburnts such as carbon monoxide and carbon. Further, coal–char formation accounts for nearly 11% of the total heat losses.

2.6 Energy Performance Assessment of Key Equipment

2.6.1 Rotary Kiln

The overall performance of a rotary kiln used in a coal-based DRI plant can be assessed considering useful heat required to convert iron ore material into sponge iron in solid state and the net heat generated through endothermic and exothermic reactions. The heat energy is primarily used to increase the temperature of feed material to sustain the reactions to reduce iron ore into iron. Different types of heat losses that can occur in a rotary kiln are listed here:

- Heat loss through off-gases comprising sensible heat and chemical heat (carbon monoxide and unburnt carbon)

- Heat loss due to moisture
- Heat loss due to char formation
- Sensible heat loss in kiln discharge consisting of sponge iron and coal–char
- Wall losses from kiln surfaces

Heat Input to Rotary Kiln (H_i)

$H_i = M_c \times GCV$

H_i = total heat input (kcal/day)

M_c = mass of coal fed (kg/day)

GCV = gross calorific value of coal (kcal/kg)

Heat Loss in Off-gases (h_g)

The off-gases from the combustion of coal and chemical reactions in reduction zone exit from feed end of the rotary kiln at about 950–1000°C, resulting in high heat losses.

Heat loss in off-gases (h_g) = $m \times C_p \times (T_g - T_a)$

where,

m = mass of off-gases (kg/day)

C_p = specific heat of off-gases (kcal/kg °C)

T_g = exit temperature of off-gases (°C)

T_a = ambient temperature (°C)

Heat Loss Due to Char Formation (h_c)

Char is formed due to occurrence of reduction reactions in rotary kiln.

Heat loss due to char formation (h_c) = $m_c \times H_c$

m_c = mass of char formed (kg/day)

H_c = Heat of formation of char (kcal/kg)

Heat Losses in Kiln Discharge (h_{kd})

The kiln discharge comprises magnetic and non-magnetic materials.

Sensible heat loss in magnetic material = $M_m \times C_m \times (T_e - T_a)$

M_m = mass of magnetic material (kg/day)

C_m = specific heat of magnetic material (kcal/kg °C)

T_e = exit temperature from rotary kiln (°C)

T_a = ambient temperature (°C)

Sensible heat loss in non-magnetic material = $M_n \times C_n \times (T_e - T_a)$

M_n = mass of non-magnetic material (kg/day)

C_n = specific heat of non-magnetic material (kcal/kg °C)

T_e = exit temperature from rotary kiln (°C)

T_a = ambient temperature (°C)

Sensible heat in kiln discharge (h_{kd}) = Sensible heat loss in magnetic material + Sensible heat loss in non-magnetic material

Heat Loss from Kiln Surface (h_s)

The heat loss from kiln surface may be attributed to high-surface temperatures of rotary kiln.

h_s =[a × (T_s – T_a)$^{5/4}$ + 4.88 × E × {(T_s /100)$_4$ (T_a/100)^4}] × A × 24

h_s = heat loss from kiln surface in kcal/day

a = factor for direction of the surface of natural convection ceiling

T_s = surface temperature (°C)

T_a = ambient temperature (°C)

E = emissivity of external wall surface of the rotary kiln

A = surface area of rotary kiln (m^2)

Useful Heat (h_u)

Useful heat (h_u) = H_i – H_L

Whereas

$H_L = h_g + h_c + h_{kd} + h_s + h_m$

H_m = moisture and unaccounted losses, which is below 0.5%.

Kiln Efficiency

$$\textit{Kiln efficiency (\%)} = \frac{\textit{Useful heat } (h_u)}{\textit{Heat input } (H_i)} \times 100$$

Measurement and Recording of Key Operating Parameters

The relevant operating parameters must be monitored, measured, and recorded for the purpose of performance assessment of rotary kiln. Data may be collated from production record and using measured data.

Key operating parameters		
Parameter	**Unit**	**Measurement frequency**
Iron ore feed rate	tonne	Continuous
Coal supply: feed end	tonne	Continuous
Coal supply: discharge end	tonne	Continuous
Dolomite	tonne	Continuous
Sponge iron production	tonne	Daily
Kiln temperature (zone wise)	°C	Continuous
Discharge temperature	°C	Daily
Off-gas temperature	°C	Daily
Surface temperature	°C	Quarterly

2.6.2 Motors

Motors are used for motive loads such as blowers and fans (shell air fans and ID), air compressors, water pumps, and conveyors for material transfer to operate connected utilities in the process. The motors must be loaded to the recommended level to ensure better performance. The loading patterns of the motors are estimated by comparing operating load with the rated load provided by the motor supplier.

$$\text{Motor loading (\%)} = \frac{\text{Input power (kW) x Design efficiency (\%)}}{\text{Rated power (kW)}} \times 100$$

2.6.3 Pumps

Pumps are used in DRI plants in cooling water circuit to transfer hot and cold water. The performance of the pump can be assessed using the following formulae.

$$\text{Hydraulic power (kW)} = \frac{Q \times (H_d - H_s) \times p \times g}{1000}$$

where

Q = pump output flow rate (m^3/s)

H_d = discharge head (metre)

H_s = suction head (metre)

ρ = density of the fluid (kg/m^3)

g = acceleration due to gravity

Pump shaft power (kW) = electrical input power (kW) × motor efficiency (%)

$$\text{Pump efficiency (\%)} = \frac{\text{Hydraulic power (kW)}}{\text{Pump shaft power (kW)}} \times 100$$

2.6.4 Air Compressor

The performance of air compressors is assessed by evaluating its SEC. It is the ratio of actual electrical power input to the free air delivery (FAD) of the air compressor.

$$\text{SEC (kW/CFM)} = \frac{\text{Actual input power (kW)}}{\text{FAD (ft}^3\text{/min)}}$$

Compressed air leakage of up to 5% is permissible, any leakage above this level will incur significant energy losses.

Compressed air leakage (kWh/year) = SEC × L × T

Where,

SEC = specific energy consumption (kW/CFM)

L = volume of air leakages (CFM)

T = annual operating hours

3 ENERGY-EFFICIENT TECHNOLOGIES IN DIRECT REDUCTION OF IRON PROCESS

Various energy losses occurring in coal-based rotary kilns clearly indicate that there is a significant scope for reducing SEC level and improving energy efficiency. Waste heat in off-gases formed in rotary kiln forms the major share of heat loss. Waste heat recovery (WHR) has been identified as one of the viable options towards maximizing the utilization of heat energy in a direct reduction of iron (DRI) plant. Apart from WHR, there are a number of energy-efficiency measures applicable for rotary kiln and associated auxiliaries to improve the overall performance of DRI production.

3.1 Waste Heat Recovery for Power Generation

3.1.1 Background

In coal-based DRI production using rotary kiln, the off-gases generated during the process leave the kiln at very high temperatures of about 950–1025°C, carrying away a significant quantity of sensible heat. The off-gases need to be cooled down to about 180°C before being transferred to electrostatic precipitator (ESP). The dust-free off-gases are let out from the chimney top at about 120°C. In place of cooling, the high-sensible heat in off-gases can be recovered using a WHR boiler to generate high-pressure steam for power generation.

A WHR plant

3.1.2 Technology Brief

The volume of off-gases generated in a 100 tpd rotary kiln generally varies in the range of 24,000±1500 Nm^3 per hour. The volume of off-gases is dependent on volatile matter (25%–28%) and fixed carbon (48%–50%) in coal. The sensible heat in off-gases accounts for about 40% of the total heat input. The ABC ensures complete combustion of injected and carryover coal fines in off-gases which further increases the sensible heat in off-gases. The WHR-based power generation system is financially viable for cumulative installed capacities of 200 tpd or more.

In a typical WHR-based power generation system, the off-gases from the rotary kiln are passed through a WHR boiler, wherein the waste heat is utilized to convert water into steam at high pressure and temperature.

WHR power generation potential

Kiln capacity (tpd)	Power generation potential (MW)
100	1.5–2.5
175	3.5–4.0
350	7.5–8.0
500	10.0–12.0

Source: *Popuri Engineering Technologies*

Specifications of a WHR boiler are tabulated here:

Specifications		
Steam generation capacity	tph	8–10
Set pressure	kg/cm^2	64
Superheated steam temperature	°C	480–490
Off-gas inlet temperature to WHR	°C	950
Off-gas outlet temperature to WHR	°C	180

Source: *Plant data*

In a typical WHR boiler system, the off-gases first pass through a superheater to increase the temperature of saturated steam to produce superheated steam. From superheater, the hot gases pass through series of boiler bank tubes to produce saturated steam. Upon further losing heat in WHR boiler, the cooled gases enter economizer for preheating feed water. The off-gases transfer a significant portion of sensible heat (about 50%–55%) to WHR boiler system. In this process, the temperature of off-gases gets reduced substantially to about 180°C. The particulates from off-gases are removed in electrostatic precipitator before being let out through the stack.

The turbo-generator system comprises a condensing turbine and an alternator. About 8–10 tph of superheated steam at 64±2 kg/cm^2 and 480±10°C is generated. The high-pressure steam is passed through turbo-generator to produce power. In a typical coal-based DRI plant having 2 × 100 tpd kilns, about 4 MW (= 2 × 2 MW) of electricity can be generated using WHR-based power generation system.

WHR-based power generation

A coal-based DRI plants in Tamil Nadu has an installed capacity of 400 tpd, from 4 rotary kilns of 100 tpd each. The plant uses imported coal. Considering the high-sensible heat available with off-gases generated from rotary kilns, the plant has installed WHR system for power generation. The power generation system comprises a WHR boiler for each rotary kiln. The steam generated from all four WHR boilers are combined together in a common header and fed to a turbo-generator which ensures operations under partial load when some of the rotary kilns are under shutdown. The full load power generation capacity of WHR system is 8 MW.

Quantity of off-gases per kiln = 24,000 Nm^3/h

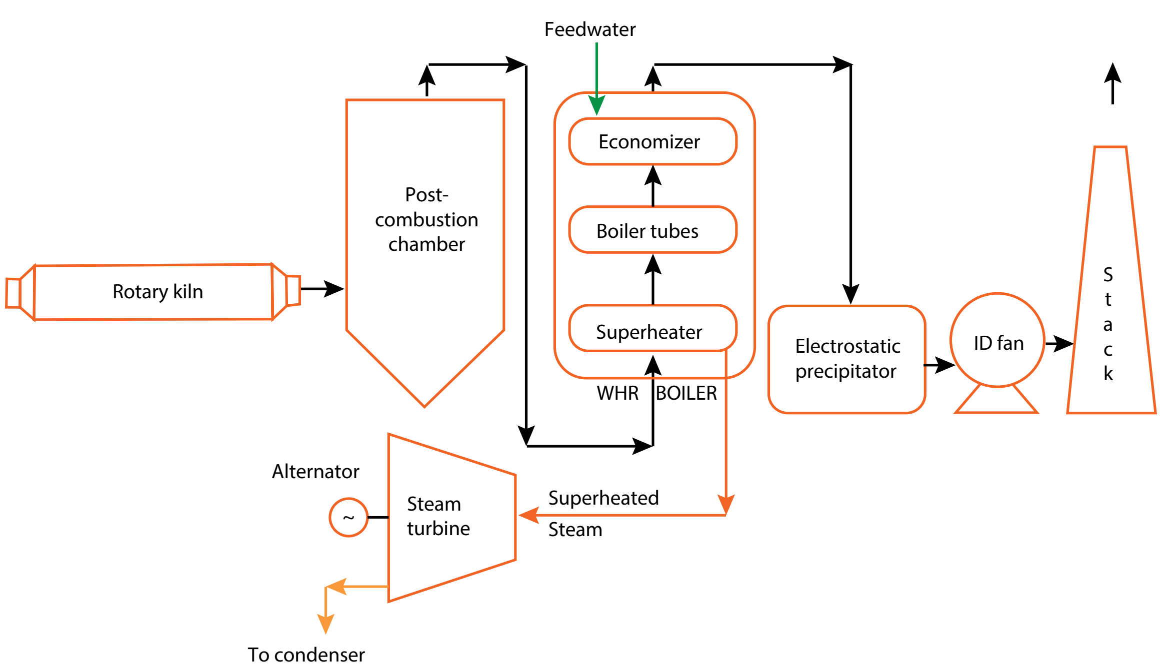
Temperature of off-gases = 950°C

Steam generation from one WHR boiler = 10 tph @ 64 kg/cm^2 and 485°C

Equivalent power generation per rotary kiln = 2 MW

Electricity available for export = 60%

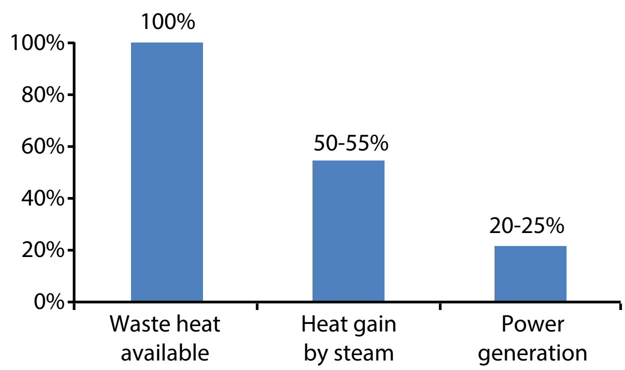
(internal use consists of 30% for DRI plant and 10% for WHR system)



WHR-based power generation

3.1.3 Savings, Investments, and Greenhouse Gas Reduction

The energy saving/credit with use of WHR-based power generation system in a DRI plant of 2 × 100 tpd kiln capacity is about 23.5 million kWh of electricity per year (~2020 toe per year). The equivalent greenhouse gas (GHG) emission reduction potential is 19,300 tonne CO_2 per year. In addition, reduced temperatures of off-gases using WHR system would decrease the requirements for cooling and the associated power requirements. The WHR-based power generation system is a potential option for all DRI plants; however, the installation is economically more viable for plants with at least 200 tpd of DRI installed capacity.



Waste utilization from rotary kiln

WHR-based power generation system		
Plant capacity	tpd	2 × 100
Potential power generation	MW	4
Total electricity generation	kWh/day	76,800
Electricity consumption in DRI plant	kWh/day	14,000
In-house consumption at WHR plant	kWh/day	9,600
Electricity available for export	kWh/day	53,200
Monetary saving	Rs lakh/year	874
Investment for WHR plant	Rs lakh	2800
Payback period	Year	3.2

Source: *Based upon interactions with sector experts*

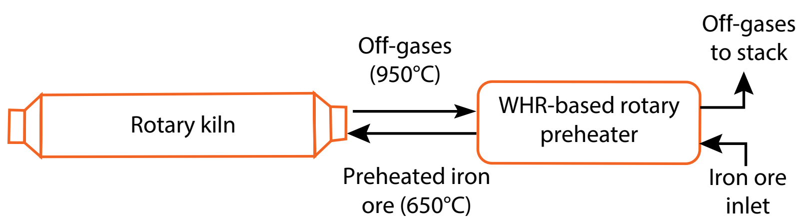
3.2 Iron Ore Preheating Rotary Kiln Using Waste Heat Recovery System

3.2.1 Background

A large quantity of sensible heat is available in high temperature off-gases. It is mainly used for WHR-based power generation system, which is viable for installed capacity of at least 200 tpd. However, plants of less than 200 tpd capacity generally let out off-gases without any heat recovery. In such cases, the sensible heat of off-gases can be recovered for preheating of iron ore, resulting in lower coal consumption. The reduction in coal consumption depends on recoverable amount of sensible heat and kiln efficiency.

