From
the People of Japan

UNDP

Low-carbon Technology Packages for Mini Steel Plants

A COMPENDIUM

2023

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CONTENT

Preface

Steel is one of the most vital metal resources driving infrastructure and economic growth. At the same time, the sector also accounts for nearly 8% of the total global greenhouse gas (GHG) emissions. Sustainable and green steel production is a key part of achieving net-zero emission targets.

United Nations Development Programme (UNDP), in collaboration with the Ministry of Steel, Government of India, and supported by the Government of Japan designed a key component to 'Assess and identify low-emission and energy efficient solutions for the hard-to-abate sector (Steel) and implement them' under an initiative on leveraging low-carbon development pathways. The Government of Japan is supporting these initiatives in over 20 countries through UNDP offices. This is only a step in the overall aim to support the hard-to-abate mini steel plant sector to follow low-carbon pathways to reduce carbon footprint in alignment with the Ministry of Steel's target to reduce 20% GHG emissions by 2030.

This initiative builds on an earlier partnership between UNDP and the Ministry of Steel with support from the Global Environment Facility and AusAid) from 2004 to 2017, where over 50 energy efficient technology (EET) packages were implemented in 321 steel units including steel re-rolling mills, electric induction furnaces, and composite mills. In addition, over 35 EET packages were identified for sponge iron and electric arc furnace units.

As a part of the ongoing intervention, an extensive range of mapping, data analysis and deployment of new and innovative technologies shall be undertaken, including (a) conducting baseline energy audits to assess current technologies being used and the emissions/efficiency levels; (b) providing technical inputs on customized low-emission (EE/RE interventions) solutions; (c) guiding and facilitating post-implementation audits to quantify benefits including GHG reductions; and (d) develop a roadmap for reducing 20% GHG emissions in mini steel plants by 2030.

This publication, 'Low-carbon Technology packages in Mini Steel Plants: A Compendium' demonstrates solutions for sponge iron units, electric enduction furnace, electric arc furnace, and steel re-rolling mills, including composite mills. It covers low-carbon technology measures, cost-benefits, and other salient features, and aims to highlight various low-carbon technology packages available for the mini steel sector to reduce their present energy consumption, mainstream renewable energy systems, and reduce associated GHG emissions. We hope policymakers and industry stakeholders will find this publication useful in their efforts to achieve more efficient ways of steel production.

Acknowledgements

This publication is an outcome of the work of different entities and individuals who worked in previous phases of energy efficiency interventions in the secondary steel sector. The guidance of senior officials from the Ministry of Steel, Government of India, and the involvement of project teams from UNDP and MoS in the implementation of previous phases of UNDP-MoS-GEF-AusAid projects is gratefully acknowledged. The participation of mini steel units in piloting and adopting low-carbon technology packages is also greatly appreciated. It is those tried-and-tested low-carbon technologies that are listed in this publication for scaling up in more units in this phase of the project.

Though a number of individuals were involved in identifying, piloting, and scaling up the technology packages listed and described in this compendium, the following have made significant contributions in shaping this present publication. We would like to acknowledge Mr Kumar Shivam for compiling different technology packages from sub-sector wise compendiums published by UNDP in the previous project phases. The contribution of editing and making appropriate layout by Mr K P Eashwar under tight timelines is greatly appreciated. We would like to acknowledge the technical review provided by Mr Arindam Mukherjee. We place on record our appreciation to Mr Ramakrishna Bhatta for providing all operational support on time and diligently. We also like to thank Mr Hari Natarajan, Mr Dilip Singh, and Mr Sarabjot Singh Saini for reading the drafts and providing suggestions to improve the compendium. Finally, we would like to acknowledge the valuable inputs provided by Dr S N Srinivas in conceptualizing and completion of this publication.

Abbreviations

AC	Alternating Current
BEP	Best Efficiency Point
BOF	Basic Oxygen Furnace
BOP	Best Operating Practices
C	Carbon
CBM	Coal-bed Methane
CFM	Cubic Feet Per Minute
CO	Carbon monoxide
CO2	Carbon dioxide
CT	Cooling Tower
DC	Direct Current
M	Demineralized water
DRI	Direct Reduced Iron
EAF	Electric Arc Furnace
EBT	Eccentric Bottom Tapping
ECM	Energy Conservation Measure
EE	Energy Efficiency
EET	Energy-Efficient Technology
EMS	Electro-magnetic stirrer
FRP	Fibre Reinforced Plastic
FY	Financial Year
GDP	Gross Domestic Product
GHG	Greenhouse Gas
H2	Hydrogen
HBI	Hot Briquetted Iron
hp	Horse Power
HP	High Power
ID	Induced Draft
IF	Induction Furnace
kcal	Kilocalorie
KPI	Key Performance Indicator
kW	Kilowatt
kWh	Kilowatt hour
Mn	Manganese
MS	Mild Steel
mt	Million tonne
NG	Natural Gas
O2	Oxygen
P	Phosphorous
SCM	Standard Cubic Metre
SEC	Specific Energy Consumption
SFC	Specific Fuel Consumption
SMS	Steel Melting Shop
Si	Silicon
SPP	Simple payback period
SRRM	Secondary Steel re-rolling mills
SS	Stainless Steel
t	tonne
toe	tonnes of oil equivalent
tpd	tonne per day
tpy	tonne per year
TTT	Tap-to-tap time
UHP	Ultra High Power
UNDP	United Nations Development Programme
VOD	Vacuum Oxygen Decarburization
WHR	Waste Heat Recovery

Steel Sector in India: A Brief Introduction

The total installed production capacity of the Indian iron and steel industry was 157.585 million tonnes (mt) in 2022, while the actual production for 2022 was around 124.72 mt, with a total capacity utilization factor of 79.1%. India's per capita steel consumption of 77.2 kg is much lower than the global average (233 kg) and that of China (646 kg).

The total crude steel production at the global level was 1831.5 million tonnes (mt) during 2022. A sustained rise in domestic crude steel production had elevated India to the second largest crude steel producer in the world. The low level of per capita steel consumption indicates a significant growth potential for the Indian steel industry in the coming years.

The production of iron and steel is highly energy intensive. The main products of the sector are pig iron, sponge iron, and finished steel. The main finished steel products are plates, strips, rods and bars, profiles (sections), wires, and tubes. Most of these products are further processed by the engineering industry as per different end-use applications, while some finished products, such as bars and profiles are directly used by the construction sector.

The Indian steel industry can be broadly categorized based on the route followed in the production process. The primary iron and steel producers manufacture steel from iron ore using Blast Furnace-Basic Oxygen Furnace (BF-BOF) route and coking coal. These producers have large integrated steel-making facilities. The secondary steel producers (mini steel plants) use scrap, pig iron, sponge iron/direct-reduced iron (DRI), and ferro-alloys to make steel through the electric arc furnace (EAF) or induction furnace (IF) route. The share of the BF-BOF route had increased from 45% to 46% of the total production, and the EAF route had increased from 29% to 31% during the period 2018 to 2022.

Share of production route in steel production

Process route	2018	2022
Basic Oxygen Furnace (BOF)	45%	46%
Electric Arc Furnace (EAF)	29%	31%
Induction Furnace (IF)	26%	23%
Total	100%	100%

Source: Annual Report, Ministry of Steel, Government of India (2022-23)

To meet the greenhouse gasses (GHG) emission reduction targets under the Paris Declaration, the Ministry of Steel has submitted the Intended Nationally Determined Contributions (INDC) for the iron and steel sector. The CO_2-reduction target for BF-BOF route is 2.2–2.4 tonne per tonne of crude steel, whereas it is 2.6–2.7 tonne per tonne of crude steel in DRI-EAF route by the terminal year of 2030. For achieving GHG emission-reduction targets, the sector needs to make consistent efforts to improve its energy performance through the adoption of energy efficient technologies and best practices. The mini steel plants sector, in general, should further consider adoption of state-of-art technologies, which would substantially bring down the energy intensity.

