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SAMEEEKSHA
Promoting Energy Efficiency in SMEs

Situation Analysis of Raipur

Secondary Steel Cluster

Situational Analysis of Raipur Secondary Steel Cluster

Disclaimer

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TABLE OF CONTENTS

ABBREVIATIONS

BEE	Bureau of Energy Efficiency
BF	Blast Furnace
BOF	Basic Oxygen Furnace
CCCI	Chhattisgarh Chamber of Commerce and Industries
CCM	Continuous Casting Machine
CF	Cupola Furnace
CFAPA	Chhattisgarh Ferro Alloy Plant Association
CGMSP	Chhattisgarh Mini Steel Plant Association
CGSIMA	Chhattisgarh Sponge Iron Manufacturers Association
CGSRA	Chhattisgarh Steel Re-rollers Association
CI	Cast Iron
CISAA	Chhattisgarh Iron and Steel Agent Association
CO	Carbon Monoxide
CO_2	Carbon Dioxide
CR	Cold Rolled
CREDA	Chhattisgarh State Renewable Energy Development Agency
CSIDC	Chhattisgarh State Industrial Development Corporation
CTD	Cold Twisted Deformed
CV	Calorific Value
CWIA	Chhattisgarh Wire Industries Association
DC	Designated Consumer
DCMSME	Development Commissioner Ministry of Micro, Small and Medium Enterprises
DIC	District Industry Centre
DIPM	District Investment Promotion Committees
DRI	Direct Reduced Iron
DTIC	District Trade and Industries Centre
EAF	Electric Arc Furnace
EBT	Eccentric Bottom Tapping

EC	Energy Conservation
EIF	Electric Induction Furnace
ESP	Electrostatic Precipitator
Fe	Iron
FO	Furnace Oil
GCV	Gross Calorific Value
GHG	Greenhouse Gases
GIZ	Deutsche Gesellschaft für Internationale Zusammenarbeit
GJ	Giga Joule
HB	Hard Bright
HF	Heating Furnace
Hp	Horsepower
HR	Hot Rolled
ID	Induced Draft
IE3	Premium Efficiency
IF	Induction Furnace
IFAPA	Indian Ferro Alloys Producers Association
IGBT	Insulated Gate Bipolar Transistor
JPC	Joint Plant Committee
kCal	Kilocalorie
kW	Kilowatt
kWh	Kilowatt-hour
LS	Lime Stone
MoSPI	Ministry of Statistics and Programme Implementation
MS	Mild Steel
MSME	Micro, Small, and Medium Enterprises
MSMEDI	Micro, Small, and Medium Enterprises Development Institute
Mtoe	Million Tonne of Oil Equivalent
MW	Megawatt
MWH	Megawatt-hour
NIC	National Industrial Classification
PAT	Perform, Achieve, and Trade

PI	Pig Iron
PLC	Programmable Logic Controller
RHF	Re-heating Furnace
RM	Rolling Mill
SA	Standalone
SAF	Submerged Arc Furnace
SAMEEEKSHA	Small and Medium Enterprises Energy Efficiency Knowledge Sharing
SCR	Silicon Controlled Rectifier
SDA	State Designated Agencies
SEC	Specific Energy Consumption
SI	Sponge Iron
SMS	Steel Melting Shop
SRRM	Steel Re-rolling Mill
SS	Stainless Steel
TERI	The Energy and Resources Institute
TMT	Thermo Mechanically Treated
Toe	Tonne of Oil Equivalent
TPD	Tonne Per Day
TPH	Tonne Per Hour
UIA	Urla Industries Association
UNEP	United Nations Environment Programme
VFD	Variable Frequency Drives
WHR	Waste Heat Recovery
WI	Wire Industries

IN-DEPTH STUDY ON SPONGE IRON

1.1 Background

Raipur, the capital city of Chhattisgarh state, is abundantly rich with large deposits of natural resources like coal, iron ore, limestone, and other mineral ores. A part of the eastern region of India, it is one of the largest clusters of MSMEs (micro, small and medium enterprises) and one of the largest secondary steel clusters comprising industries like 'direct reduced iron' (DRI)/sponge iron, pelletization, electric induction furnace (EIF), steel re-rolling mill (SRRM), foundry, forging, ferroalloy, and wire drawing industries (Figure 1).

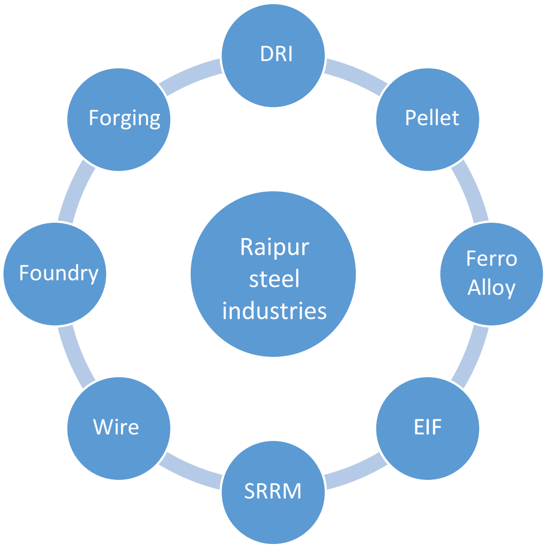

Figure 1: Secondary steel industries in Raipur

There are more than 1200 mineral and metal based registered MSME industries[i] in Raipur and its surrounding areas; out of these, close to 140 industries belong to medium and large categories. A majority of steel industries[ii] are located in Urla, Siltara, Rawabhatha, Tatibandh, Sarola, Bagoli, Bhanpuri, Gaugaon, and Tendua (Figure 2).

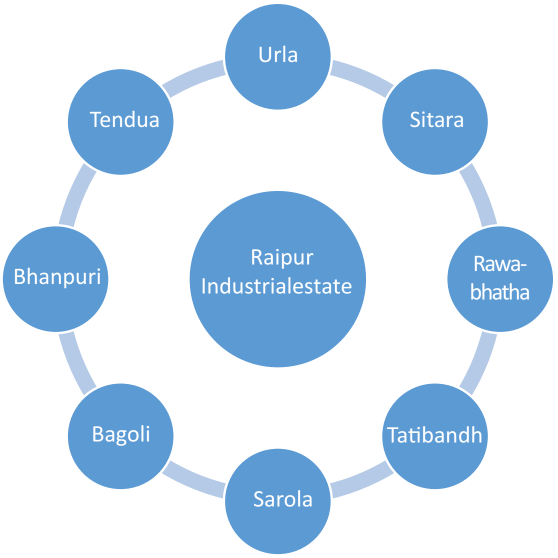

Figure 2: Industrial estates of Raipur cluster

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i DIC and DCMSME , Raipur

ii Website of CSIDC, Raipur.