3.2.2 Technology Brief

In a solid coal-based DRI process plant using 100 tpd kiln, about 40% of the total heat input is lost in off-gases. The sensible heat in off-gases can be used in a rotary preheater. In an iron ore preheating system, the off-gases from rotary kiln flow through rotary preheater in a counter-flow arrangement and transfer heat directly to incoming iron ore. The counter-flow- type WHR system helps in maximizing heat transfer and reduces space requirements. The preheated iron ore at about 650°C enters rotary kiln instead of being fed at ambient temperatures. Preheating of iron ore may marginally increase the generation of fines due to more handling.



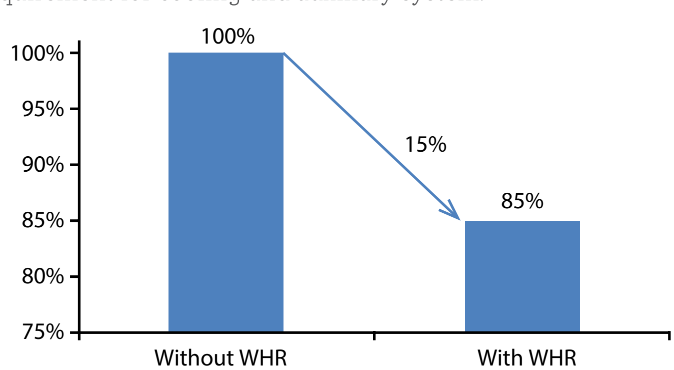
Preheating rotary kiln for iron ore using WHR system

3.2.3 Savings, Investments, and Greenhouse Gas Reduction

Considering a DRI plant of 100 tpd, the potential energy saving from iron ore preheating is about 15%. The annual energy saving with iron ore preheating system is 5200 tonne coal per year (2700 toe per year). The GHG emission reduction potential is 9300 tonne CO_2 per year.

Other benefits associated with WHR-based iron ore preheating system include the following:

- Higher productivity since the heating zone is shifted to the preheater system and the reduction zone inside the kiln will increase.
- Reduction in energy costs.
- Reduction in power requirement for cooling and auxiliary system.



Energy saving with WHR for iron ore preheating

WHR-based iron ore preheating system		
Kiln capacity	tpd	100
Iron ore consumption	tpd	154
Preheated temperature of iron ore	°C	650
Coal saving	%	15
Annual coal saving	tpy	5200
Energy saving	toe	2700
Monetary benefits	Rs lakh/year	325
Investment	Rs lakh	350
Payback	Year	1.1

Source: *Based upon interactions with sector experts*

3.3 Coal Gasification for Partial Substitution in Rotary Kiln

3.3.1 Background

The rotary kiln uses solid coal for both thermal energy requirements and reduction reactions for transformation of iron ore into sponge iron. In a rotary kiln, 40%–50% coal of size 8–20 mm is fed along with raw materials at the feed end. About 50%–60% of coal of size 0–8 mm is injected along with low-pressure air at the discharge end. The coal injected at the discharge end can be converted to producer gas in a gasifier which can be supplied to the rotary kiln from discharge end to improve the overall efficiency of the rotary kiln.


Coal injection plant

3.3.2 Technology Brief

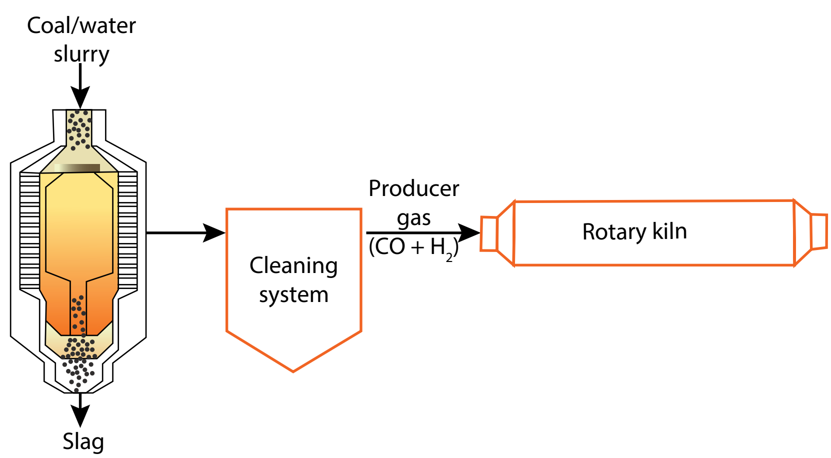
The principle of coal gasification process involves partial combustion of coal to form a mixture of carbon monoxide (CO) and hydrogen (H_2), known as 'producer gas' with traces of methane (CH_4) and carbon dioxide (CO_2). The trace elements from the gas mixture are removed and sent to rotary kiln. Coal gasification process consists of pyrolysis and gasification processes at about 350–700°C. Apart from desirable gas composition, that is, CO and H_2, the process also results in the formation of CO_2, CH_4, water vapour, tar, and char.

The gasification process is mainly endothermic involving the following reactions:

$C + O_2 = CO_2 - 94.05$ kcal/mol

$2H_2 + O_2 = 2H_2O - 68.3$ kcal/mol

The gasifier system comprises a vertical chamber wherein coal–water slurry is fed from the top and air supply is met through a blower. The producer gas is passed through either cyclone separator or wet scrubber to clean the gases. The coal gasifier system is provided with programmable logic controller (PLC) control system for automatic monitoring and control of producer gas generation.



Coal gasification system for rotary kiln in sponge iron production

3.3.3 Savings, Investments, and Greenhouse Gas Reduction

The energy saving with partial substitution of solid coal used in rotary kiln of 100 tpd capacity with producer gas from coal gasification process is about 20%. The annual energy saving with coal gasification system is 4200 tonne coal per year, which is equivalent to a monetary savings of approximately Rs 260 lakh per year. However, the plant will have to invest for setting up of a producer gas system of corresponding capacity. The GHG emission reduction potential is 7500 tonne CO_2 per year.

Benefits of using coal gasifier

Apart from energy savings, the other benefits due to replacement of coal-fine injection with producer gas at the discharge end include:

(1) Close control over kiln operating parameters and hence smooth operation

(2) Increased kiln capacity by 20%

(3) Increased campaign

(4) Increased metallization and hence better recovery of metal

3.4 Waste Heat Recovery-based Absorption Chiller

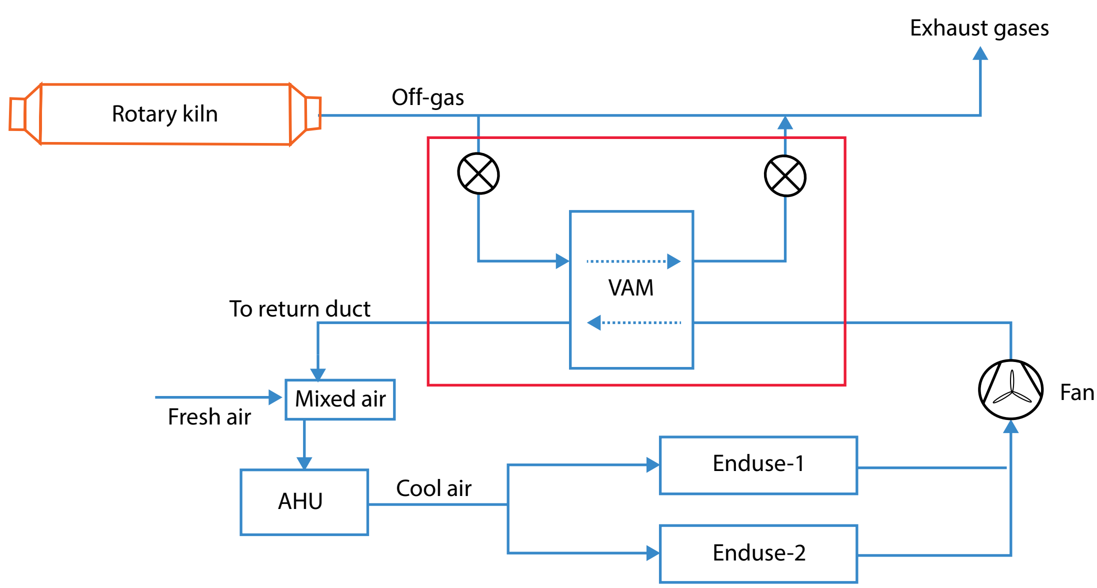
3.4.1 Background

Direct reduction of iron plants require comfort cooling in control rooms and administrative buildings. The cooling load is met primarily through stand-alone air-conditioning system. One of the potential options is to use a fraction of the sensible heat available in off-gases in a WHR-based system, that is vapour absorption machine (VAM) to replace existing cooling arrangements. The WHR-based VAM system can be installed in all DRI plants irrespective of existing WHR systems such as WHR-based power generation or WHR-based iron ore preheater.

3.4.2 Technology Brief

The compact stand-alone air-conditioning systems can be replaced with energy-efficient VAM system. A VAM system primarily replaces conventional compression system, which is energy intensive. It uses a generator-cum-absorber system to ensure circulation of refrigerant. Lithium bromide water solution is generally used in VAM systems.

In a DRI plant, a small quantity of off-gases from rotary kiln is required to operate VAM system, which eliminates electricity requirements for operating compressor system except for operating a low-capacity pump. The absorption chillers can be customized to suit wide range of capacities with single, double, or triple effect.



VAM-based absorption chiller

3.4.3 Investments, Energy Saving, and Greenhouse Gas Reduction

A WHR-based VAM system can be customized to meet chilling loads with negligible energy consumption. Practically, energy saving that can be achieved by replacing conventional chillers with a VAM-based system of 10 TR capacity to cater to the requirements of instrumentation and control room is estimated to be 42,000 kWh per year (4 toe per year). The GHG emission reduction potential with use of proposed VAM is 34 tonne CO_2 per year.

WHR-based VAM system		
Parameter	**Unit**	**Value**
Cooling load	TR	10
Quantity of off-gas required*	Nm^3/h	~1
Electricity saving	kWh/year	42,000
Monetary benefits	Rs lakh/year	2.9
Investment	Rs lakh	7
Payback	year	>2

** Considering 90% heat transfer efficiency and 370°C temperature gain.*

Source: *TERI*

3.5 Decentralized Control of Shell Air Fans

3.5.1 Background

The typical dimensions of a rotary kiln of 100 tpd capacity are 42 metre length and 3 metre diameter. The raw materials comprising iron ore, non-coking coal, and dolomite are mixed in required ratio before feeding into the kiln. All shell air fans in the kiln are controlled centrally by a single VFD. However, finer and regular adjustment of air flow across the kiln is ensured through manual control of mechanical dampers in each fan on daily/shift basis. The use of damper at delivery side increases air flow and affects the power consumption. Precise control of temperatures can be attained with dedicated VFD for each fan, which will ensure air flow with least resistance.

3.5.2 Technology Brief

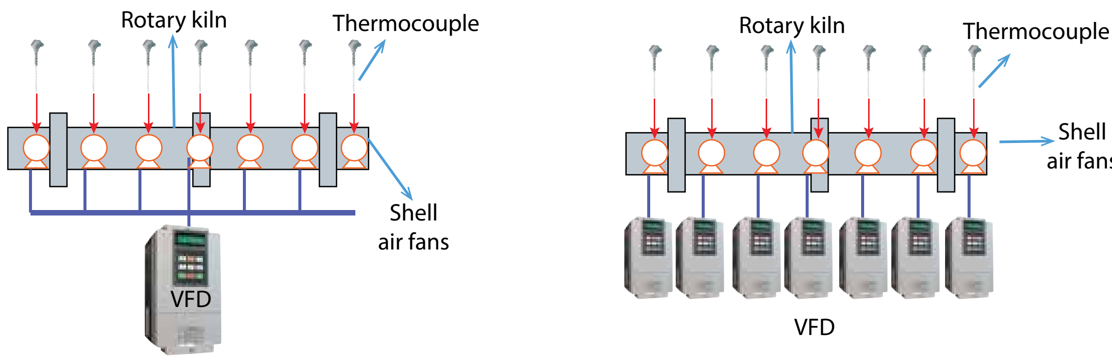
In kiln automation, the rpm of each shell air fan is varied using a dedicated VFD system and thermocouple. The proportional integral derivative (PID) system continuously senses the signal from a thermocouple to maintain the set temperature by varying the air flow in the zone. Whenever temperature variation occurs, the control loop of the PID system actuates the VFD to change the air flow. Thus, the speed of individual shell air fan can be increased or decreased without affecting the speed of other fans. The power consumption is proportional to the cube of the fan rpm.

Decentralized control of shell air fans

In a typical 100 tpd kiln, about 7 shell air fans each of 11 kW (15 HP) and 2900 rotations per minute (rpm) capacity are installed to supply air. Together, these fans are controlled by a single VFD system of 75 kW capacity to alter the speed. Hence, all the fans are run at the same speed in a conventional kiln.

Under kiln automation, each individual shell air fan is provided with a VFD system of 11 kW capacity to control the air flow. When a temperature variation is observed in a particular zone, the thermocouple sends signal to PID controller, which in turn activates VFD to vary air flow.

Source: *UNDP*



Decentralized VFD system in rotary kiln

Source: *UNDP, India*

3.5.3 Investments, Energy Saving, and Greenhouse Gas Reduction

The annual energy saving with installation of decentralized VFD systems for shell air fans for 100 tpd capacity rotary kiln is 19,000 kWh per year (1.6 toe per year). The GHG emission reduction potential is 16 tonne CO_2 per year.

Automation and control system in rotary kiln		
Energy saving	toe/year	1.6
Monetary benefits*	Rs lakh/year	0.5
Investment	Rs lakh	2.8
Payback	Year	5.2

** Monetary savings estimated using cost of export power*

Source: *TERI's analysis*

The main advantage with the use of decentralized VFDs is that it eliminates the manual intervention in controlling air flow across the kiln, leading to close control over temperature in each zone. It is worth mentioning that the payback period of a decentralized system will be much lower, considering the other benefits and electricity costs from grid source.

3.6 Mullite-based Kiln Lining

3.6.1 Background

In conventional rotary kiln, high-alumina low-cement castable refractories are used as inner lining to withstand a temperature of close to 1050°C. The thermal conductivity of high-alumina refractories is quite high, of about 2.7 W/m-K, which leads to higher radiation or surface heat loss in the kiln. The temperatures of external surfaces of the kiln are about 180–250°C in reduction zone and 150–180°C in discharge end. The radiation heat loss of the rotary kiln typically accounts for about 5% of the total heat input, which can be reduced with application of low-thermal conductivity material such as mullite-based kiln lining.

3.6.2 Technology Brief

Every 10°C increase in surface temperature increases the radiation loss from the exposed surfaces by 6%–7%.

The high-alumina low-cement castable refractory material can be replaced with mullite-based high-alumina castable refractory of thermal conductivity of 1.7 W/m-K. Two of the many advantages associated with mullite-based refractories are: (i) excellent high- temperature strength and (ii) high resistance to thermal shock, oxidation, and abrasion. With use of mullite-based high-alumina castables, the outer shell temperature of the rotary kiln gets reduced by 50–80°C, thereby reducing heat loss through kiln shell by at least 30%.