Conversion factors

Energy Value

Energy source	Value
Electricity	860 kcal/kWh
Furnace oil	9346 kcal/litre
Coal	5600 kcal/kg
Natural gas	8600 kcal/^{3}

GHG Emission

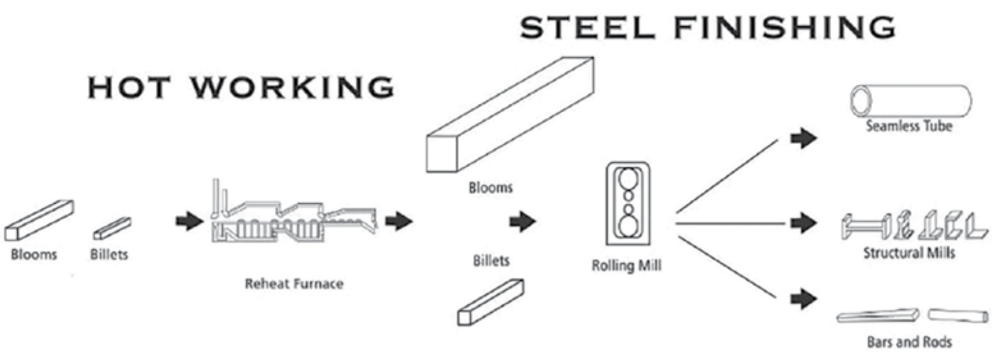
Energy source	Value
Electricity	0.71 kg of CO_2/kWh
Coal	2.5 kg of CO_2/kg
Furnace oil	2.8 kg of CO_2/litre
Natural gas	2.1 kg of CO_2/m^3

SECTION 1:
Steel Re-Rolling Mills

Steel Re-Rolling Mill (SRRM): A Process Overview

Rolling and re-rolling is the process of plastically deforming the metal by passing it between a set of rolls revolving in opposite directions. It is carried out on crude or scavenged steel/scrap products for shaping into semi-finished or finished forms in a re-rolling mill or a partially automated or a manual rolling mill. Rolling is the most widely used metal forming process. It is employed to convert metal ingots into products such as blooms, billets, sheets, plates, and strips. The main objective of rolling is to decrease the thickness of the metal and give it a desired profile. Rolled products are used for different engineering, constructional, and fabrication purposes.

As steel is not ductile at room temperature, heavier reductions require it to be heated to a temperature of 1200–1500 °C to make it ductile by reaching the recrystallization temperature. In re-rolling mills, this operation is called the re-heating process and is carried out in re-heating furnaces. Hot rolling operation is always preceded by re-heating operation.



Process flow of SRRM

A re-rolling mill has three main sections:

- Raw material section
- Re-heating furnace
- Rolling mill.

Raw material section: In this section, the raw materials such as ingots and billets are prepared for further rolling operation. Visual inspection is made to detect any defects such as surface cracks, piping, and bulge-outs. Accordingly, sorting, testing, cutting, and grinding operations are performed in this section.

Re-heating furnace section: There are various sub-sections of re-heating furnace section and their functions are as listed below.

- Fuel handling section: The fuel-handling section may include coal pre-crushers, coal pulverizer, conveyor belt, gas train, gas pipes, pressure relief valve, etc. The main function of this section is to prepare the fuel for proper/efficient combustion in re-heating furnaces.

- Pusher section: The material to be heated is put on the pusher platform for charging into the furnace. As per production/discharging rate, the material is pushed into the furnace at regular intervals with the help of motorized/hydraulic pusher.
- Re-heating furnace: In this section, the chemical energy of fuels is converted to heat energy and heat the material to required temperature efficiently and economically. Re-heating furnace prepares the sock material for further hot rolling operation. The re-heating operation includes charging, pushing, heating, and discharging/conveying to the rolling mill.
- Conveyor table: A conveyor table is used to o carry the heated discharged material to the rolling mill for rolling operation.

Rolling mill: In a rolling mill, the hot crude steel products are rolled into the desired shape by passing and squeezing it between a set of revolving rolls. The rolls may be plain or grooved rolls depending on the product. The rolling operation may contain one or more roll stands depending on reductions required. The rolling mill comprises of the following sub-sections:

- Drive mechanisms
- Roughing stands
- Intermediate stands
- Finishing mill
- Cooling bed
- Shearing section/finishing yard
- Dispatch yard

Tech 1: Energy Efficient Re-heating Furnace

1.1 Baseline scenario

A re-heating furnace is considered the heart of a rolling mill. Typically, top-fired pusher-type re-heating furnaces are used in steel re-rolling mill (SRRM) units to heat the raw material – i.e., ingots, billets or scraps – to the recrystallization temperature, which is about 1200 °C for mild steel. The furnace is fired with a variety of fuels such as lump coal, pulverized coal, furnace oil, natural gas, coal-based producer gas, biomass-based producer gas, etc. An optimum design of the furnace is important for higher productivity at least cost. A conventional furnace is not based on engineering design. Usually, such furnaces are used more as heating chambers. The furnace walls are at excessive high temperature with flames gushing out of the openings. The furnace does not have any waste heat recovery system; so large quantity of heat is wasted into the atmosphere. The furnaces are equipped with a long pre-heating zone and a heating zone is almost not present. Heavy firing is done through furnace front burners, which often leads to high scale formation and energy consumption. Refractories in these types of furnaces are regularly replaced. Overall, the furnace performs at an efficiency level of below 25%.

1.2 Energy efficient technology

An energy efficient design of the re-heating furnace primarily aims at highest possible productivity and least possible fuel consumption and burning loss. The characteristics of an energy efficient furnace are listed below.

- Complete combustion with minimum excess air
- Proper heat distribution
- Operation at optimum furnace temperature
- Reducing heat losses through furnace openings
- Maintaining correct amount of furnace draught
- Optimum hearth area utilization
- Maximum waste heat recovery from the flue gas
- Minimum heat loss through refractory
- Control and instrumentation of the furnace

An energy efficient furnace is based on engineering design considering a variety of parameters. Although the capital cost for such a furnace may be almost 1.5 times that of a conventional furnace, the simple payback period is less than a year. Designing an energy efficient furnace primarily depends on the type of fuel, raw material, productivity, and discharge temperature.

1.3 Benefits of technology

The installation of energy efficient furnace leads to following benefits:

- Uniform heating of stock is achieved
- Optimum hearth utilization
- Proper combustion
- Air-fuel ratio controlled with optimum specific energy consumption (SEC)
- Higher efficiency of furnace