INDUSTRIES AND ENERGY-USE AND GHG EMISSIONS

2.1 Industry types

There are about 316 secondary steel industries presently operating at present in Raipur cluster. These industries include direct reduced iron (DRI)/sponge Iron, electric induction furnace (EIF), steel re-rolling mill (SRRM), ferro alloy, wire drawing (WI) and others including foundry and forging industries. The industries are grouped in two ways considering total annual energy consumption in the plant, or number of process steps integrated in the manufacturing line to produce the final product of the plant. One of the groupings considers gate to gate annual energy consumption of the plant, under which the plant could either be in 'designated consumer' (DC) category of the Bureau of Energy Efficiency (BEE) under the 'perform, achieve and trade' (PAT) scheme, or non DC. The other grouping is termed as either 'composite' or 'stand-alone' industries. Here, composite industries will have multiple process steps that are integrated mostly in series; while units with a single process step to manufacture the final product(s) are termed as stand-alone.

About 27 (8.5%) industries out of 316 secondary steel industries in the cluster are DCs—in which 24 (89%) DCs are DRI industries and the remaining three DCs are ferro-alloy industries. Around 52 (16.5%) industries are composite type, which includes 25 DRI and 27 SRRM, with EIF and WI. Stand-alone units account for a major share in the total industries, with 264 units (83.5%)(see Figure 3). jdfdfdkkdndisa Most of the secondary steel are non designated consumers (non DC) category (91.5%) and only 8.5% are the DCs (Figure 4).

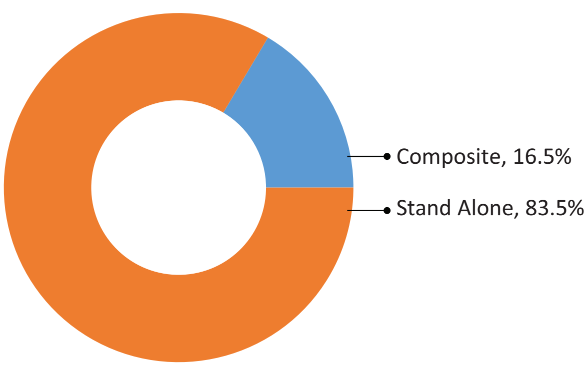

Figure 3: Share of composite and stand-alone industries

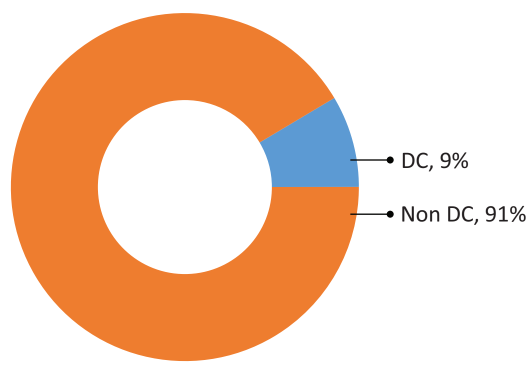

Figure 4: Share of DC and non DC secondary steel industries in Raipur cluster

The details of the secondary steel industries in the Raipur cluster are provided in Table 1.

Table 1: Details of steel secondary industries in the Raipur cluster

Type	Operative Units	DC	Non DC	Composite	Stand-alone
DRI	45	24	21	25	20
EIF	69	24	45	52	17
SRRM	115	17	98	44	71
FERRO-ALLOY	21	3	18	0	21

Type	Operative Units	DC	Non DC	Composite	Stand-alone
WI	111	0	111	6	105
Other	30	0	30	0	30
Prime/actual total	**316**	**27**	**289**	**52**	**264**

2.2 Energy Consumption and CO_2 Emissions

Secondary steel industries in the Raipur cluster mostly use coal and electricity to meet energy requirements in the manufacturing process. It may be appropriate to mention that enterprises with downstream processes, like annealing and galvanizing in wire industries, use furnace oil (FO) in such operations. The total energy consumption of Raipur secondary steel cluster is estimated to be 3.65 million toe and the corresponding emissions[iii] at the cluster level are 17.75 million tonne CO_2. Table 2 provides the share of energy consumption and CO_2 emissions by industry sub-sectors.

Table 2: Share of energy consumption and CO_2 emissions by secondary steel industries in the Raipur cluster

Industry	Energy source	Energy consumption (mtoe)			CO_2 emissions (m t-CO_2)
		Thermal	Electricity	Total	
DRI	Coal, electricity	2.82	0.18	3.00	13.29
EIF	Electricity	0	0.23	0.23	1.94
SRRM	Coal, electricity	0.16	0.04	0.20	1.03
Ferro-alloy	Coal, electricity	0.06	0.13	0.19	1.33
WI	Electricity, FO	0.01	0.01	0.02	0.10
Others*	Coke, electricity, FO	0.01	0	0.01	0.06
Total		**3.06**	**0.59**	**3.65**	**17.75**

** others include foundry and forging*

The share of annual thermal energy consumption accounts for around 84% (3.06 mtoe) of the total annual energy consumption of 3.65 mtoe in the cluster; while the share of electricity is about 16%, i.e., 0.59 mtoe (Figure 5). DRI alone accounts for about 82.2% of total energy consumption, followed with

iii https://cea.nic.in/wp-content/uploads/baseline/2023/01/Approved_report_emission__2021_22.pdf

SRRM with 5.5% (Figure 6). Similarly, DRI industries account for most of the CO_2 emissions in the cluster with a share of 74.9%; SRRM follows next having a 5.8% share (Figure 7)

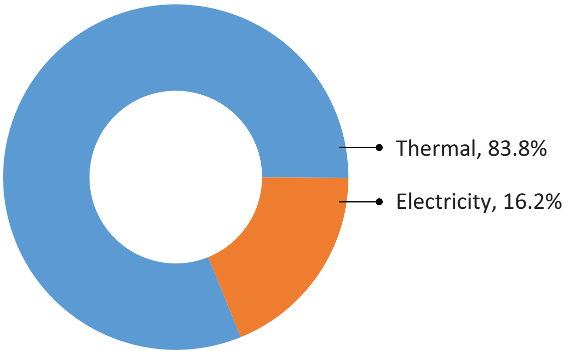

Figure 5: Share of energy consumption

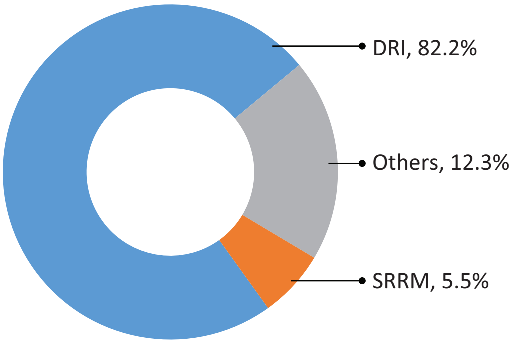

Figure 6: Energy consumption share of industries in Raipur cluster

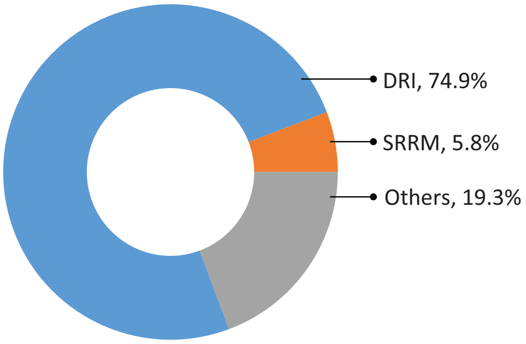

Figure 7: Emission share of industries in Raipur cluster

DRI INDUSTRY

3.1 Details of DRI industries

There are about 69 DRI/sponge iron[iv] industries in Raipur's secondary steel cluster, of which 45 industries are reported to be in operation. Considering installed plant capacity, 56% of operational DRI industries with 300 tpd or more production capacity are large in size; small (50–150 tpd) and medium (200–250 tpd) sized industries account for 22% each (Figure 8).