3.6.3 Savings, Investments, and Greenhouse Gas Reduction

The annual energy saving with mullite-based lining of rotary kiln of 100 tpd capacity is 580 tonne coal per year (300 toe per year). The GHG emission reduction potential is 1050 tonne CO_2 per year.

Mullite-based kiln lining		
Reduction in radiation losses	%	30
Energy saving	toe/year	300
Monetary benefits	Rs lakh/year	36
Investment	Rs lakh	50
Payback	Year	4.1

Source: *UNDP*

3.7 Switch Over to Iron Ore Pellets

3.7.1 Background

The coal-based DRI plants use iron ore lumps of size 5–20 mm, which are commonly known as calibrated lump ore (CLO). The mined iron ore available to DRI plants has generally low-iron content. Further, the processing of lumps results in formation of fines and requires agglomeration to maintain the yield. Iron ore pellets can be used in place of lumps to increase the yield.

Use of iron ore pellets in DRI production

The iron ore used in coal-based rotary kilns is in the form of sized lumps or pellets. These can be either procured or processed in-house. The in-house processing of large lumps generates fines, resulting in iron ore losses. Switch over to pellets offers the following advantages:

- Minimizes raw material preparation facility
- No loss on ignition, resulting in better yield
- Uniform metallization
- Less fine generation, leading to lower accretion and reduced load on bag filters
- Reduces slag quantity and related handling
- Improves yield
- Eliminates the use of magnetic separators
- About 20% more throughput per unit of rotary kiln volume
- Reduce thermal load for direct reduction

Source: *UNDP*

3.7.2 Technology Brief


Iron ore pellets

Pelletizing is an agglomerating process of converting iron ore fines into uniform-sized material which can be charged directly into the rotary kiln for DRI production. Iron pellets are prepared by mixing iron ore fines having a size of less than 200 mesh (0.074 mm) with additives like bentonite and shaping into oval or spherical balls with size in the range of 8–16 mm diameter in a pelletizer. The iron pellets are further hardened by firing separately. The use of uniform size and shaped pellets as against the non-uniform and varying size of lumps as charge material results in improved performance of the kiln. The use of iron ore pellets reduces loss on ignition. Two of the different iron ore pelletization processes are (i) straight travelling grate process and (ii) grate kiln process.

3.7.3 Investments, Energy Saving, and Greenhouse Gas Reduction

The energy-saving potential with use of iron ore pellets in place of iron ore lumps is 15%. The annual energy saving for a DRI plant of 100 tpd capacity is 2730 toe per year. The total monetary benefit that can be accrued with the use of iron ore pellets is estimated to be Rs 326 lakh. The GHG emission reduction potential is 9400 tonne CO_2 per year.

3.8 Artificial Neural Network for Accretion Control

3.8.1 Background

Accretion in rotary kiln refers to deposition or build-up of low-melting oxide compounds on the internal surface in reduction zone. This leads to decrease in fusion temperature of the charge material which adheres to the kiln surfaces. Accretion results in formation of slag layer, which affects the metalizing reactions. The accretion forms ring structure inside the kiln due to rotation and the thickness increases over a period of time. Continuous deposits lead to increase in thickness, resulting in reduced working volumes and forces unscheduled kiln shutdown as those cannot be removed in-place during operation. The optimum performance of DRI plant would require addressing of operating parameters such as accretion control, product quality, and kiln availability. Optimization of these parameters would help in reducing accretion, increasing product quality, and enhancing kiln availability, thereby improving the energy performance of rotary kilns.

3.8.2 Technology Brief

Accretion formation largely depends on quality of feed material such as gangue content iron ore, ash in coal, and operating temperatures. It can be minimized by adopting the following measures:

(i) Using iron ore with low-gangue content, high-tumbler index, and low-aberration index.

(ii) Using non-coking coal with low-ash content, high reactivity, high-ash fusion temperature, and low swelling and caking index.

(iii) Maintaining temperature profile below the sintering temperature along the entire kiln length.

(iv) Using suitable alloy additives to increase the fusion temperature, and coatings on refractory wall to withstand high temperature and aberration.

A dynamic operation model using artificial neural network (ANN) can be effectively used for controlling accretion in kilns, improving product quality, and enhancing kiln availability. The key parameters and their interrelations are used to control accretion and product quality. A close monitoring and control of rotary kiln temperatures in different zones is of paramount importance for controlling accretion in rotary kilns. The neural network predicts temperatures in different zones based on parameters such as fixed carbon content in coal, kiln pressure and multilayered damper (MLD) position of ID fans using regression analysis which in turn is used to control accretion in the kiln. The ANN can be further used to control quality of the product, which uses parameters such as fixed carbon in coal, kiln RPM, and air flow through fans.

Recycling of in-house wastes

(i) Waste char used in DRI plants is generally used as fuel in WHR boilers. However, smaller capacity plants may recycle waste char along with prime coal to reduce energy consumption.

(ii) Coal fine wastes can be briquetted and recycled through feed end. This could result in a coal saving of 8%–10%.

3.8.3 Energy Saving and Greenhouse Gas Reduction

The major benefits of using ANN include (i) reduced fluctuations of kiln inlet and outlet pressure, (ii) auto operation of MLD of ID fan, (iii) reduced shutdowns and significant gain in operating days, and (iv) about 5%–7% increase in production. All these benefits will lead to reduction in overall SEC level and GHG emission over kiln's life cycle.

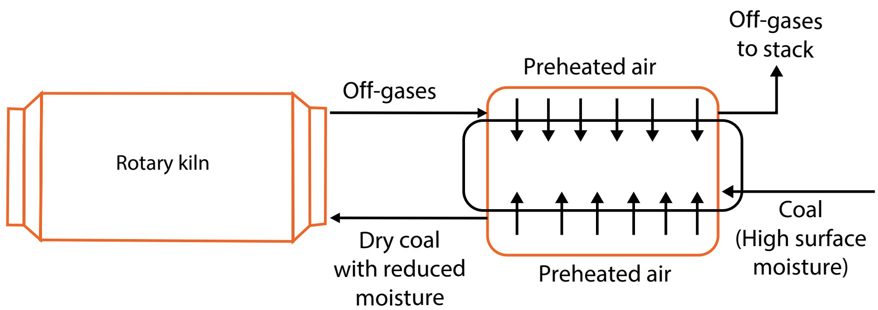
3.9 Moisture Reduction from Coal

3.9.1 Background

The coal-based DRI plants in India use either domestic coal or imported coal, depending on landed costs and quality. Generally, the moisture content in coal is in the range of 8%–12%, depending on ambient conditions. The moisture content is reduced to 4%–5% before feeding into the kiln. Open sun drying is practised to reduce surface moisture. Reduction or minimization of surface moisture present in coal would help in bringing down heat losses due to moisture content in coal and effectively reduces the overall coal consumption.

3.9.2 Technology Brief

Other than sun drying, the DRI plants can also use rotary drum dryer for moisture removal. The rotary drum dryer is a direct-type heat exchanger in which preheated air and green coal are fed. The green coal is fed in the opposite direction which picks up heat from hot air at about 250–300°C and the surface moisture is optimally removed in the dryer. Hot air is generated by picking up heat from off-gases through separate heat exchanger. This arrangement would eliminate potential fire hazards of using directly off-gases over low-moisture coal. The dry coal can be directly fed to rotary kiln and eliminate heat losses due to surface moisture in coal. The WHR-based rotary drum dryer can be installed in all existing DRI plants irrespective of the installed capacities and having other WHR-based applications.



WHR-based rotary drum dryer for surface moisture removal for coal

3.9.3 Savings, Investments, and Greenhouse Gas Reduction

The energy-saving potential with rotary drum dryer for a 100-tpd kiln using DRI process is about 3%. The coal saving from rotary dryer is estimated to be 1065 tpy (554 toe per year). The GHG emission reduction potential is 1900 tonne CO_2 per year.

WHR-based rotary drum dryer for surface moisture removal from coal		
Temperature of off-gases	°C	550
Quantity of off-gas required*	Nm³/h	15
Temperature of preheated air	°C	250
Initial surface moisture in coal	%	10±2
Final surface moisture in coal	%	4
Energy saving	%	3.5
Coal saving	tpy	1275
Monetary benefits	Rs lakh/year	66
Investment	Rs lakh	100
Payback	Year	1.5

** Considering overall system efficiency of 40%; marginal increase in energy consumption due to blower and drum operation.*

Source: *TERI*

3.10 Energy-efficient Motors

3.10.1 Background

The share of electricity consumption in DRI production process is very low compared to thermal energy consumption; however, its share is quite significant in terms of absolute value. The motive loads are the major consumers of electricity, which includes equipment like kiln drive, ID fan, shell air fans, crushers, cooling tower pumps, material handling system, and air compressor. For a 100-tpd coal-based DRI plant, the motor capacity is in the range of 7.5 kW to 75 kW. Most of the motors used are of standard type.

3.10.2 Technology Brief

High-efficient motors consume less power, both at part load and at full-load conditions and, hence, the inefficient motors can be replaced with premium efficiency IE3 motors. There is a difference of 2%–4% for energy-efficiency improvements with the use of IE3 motors, depending on motor capacities. The quantum of energy savings is much higher for rewound motors.

Comparison of energy efficiency of motors						
Motor rating (kW)	Efficiency (%)					
	2-pole		4-pole		6-pole	
	Standard	Energy efficiency	Standard	Energy efficiency	Standard	Energy efficiency
7.5	86.0	90.1	86.0	90.4	84.7	89.1
15	88.7	91.9	88.7	92.1	88.7	91.2
30	90.7	93.3	90.7	93.6	90.2	92.9
45	91.7	94.0	91.7	94.2	91.4	93.7
75	92.7	94.7	92.7	95.0	92.6	94.6
90	93.0	95.0	93.0	95.2	92.9	94.9

Source: *IS 12615:2011 (three-phase, 50 Hz, single speed and squirrel cage induction motors)*

3.10.3 Savings, Investments, and Greenhouse Gas Reduction

A typical example of electrical motor application is ID fan in rotary kiln, which uses 75 kW standard motor in a 100-tpd plant. This standard motor can be replaced with an IE3 (4-pole) motor, having efficiency of 95%. Increase in the efficiency is possible, depending upon base case. The annual energy saving with use of IE3 motor in ID fan is 22,100 kWh per year (2 toe per year). The GHG emission reduction potential with use of IE3 motor is 18 tonne CO_2 per year.

IE3 motors for crushers			
Parameter	Unit	Existing	IE3
Motor capacity	kW	75	75
Efficiency	%	90	95
Energy saving	kWh/year		22,100
Monetary benefits*	Rs lakh/year		0.63
Investment	Rs lakh		3.0
Payback	Year		4.7

** Based on cost of export power to grid.*
Source: *TERI analysis*

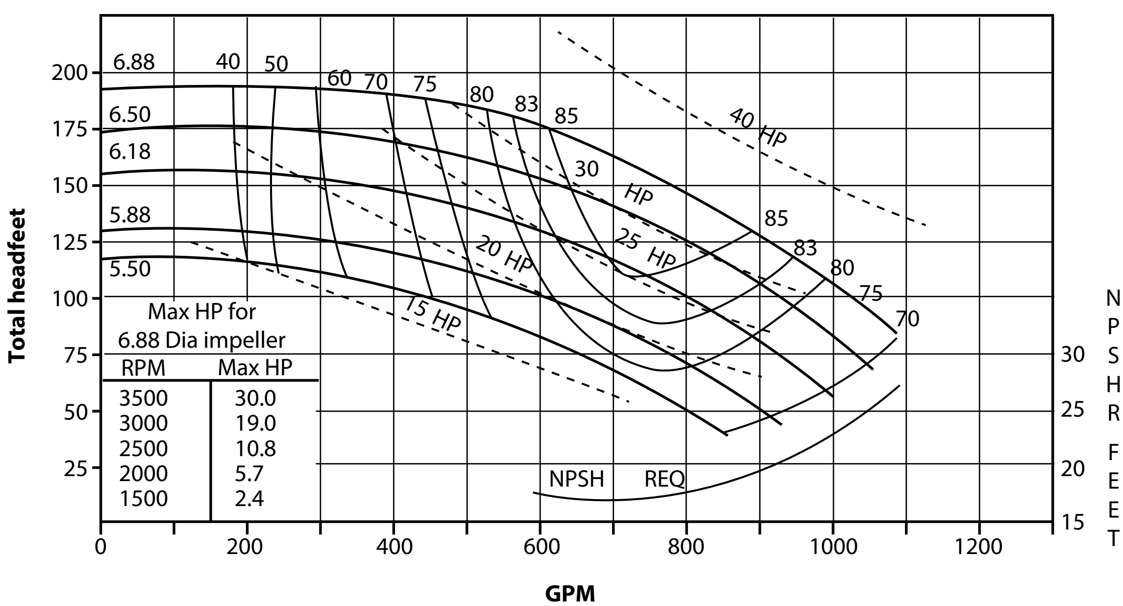
3.11 Energy-efficient Pumps

3.11.1 Background

Cooling water is used in rotary cooler for reducing the temperature of the DRI product from 950°C to 120°C to avoid oxidation of sponge iron. Water is sprayed over the outer surface to reduce the temperature of the material indirectly. The efficiency of the pumps used in cooling water circuit are generally low, at about 50%. The use of energy-efficient pumps would lead to reduced energy consumption by pumping system.

3.11.2 Technology Brief

An efficient pumping system depends on factors such as water flow rate, piping layout, control techniques, and pump selection. Energy-efficient centrifugal pumps can be used in place of inefficient pumps, which provide advantages such as high-flow rates, smooth and non-pulsating delivery, and regulation of flow rate over a wide range. Centrifugal pumps are compact and can be easily disassembled for maintenance purposes. The wear caused by normal operation is minimal in the case of centrifugal pump due to less number of moving parts.



Characteristic curve for a pump

The performance curve of a pump is an important consideration for selection of an energy-efficient pump. A pump can be operated efficiently by keeping its operation close to the best efficiency point (BEP), while meeting the requirements such as flow rate and head required. To minimize energy consumption, the pump should be selected in such a manner that the system curve intersects the pump curve within 20% of its BEP. In order to maximize the efficiency, the pump impeller should be selected in the mid-operating range.

3.11.3 Savings, Investments, and Greenhouse Gas Reduction

As an example, the inefficient pump of the cooling tower can be replaced with an energy-efficient pump while keeping similar hydraulic power output. The motor rating of an energy-efficient system will be 18.5 kW, replacing 30-kW inefficient pump. The energy saving is estimated to be 84,100 kWh per year (7.2 toe per year). The investment requirement is about Rs 1.3 lakh with a payback period of about 0.5 year. The GHG emission reduction potential is 69 tonne CO_2 per year.

Energy-efficient pumps for rotary cooler			
Parameter	**Unit**	**Existing**	**EE pump**
Flow rate	m³/h	300	300
Head	M	15	15
Pump efficiency	%	50	70
Motor efficiency	%	85	93
Electricity saving	kWh/year		84,100
Monetary benefits	Rs lakh/year		2.4
Investment	Rs lakh		2.0
Payback	Year		<1

** Based on cost of export power to grid.*

Source: *TERI analysis*

3.13 Variable Frequency Drives for Air Compressors

3.13.1 Background

In DRI plants, compressed air is used both in process and in service requirements. Compressors execute load–unload mode or on-off line control of operation. In load–unload compressor, motor keeps running continuously but unloads the compressor at set discharge pressure. The power consumption of air compressor during unload varies about 30%–40% of rated power consumption for rotary screw compressor (without VFD) and 15%–20% for reciprocating-type air compressor.