1.4 Limitations of technology

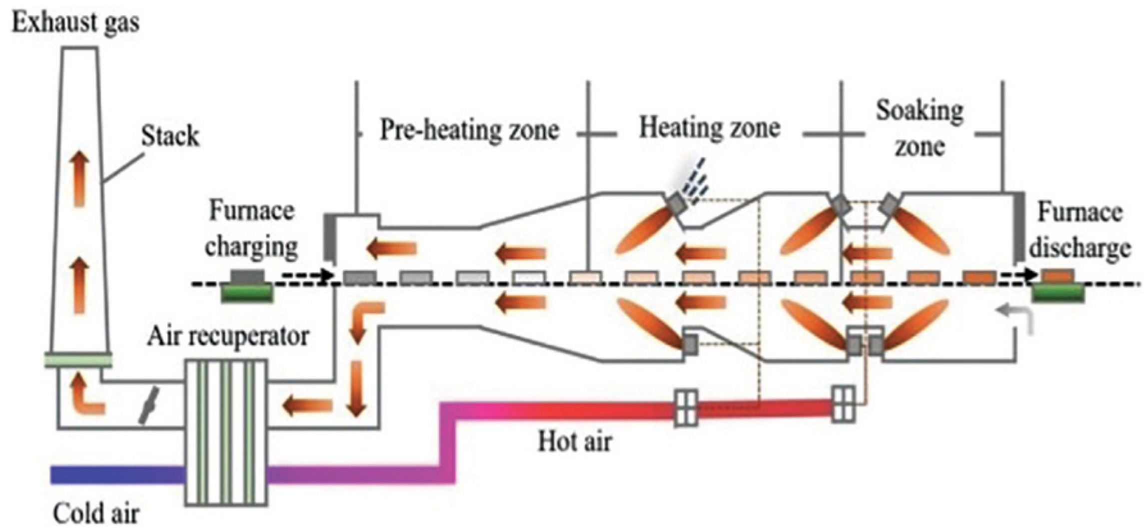
Investment for an energy efficient re-heating furnace is higher than that for a conventional re-heating furnace. Also, the downtime for installation is quite high. So, installation is only feasible when the operational reheating furnace lifetime cycle is completed. An energy efficient design of the furnace is based on the type of fuel, capacity, charge size, layout, etc.

1.5 Investment required, energy and GHG saving potential, and cost-benefit analysis

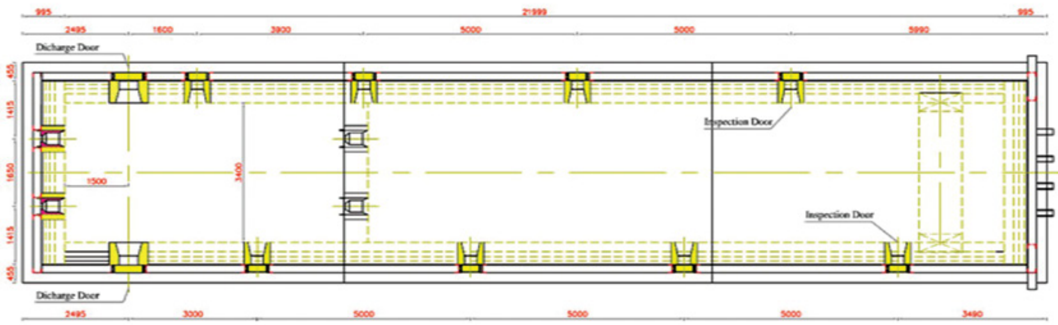
To understand the cost-benefit analysis, let us consider a re-heating furnace of 15-tonne capacity. The cost-benefit analysis for energy efficient reheating furnace is tabulated below.

Sl no.	Parameters	Value
	Inefficient furnace	
1	Initial cost of furnace	INR 50 lakh
2	Lifetime	15 years
3	Days in a year	300
4	Hours of operation per day	16
5	Fuel consumed	1142 kg/h
6	Fuel consumed in lifetime	82224 t
7	Cost of fuel	INR 7/kg
8	Fuel cost in lifetime	INR 5756 lakh

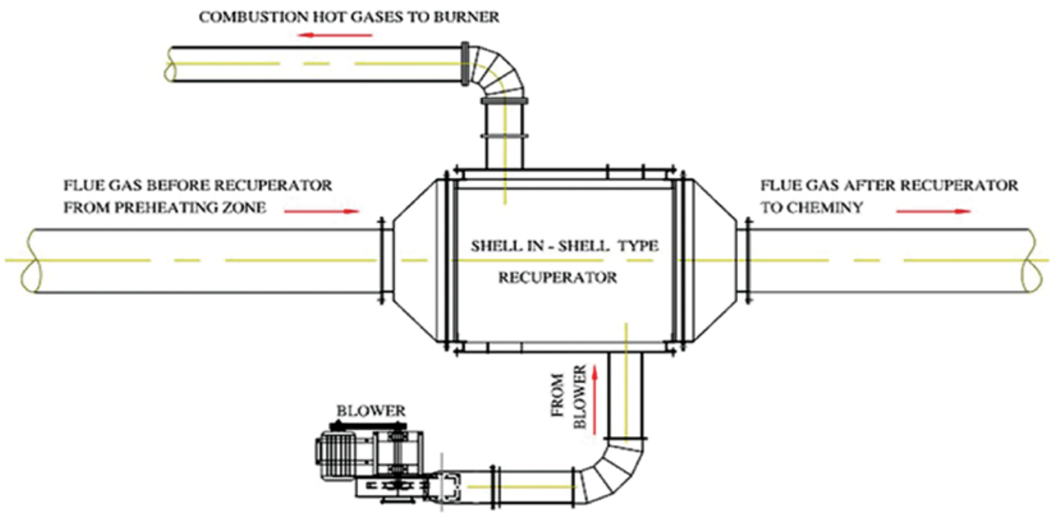
Sl no.	Parameters	Value
	Efficient furnace	
9	Initial cost of furnace	INR 80 lakh
10	Lifetime	20 years
11	Days in a year	300
12	Hours of operation per day	16
13	Fuel consumed	900 kg/h
14	Fuel consumed in 15 years	64,800 t
15	Cost of fuel	INR 7/kg
16	Fuel cost in lifetime	INR 4536 lakh
17	Saving in fuel cost over a period of 15 years	INR 1220 lakh
18	Difference in initial cost	INR 30 lakh
19	Net energy cost saving over 15 years	INR 1190 lakh
	Cost saving due to extra life of efficient furnace	
20	Cost per year for inefficient furnace with 15 years lifetime	INR 3.33 lakh
21	Cost per year for efficient furnace with 20 years lifetime	INR 4 lakh
22	Extra life of efficient furnace	5 years
23	Saving due to longer life of efficient furnace	INR 3.27 lakh
	Energy cost saving during extra life of efficient furnace	
24	Extra life of efficient furnace	5 years
25	Fuel saved per hour	242 kg
26	Days of operation in a year	300
27	Hours of operation per day	16
28	Fuel saving during extra life of efficient furnace	5808 t
29	Cost of per unit fuel	INR 7/kg
30	Saving in energy cost due to extra life of efficient furnace	INR 406.56 lakh
31	Net savings due to use of efficient furnace	INR 1600 lakh
32	Annual monetary saving	INR 80 lakh/y
33	Investment required	INR 120 lakh
34	Simple payback period	18 months
35	Annual energy saving potential	638 toe/y
36	Annual GHG emission reduction potential	2850 tCO_2/y