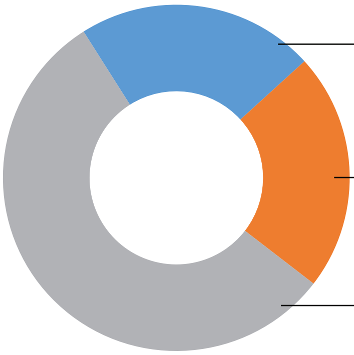

Figure 8: Capacity-wise distribution of DRI plants

Within DRI industries, 25 plants are composite (56%) with integrated secondary steel manufacturing facilities such as steel melting shops (SMS) having both EAF and EIF, or only EIF, continuous casting machines (CCM), and SRRM. Remaining 20 DRI plants are of standalone (44%) and the final product from these units is sponge iron (Figure 10). Out of the 45 DRI units that are operational, about 24 large capacity DRI industries[v] (53% of total units) in the clusters are DCs under the PAT scheme, as their gate-to-gate total energy consumption exceeds the threshold limit[vi] of the steel sector, i.e., >= 20000 toe per year (Figure 9). DRI industries in the Raipur cluster provide direct or indirect employment to more than 15,000 people.

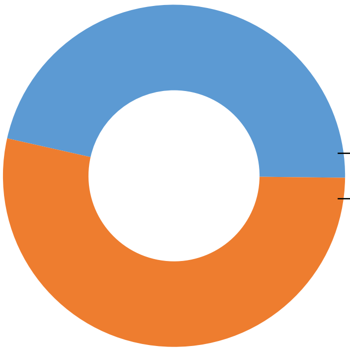

Figure 9: Share of DCs within DRI industries in Raipur cluster

Figure 10: Structure-wise distribution of DRI plants

3.2 Production of sponge iron

The total sponge iron production in Raipur cluster is estimated to be 5.34 million tonne per year (tpy) (Table 3). About 80% of sponge iron production is accounted by the large DRI plants and 15% by medium sized plants (Figure 11).

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iv JPC report 2021-22, GIZ report, SIMA-Chhattisgarh chapter, 3rd edition of member directory 2018 of Chhattisgarh Iron and Steel Agent Association

v JPC report 2021-22

vi PAT-cycle, revised threshold limit for DC under steel sector 2019

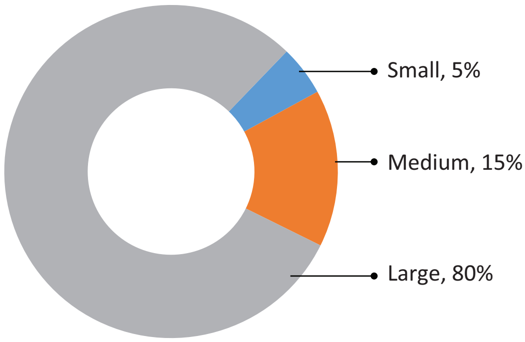


Figure 11: Production share of DRI in Raipur cluster

Table 3: Sponge iron production from Raipur cluster

Industry category	Number of DRI plants	Capacity (tpd)	Production (million tpy)
Small	10	50–150	0.26
Medium	10	200–250	0.82
Large	25	300–2000	4.26
Total	45		5.34

3.3 Manufacturing process

The production of sponge iron is a reduction of iron ore in solid state at a temperature below the melting point of iron. The carbon-bearing non-coking coal is used as a source of heat for preheating the iron ore and reducing agent carbon monoxide to complete the reduction process. The DRI is also termed 'sponge iron' due to its spongy honeycomb like texture while viewed under a microscope. DRI manufacturing primarily includes (i) reduction of iron ore, (ii) cooling of hot sponge iron, and (iii) separation and screening. A schematic of the DRI production process is shown in Figure 12.

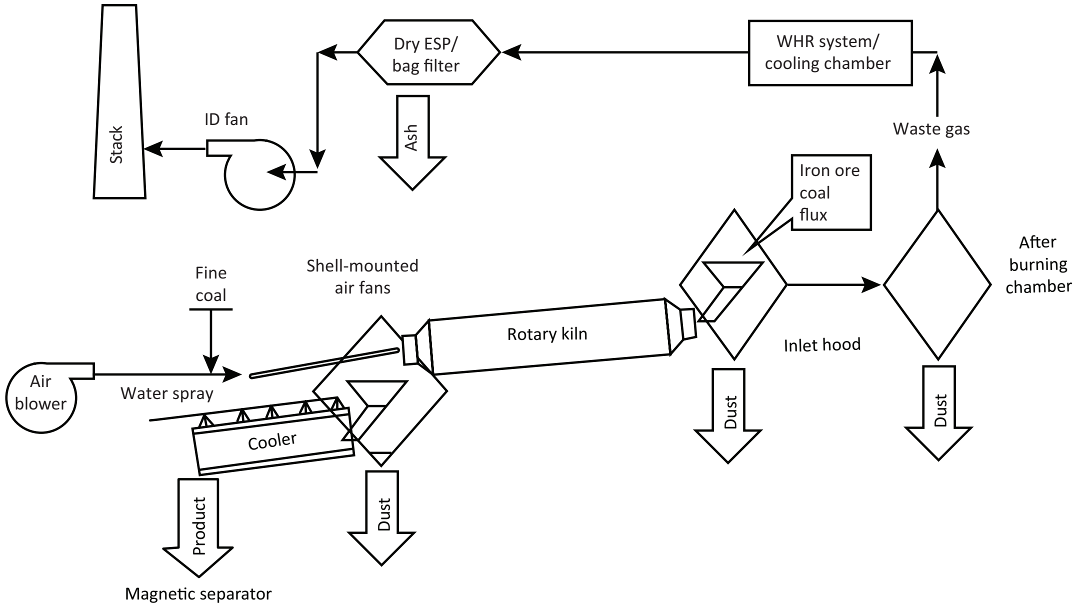


Figure 12: Schematic layout of DRI manufacturing process

3.3.1 Reduction of iron ore

The raw materials comprising iron ore and a part of sized coal are supplied from the feed end of the inclined rotary kiln. The feed input is gradually heated while moving from the pre-heating zone to the reduction zone by counter flow hot gases. In the pre-heating zone, the moisture is initially removed before the temperature reaches to the reducing reaction point. In the reduction zone of the kiln, the oxygen in iron ore is removed, forming carbon monoxide (CO) leaving the metallic iron. A part of coal is pulverized and injected through the exit end of the rotary kiln. This injected coal completes the reaction process. A temperature of about 900–1050oC is maintained in the kiln. Higher the temperature, faster the oxygen removal. A critical factor in the reduction of iron is the formation of carbon monoxide through controlled combustion of fuel. The optimum batch cycle for the process is 8–10 hours.