3.13.2 Technology Brief

The VFD is used to minimize electricity consumption during unload in rotary screw compressor. VFD-enabled air compressors can deliver variable air flow to maintain set pressure based on end-use points. The energy consumption and air flow of a VFD-based air compressor is directly proportional to motor speed and, hence, results in higher energy savings as compared to fixed-speed compressors with partial loading. The VFD control adjusts the speed of drive motor and coupled compressor to respond to changes in air demand while maintaining constant pressure. In a multi-air compressor system, fixed-air compressors are used to meet the base load, while VFD-based air compressor is used to supply the fluctuating or trim load.

3.13.3 Savings, Investments, and Greenhouse Gas Reduction

The annual energy saving with use of VFD-based rotary air compressor in DRI plant is 70,000 kWh per year (6 toe per year). The GHG emission reduction potential is 63 tonne CO_2 per year.

VFD application in air compressor			
Parameter	**Unit**	**Inefficient compressor**	**VFD-built compressor**
Rated capacity	CFM	126	63–142
Rated power	kW	22	22
Full load time	h/year	4,320	3,110
Annual energy consumption	kWh/year	145,700	75,200
Monetary benefits	Rs lakh/year		2.3
Investment	Rs lakh		3.0
Payback	Year		1.3

** Based on cost of export power to grid*
Source: *TERI analysis*

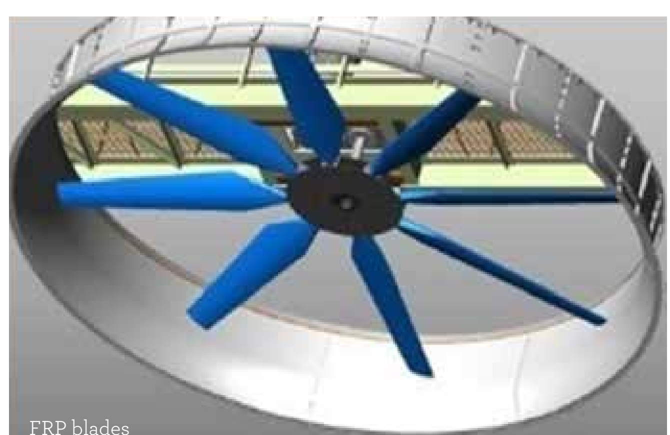
3.14 Fibre-reinforced Plastic Blades for Cooling Tower Fans

3.14.1 Background

Water is sprayed on the top of rotary cooler to cool down the products indirectly. Metal blades—made of aluminium—are generally used in a large number of cooling tower fans. It is important to note that, the use of metal blades substantially increases the overall weight of the cooling system, leading to higher power consumption.

3.14.2 Technology Brief

The metal blades in cooling tower fan can be replaced with lighter fibre-reinforced plastic (FRP) blades, which would reduce the power consumption of the cooling tower system. Further, it increases the possibility of de-rating or resizing the motor capacity of cooling tower fan to allow the use of lower-sized motor. The other advantages of FRP blade include high reliability and better performance due to lower failure rate.



FRP blades

3.14.3 Savings, Investments, and Greenhouse Gas Reduction

The typical energy saving with use of FRP fan blades in cooling towers is about 15%. The annual energy saving is 10,300 kWh per year (0.9 toe per year). The GHG emission reduction potential is 8 tonne CO_2 per year.

IE3 motors for crushers			
Parameter	**Unit**	**Existing**	**IE3**
Motor capacity	kW	10	7.5
Efficiency	%	85	91
Energy saving	kWh/year		10,300
Monetary benefits*	Rs lakh /year		0.29
Investment	Rs lakh		0.7
Payback	Year		2.4

** Based on cost of export power to grid.*

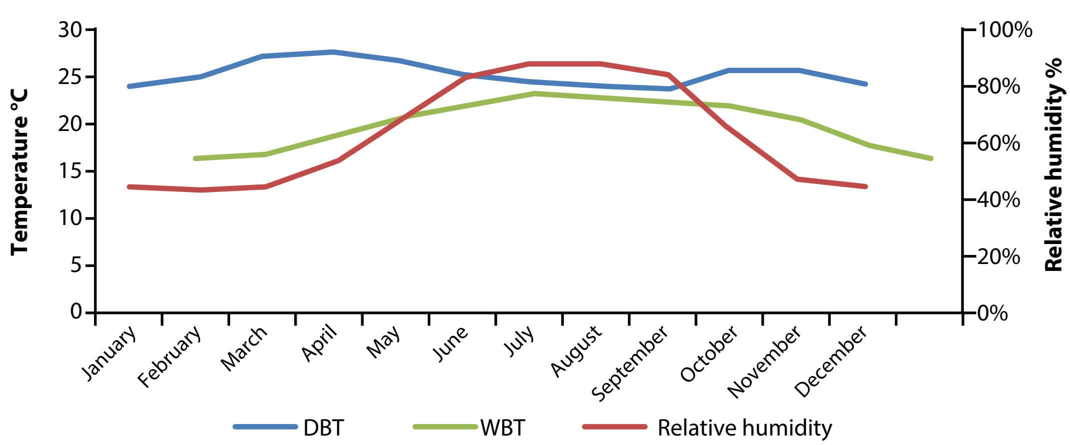
Source: TERI analysis

3.15 Thermostatic Controller for Cooling Tower

3.15.1 Background


Rotary cooler

The cooling tower is used to reduce the temperature of incoming water based on wet bulb temperature and relative humidity of ambient conditions. Most of the cooling towers are not equipped with automatic control system to regulate the fan operation. Some of the plants use manual controls based on outlet temperature of cooling water. The seasonal variations in ambient temperatures and relative humidity clearly indicate that continuous monitoring of temperatures is required in cooling tower for effective operation. The maximum possible drop in temperature of cooling water is limited to the wet bulb temperature of the ambient conditions.



Typical seasonal variations in ambient conditions

3.15.2 Technology Brief

Automatic control system is preferred in place of manual controls. The most common system used in cooling towers is thermostatic controller which senses the outlet temperature of the cooling water. The controller switches on or off the fan automatically based on prevailing level of cooling water temperature.

3.15.3 Savings, Investments, and Greenhouse Gas Reduction

The typical energy saving with installation of thermostatic controllers in cooling water circuit is about 20%, depending on geographical location due to variations in winter season. The annual energy saving is 13,800 kWh per year (1.2 toe per year). The GHG emission reduction potential is 11 tonne CO_2 per year.

Thermostatic controller in cooling tower		
Parameter	**Unit**	**Value**
Motor capacity	kW	10
Energy saving	%	20%
	kWh/year	13,800
Monetary benefits*	Rs lakh /year	0.4
Investment	Rs lakh	0.15
Payback	Year	0.5

** Based on cost of export power to grid.*
Source: *TERI analysis*

3.16 Automatic Power Factor Controller

The electrical loads associated with rotary kiln-based DRI plant mainly include ID fan, kiln drive, shell air fan, bag filter system, raw material crusher, water pump, air compressor. The overall power factor of the plant is associated with electrical billing. Lower power factor will attract penalties, whereas maintaining higher power factor will earn rebate on the billed amount. It is essential for the plant to regularly inspect the power factor and take remedial actions, if necessary. The power factor can be improved and kept close to unity by installing automatic power factor controller (APFC) at incomers and high-load centres.

Power factor at load centres	
Load centre	**Preferable power factor**
Induction motor	0.95
Distribution system	0.99
Welding machine	0.90 and above
DC drive	0.90 and above
Fluorescent lamp	0.95 and above

4 POTENTIAL LOW-CARBON TECHNOLOGY OPTIONS FOR INDIAN DIRECT REDUCTION OF IRON SECTOR

The Indian direct reduction of iron (DRI) sector is unique as coal-based route is generally employed unlike globally accepted gas-based options. The wide use of coal-based route in India is mainly attributed to the availability of large quantity of non-coking coal. In comparison to gas-based processes, the coal-based DRI production process is quite energy intensive and poses environment-related issues. Being a developing country with steel demand projected to reach between 500 and 760 million tonne (Mt) by 2050, the country needs to adopt energy-efficient and environment-friendly steel production technologies to meet the growing steel demand.

One of the best options to improve the energy efficiency and reduce greenhouse gas (GHG) emissions from Indian DRI sector is to switch over to gas-based route in future and work towards making gas-based route commercially viable. Another option that Indian DRI plants can explore is to adopt efficient coal-based technologies that are being used for DRI production globally.

Coal-based DRI processes			
Process	**Raw material**	**Product**	**Largest single module (Mtpa)**
ACCAR/grate car	Fines	Solid	0.35
AISI/cyclone	Fines	Molten	0.5
AISI/pellet	Pellets	Molten	0.35
Circofer	Fines	Solid	0.5
COREX	Pellets/lumps	Molten	1.2
DIOS	Fines	Molten	1.0
DRC	Pellets/lumps	Solid	0.15
FASTMET	Fines	Solid	0.45
FINEX	Fines	Solid	0.25
HIsmelt	Fines	Molten	0.50
INMETCO	Fines	Solid	0.3
Romelt	Fines/lumps	Molten	0.4
SL/RN	Pellet/lump/fines	Solid	0.25
Tecnored	Fines	Molten	0.3
Coal gasification + HYL self-reforming (ZR) plant	Pellets/lumps	Molten	-
Coal-based ULCORED	-	Solid	-

Sources: *Duarte (n.d.); Sikstrom (2013)*

A brief highlight of the select technological options that are best suited for DRI production in India is provided in this section. The options have been categorized into three sub-sections. Section 4.1 covers the technologies using direct coal; Section 4.2 details out the technologies using coal gasification route; and technologies using gas route (natural gas and hydrogen) are covered in Section 4.3. In addition, a separate section highlights the usage of hydrogen for Indian iron and steel sector (Section 4.4).

4.1 Direct Reduction of Iron Production Using Solid Coal

4.1.1 FASTMET and FASTMELT Process

Background

The FASTMET process is a coal-based DRI, jointly developed by Kobe Steel and MIDREX Technologies Inc. In this process, the iron ore fines and/or steel mill wastes are converted into metallic iron in a rotary hearth furnace (RHF) using carbon as the reductant. The current FASTMET technology has its roots in the heat-fast process—a natural gas/air-fired rotary-hearth-based DRI process developed by Midland Ross Corporation, National Steel Corporation, and Hanna Mining in 1965. The demonstration plant of FASTMET process was built in 1995 at Kobe Steel's Kakogawa Works. The first commercial plant was supplied to the Nippon Steel Co. (Hirohata Works) for reducing 190,000 tonne per year (tpy) of steel mill waste.

Process Description

In the FASTMET process, the feed pellets, that is, composite agglomerates comprising iron oxide fines and carbon sources (coal, charcoal, etc.) are placed in one or two even layers over the hearth and are heated using radiation heat. The indirect heating helps in preventing oxidation of agglomerates. During the movement over the hearth, the pellets are heated by burners placed above the hearth. A rapid heating method is adopted for heating the pellets/briquettes to a temperature of about 1350°C. A combustible gas generated from burning of carbon present in agglomerates helps in secondary combustion which suppresses the formation of NO_x despite high temperature of the furnace. The air/gas ratio maintained in the furnace helps in achieving heating and reduction of agglomerates simultaneously.

$Fe_2O_3 + 3C = 2Fe + 3CO$

$Fe_3O_4 + 4C = 3Fe + 4CO$

$Fe_2O_3 + 3CO = 2Fe + 3CO_2$

$Fe_3O_4 + 4CO = 3Fe + 4CO_2$

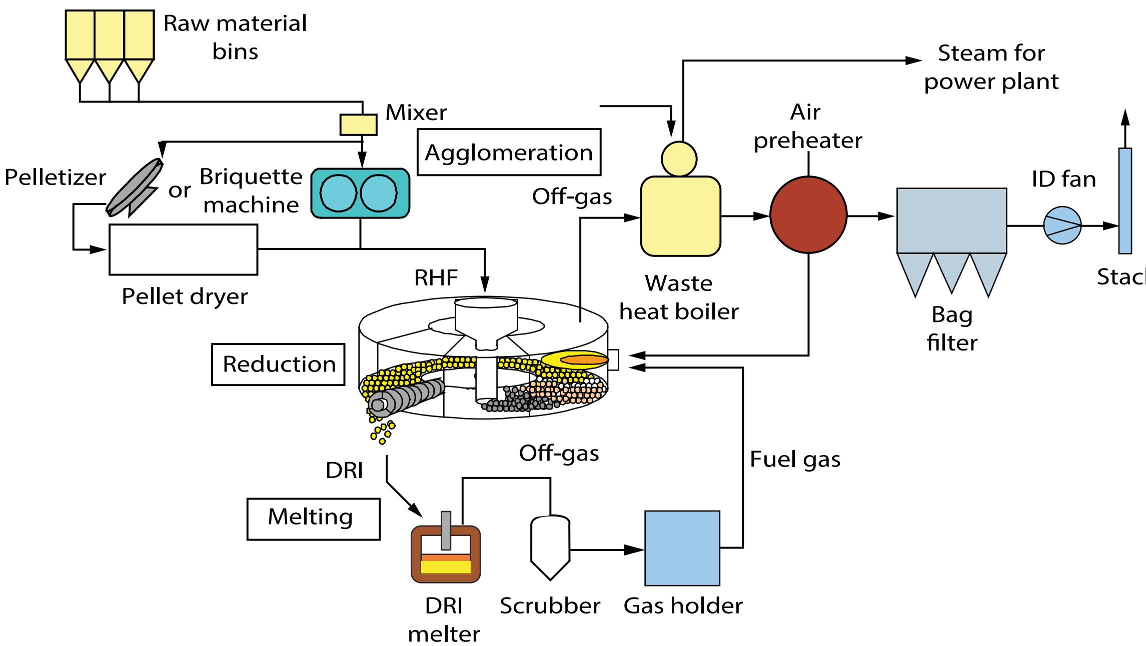
$FeO + CO = Fe + CO_2$

$ZnO + CO = Zn + CO_2$

The FASTMET DRI is discharged continuously from the furnace using a water-cooled screw arrangement. The agglomerates are converted into DRI within 8–16 minutes, which can be either fed into a blast furnace or used directly into the melting process.

FASTMELT Process

FASTMELT process is same as the FASTMET process with addition of an electric iron melting furnace (EIF) to produce liquid iron or hot metal. The FASTMELT process was introduced by MIDREX Technologies as an alternative to FASTMET process to overcome the issues pertaining to higher gangue and sulphur content in coal. In this process, the DRI is produced using rotary hearth furnace (the FASTMET process). The high temperature DRI is transferred to a melting furnace (EAF or coal-based melter), wherein it is melted, sulphur is removed, and slag is separated to produce molten iron. A pilot plant was built by MIDREX Technologies in 1995 based on the FASTMELT process by adding EAF to the FASTMET pilot plant.