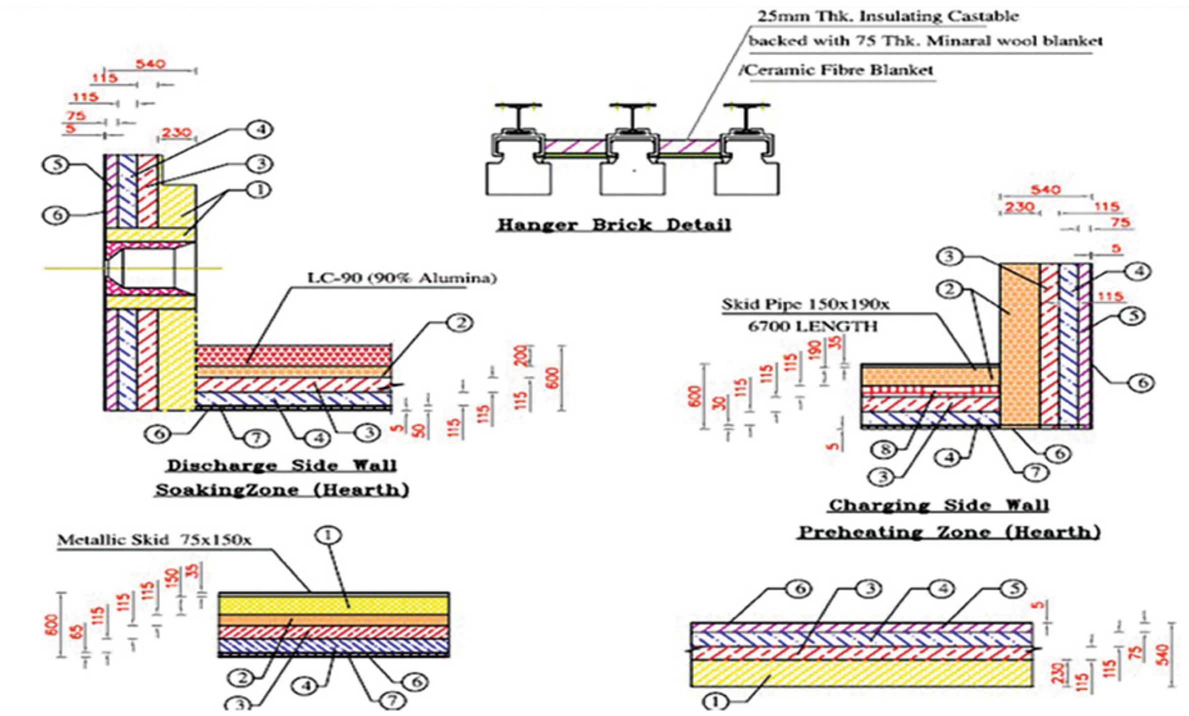
Schematic diagram of pulverized coal-fired, top-fired, pusher-type energy efficient furnace



Plan view of a 15 tph pulverized coal fired top fired pusher type energy efficient furnace

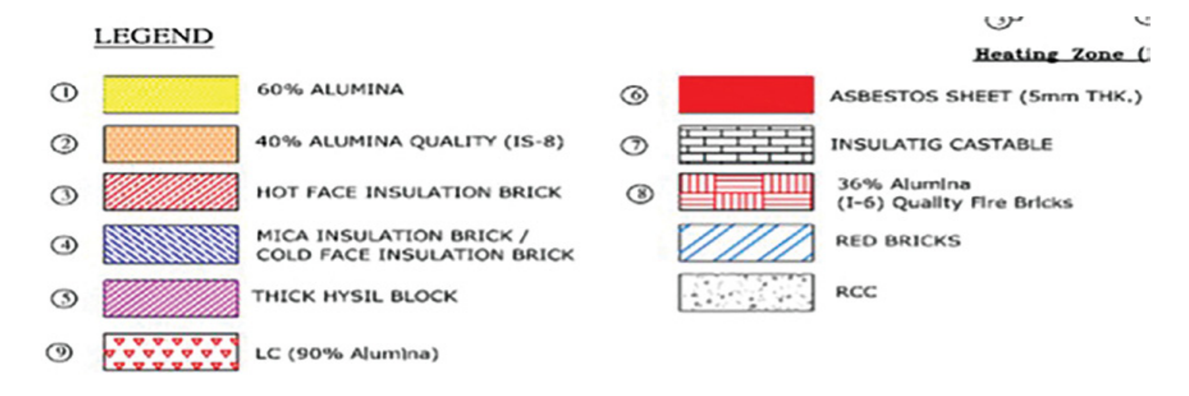


Flow of exhaust flue gas



Heating zone (Hearth)

Soaking and heating zone side wall



Indicative refractory and insulation lining for top-fired pusher-type furnace

Energy efficient re-heating furnace

Source: https://www.thesteefogroup.com/all-about-the-basics-of-reheating-furnaces/

1.6 Technology summary

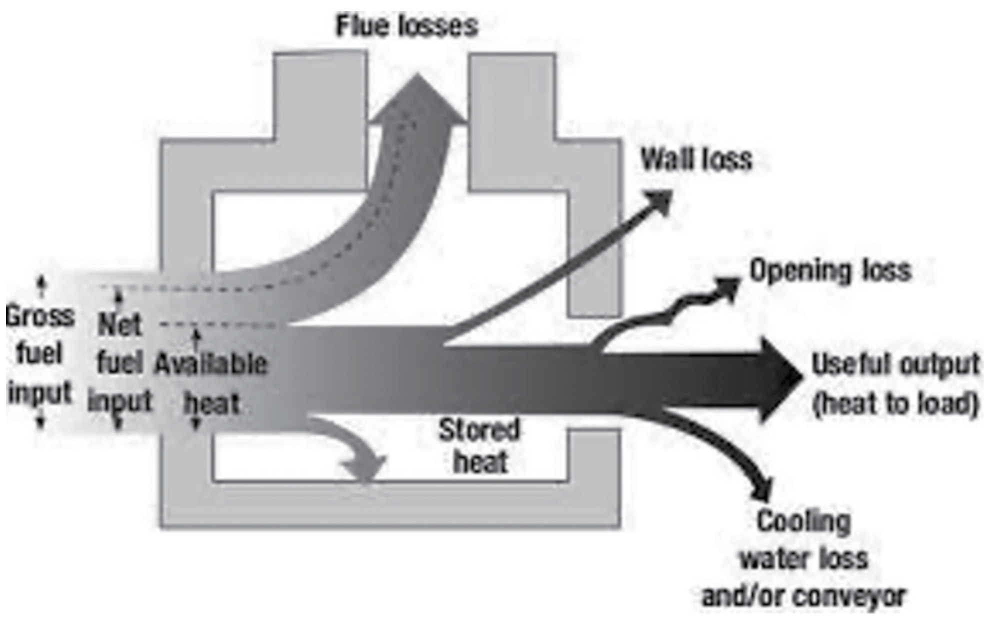
The technology impacts for energy efficient re-heating furnace are summarized below.

- Annual energy saving : 550–700 toe/y
- Annual GHG emission reductions : 2500–3500 tCO_2/y
- Annual monetary saving : INR 60–120 lakh/y
- Investment : INR 80–150 lakh
- Payback period : 15–24 months

Tech 2: Installation of High-efficiency Metallic Recuperator in Re-heating Furnace

2.1 Baseline scenario

Most of the SRRM units use top-fired pusher-type re-heating furnaces with solid, liquid or gaseous fuel. In a typical furnace, only 30%–40% of the total heat input is converted to useful heat. Rest of the energy is lost through different areas and forms.