3.3.2 Cooling of sponge iron

On completion of metallization through the reduction process, the mixture of sponge iron and residual charge are transferred to a rotary cooler through a belt conveyor at about 250oC, before the hot product comes in contact with ambient air. At more than 250oC, the sponge iron would tend to oxidize using oxygen from ambient air. The sponge iron is further cooled down to about 100oC through indirect cooling in rotary cooler.

3.3.3 Separation and screening

Solid discharge from the rotary cooler is the mixture of sponge iron and dola char. It is passed through an electromagnetic separator to separate sponge iron from char and other impurities. The separated sponge iron grains are screened in series to different size fractions to separate lumps and fines for storage and dispatch.

3.4 Technology description

The DRI industries in the Raipur cluster use coal-based horizontal rotary kilns for production of sponge iron (Figure 13). The rotary kiln is provided with an inside refractory lining of 150–200 mm to protect the shell and has a slope of 2.5% to 3.0% towards the discharge end.

Figure 13: Rotary kiln for sponge iron production

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 – Fe_2O_3), non-coking coal, and limestone/dolomite. Hematite, 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.

The iron ore and non-coking coal are reduced to the required size in crushers. Iron ore, coal, and dolomite of the required proportion are continuously fed into the kiln from the feed end, using weigh feeders. The raw materials move along the length of the kiln with the pre-set rotation. The secondary air is blown into the kiln through air pipes located along the kiln length. The temperatures of different heating zones are measured and controlled using thermocouples mounted across the length of 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 the preheating zone is provided by combustion of a part of coal.

The section of rotary kiln after the preheating zone is called 'reduction zone'. Here, the oxygen present in the iron ore dissociates and oxidizes, reducing the carbon element in non-coking coal to form carbon monoxide, leaving the metallic iron. The rotation of the kiln and its slope ensure 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 900–1050oC is maintained in the reduction zone. Higher the temperature, faster 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. The residence time for iron ore inside the kiln is about 8–10 hours to form metallic iron. The quality of metallization is assessed with the density of sponge iron and the metallic luster.

3.5 Waste heat recovery based power generation

A number of DRI plants in the Raipur secondary steel cluster have installed 'waste heat recovery' (WHR) based power generation systems (steam based) to recover high-temperature heat available in off-gases leaving rotary kilns. It is pertinent to mention that the sensible heat in off-gases accounts for around 40% of the total heat input to the rotary kiln. The sensible heat of exhausted off-gases from the rotary kiln can be suitably pre-treated and passed through a waste heat recovery system, like the WHR boiler, to generate steam at high pressure and temperature, which can be utilized for power generation.

The power generation potential using off-gases from the rotary kiln depends on the average production capacity of the kiln in operation. Table 4 provides the tentative power generation potential[vii] from off-gases of the rotary kiln with different production capacities that are in operation for DRI manufacturing.

[vii] Popuri Engineering Technologies

Table 4: Potential power generation from different rotary kiln of DRI industries

Rotary Kiln production capacity (tpd)	Power generation potential (MW)
100	1.5–2
200	3.5–4.0
350	7.5–8.0
500	10–12.0

Installation of WHR based power generation is not financially viable if daily average production of the DRI plant is less than 200 tonne. Due to lower production capacity, around 70% out of the total operating DRI industries (45) in the Raipur cluster have WHR based power generation systems.

3.6 Specific energy consumption

Non-coking coal is the major fuel used in DRI plants—both for thermal energy needs and chemical reactions. The specific coal consumption of sponge iron production is 0.95–1.05 tonne per tonne of sponge iron production. Coal accounts for about 95–98% of total energy consumption, whereas electricity accounts for only 2–5% of total energy consumption of DRI plants.

DRI plants use grid electricity to meet electricity demands in absence of WHR based captive power plants facility within the plant. The specific energy consumption of sponge iron production—considering both thermal and electricity input in DRI manufacturing—varies in the range of 4.81–5.32 Gcal per tonne sponge iron (Table 5).

Table 5: Specific energy consumptin of DRI production

Energy source	Unit	Minimum	Maximum
Thermal#	(tonne/tonne of DRI)	0.95	1.05
	(GCal/tonne of DRI)	4.75	5.25
Electricity	(kWh/tonne of DRI)	70	80
	(GCal/tonne of DRI)	0.06	0.07
SEC	(GCal/tonne of DRI)	4.81	5.32

considered GCV of used thermal energy source (coal) is 5000 kCal/kg

Significant variations in SEC level can be observed in coal-based DRI production as SEC levels are plant specific and depend on various factors such as iron content in iron ore, fixed carbon and volatile matter in coal, temperature profile of kiln, operating practices, etc.

3.7 Energy consumption and GHG emissions

The total energy consumption in DRI industries in the Raipur cluster is arrived at by adding energy consumption at the existing process areas, considering the production amount processed and the SEC as applicable. The summary of baseline data used for calculating energy consumption in DRI industries in the Raipur cluster is given in Table 6.

Table 6: Summary of baseline data of DRI industries in Raipur

Process area	Production	Specific energy consumption (unit/tonne of product)		
	(tpy)	Coal tonne	Thermal kCal	Electricity kWh
Pelletization	4,955,586	0.05	250,000	100
DRI	5,339,191	1	5,000,000	80
SMS (EIF and CCM)	1,023,764	-	-	900
SRRM	441,542	0.1	500,000	5
Rolling Mill	1,450,654	-	-	100
Utilities	1,450,654	-	-	50

Annual energy consumption of Raipur's DRI industries is estimated to be 3 million tonne of oil equivalent (mtoe), which includes both thermal and electricity. The corresponding emissions are estimated to be around 13.29 million tonne of CO_2 (Table 7).

Table 7: Energy consumption and GHG emissions of DRI industries in the Raipur cluster

Energy type	Unit	Annual consumption	Equivalent energy (million toe)	GHG emissions (million t - CO_2)
Coal	million tonne/year	5.63	2.82	11.83
Electricity	million kWh/year	2063.89	0.18	1.46
Total	3	13.29		

Annual non-coking coal consumption accounts for more than 94% of total energy consumption of DRI industries in the cluster (Figure 14). More than 89% CO_2 emissions are accounted by the consumption of non-coking coal (Figure 15).