FASTMELT process
Source: Kobelco

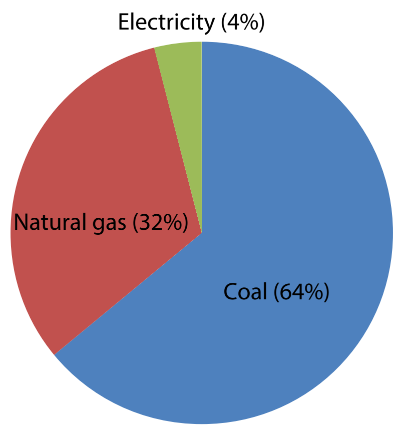
Resource consumption in FASTMET process		
Description	**Unit**	**Specific consumption**
Iron ore fines	tonne	1.2–1.35
Coal	tonne	0.3–0.4
NG	GJ	2.1–2.9
Electricity	kWh	80–100
Bentonite	tonne	0.030–0.040
Nitrogen	Nm^3	2.5
Water	m^3	1–2

Source: *Kekkonen and Holappa (2000)*

The average SEC of FASTMET process is 1.86 Gcal/t-DRI (ranging from 1.59 to 2.14 Gcal/t-DRI). Coal accounts for about two-thirds of the total energy consumption in the process. The average GHG emissions with FASTMET process is 0.72 tCO_2/t-DRI.

Technology Status

The installed capacity of FASTMET technology-based DRI plants varies in 16,000–190,000 tpa range.



Energy share in FASTMELT process

Status of technology			
Plant	**Location**	**Year of commissioning**	**Capacity (tpa)**
Nippon Steel	Hirohata, Japan	2000	190,000
Kobe Steel	Kakogawa, Japan	2004	16,000
Nippon Steel	Hirohata, Japan	2005	190,000

Source: *Ishikawa, Kopfle, Mcclelland, et.al. (2008)*

4.1.2 ITmk3

Background

ITmk3 (Ironmaking Technology Mark 3) is a rapid iron-making process that uses iron ore fines and coal fines. With reference to generation classes of iron-making processes, ITmk3 is third-generation iron-making process. The blast furnace (BF) and the direct reduction iron making (DRI) are typified by the MIDREX process as the first- and second-generation processes, respectively. The development of this process was started by Kobe steel in 1996. Later on the collaborative research involving universities and institutes (Tohoku University, Tokyo Institute of Technology, University of Surrey (UK), and Max Planck Institute in Germany) resulted in further refinement and development of the process. The first commercial plant using ITmk3 technology is Steel Dynamics, Inc., USA started the production in 2010.

Process Description

In this process, iron ore concentrate and non-coking coal (reducing agent), limestone (flux), and bentonite (binder) are mixed together and agglomerated into green self-reducing pellets. These pellets are fed into a rotary hearth furnace (RHF) where self-reducing, fluxing dried green balls are reduced, carburized, and smelted. The product is granular iron called iron nuggets (96%–97% pure). Iron nuggets improve the productivity and energy efficiency of electric arc furnaces (EAFs). With better melt-ability than blast-furnace pig iron, iron nuggets can be continuously fed into EAFs.

In the ITmk3 process, a series of reactions occur within about 10 minutes at about 1350°C. The reactions occur much faster than BF (8 hours) or MIDREX process (6 hours). The reactions between iron ore and coal remain the same as that for general iron making.

$Fe_xO_y + yCO = xFe + yCO_2$ ....(1)

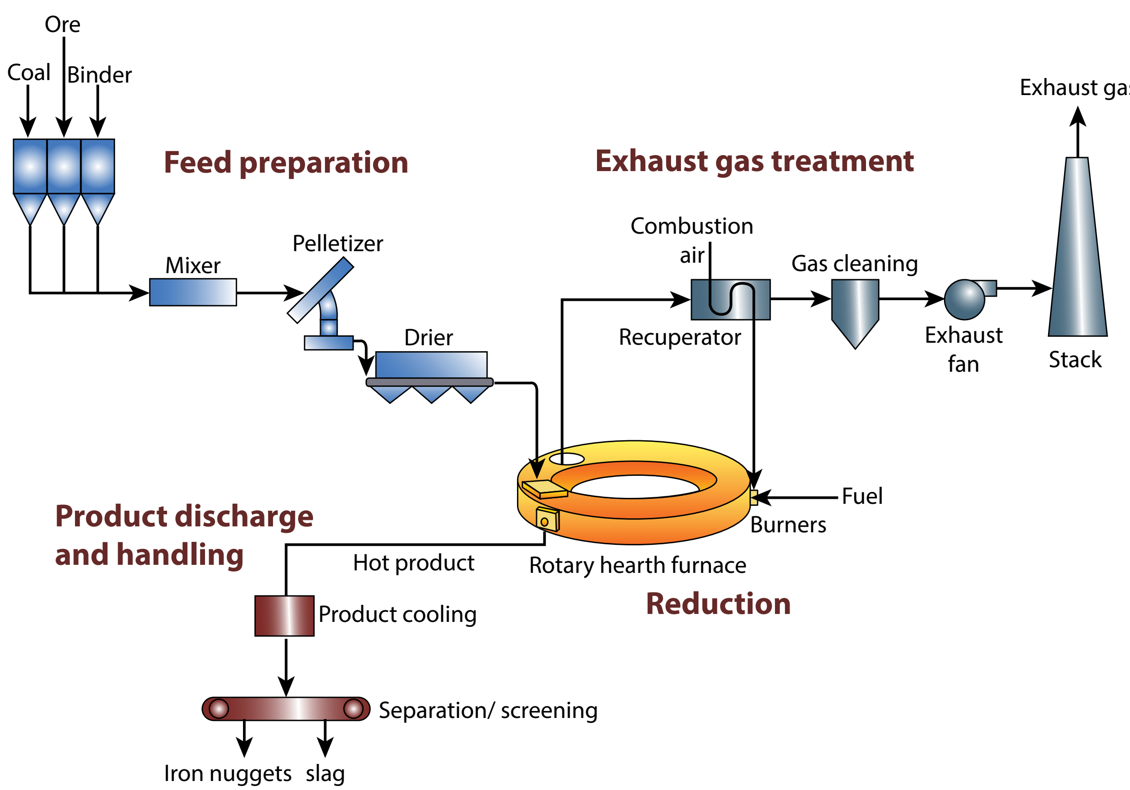
$CO_2 + C = 2CO$ ....(2)

C(s) = C (carburized) ....(3)

Fe(s) = Fe(l) (melt) ....(4)

Iron nuggets

Reactions (1) and (2) occur in the FASTMET process. Reactions (3) and (4) are additional reactions in the ITmk3 process in which the slag is separated from the metallic iron. Since the ITmk3 process separates metal and slag in one step, it effectively concentrates the iron ore. The process can use coal, petroleum coke, or other forms of solid reductants.



ITmk3 process

Source: Kobelco

Resource Consumption

ITmk3 process consumes about 30% less energy and the GHG emissions are about 20% lower as compared to BFs.

Specific consumption of input materials	
Input	Specific consumption (per tonne iron nuggets)
Iron ore fine	1.5 tonne (> 60% Fe)
Non-coking coal	0.5 tonne
Fuel gas	4.6 GJ
Electricity	200 kWh
Water	2 m^3
Air	85 m^3
Nitrogen	12 m^3

Source: *Kar (2015)*

Technology Status

Itmk3 technology is commercially available. The installed capacity of first commercial plant, which is a joint venture of Kobe Steel and SDI, was 500,000 tpa.

Status of technology			
Plant	**Location**	**Year of commissioning**	**Capacity (tpa)**
Mesabi Nugget Delaware, LLC	Hoyt Lake, Minnesota, USA	2010	500,000

Source: *Kobelco*

4.2 Direct Reduction of Iron Production Using Coal Gasification

4.2.1 MIDREX Process (MxCol Process)

MxCol® is the trademark for use of syngas derived from coal in the commercially proven MIDREX® direct reduction process. MIDREX has collaborated with Siemens VAI Metals Technologies GmbH, Paul Wurth SA., Lurgi GmbH, Synthesis Energy Systems, Inc. and Praxair, Inc. to develop innovative solutions towards generation and use of reducing gas for direct reduction process.

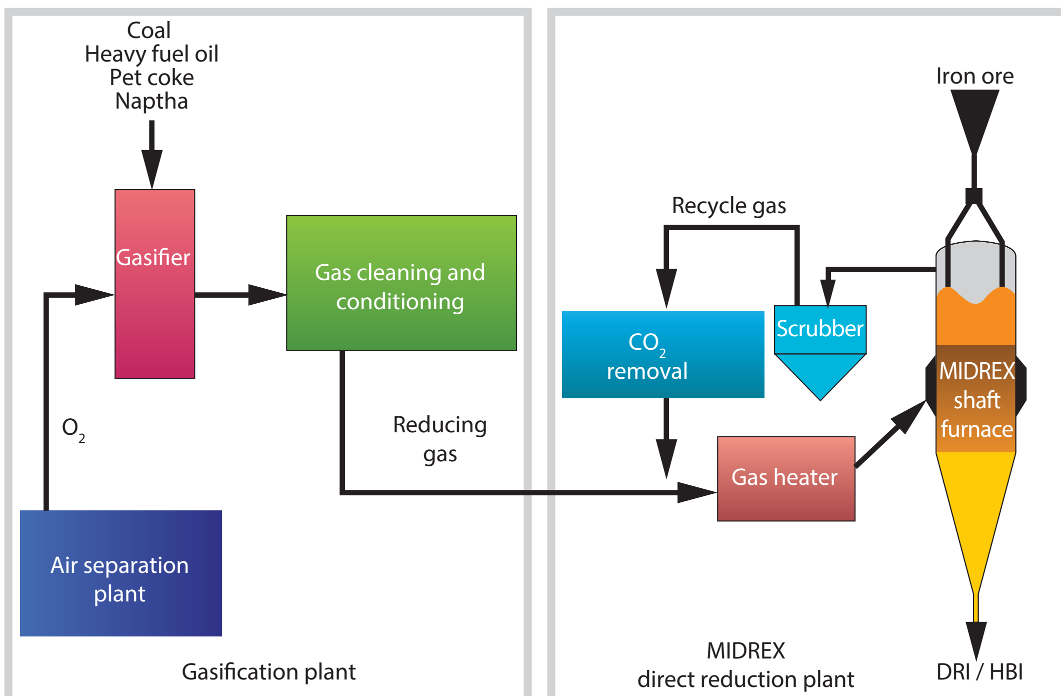
Process Description

In this process, the MIDREX reactor and its auxiliary systems are the same as for gas-based MIDREX plants. The reactor includes dynamic top and bottom seals and operates at a relatively low pressure of 1.5 bar. The oxide material flows downwards by gravity through reduction, transition, and cooling zones, and the product is discharged at a controlled rate from the bottom. In the MIDREX plant, the cold syngas is depressurized at about 3 bar. In the case of high- flow rate of syngas, a turbo generator is used for depressurizing the process. The low pressure syngas is mixed with recycled gas to produce reducing gas. The mixed syngas is heated to about 900°C, which enters the MIDREX shaft furnace and reacts with iron oxide to produce DRI.

The involved reduction reactions are as follows:

$Fe_2O_3 + 3H_2 = 2Fe + 3H_2O$

$Fe_2O_3 + 3CO = 2Fe + 3CO_2$



Gasifier-MIDREX flow sheet

Source: MIDREX

The spent gas (top gas) from the shaft furnace is cleaned and cooled in a venturi scrubber and further cleaned for CO_2 and H_2S. This reduces the CO_2 content to about 5% or below which ensures that mixed reducing gas (syngas from gasification plant and recycled top gas from MIDREX plant) has an acceptably high reductant (H_2 + CO) to oxidant (H_2O + CO_2) ratio (>10) for efficient iron ore reduction. Similar to NG-based MIDREX process, the H_2/CO ratio is kept about 1.6. The DRI is discharged from the shaft furnace at about 700°C. The treated gas is recycled into reducing gas circuit. The gasification process allows for use of various bituminous and sub-bituminous coals, lignite, petcoke, and petroleum refinery bottoms. The slag produced by gasifier is granulated and has commercial value. Three types of gasifiers, namely, fixed bed, entrained flow, and fluidized bed are available; due to their ability to use high-ash coal, the fixed bed (for example, Lurgi coal gasifiers) and fluidized bed are more suited for coal gasification routes for India.

Resource Consumption

The resource consumption for MXCOL process based on a plant capacity of 180,000 tpy of hot DRI (with characteristics as 93% metallization, 1.8% carbon, and 700°C discharge temperature) using high-ash coal is provided here.

Resource consumption - MXCOL process (for Indian conditions)		
Input	**Unit**	**Quantity (per tonne hot DRI)**
Iron ore	tonne	1.42
Coal (as mined)	tonne	0.75
Coal (ash free)	tonne	0.41
High-pressure steam	tonne	0.6
Low-pressure steam	tonne	0.4
Oxygen	Nm^3	150
Nitrogen	Nm^3	200
Electricity	kWh	175

Technology Status

MXCOL technology is commercially available. The details of plants which have adopted MXCOL process are given here.

Details of plants using MXCOL process		
Plant	**Location**	**Capacity (Mtpa)**
Arcelor Mittal Steel South Africa (formerly Saldanha Steel)	Saldanha Bay, South Africa	0.8
Jindal Steel & Power Limited (JSPL)	Angul (Odisha, India)	1.80
JSW Steel Limited	Vijayanagar (Karnataka, India)	1.20
JSW Steel Limited	Dolvi, Raigarh (Maharashtra, India)	1.6

4.2.2 Coal-based HYL/ Energiron Process

Background

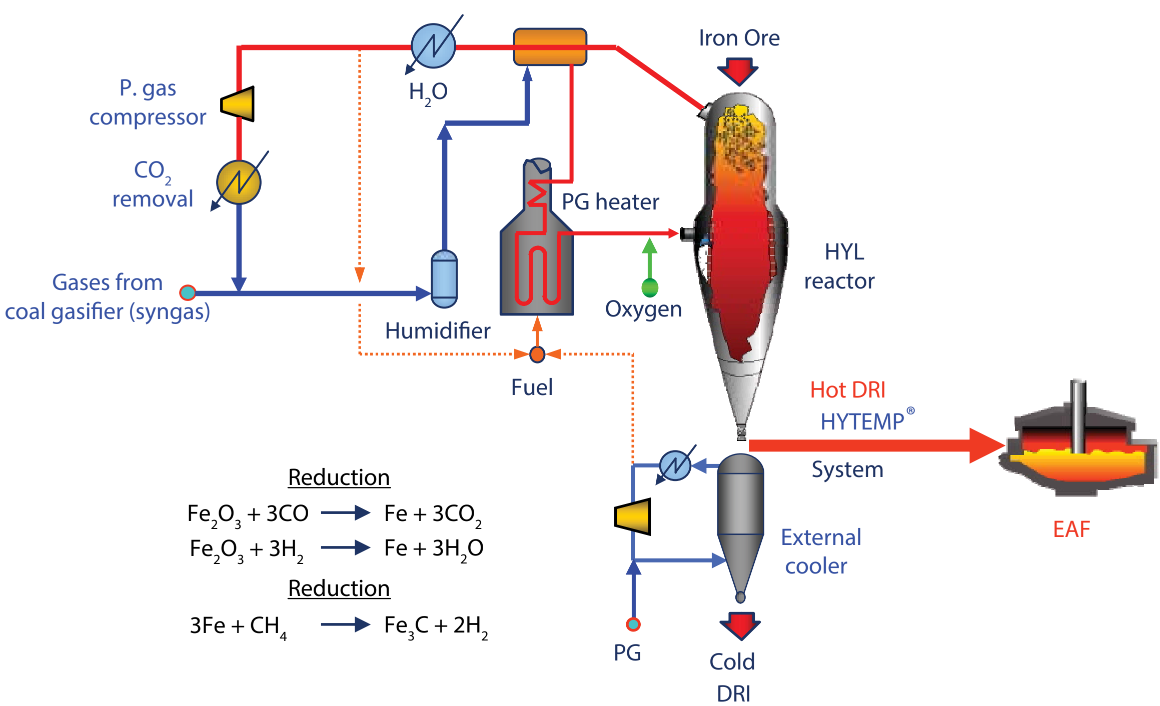
HYL process is designed for the conversion of iron ore (pellet/lump ore) into metallic iron, by the use of reducing gases in a solid-gas moving bed reactor. Oxygen (O_2) is removed from the iron ore by chemical reactions based on hydrogen (H_2) and carbon monoxide (CO) for the production of highly metallized direct reduced iron (DRI)/hot-briquetted iron (HBI). Energiron, a trademark of the strategic alliance between Tenova HYK and Danieli, provides design and construction of gas-based DR plants. Energiron

DRI is a highly metallized product with controllable carbon content in the range of 1.5%–4.0%. While HYL-I used batch process and HYL-II focused on its improvements, HYL-III uses continuous shaft furnace, leading to high productivity, superior DRI quality, and lower energy consumption.