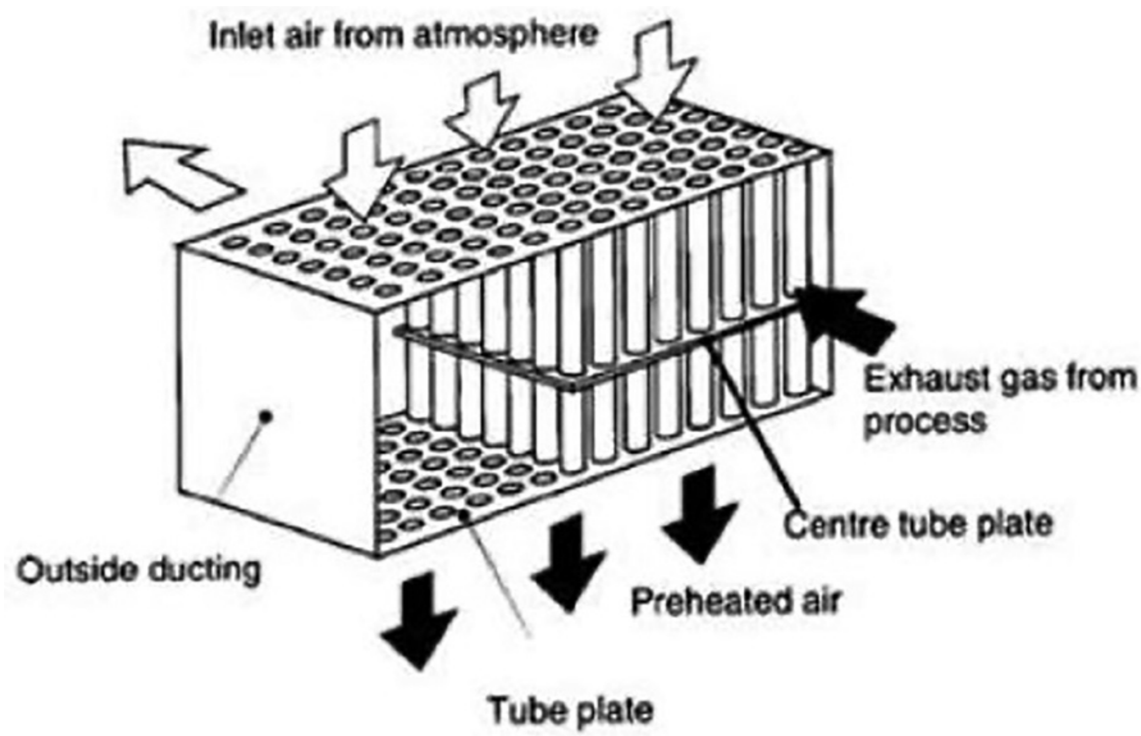


Sankey diagram: Re-heating furnace

The waste flue gas loss forms the major loss in a re-heating furnace, which accounts for 30%–35% of the total heat input. Exhaust flue gas from the furnace at a temperature of 500–700 °C has a potential to be re-used in the furnace. Traditionally, flue gases from the re-heating furnace were let out into the atmosphere through the chimney. Thus, significant amount of heat of flue gas was wasted.

2.2 Energy efficient technology

As an alternative to the conventional practice, a recuperator (i.e., a heat exchanger) is installed in the flue duct and used to recover the waste heat from the flue gases. In a recuperator, heat exchange takes place between the flue gases and the inlet combustion air through metallic or ceramic walls. Ducts or tubes carry the combustion air to be pre-heated; the other side consists of the waste heat stream. The system works based on the basic principle of physics, which says energy moves from a hot body to a cold one. Thus, in the process, the inlet combustion air from the atmosphere is pre-heated using the waste gas. The pre-heated combustion air is fed directly into the burner. The result is saving in terms of fuels, increase in flame temperature, and improvement in furnace efficiency. The recuperator efficiency depends upon two important parameters: (1) surface area and time available for heat exchange and (2) recuperator material.



Waste heat recovery using recuperator

2.3 Benefits of technology

The installation of high efficiency metallic recuperator leads to following benefits:

- Proper combustion
- Reduction in fuel consumption leads to lower SEC
- Improvement in furnace efficiency

2.4 Limitations of technology

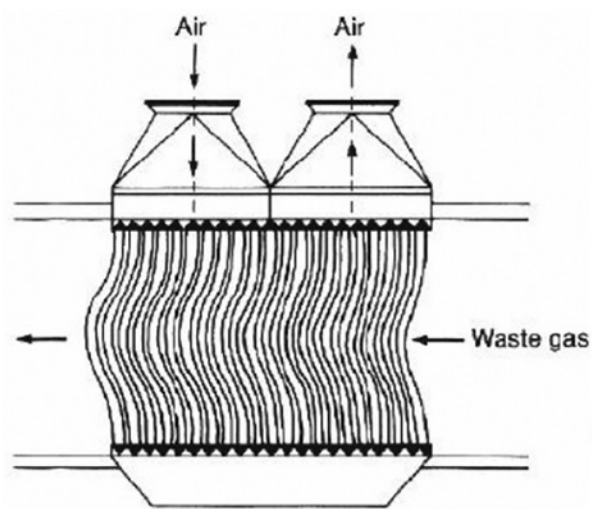
Combustion air temperature to be maintained below 400 °C for pulverized coal as the same may get ignited. Combustion air pipeline should be properly insulated. The design of the recuperator depends on the type of fuel and the flue gas characteristics.

2.5 Investment required, Energy and GHG saving potential, and Cost- Benefit Analysis

To understand the cost-benefit analysis, let us consider a re-heating furnace of 15-tonne capacity. The cost-benefit analysis for installation of high efficiency metallic recuperator is tabulated below.

Sl no.	Parameter	Without recuperator	With high efficiency metallic recuperator
1	Productivity	15 t/h	15 t/h
2	Operating hours per day	16	16
3	Operating days per year	300	300
4	Combustion air temperature	35 °C	350 °C
5	Specific fuel consumption*	75 kg/t	64.26 kg/t
7	Annual fuel consumption	5400 t/y	4627 t/y
8	Annual saving in coal consumption	773 t/y	
9	Monetary saving due to saving in coal consumption	INR 54.1 lakh	
10	Investment required (high efficiency metallic recuperator)	INR 27 lakh	
11	Simple payback period	6 months	
12	Annual energy saving potential	433 toe/y	
13	Annual GHG emission reduction potential	1933 tCO_2/y	

*with every 22 °C rise in combustion air pre-heat temperature, there is a saving of 1% of fuel.



Schematic diagram of high efficiency metallic recuperator

Source: https://beeindia.gov.in/sites/default/files/2Ch8.pdf

Recuperator

Source: https://encon.co.in/recuperators/

2.6 Technology summary

The technology impacts for high efficiency metallic recuperator are summarized below.

- Annual energy saving : 400–500 toe/y
- Annual GHG emission reductions : 1850–2200 tCO_2/y
- Annual monetary saving : INR 40–70 lakh/y
- Investment : INR 15–40 lakh
- Payback period : 5–12 months

Tech 3: Installation of Automation and Control System in Re-heating Furnace

3.1 Baseline scenario

A re-heating furnace is considered the heart of a rolling mill. Typically, top-fired pusher-type re-heating furnaces are used in SRRM units to heat the raw material (i.e., ingots, billets or scraps) to the recrystallization temperature of about1200 °C. The furnace is fired with a variety of fuel such as lump coal, pulverized coal, furnace oil, natural gas, coal-based producer gas, etc. Optimum efficiency of the furnace can be ensured by maintaining correct temperature regime, ensuring optimum air-fuel ratio including correct amount of excess air and maintaining optimum furnace pressure. Optimum efficiency of the furnace can lead to optimum specific fuel consumption and burning loss. Even today, most of the re-heating furnaces in the country are manually operated. Such conventional furnaces are not equipped with basic monitoring equipment systems such as thermocouples. Manually operated furnaces do not have any control on maintaining the correct temperature regime and the correct air-fuel ratio required for combustion. Such furnaces are often over-fired leading to high energy consumption and burning loss.

3.2 Energy efficient technology

Optimum furnace efficiency can be achieved through complete automation and control systems in the furnace. To start with, all furnaces should be equipped with basic monitoring instruments such as thermocouples. Automation and control system for re-heating furnace exists at three levels:

- Level 1: On-off Control
- Level 2: A proportional integral derivative (PID) controller-based system
- Level 3: A programmable logic controller (PLC) based system.