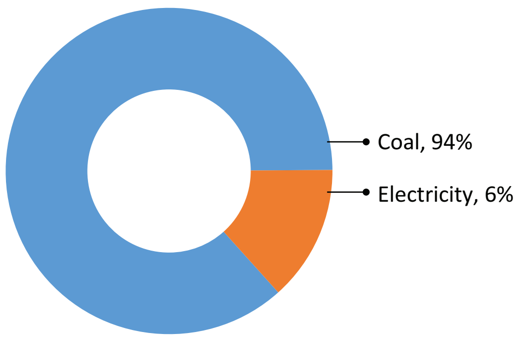


Figure 14: Share of energy consumption in DRI units

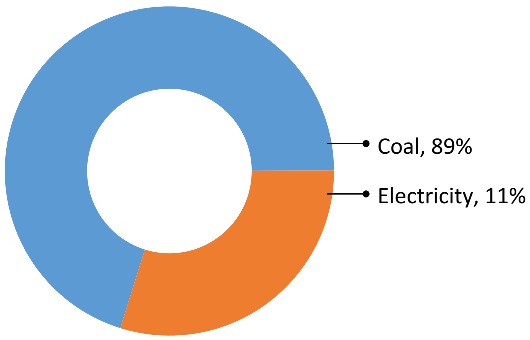


Figure 15: Share of emissions in DRI units

3.8 Energy efficient technologies

In coal-based DRI industries, coal accounts for most of the share of energy consumption within the plant. Coal is primarily used in rotary kiln operation for heating the input raw material mixture and completing reducing operation. More than 60% of the input energy in rotary kilns is lost, of which off-gas loss accounts for more than 40%. Various energy losses occurring in coal-based rotary kilns clearly indicate that there is significant scope for reducing SEC by improving energy efficiency (Figure 16). The most suitable potential option to recover heat from off-gases is WHR for power generation. Potential short-term energy-efficient measures associated with coal-based DRI plants in the Raipur cluster include the following:

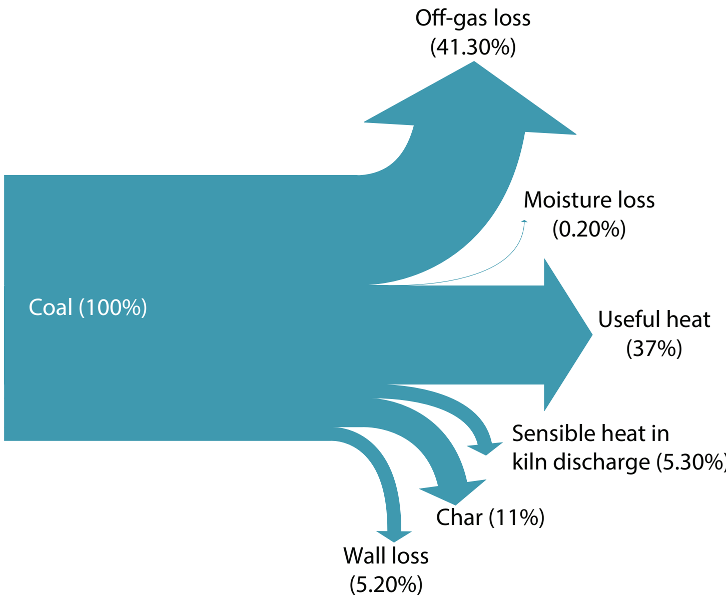


Figure 16: Energy losses in coal-based rotary kiln

i. **WHR system to recover sensible heat from rotary kiln off-gases in DRI industries**
   - Power generation using WHRB
   - Preheating of input iron ore

ii. **Adoption of alternative technologies/operating practices**
   - Use of producer gas in place of coal at discharge end in rotary kiln
   - Use of iron ore pellets in place of iron ore lumps
   - Mullite-based kiln lining
   - De-centralized VFD control of shell air fans

iii. **Energy efficiency improvement in utilities**

A brief description of the potential energy efficiency measures is provided below, along with indicative cost benefit details.

3.8.1 Waste heat recovery for power generation

Background

In coal-based DRI production using rotary kiln, the off-gases generated during the process leave the kiln at a very high temperature (about 950–1025°C), carrying away a significant amount 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. The high sensible heat in off-gases can be recovered using a WHR boiler to generate high-pressure steam for power generation.

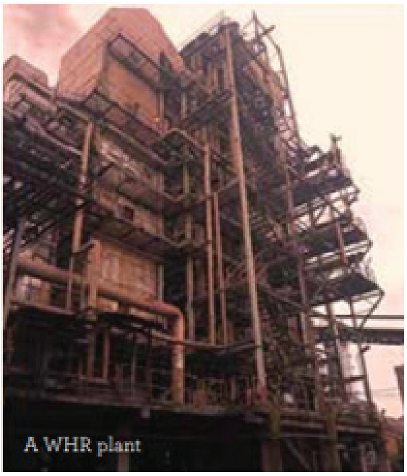


Figure 17: WHR plant in a DRI plant

Technology brief

The volume of off-gases generated in a 100 tpd rotary kiln generally varies in the range of 24,000±1500 Nm3 per hour. The volume of off-gases is dependent on the 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 exit off-gases from a rotary kiln generally carry coal fines that are burnt while it passes through a chamber called the after burner chamber (ABC). The purpose of ABC is to ensure the completion of combustion of 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 a cumulative installed capacity of 200 tpd or more.

In a WHR based power generation system, the off-gases from the rotary kiln are transferred through an integrated piping network to the installed WHR boiler, wherein the waste heat is utilized to convert water into steam at high pressure and temperature (Figure 18).

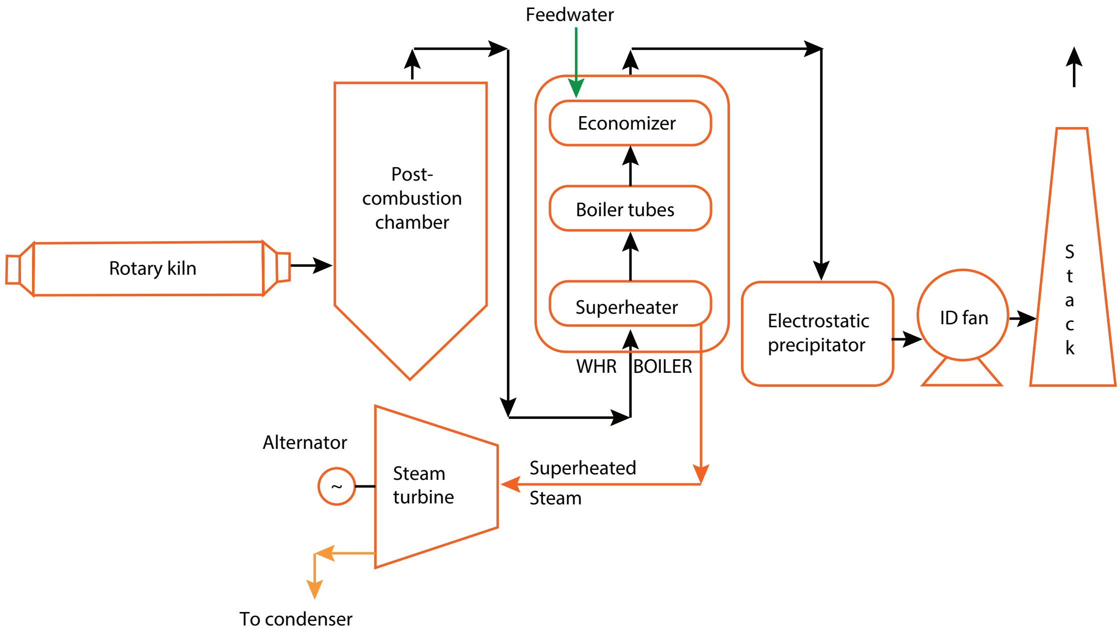
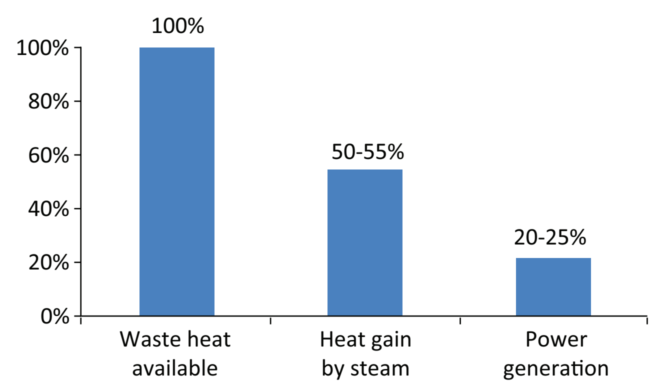