Process Description

In HYL process, oxide material is fed from top and is reduced by a counter current flow of H_2 and CO containing gas. The furnace top gas is cooled, cleaned, and its CO_2 is captured and recycled into reducing gas circuit. Reducing gas is produced in a coal gasifier which uses all types of carbon-bearing material. The main characteristics of the HYL process include: (i) utilization of H_2-rich reducing gases (H_2/CO ratio> 4), (ii) high-reduction temperature (usually >930°C), and (3) high-operating pressure (5-kg/cm^2). The high-operating pressure in the shaft furnace also results into a high-furnace productivity of around 9 T/h/m^{2}area. Since HYL reactor is designed to work with a reducing gas of high H_2 content, and the reducing gases contain significant quantities of CO, a gas shift reactor is required to convert CO into H_2. The reaction involved is as follows:

$CO + H_2O \rightarrow CO_2 + H_2$



HYL-ZR DR plant with syngas from gasifier

Source: *HYL*

The shift reactor is installed before CO_2 removal system. The temperature and pressure of the gas are then regulated before injecting into the reactor. The mixture of syngas make-up and recycle gas is preheated in a direct gas heater up to 930°C and fed to the reactor. After reduction of iron ore, the top exhaust gas is passed through a scrubbing unit and recycled by the compressor. A top gas recuperator can be installed to reduce the energy consumption of the system.

Resource Consumption

To facilitate understanding, an example of resource consumption in HYL-DR plant operation with coal gasifier is provided in the following table.

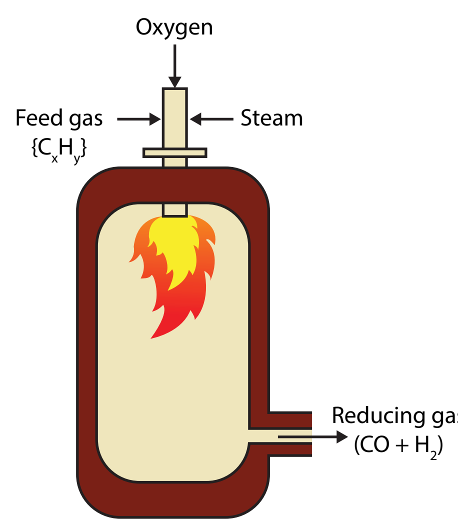
Resource consumption of HYL-DR plant with coal gasifier		
DR plant	**Unit**	**Value**
Production capacity	tpa	1,200,000
Metallization	%	>=93
Carbon	%	2
DRI temperature at EAF	°C	600
Specific consumption		
Pellets	tonne	0.97
Lump ore	tonne	0.41
Total syngas	Nm^3	685
Electricity	Kwh	65
Oxygen	Nm^3	5
Water	m^3	1

Source: *Duarte (n.d.)*

4.2.3 ULCORED Process

Background

ULCORED is one of the research areas within the ULCOS project that aims to enhance the direct reduction technologies based on natural gas. This is achieved by replacing traditional reforming technology with partial oxidation of natural gas (NG). Designed in 2006 by LKAB, Voestalpine and MEFOS, an in-depth fundamental model studies for the ULCORED DR process have been completed. The process has the potential to retrofit existing direct reduction plants at commercial scales.



Production of reducing gas by partial oxidation
Source: *Steel 360*

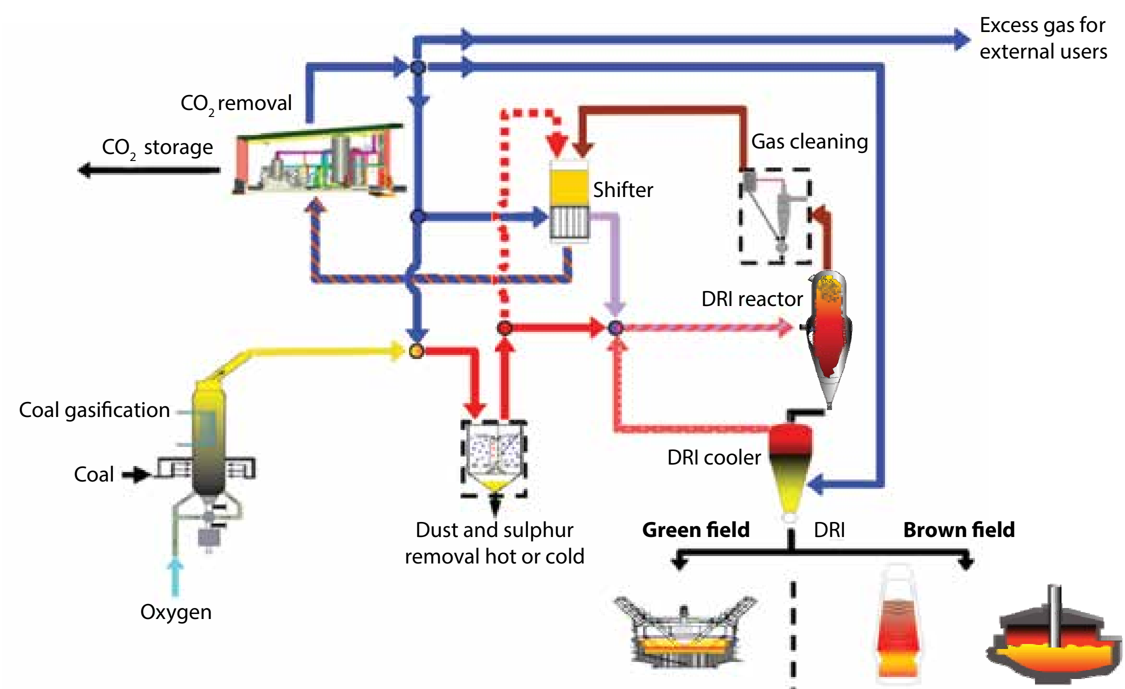
Process Description

ULCORED is a direct reduction process which produces DRI in a shaft furnace, either from natural gas or from reducing gas obtained through coal gasification. The off-gas from the shaft is recycled into the process after CO_2 removal. The DRI step produces a solid product which is melted in EAF. The main features of the ULCORED process are (i) use of oxygen (O_2) instead of air (indicating there is no or low nitrogen in the gas) that results an off-gas of nearly 100% CO_2, (ii) possibilities to reduce NG requirement by about 15%–20%, and (iii) potential to use coal/ biomass/bio-waste gasification and H_2 as an alternative to NG. The ULCORED process uses partial oxidation of NG instead of reformers and shifter for production of CO_2-free reduction/excess gas. The reaction that occurs is given here:

$$CH_4 + 0.5O_2 = CO + 2H_2 + \Delta H$$

$$\Delta H = -8.6 \text{ kcal/mol}$$

The coal-based concept relies on the production of reducing gas using existing coal gasification technology and either cold desulphurization (based on existing technology) or hot gas desulphurization. The concept uses O_2 instead of air and includes CO_2 storage. The high H_2 content in the reduction shaft is achieved through water gas shifter. The use of coal gasifier and shifter in the system makes it possible to by-pass some of the syngas directly to the shifter, generating more gas than necessary for the direct reduction plant. This feature makes it possible to generate a CO_2 clean fuel for the steel plant.



Coal based ULCORED process

Source: *Steel 360*

Resource Consumption

The specific energy consumption (SEC) is 7.95GJ/t-DRI (1.9 Gcal/t-DRI) for cold discharge and 8.3 GJ/t-DRI (1.98 Gcal/t-DRI) for hot discharge. The CO_2 emission of the process is 0.435 kg/t-DRI (including carbon in the DRI/cold-DRI). The ULCORED process when combined with carbon capture and storage (CCS) has the potential to reduce 70% of CO_2 emissions as compared to BF route.

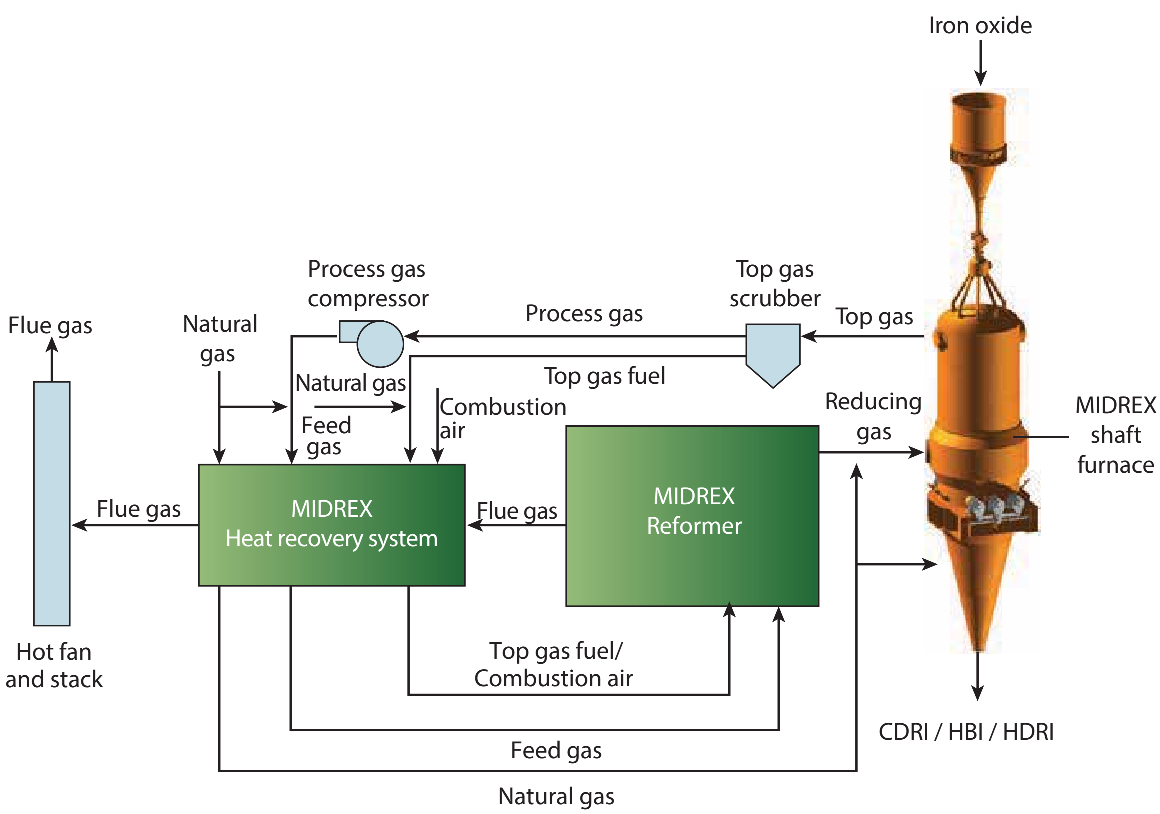
4.3 Direct Reduction of Iron Production Using Gas Route

4.3.1 MIDREX NG Process

MIDREX NG uses MIDREX reformer to produce reducing gases for iron ore reduction reactions in the shaft furnace. Iron ore (either lumps or pellets), charged from the top of the shaft furnace, is reduced and discharged from the bottom of the furnace. The reductant gas entering at the middle of the furnace reduces the raw material to iron metal and leaves from the top of the furnace. The cooling gas, which circulates at the lower portion of the furnace, cools the DRI to about 50°C. The charging port and discharging port are dynamically sealed by a sealing gas, thereby allowing continuous charging and discharging processes. The reactions occurring in the shaft furnace are as follows:

$Fe_2O_3 + 3CO \Leftrightarrow 2Fe + 3CO_2$

$Fe_2O_3 + 3H_2 \Leftrightarrow 2Fe + 3H_2O$



MIDREX NG process

Source: *MIDREX*

The exhaust gas (top gas) emitted from the top of the shaft furnace is cleaned and cooled by a wet scrubber (top gas scrubber) and recirculated for reuse. The top gas, containing CO_2 and H_2O, is pressurized by a compressor and, after mixing with natural gas, is preheated and fed into the reformer furnace. The reformer furnace comprises reformer tubes filled with nickel catalyst. On passing through these tubes, the mixture is reformed to produce reductant gas. The reactions occurring in the reformer are as follows:

$CH_4 + CO_2 \rightarrow 2CO + 2H_2$

$CH_4 + H_2O \rightarrow CO + 3H_2$

$2CH_4 + O_2 \rightarrow 2CO + 4H_2$

$CO + H_2O \rightarrow CO_2 + H_2$

$CH_4 \rightarrow C(s) + 2H_2$

The typical composition of reducing gas comprises 55% of H_2 and 36% of CO (H_2 /CO ratio ~1.5). The MIDREX plant with other syngas can operate with a H_2/CO ratio between 0.4 and 3.5. In addition to providing the reducing gas, the reformer also provides the energy needed for the reduction reactions within the shaft furnace. The MIDREX process has the flexibility to use coke oven gas and other reducing gases derived from petcoke.

To improve the SEC and productivity of the plant, including the downstream steelmaking process, it is possible to discharge hot DRI (HDRI) or make hot-briquetted iron (HBI). HBI is made by compressing DRI discharged from the MIDREX shaft furnace at ≥ 650°C into pillow-shaped briquettes with a typical size of 30 × 50 × 110 mm and a density ≥ 5 gm per cc. No binder is used to make HBI. The HBI is the preferred product for the merchant metallics market as it is denser than cold DRI, which reduces the re-oxidation rate. This enables HBI to be stored and transported without special precautions for shipping solid bulk cargoes. HBI can be used in EAF, BF, and BOF. HDRI with temperature up to 650°C can be transferred to an adjacent EAF for utilizing the sensible heat.