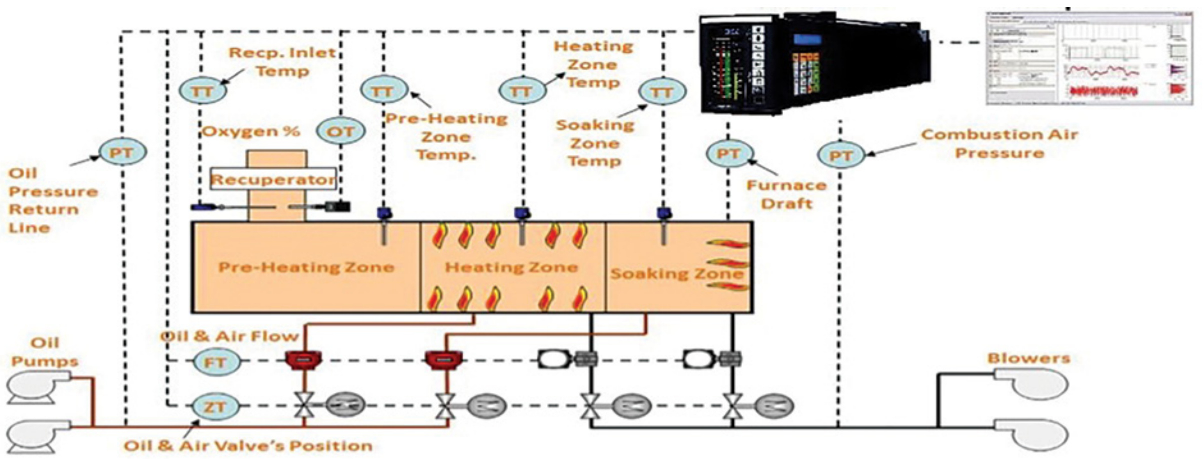
Automation and control system in re-heating furnace ensures the following: (a) maintains proper temperature regime across the length of the furnace, (b) maintains air-fuel ratio including correct amount of excess air, and (c) maintains correct furnace pressure and draught.

Re-heating furnace automation and control system consists of monitoring instruments such as:

- thermocouples for measuring temperature,
- zirconium-based online oxygen analyzer to measure the oxygen percentage in flue gas,

- pressure transducers to measure the furnace pressure,
- control instruments such as variable frequency drives (VFDs) in FD and ID fans,
- solenoid valves in air and fuel line,
- DC motor-driven screw feeder, and
- a control circuit.

All instruments and control settings are installed in a closed loop. During the running of the furnace, feedback from the monitoring instruments such as thermocouple, oxygen analyzer, and pressure transducers are received by the control circuit; which, in turn, controls the DC motor-driven screw feeder to control the coal flow and VFD to control air flow. The FD and ID fan speed is synchronized to maintain proper draught and furnace pressure. The control circuit can be either PID- or PLC-based. The air-fuel flow is accordingly controlled based on different running conditions of the furnace. The controlling of temperature, oxygen, and pressure in a furnace is 43, known as 'Tops' control. The figure below shows the process and instrumentation for a typical re-heating furnace.



Process and instrumentation of re-heating furnace

3.3 Benefits of technology

The installation of automation and control system in the furnace leads to following benefits:

- Proper temperature across the furnace.
- Optimum air-fuel ratio leads to proper combustion.
- Maintains correct furnace pressure and draught.

3.4 Limitations of technology

Skilled manpower for operation and regular maintenance of system and instruments is required.

3.5 Investment required, Energy and GHG saving potential, and Cost- Benefit Analysis

To understand the cost-benefit analysis, let us consider a re-heating furnace of 15-tonne capacity. The cost-benefit analysis of installation of automation and control system in re-heating furnace is tabulated below.

Sl no.	Parameter	Without automation	With automation
1	Oxygen level	11.2%	7.2%
2	Excess air	114.29%	52.17%
3	Total air supplied	15.21 kg/kg of coal	10.8 kg/kg of coal
4	Sensible heat loss	2432.14 kcal/kg of coal	1770.65 kcal/kg of coal
5	Dry flue gas loss	32.78%	24.59%
6	Sensible heat loss	200749.07 kcal/t	146149.63 kcal/t
7	Annual operating hours	6000 h/y	6000 h/y
8	Reduction in fuel consumption	45499.5 kg/y	
9	Unit cost of fuel	INR 7/kg	
10	Savings (fuel saving)	INR 3.2 lakh/y	
11	Material saving due to reduced burning loss	72 t/y	
12	Unit cost of material	INR 35, 000/t	
13	Savings (material saving)	INR 25.2 lakh/y	
14	Total savings	INR 28.4 lakh/y	
15	Investment required	INR 20 lakh	
16	Simple payback period	8.5 months	
17	Annual energy savings potential	25.5 toe/y	
18	Annual GHG emission reduction potential	113.7 tCO_2/y	

3.6 Technology summary

The technology impacts for automation and control system are summarized below.

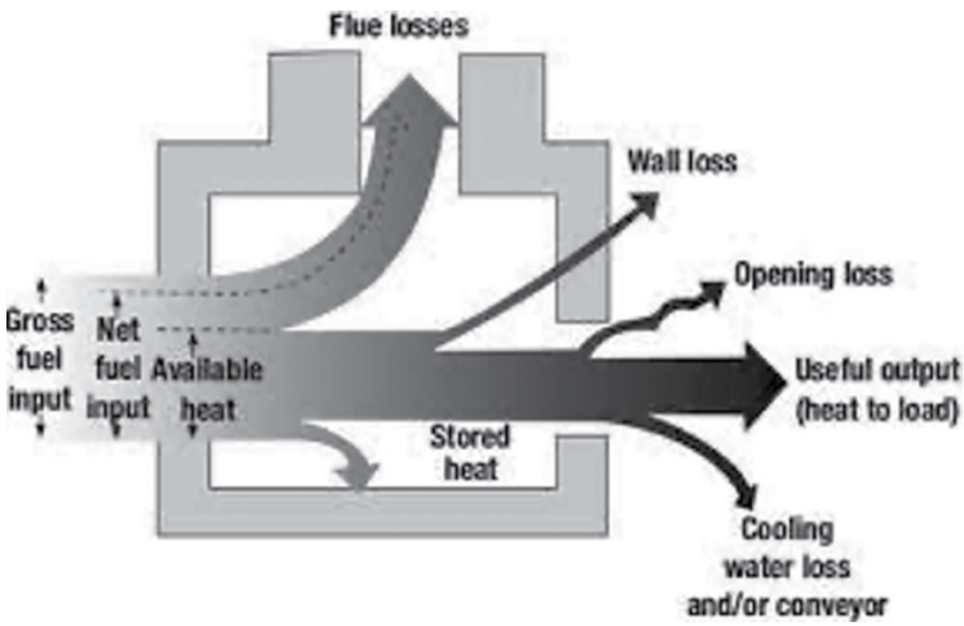
- Annual energy saving : 20–35 toe/y
- Annual GHG emission reductions : 80–130 tCO_2/y
- Annual monetary saving : INR 20–40 lakh/y
- Investment : INR 18–30 lakh
- Payback period : 7–14 months

Tech 4: Installation of Optimum Refractories and Insulation in Re-heating Furnace

4.1 Baseline scenario

A re-heating furnace can typically be defined as a chamber consisting of four walls, hearth, and roof, built with refractory bricks and insulation material enclosed within a steel structure. All the six faces of the chamber are exposed to high temperatures ranging from 800 to 1200 °C. So, the material of the wall, hearth, and roof should be carefully selected so as to withstand the high temperature. As the inside temperatures of the furnace are high, a considerable amount of heat energy is lost by heat conduction through the walls, roof, and hearth. Therefore, it is imperative to use material that is of as low thermal conductivity as possible for minimizing the heat loss.

Moreover, small-scale re-rolling mills do not run for 24 hours on a continuous basis. Every day, the furnaces are cooled after stopping the rolling and then again they are heated up the next day. During this process, heat energy is accumulated and then dissipated during the idling period of the furnace. For minimizing this loss, the wall material should be of lower thermal mass so that heat accumulation can be minimized. Also, the refractory material should be able to withstand thermal shock due to cyclic operation. Thermal shocks lead to spalling and, therefore, the refractory material should have good spalling resistance.