Figure 18: WHR based captive power plant for a DRI plant utilization in rotary kiln

Upon losing heat in the WHR boiler, the cooled off-gases enter the economizer in place for preheating feed water. The off-gases transfer a significant portion of sensible heat (about 50%–55%) to the 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 an electrostatic precipitator (ESP) 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/cm2 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 the WHR-based power generation system.

Savings, investments, and GHG emissions reduction



The energy saving with the 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 GHG emissions reduction potential is 19,300 tonne CO_2 per year. In addition, reduceing the temperatures of off-gases using the WHR system would decrease cooling requirements 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. An indicative cost benefit analysis for installing WHR based power generation system in a DRI plant having two operational 100 tpd rotary kilns in given in Table 8.

Table 8: Cost benefit analysis of installing WHR based power generation system

Parameter	Unit	Value
Plant capacity	tpd	2 X 100 tpd
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	INR lakh/year	874
Investment for WHR plant	INR lakh	2800
Payback period	Year	3.2

Source: Based upon interactions with a sector expert

3.8.2 Iron ore preheating in rotary kiln using WHR system

Background

A large quantity of sensible heat is available in high temperature off-gases. It is mainly used for a WHR based power generation system, which is viable for an 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 the amount of sensible heat that is recoverable as well as kiln efficiency.

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 the 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 the rotary kiln instead of being fed at ambient temperatures (Figure 19). Preheating of iron ore may marginally increase the generation of fines due to increased handling.

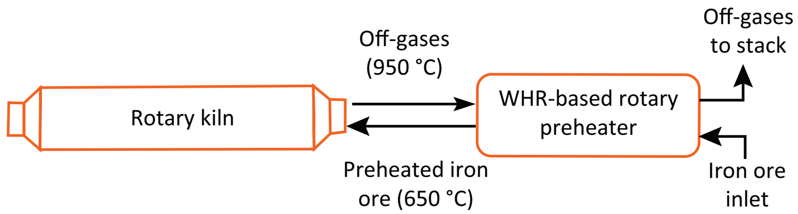


Figure 19: Preheating of iron ore using rotary kiln WHR

Savings, investments, and GHG emissions reduction

Considering a DRI plant of 100 tpd, the potential energy saving from iron ore preheating is about 15%. The annual energy saving with an iron ore preheating system is 5200 tonne coal per year (2700 toe per year). The GHG emissions reduction potential is 9300 tonne CO_2 per year. Other benefits associated with WHR-based iron ore preheating system include:

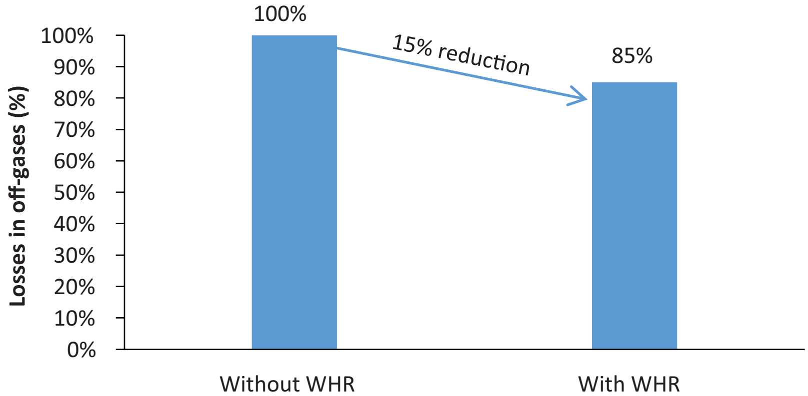


Figure 20: Energy saving with WHR for iron ore preheating

- 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 requirements for cooling and auxiliary system

The cost benefit details of installing a WHR based iron ore preheating system is provided in Table 9.

Table 9: Cost benefit analysis of installing WHR based iron ore pre-heating system

Parameter	Unit	Value
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	INR lakh/year	325
Investment	INR lakh	350
Payback	Year	1.1

Source: Based upon interactions with a sector expert

3.8.3 Coal gasification for partial substitution in rotary kiln

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 fed along with raw materials at the feed end is 8–20 mm in size. About 50%–60% of the coal injected along with low-pressure air at the discharge end is 0–8 mm in size. The coal injected at the discharge end can be converted to producer gas in a gasifier, which can then be supplied to the rotary kiln from the discharge end to improve overall efficiency.

Technology brief

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

The gasification process is mainly endothermic, involving the following reactions:

$$C + O_2 = CO_2 \; - 94.05 \text{ kcal/mol}$$

$$2H_2 + O_2 = 2H_2O - 68.3 \text{ kcal/mol}$$

The gasifier system comprises a vertical chamber, wherein a coal–water slurry is fed from the top and air supply is met through a blower. The producer gas is passed through either a cyclone separator or a 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 (Figure 21).