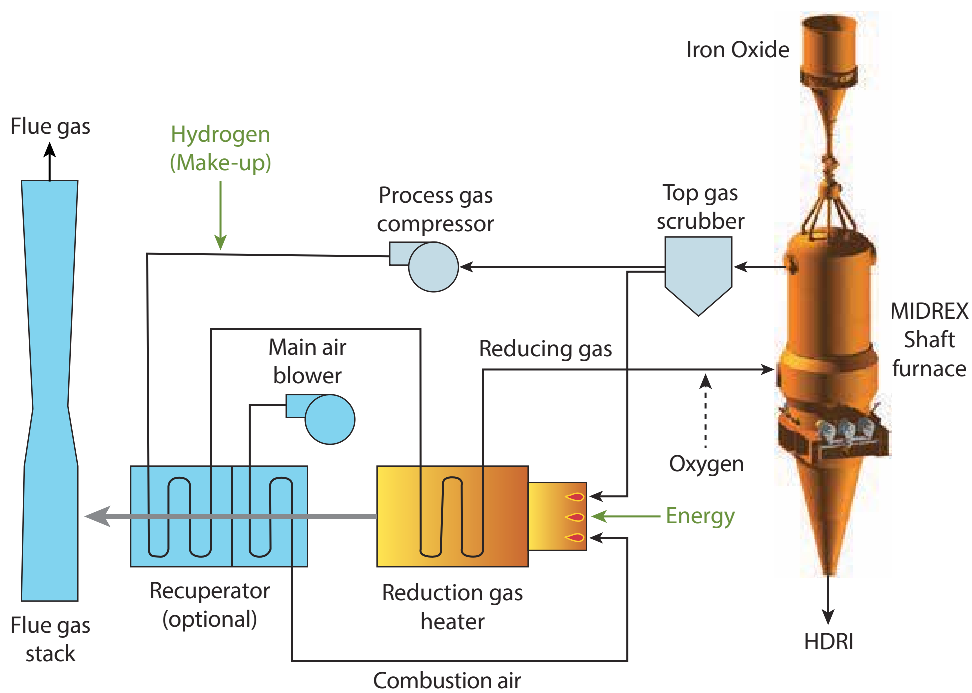
Benefits of HDRI

The use of HDRI in EAF helps in the following:

- Reduces electricity consumption (20 kWh per tonne liquid steel for each 100°C increase in DRI charging temperature).
- Shorter overall melting cycle, resulting in reduction in electrode consumption (by at least 0.5–0.6 kg per tonne liquid steel).
- Decreases refractory consumption (1.8–2 kg per tonne liquid steel).

4.3.2 MIDREX H_2 Process

The natural gas-based MIDREX process, coupled with an EAF, has the lowest CO_2 emission of any steelmaking route using iron ore. There is room to further decrease emissions by using hydrogen as a fuel and chemical reactant in the process. One of the best options available in the near future is to use hydrogen to produce DRI as feedstock for steelmaking, which is known as MIDREX H_2. At present, due to non-availability of hydrogen at sufficient scale it is not possible to transit from coal/NG to hydrogen. However, in the existing MIDREX NG process, up to 30% of NG can be replaced with hydrogen without any change in the existing process. In future, as and when the use of hydrogen becomes economically viable, it can be increased in the process with minor equipment modifications. It is possible to use 100% hydrogen in the reactor by optimizing the carbon in DRI in the melt shop. For a DRI output with 1.4% carbon, the typical bustle gas composition is about 90% hydrogen and the balance is a mixture of CO, CO_2, H_2O, and CH_4. The typical consumption of hydrogen is approx. 650 Nm^3/t-DRI (54 kg/t).



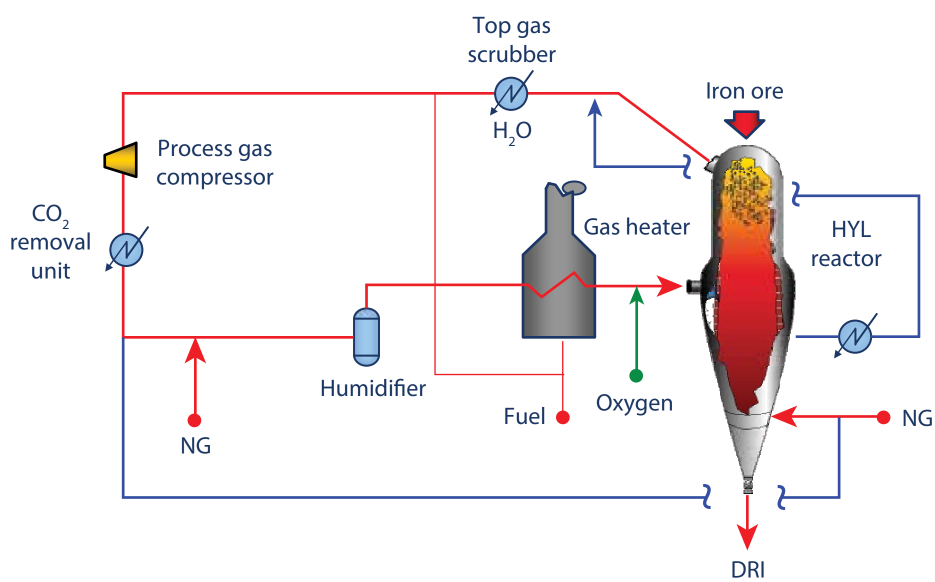
MIDREX H_2 process
Source: *MIDREX*

4.3.3 HYL

The HYL reactor and its peripheral systems and principles of operation are same as described for coal gas-based system in Section 4.2.2. The iron ore is fed from the top and is reduced by a counter-current flow of gas containing H_2 and CO. The furnace top gas is cooled, cleaned, and its CO_2 is captured and recycled into reducing gas circuit. The reducing gases can be generated (i) directly, by *in-situ* reforming of natural gas inside the shaft furnace, (ii) in an external natural gas/steam reformer, (iii) as syngas from gasification of fossil fuels, biomass, etc., (iv) from exhaust gas of smelting reduction process such as COREX, or (v) from coke-oven gas (COG) sources. In all the cases, the process configuration corresponds to the same basic zero reformer (ZR) schemes, adjusting the relative sizes of equipment for the particular application.

Energiron ZR

The ENERGIRON ZR process scheme is the latest achievement in reducing the size and improving the efficiency of direct reduction plants. The process is fed by NG and reducing gases are generated by in-situ reforming within the reduction reactor without any requirement for the reformer. The elimination of the need for an external gas reformer has a significant impact on plant size. For a capacity of 1 million tonne per year of DRI, the area requirement for the plant reduces by around 60%. The Fe contained in the DRI produced by the process itself acts as the necessary, renewable, and continuous catalyst for reforming of CH_4 into H_2 and CO. The Energiron ZR process is independent of the reducing gas source, as the process does not require recirculation of gases back to the reformer to complete the process chemistry loop.

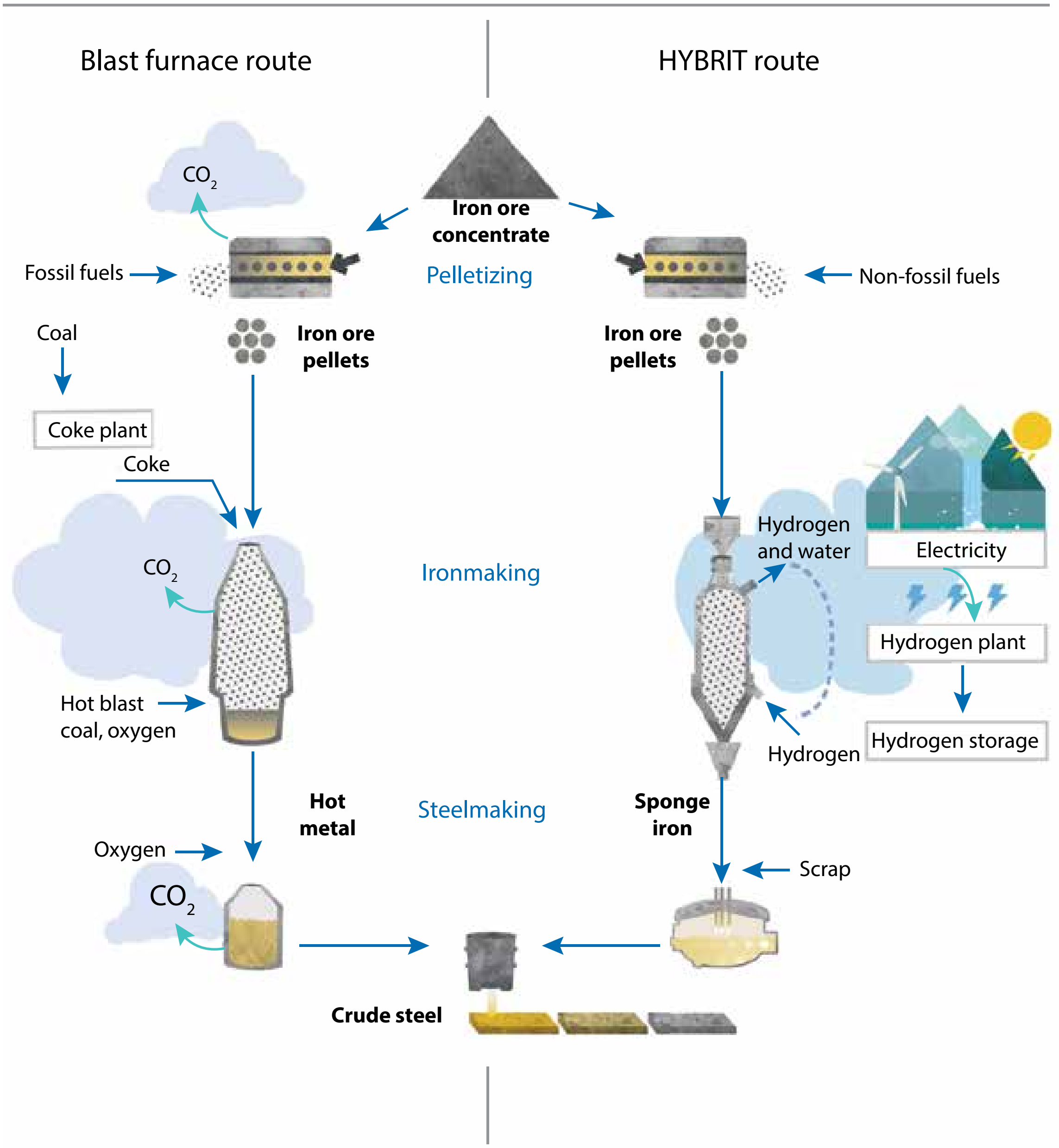


Energiron ZR process
Source: HYL

Another advantage of this process is its flexibility to carburize the DRI as per the requirements of the steel. The carbon level up to 5% can be obtained in the DRI, due to high methane (CH_4) concentration in the process gas introduced into the reactor and the high temperature of the bed (>860°C). Both these conditions favour the diffusion of carbon into the iron matrix and precipitation of iron carbide (Fe_3C) in the DRI product.

HYBRIT

HYBRIT (Hydrogen Breakthrough Ironmaking Technology) is a joint venture between Swedish companies, SSAB (global leader in high-strength steels), LKAB (Europe's largest iron ore producer) and Vattenfall (one of Europe's largest electricity producers), that aims to replace coal with hydrogen in steelmaking process. In this process, iron metal is produced by using hydrogen gas as the main reductant. The production route is similar to existing DR processes, except for CO_2 emissions. Hydrogen reacts with iron oxides to form water instead of carbon dioxide. In the demonstration project in Sweden, hydrogen will be produced by electrolysis of water using fossil-free electricity.

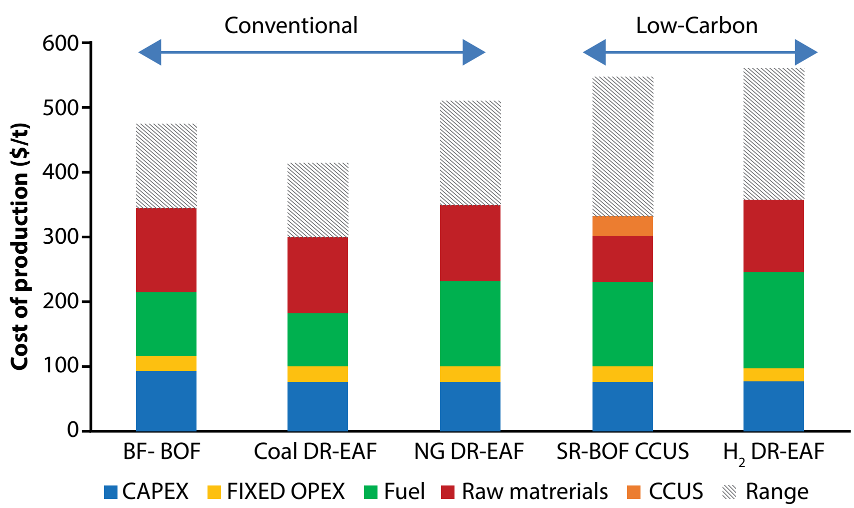


Comparison of blast furnace route and HYBRIT route

Source: HYBRIT

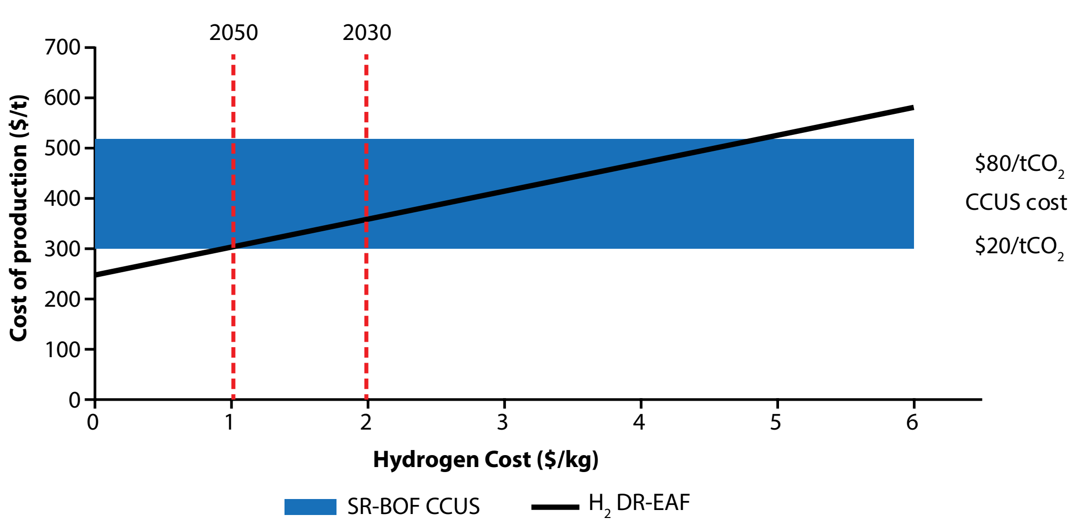
4.4 Hydrogen Use in Indian Iron and Steel Sector

With growing economy, the Indian iron and steel sector is set to grow rapidly over the coming decades. As per TERI's analysis under a low-carbon scenario, the steel demand will rise to around 300 million tonne by 2050. To meet this demand in a sustainable manner, it is important that the low-carbon pathways are deployed for new capacity addition. Owing to cumulative impact of the factors such as falling cost of renewable electricity and electrolyser technologies, coupled with concerted and more coordinated action on climate change, TERI assesses that in the long run hydrogen direct reduction is amongst the most promising options for Indian steel sector to grow sustainably.