Sankey diagram of re-heating furnace

Thus, the selection of correct refractory and insulation is of significance. In conventional furnaces, due care is not given towards selection of correct refractory and insulation linings. This often leads to:

- Higher heat losses through the furnace walls,
- Lower life of refractory and insulation, and
- Higher energy consumption.

Almost 10%–12% of the total heat input is lost as radiation and conduction losses through the furnace walls. Higher furnace skin temperatures are common symptoms of inadequate refractory and insulation material. In addition, a large amount of radiation heat losses happens through openings in the furnace, such as inspection doors and ejector space. The radiation losses increased considerably as temperature increases.

4.2 Energy efficient technology

Design of optimum refractory and insulation lining need to meet the following requirements:

- Selection of suitable material to meet the service requirements.
- Design of optimum lining thickness considering minimum heat loss and payback period.
- Selection of material considering cost, service life, and fuel economy

The furnace is divided into soaking, heating, and pre-heating zones. The pattern of the refractory lining varies with these zones at the furnace roof, side walls, and end walls. Constituents of lining at different locations of furnaces are selected based on the temperature profile.

The suggested refractory and insulation pattern for different zones of the re-heating furnace has been tabulated below.

Furnace surface	Furnace zone	Suggested refractory and insulation lining pattern
Roof	Soaking zone	250-mm-thick special-shaped bricks (hanger bricks) made of 60% alumina refractories backed by 25-mm-thick insulating castable backed by 75-mm-thick ceramic fibre blanket / mineral wool blanket
	Heating zone	250-mm-thick special-shaped bricks (hanger bricks) made of 60% alumina refractories backed by 25-mm-thick insulating castable backed by 75-mm-thick ceramic fibre blanket / mineral wool blanket
	Pre-heating zone	250-mm-thick special-shaped bricks (hanger bricks) made of 40% alumina refractories backed by 50-mm-thick insulating castable/ ceramic fibre.

Furnace surface	Furnace zone	Suggested refractory and insulation lining pattern
Side walls and end walls	Discharge end wall	230-mm-thick 60% alumina quality refractories backed by 115-mm hot-face insulation bricks, 115-mm-thick cold (Mica) insulation bricks (IS-2042) and 75-mm-thick Hysil blocks insulation and 5-mm-thick asbestos sheet backed by steel sheets.
	Side walls (heating and soaking zones)	230-mm-thick 60% alumina quality refractory bricks backed by 115-mm-thick hot-face insulation bricks, 115-mm-thick Mica insulation bricks / cold-face insulation bricks, 75-mm-thick Hysil block insulation and 5-mm-thick asbestos sheet backed by steel sheets
	Side walls (pre-heating zone)	230-mm-thick 40% alumina quality (IS-8) refractory bricks backed by 115-mm-thick hot-face insulation bricks, 115-mm-thick Mica insulation bricks, 75-mm-thick Hysil block insulation and 5-mm-thick asbestos sheet backed by steel sheets
	End wall (charging side)	230-mm-thick 40% alumina quality (IS-8) refractory bricks backed by 115-mm-thick hot-face insulation bricks, 115-mm-thick Mica insulation bricks,75-mm-thick Hysil block insulation and 5-mm-thick asbestos sheet backed by steel sheets
	Flue offtake/ down corners	150-mm-thick ceramic fibre blanket (RT128) to be held imposition by heat resisting (stainless steel) studs and washers in case of flue port at the roof. If the flue line is below the hearth, lining pattern will be same as that of charging side end wall
Hearth	Soaking zone	200-mm-thick high alumina fire bricks (LC-90 / TRL- 88 / high chromium castables) backed by 115-mm-thick hot-face insulation backed by 115-mm cold-face insulation backed by 50-mm insulating castables and 5-mm-thick asbestos sheet
	Heating zone	150-mm-thick high alumina quality fire bricks (60% alumina) backed by 115-mm 40% alumina (IS- 8) backed by 115-mm hot-face insulations, 115-mm cold-face insulation, backed by 65-mm insulating castables and 5-mm thick asbestos sheet
	Pre-heating zone	190-mm-thick high alumina fire bricks (40% alumina) backed by 115-mm hot-face insulation bricks, 115-mm-thick cold-face insulation bricks, 115-mm 36% (IS-6) quality fire bricks, 30-mm insulating castables and 5-mm-thick asbestos sheet
Others	Charging end doors	175-mm-thick RT128-grade ceramic fibre module backed by 25-mm-thick mineral wool insulation blanket
	Discharge end doors	225-mm-thick RT128-grade ceramic fibre module backed by 25-mm-thick mineral wool insulation blanket
	Recuperator area	115-mm-thick IS-8 quality firebricks backed by 15-mm-thick Mica insulating bricks and 50-mm-thick calcium silicate block insulation
	Flue duct from recuperator up to chimney	115-mm-thick IS-6 quality fire bricks backed by 115-mm-thick Mica insulating bricks

For effective insulation of the furnaces, it is recommended to install ceramic fibre insulation in the inspection doors. All openings in the burner blocks should be closed using ceramic fibre blankets. A significant amount of energy can be saved by adoption of optimum refractory and insulation and sealing of furnace openings.

4.3 Benefits of technology

The installation of automation and control system in the furnace leads to following benefits:

- Lower heat losses through the furnace walls
- Prolong life of refractory and insulation
- Lower energy consumption
- Higher productivity

4.4 Limitations of technology

The life of the refractory also depends on the operating practices of the furnace. The refractory schedule provided above is prescriptive and shall vary based on the actual site requirement.

4.5 Investment required, energy and GHG saving potential, and cost-benefit analysis

To understand the cost-benefit analysis, let us consider a re-heating furnace of 15-tonne capacity. The cost-benefit analysis of installation of optimum refractories and insulations in re-heating furnace is given in the table below.

Sl no.	Particular	Existing furnace	Furnace with optimum refractory and insulation
1	Radiation heat losses through wall (soaking zone)		
	Total wall area	15.84 m^2	15.84 m^2
	Average temperature of wall	268 °C	95 °C
	Ambient temperature	35 °C	35 °C
	Heat loss from walls	3872 kcal/h/m^2	595 kcal/h/m^2
	Heat loss from walls (entire area)	61332 kcal/h	9425 kcal/h
2	Radiation heat losses through wall (heating zone)		
	Total wall area	16.8 m^2	16.8 m^2
	Average temperature of wall	185 °C	70 °C
	Ambient temperature	35 °C	35 °C
	Heat loss from walls	2008 kcal/h/m^2	305 kcal/h/m^2
	Heat loss from walls (entire area)	33,734 kcal/h	5124 kcal/h

Sl no.	Particular	Existing furnace	Furnace with optimum refractory and insulation
3	Radiation heat losses through wall (pre-heating zone)		
	Total wall area	2.6 m^2	2.6 m^2
	Average temperature of wall	85 °C	60 °C
	Ambient temperature	35 °C	35 °C
	Heat loss from walls	472 kcal/h/m^2	202 kcal/h/m^2
	Heat loss from walls (entire area)	1227 kcal/h	525 kcal/h
4	Radiation heat losses from ceiling		
	Total wall area	48 m^2	48 m^2
	Average temperature of wall	90 °C	70 °C
	Ambient temperature	35 °C	35 °C
	Heat loss from walls	622 kcal/h/m^2	356 kcal/h/m^2
	Heat loss from walls (entire area)	29,856 kcal/h	17,088 kcal/h
5	Radiation heat losses from hearth		
	Total wall area	41.6 m^2	41.6 m^2
	Average temperature of wall	70 °C	60 °C
	Ambient temperature	35 °C	35 °C
	Heat loss from walls	245 kcal/h/m^2	164 kcal/h/m^2
	Heat loss from walls (entire area)	10,192 kcal/h	6822 kcal/h
6	Total heat loss from furnace skin	1,36,342 kcal/h	38,984 kcal/h
7	Heat loss in terms of fuel	24.3 kg/h	7.0 kg/h
8	Saving in fuel	17.4 kg/h	
9	Annual operation hours	4800	
10	Annual fuel savings	83.4 t/y	
11	Annual monetary savings	INR 5.8 lakh	
12	Investment required (for optimum refractories and insulation)	INR 15 lakh	
13	Simple pay-back period	30.8 months	
14	Annual energy saving potential	46.7 toe/y	
15	Annual GHG emission reduction potential	209 tCO_2/y	

4.6 Technology summary

The technology impacts for optimum refractories and insulations are summarized below.