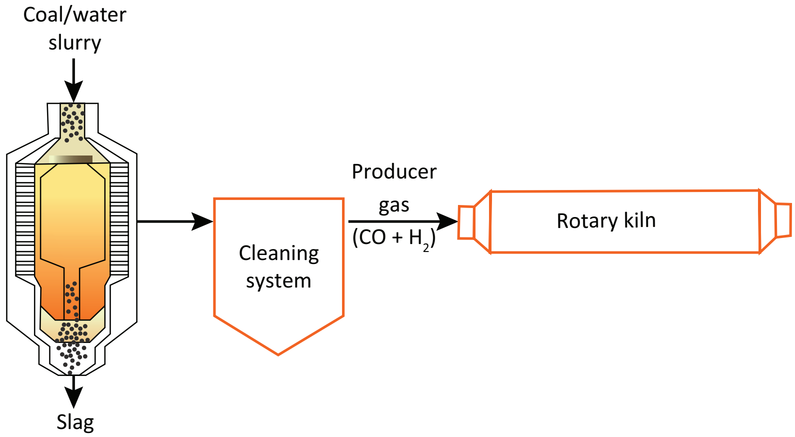


Figure 21: Coal gasification system for rotary kiln in sponge iron production

Benefits of using coal gasifier

Apart from energy savings, the other benefits of replacing a 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, leading to better recovery of metal

Savings, investments, and GHG emissions 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 (Table 10). 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.

Table 10: Cost benefit analysis of installing coal gasification system

Parameter	Unit	Value
Kiln capacity	tpd	100
Coal injection at discharge end	tpd	60
Potential energy saving	%	20
Coal saving	tpy	4200
Monetary benefits	INR lakh per year	260

Source: Based upon interactions with sector expert

3.8.4 Switch to iron ore pellet

Background

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 generally has a 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.

Technology brief

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 that are less than 200 mesh (0.074 mm) in size with additives like bentonite, and shaping then into oval or spherical balls in a pelletizer. For each pellet, the size is in the range of 8–16 mm diameter (Figure 22). The iron pellets are further hardened by firing separately. The use of a uniform size and shape of pellets as charge material—as opposed to non-uniform and varying sizes of lumps—improves kiln performance. Iron ore in pellet form reduces loss on ignition. There are two different iron ore pelletization processes: (i) straight travelling grate process and (ii) grate kiln process. The advantages with using iron ore pellets in DRI production are:

Figure 22: Iron ore pellets

- Minimization of 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 use of magnetic separators
- About 20% more throughput per unit of rotary kiln volume
- Reduction thermal load for direct reduction

Savings, investments, and GHG emissions reduction

The energy-saving potential with use of iron ore pellets (in place of iron ore lumps) is 15%. 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 INR 326 lakh (Table 11). The GHG emission reduction potential is 9400 tonne CO_2 per year.

Table 11: Benefits of switching to iron ore pellets

Parameter	Unit	Value
Kiln capacity	tpd	100
Energy saving	%	15
Coal saving	tpy	5250
Monetary benefits	INR lakh/year	326

Source: TERI analysis

3.8.5 Mullite-based Kiln Lining

Background

In a 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 (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 the reduction zone and 150–180°C in the discharge end. Radiation heat loss of the rotary kiln typically accounts for about 5% of the total heat input, which can be reduced with the application of low-thermal conductivity material such as mullite-based kiln lining.

Technology brief

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 is reduced by 50–80°C, thereby reducing heat loss through kiln shell by at least 30%.

Savings, investments, and GHG emissions reduction

Annual energy saving with a mullite-based lining in a rotary kiln (of 100 tpd capacity) is 580 tonne coal per year, i.e., 300 toe per year (Table 12). The GHG emission reduction potential is 1050 tonne CO_2 per year.

Table 12: Mullite-based kiln lining

Parameter	Unit	Value
Reduction in radiation losses	%	30
Energy saving	toe/year	300
Monetary benefits	INR lakh/year	36
Investment	INR lakh	50
Payback	Year	4.1

Source: UNDP

3.8.6 Decentralized control of shell air fans

Background

Typical dimensions of a rotary kiln of 100 tpd capacity are 42 m length and 3 m diameter. The raw materials—iron ore, non-coking coal, and dolomite—are mixed in the 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 a daily/shift basis. The use of damper at delivery side increases air flow and affects power consumption. Precise control of temperature can be attained with dedicated VFD for each fan, which will ensure air flow with least resistance.

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 an individual shell air fan can be increased or decreased without affecting the speed of other fans in a decentralized VFD system (Figure 23). The power consumption is proportional to the cube of the fan rpm.

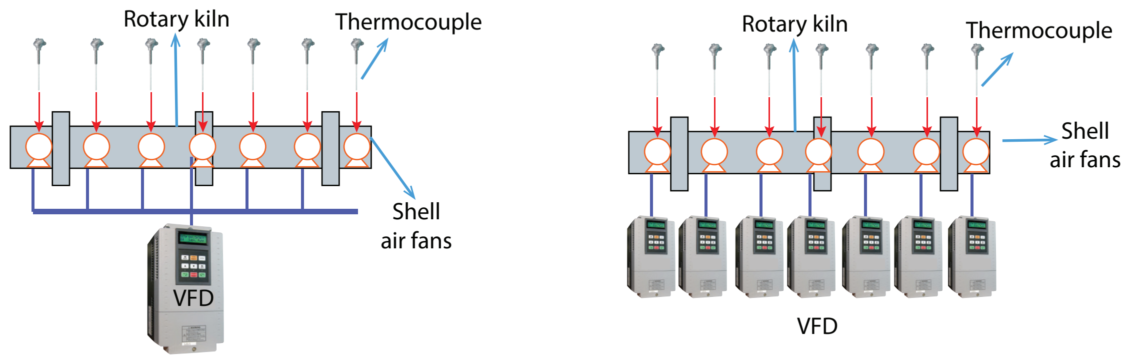


Figure 23: Decentralized VFD system in rotary kiln

Savings, investments, and GHG emissions reduction

The annual energy saving with installation of decentralized VFD systems for shell air fans, for a 100 tpd capacity rotary kiln, is 19,000 kWh per year (1.6 toe per year) (Table 13). The GHG emissions reduction potential is 16 tonne CO_2 per year.

Table 13: Benefits of installing automation and control system in rotary kiln

Parameter	Unit	Value
Energy saving	toe/year	1.6
Monetary benefits	INR lakh/year	0.5
Investment	INR lakh	2.8
Payback	Year	5.2

Source: TERI's analysis

3.8.7 Other energy efficiency measures

Other important energy efficiency measures for DRI industries include:

(1) artificial neural network for accretion control,

(2) variable frequency drives for air compressors,

(3) arresting compressed air leakages,

(4) reduction of pressure setting in air compressor, and

(5) energy efficient motors and multistage centrifugal pumps.

These would help in improving the overall energy performance of DRI plants.

3.9 Decarbonization options

Energy efficiency measures are short-term and reduce dependency on carbon based energy sources, but decarbonization of the DRI manufacturing process can be achieved through the transition to new technologies—by replacing existing coal-based rotary kilns with hydrogen based rotary kilns and replacing existing grid supply electricity with renewable-based green electricity. The phases of gradual transition to complete decarbonization of DRI manufacturing processes are mentioned below.

i. **Transition to new technology**
   - » Switch to electrical based process technologies, from the existing fossil fuel based processes for SRRM units
   - » Transition to gas based technologies to replace fossil fuel based process technologies

ii. **Deep decarbonization technologies**
   - » Switch to green electricity sources for the existing electricity based processes
   - » Switch to hydrogen-based technology options in DRI, to replace gas based technologies

A brief overview of hydrogen-based technology options is provided below.