Costs of production from various routes, 2020

Sources: TERI analysis based on IEA (2019); BNEF (2020); sector experts



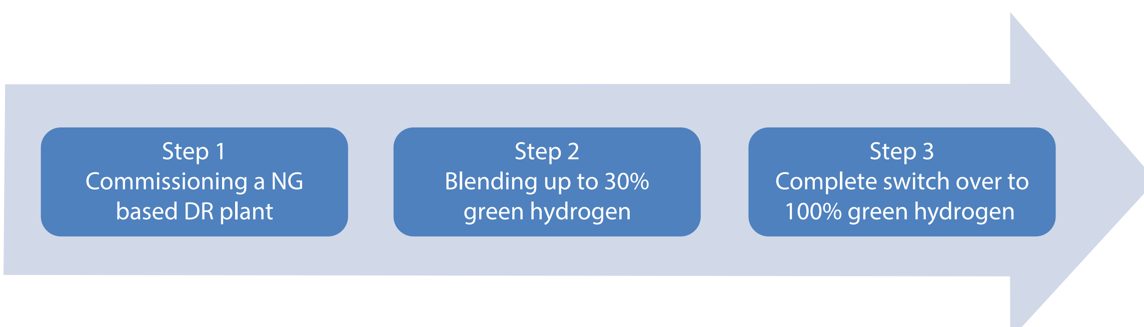
Costs of steel production - H_2 -DR vs SR-BOF with CCUS routes

Sources: *TERI analysis based on IEA (2019; Hall, Spencer, and Kumar (2020); BNEF (2020)*

The pilot plants using high shares of low-carbon hydrogen are already being established in Europe. The HYBRIT project in Sweden recently started with the demonstration plant (September 2020) and aims to have a commercial-scale plant up and running by 2026, with the intention to switch over their entire fleet by 2045 (SSAB 2019).

If supplied with zero-carbon hydrogen and combined with an EAF supplied with zero-carbon electricity, the hydrogen direct reduction route has the potential to reduce emissions by over 94% compared with conventional technologies. Residual emissions occur with the use of graphite electrodes in the EAF. This holds true with the utilization of lime and natural gas as well. Emissions could be brought down to zero with further research and development.

Hydrogen is already used extensively in India, mainly as an industrial feedstock in the creation of ammonia-based fertilizers. Therefore, the capacity to handle and use hydrogen at industrial scale is already available in the country. The main barriers relate to cost of low-carbon hydrogen and access to renewable electricity. The conventional routes will likely be cheaper in the near term, driven mainly by the lower input costs and lack of infrastructure for carbon capture utilization and storage (CCUS). As per TERI's analysis, the cost of hydrogen-based direct reduction will start to be competitive with smelting reduction – basic oxygen furnace along with CCUS by 2030.



A stepwise approach to reduce CO_2 emissions via the direct reduction route.

In the journey of low-carbon steel production in the long run, NG can play a crucial role as a transition technology for the steel sector. The key technology providers are already promoting NG to H_2 transition as a route to deep decarbonization.

To facilitate the increased use of hydrogen in the steel sector, the following three key issues need to be addressed:

(i) Enabling policy framework for promoting hydrogen production and use in the steel sector.

(ii) Facilitating establishment of pilot and demonstration plants to familiarize the industry with the H_2-DR process, address any technical issues, and build-up the confidence of the industry.

(iii) Access to green finance to enable large-scale investments by steel manufacturers.

5 CONCLUSION

Steel industry is one of the most important sectors and contributes significantly to the growth of a country as various industrial and construction activities are closely linked with the steel sector. India is the second-largest producer of steel on a global scale and direct reduction of iron (DRI) sector contributes significantly to the overall production of steel in India. DRI/sponge iron through the reduction of iron ore using non-coking coal or natural gas as reductant was developed as a substitute for ferrous scrap. Initially sponge iron manufacturing gained prominence in India owing to short supply and high prices of scrap, low-technology barriers, and a high presence of EAF plants in the domestic market.

The Indian DRI sector accounts for about 39.3% of the total global production (WSA 2020). Most of the Indian DRI plants use coal-based processes due to less investment, lower-gestation period, easy availability of coal, and limited accessibility of gas. The overall capacity utilization of the DRI plants stands low, at about 60%. The poor quality of iron ore further results in lower yield of the sector. The specific energy consumption (SEC) of DRI production of coal-based rotary kiln varies in the range of 4.10–5.26 Gcal/t averaging about 4.51 Gcal/t. There is a significant potential among the coal-based DRI plants to adopt energy-efficient technologies. Of these, one of the most attractive options is waste heat recovery (WHR)-based power generation, particularly for plant capacities of 200 tpd and above. Smaller capacity plants, for example, 100 tpd or less, can adopt other WHR options such as iron ore preheating and coal drying, which can improve the energy performance substantially.

Apart from WHR-based technologies, the other energy-efficiency options include switch over to iron ore pellets, mullite-based lining, accretion reduction, coal gasification for partial substitution of coal, and use of energy-efficient electrical systems. These energy-efficiency options along with WHR-based recovery systems can lead to a reduction in SEC level of 2.3 Gcal/t-DRI.

Considering the projected growth of steel sector in India, it is expected that the DRI route will continue to play a significant role in the country. Accordingly, it is important that DRI plants improve their energy and environmental performance. In addition to adopting viable energy-efficient technological options in the existing processes, the new DRI capacities must explore and focus on adoption of low-carbon technologies. The process requirements can either be met through coal gasification or natural gas reforming routes, which are commercially available. In long-term, carbon neutral DRI production can be established through adoption of hydrogen route, which is presently under development and being explored internationally.

A summary of energy-efficient technology options for Indian DRI sector is tabulate here. The energy saving is quantified considering a plant capacity of 100 tpd and coal with a calorific value of 5200 kcal per kg. For WHR-based power generation, energy saving has been estimated considering a plant capacity of 200 tpd.

Summary of energy-efficient technology options for rotary kiln-based DRI industry					
S. No.	**Energy-efficient technology**	**Energy saving (Gcal/year)**	**Investment (Rs lakh)**	**Payback (year)**	**GHG reduction (tCO_2/year)**
1	WHR – power generation	20,227	2800	3.2	19,286
2	WHR– iron ore preheating	22,360	350	1.3	7,726
3	Coal gasification for partial substitution	21,840	NA	-	7,546
4	WHR – vapour absorption chiller	36	7	2.0	34
5	Decentralized VFDs for shell air fans	16	3	5.2	16
6	Mullite-based kiln lining	3,033	150	4.1	1,048
7	Switch over to iron ore pellets	27,300	-	-	9,433
8	WHR – coal moisture reduction	5,539	100	1.5	1,914
9	Energy-efficient motors	19	3	4.8	18
10	Energy-efficient pumps	72	2	0.8	69
11	VFDs for air compressors	71	3	1.3	67
12	FRP blades for cooling tower fans	9	0.7	2.4	8
13	Thermostatic controller for cooling tower	12	0.2	0.4	11

NA - not available

Technology Vendors – Energy-efficient Equipment and Systems

The energy-efficiency improvements in DRI sector would require significant modifications and adoption of commercially available energy-efficient and state-of-the-art technologies in the process. A select list of key technology vendors for energy-efficient technologies in DRI process and associated auxiliary system is provided here.

Vendor	Contact details
WHR-based power plant	
Popuri Engineering Services Private Limited	12-2-460/2 Sai Sudha Nilayam New HUDA Layout Gudimalkapur, Mehdipatnam Hyderabad –500 028, Andhra Pradesh Phone : (040) 23510649, 23510844, 23513468 Fax : (040) 23510111 http://popurigroup.com
Thermax Limited	No. D13, MIDC Industrial Area, RD Agra Road, Chinchwad Pimpri, Chinchwad– 411019 https://www.thermaxglobal.com
WHR-based preheating system (iron ore and coal)	
Popuri Engineering Services Private Limited	12-2-460/2 Sai Sudha Nilayam New HUDA Layout Gudimalkapur, Mehdipatnam Hyderabad –500 028, Andhra Pradesh Phone : (040) 23510649, 23510844, 23513468 Fax : (040) 23510111 http://popurigroup.com
Iron ore pelletizer plant	
Popuri Engineering Services Private Limited	12-2-460/2 Sai Sudha Nilayam New HUDA Layout Gudimalkapur, Mehdipatnam Hyderabad – 500 028, Telangana Tel : (040) 23510649, 23510844, 23513468 Fax : (040) 23510111 http://popurigroup.com

Vendor	Contact details
Outotech	Balaji Building No. 3, Ground Floor, Hennur Main Road, Opposite Kothanur PO, Kothanur V&P Bengaluru – 560077, Karnataka Tel: (080) 2308 1600 South City Pinnacle, 12th Floor, Sector V Block EP, Salt Lake, Kolkata – 700 091, West Bengal Tel: (033) 4014 0400
FLSmidth Private Limited	Plot No. 34, Egatoor, Near Rajiv Gandhi Salai, Kelambakkam, Chennai – 603103, Tamil Nadu Tel: (044) 4748 1000
Mesto India Private Limited	44 Park Street, 3rd Floor, Saket Building, Kolkata – 700 016, West Bengal Tel: (33) 3025 4611 1404, 14th Floor, Rupa Solitaire, Millennium Business Park, Thane-Belapur Road, Mahape – 400 710 Navi Mumbai Tel: (22) 61221800
Kobelco	2-4, Wakinohama-Kaigandori 2-chome, Chuo-ku, Kobe, Hyogo, 651-8585, Japan Tel: +81-78-261-5111 Fax: +81-78-261-4123 https://www.kobelco.co.jp/english/
Coal gasification	
Nippon Steel Engineering	Plant and Machinery Division Osaki Center Building, 1-5-1, Osaki, Shinagawa-ku Tokyo 141-8604 Japan Tel: +81-3-6665-2000 Fax: +81-3-6665-4847 https://www.eng.nipponsteel.com/english/whatwedo/steelplants/ironmaking/direct_reduced_iron_process/
Vapour absorption machines	
Thermax India Limited	Energy House, D-II Block, Plot No. 38 & 39, MIDC Area, Chinchwad, Pune – 411 019, Maharashtra, India Fax: +91-20-6730 8948. Tel: +91-20- 67308915 www.thrmaxindia.com

Vendor	Contact details
Transparent Energy Systems Private Limited	Ist floor, Pushpa Height, Bibwewadi Corner Pune – 4011037, Maharashtra www.tespl.com
Insulation	
Lloyds Insulation	6 Middleton Street, Kolkata –700071, West Bengal Tel: (033) 3058 5214 http://lloydinsulations.com/ http://lloydinsulations.com/CompanyLocation.aspx
Murugappa Morgan Thermal Ceramics Limited	Dare House, NSC Bose Rd, Parry's Corner, George Town, Chennai– 600001 Tamil Nadu, India www.murugappa.com
Rockwool (India) Limited	Plot No. 21 and 22, 1st Floor, Century Building Rohini Layout, Madhapur Hyderabad – 500084, Telangana Tel: 040-30408650 www.rockwoolindia.com
Motors	
ABB India	ABB Ahmedabad Office, 5th Floor, A-6 Safal Profitaire, Corporate Road, Ahmedabad – 380015, Gujarat Tel: +91 96 2436 0600
Crompton Greave Limited	No. 50, 5th and6th Floors, Lisco House, Chowringhee Road, Middleton Row, Kolkata –700071, West Bengal
Kirloskar Brothers Limited	M-11, 3rd floor, Middle Circle, Connaught Place, New Delhi –110 001 Tel: 011 – 41501056 www.kirloskarpumps.com
Siemens Limited	Birla Aurora, Level 21, Plot No. 1080, Dr Annie Besant Road, Worli, Mumbai – 400030, Maharashtra Tel: 022-39677000
Variable frequency drives	
ABB India Limited	ABB Ahmedabad Office, 5th Floor, A-6 Safal Profitaire, Corporate Road, Ahmedabad – 380015, Gujarat Tel: +91 96 2436 0600

Vendor	Contact details
Siemens India Limited	Birla Aurora, Level 21, Plot No. 1080 Dr Annie Besant Road, Worli, Mumbai – 400030 Tel: (022) 39677000
Apex Industries	No. 5, Mathura Road, Old Faridabad, Faridabad – 121002, Haryana
FUJI Electric India Private Limited	78 A, Park St, Mallik Bazar, Park Street area, Kolkata – 700017, West Bengal
Schneider Electric India Private Limited	DLF Building, Tower C, N-10, DLF Cyber City, DLF Phase 2, Sector 24 Gurugram – 122002, Haryana
Energy-efficient pumps	
KSB Pumps limited	KSB Pumps Limited, KSB House, A-96, Sector IV Dist. Gautam Budh Nagar NOIDA – 201 301, Uttar Pradesh Tel: (120) 2541 091 Fax: (120) 2550 567
Kirloskar Brothers Limited	M-11, 3rd Floor, Middle Circle, Connaught Place, New Delhi –110 001 Tel: 011 – 41501056 Email: delhi@kbl.co.in
Grundfos Pumps India Private Limited	118 Rajiv Gandhi Salai, Thoraipakkam, Chennai – 600 097, Tamil Nadu Tel: (044) 4596 6800 Fax: (44) 4596 6969 Toll Free : 1800 345 4555 Email: salesindia@grundfos.com
Cooling tower fan control (thermostatic)	
Delta Cooling Towers Private Limited	1st Floor, Bhagwati Sadan, Plot No. 8, Community Centre, BH Block, Shalimar Bagh, Delhi – 110088 Tel: +91-11-27495801/27495802/27495803 Fax: +91-11-27495804 Email: delta@deltactowers.com, delta@nde.vsnl.net.in
Airtech Cooling Process Private Limited	145A, HSIIDC Internal Road, Sector 31, Faridabad – 121003, Haryana Tel: (129) 4177211/ 4177212 Fax: (129) 4177213 Mobile : 9350511679 E-mail: airtechdelhi@yahoo.com, info@airtechengineers.com

Vendor	Contact details
Fibre-reinforced plastic (FRP) fan blades	
Delta cooling towers Private Limited	1st Floor, Bhagwati Sadan, Plot no. 8, Community Centre, BH Block, Shalimar Bagh, Delhi –110088 Tel: +91-11-27495801 / 27495802 / 27495803 Fax: +91-11-27495804 Email: delta@deltactowers.com, delta@nde.vsnl.net.in
Paharpur Cooling Towers Limited	Paharpur House 41 Cunningham road cross Bengaluru –560052, Karnataka Tel: (080) 2226 5566-7, 2234 1911 Email: pctblr@paharpur.com
Himgiri Cooling Tower	2/320, Mahesh Industrial Estate, Opposite Silver Park, Mira Road (East), Mumbai – 401104, Maharashtra Tel: (022) 2811 0937, 2811 8581 Email: yash.bhuva@himgiricooling.com
Airtech Cooling Process Private Limited	145A, HSIIDC Internal Road, Sector 31, Faridabad –121003, Haryana Tel: (0129) 4177211/ 4177212 Fax: (0129)-4177213 Mobile: 9350511679 E-mail : airtechdelhi@yahoo.com, info@airtechengineers.com
Automatic power factor controller	
ABB India	Bengal Intelligent Park Limited, Omega Blk EP and GP, Sector V, Salt Lake City, Kolkata –700091, West Bengal
Sai Electricals	301, Czar Woods, Om Gardens, Maitree Vihar, Chandrashekharpur, Bhubaneswar – 751 023, Odisha Tel: (0674) 2301141, 2301288 E-mail: ro.odisha@saielectricals.com http://saielectricals.com/contact-us/
Siemens Limited	Birla Aurora, Level 21, Plot No. 1080, Dr Annie Besant Road, Worli, Mumbai – 400030, Maharashtra Tel: (022) 39677000
Schneider Electric India	DLF Building, Tower C, N-10, DLF Cyber City DLF Phase 2, Sector 24 Gurugram – 122002, Haryana

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