3.9.1 MIDREX H_2 process

One of the best options, available in the near future, for decarbonization of the steel industry is to use green hydrogen to produce DRI as feedstock for steelmaking: known as MIDREX H2 (Figure 24). In the existing MIDREX Natural Gas process, up to 30% of NG can be replaced with hydrogen without any change in the existing process. When the availability of green hydrogen becomes economically viable, use of H_2 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 about 650 Nm3/t-DRI (54 kg/t).

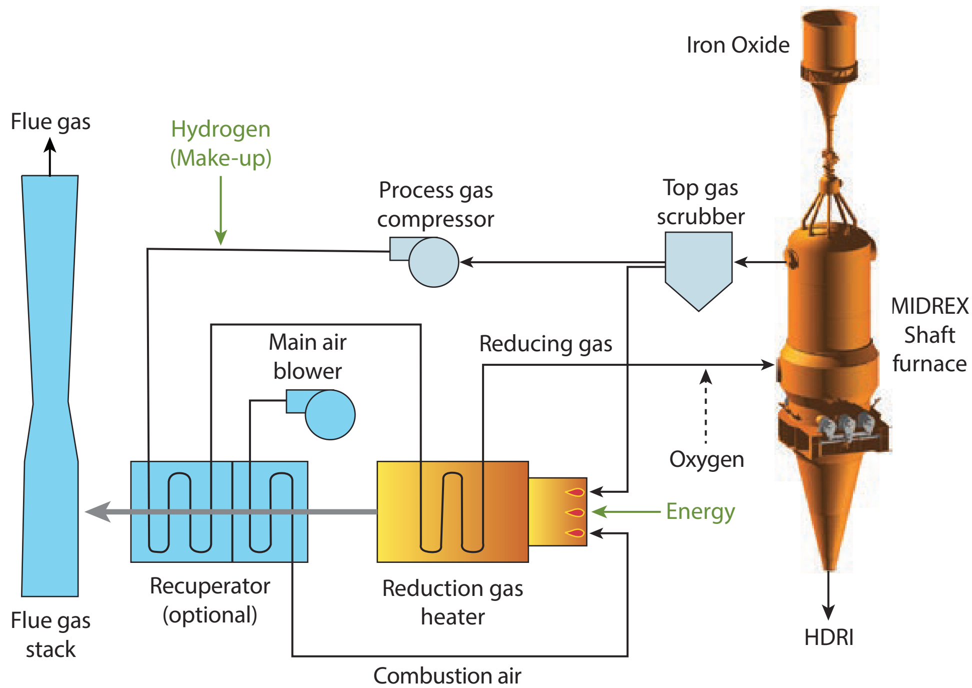


Figure 24: MIDREX H_2 process for DRI production

3.9.2 HYBRIT process

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 the steelmaking process. In this process, iron metal is produced by using hydrogen gas as the main reductant (Figure 25).

The production route is similar to the 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.

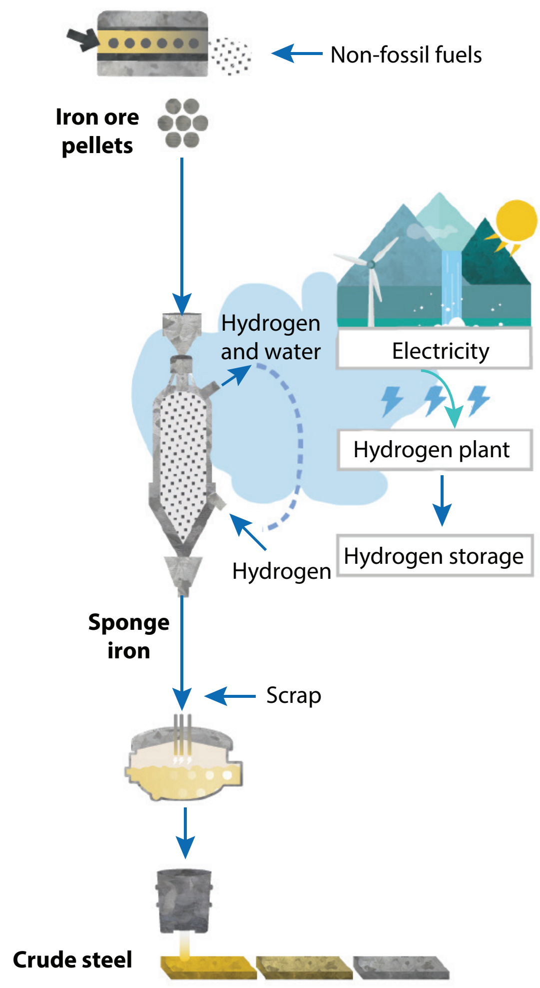


Figure 25: HYBRIT process for DRI production

INDUSTRY ASSOCIATIONS

Industry associations are one of the key stakeholders in the cluster, facilitating networking and addressing pertinent issues. Some of the active industry associations also facilitate technical support to the member industries, by organizing events such as workshops, training, etc. Industry associations pertaining to secondary steel industries in the Raipur cluster are shown in Table 14.

Table 14: Industry associations in Raipur's secondary steel cluster

Institution/organization	Contact details
Raipur Iron and Steel Trade Association (RISTA)	RISTA c/o.308, 3rd floor, Samta shopping arcade, Samta colony, Raipur - 492001, Chhattisgarh
Chhattisgarh Sponge Iron Manufacturing Association (CGSIMA) – Raipur chapter	House no. 11, Jal Vihar Colony, Telibandha, Raipur – 492001, Chhattisgarh
Chhattisgarh Wire Industries Association (CWIA)	Samta Shopping Arcade, Main Road, Samta Colony, Raipur – 492001, Chhattisgarh
Chhattisgarh Ferro Alloy Plant Association (CFAPA)	Samta Colony, Raipur – 492001, Chhattisgarh
Chhattisgarh Mini Steel Plant Association (CGMSP)	Shop no. 408, Samta Shopping Arcade, Main Road, Samta Colony, Raipur - 492001, Chhattisgarh
Urla Industries Association (UIA)	Urla Industrial complex, Raipur - 492001, Chhattisgarh
Chhattisgarh Chamber of Commerce and Industries (CCCI)	Ch. Devilal Vyapar Udyog Bhawan 2nd Floor, Bombay Market, Raipur - 492001, Chhattisgarh

CONCLUSION

The DRI industries are the most important segment of Raipur's secondary industry cluster, as they account for more than 82% of total energy consumption—resulting in around 75% of the GHG emissions from the cluster. The present status of DRI industries clearly indicates that there is immense scope for energy efficiency improvements. A range of best available technology (BAT) that are economically viable are available for improving energy efficiency. It is important to raise awareness on these decarbonization options among the DRI sector and develop a suitable roadmap for achieving net-zero emissions by the industry. This would include technology demonstration, development of infrastructure, and availability of appropriate financing options and policies for adopting energy efficiency and net-zero technology options.

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