- Annual energy saving : 35–50 toe/y
- Annual GHG emission reductions : 150–250 tCO_2/y
- Annual monetary saving : INR 5–7 lakh/y
- Investment : INR 12–18 lakh
- Payback : 25–40 months

Tech 5: Installation of Energy Efficient Pulverizer

5.1 Baseline scenario

In recent times, pulverized coal has emerged as the most widely used fuel in the SRRM sector. Easy availability of coal, cost-economics of its use, and lower capital investment required for switch-over have made pulverized coal popular in the industry. However, to get optimum output, it is important that the supply chain of coal is properly maintained. Right from procurement till feeding of coal into the furnace, each step needs to be carefully monitored and controlled for better outputs.

Most of the operators of pulverized coal lack understanding of best operating practices related to its use. The coal typically used in the SRRM sector is characterized by high ash and low calorific content. Using coal of high ash content leaves ash deposits on the refractory bricks, which react with the iron content of the bricks. This leads to premature cracks and failure of the refractory lining. Ash deposits require more heat to be added to the charge for attaining desired temperature, thus increasing burning losses. Also, high ash content leads to choking of recuperator tubes. This necessitates frequent cleaning, thus leading to high maintenance cost and reduced performance of heat exchangers. The ideal size of pulverized coal should be at least 75%–80% of 75 microns. In the conventional system, fine coal ranges from only 10% to 30%.

Non-uniform coal particles undergo partial combustion and result in deposition on the furnace walls. These coarse particles escape from the furnace with flue gas in the form of unburnt carbon or ash.

5.2 Energy efficient technology

The energy efficient alternative to use pulverized coal as fuel starts with the procurement of good quality coal. Coal with high calorific value and low ash content (e.g., Assam coal) is most ideally suited for the use as pulverized coal. Coal quality should be regularly examined in-house in order to keep a check on the sourcing of coal. For in-house testing of coal, laboratory size bomb calorimeters should be used.

Once good quality coal is sourced, the next step is to process or pulverize the coal into the desired fineness consistently. To do so, certain modifications in the pulverizer are required. The critical components of a pulveriser are:

- Hammer
- Mild steel liner

- Classifier
- In-built blower

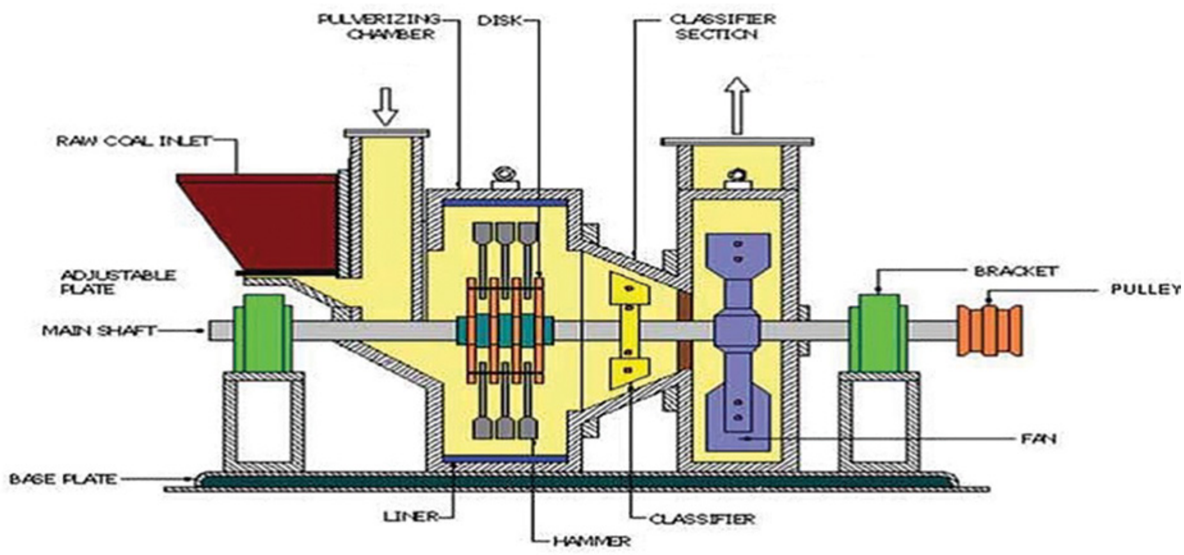
To achieve pulverized coal to the desired fineness in a consistent manner, the following modifications to existing pulverizer are suggested.

Hammer: Improve metallurgy with the addition of manganese (13%), carbon (1.13%), silicon (0.4%), sulphur (0.003%), and phosphorus (less than 0.2%) to increase its resistance to wear and tear.

Liner: Use grooved EN-31 hardened steel plates or casted high manganese.

Classifier: Ensure proper dimensions and thickness (gap between the classifier tip and casing to be less than 1 mm) to classify the pulverized coal to achieve 65%–80% of desired minus-200 mesh size. The classifier should be high chrome, high nickel alloy.

The performance of a coal pulverizer can be gauged from the size and uniformity of the coal output. Thus, it becomes imperative to measure and maintain the fineness of coal coming out of the pulverizer. A metal sieve of minus-200 mesh size or 75 microns can be used for the purpose.



Sectional view of pulverizer

Coal-based pulverizer

Source: https://www.mahalaxmi-engineering.com/steel-rolling-mill-machinery.html

5.3 Benefits of technology

The installation of energy efficient pulverizer in the furnace leads to following benefits:

- Efficient combustion
- Consistent and controlled heating
- Lower energy consumption with increased furnace productivity
- Improved steel quality

5.4 Limitations of technology

The pulverizer grinding capacity is finite, and it may not always match the fuel demand of the re-heating furnace, especially during peak operational periods. Also, due to wear and tear, pulverizers require regular maintenance to ensure their optimal performance.

5.5 Investment required, Energy and GHG saving potential, and Cost- Benefit Analysis

To understand the cost-benefit analysis, let us consider a re-heating furnace of 15-tonne capacity. The cost-benefit analysis of installation of energy efficient pulverizer in re-heating furnace is tabulated below.

Sl no.	Parameter	Baseline	Post implementation
1	Productivity	15 t/h	15 t/h
2	No. of operating hours per day	16	16
3	No. of working days in a year	300	300
4	Specific fuel consumption (baseline)	75 kg/t	-
5	Saving in specific fuel consumption (SFC) after installation of energy efficient pulverizer	5%	
6	SFC (post implementation)	-	71.25 kg/t
7	Annual production	72000 t/y	
8	Annual fuel consumption	5400 t/y	5130 t/y
9	Annual saving of coal	270 t/y	
10	Price of coal	INR 7000/t	
11	Annual monetary savings	INR 18.9 lakh/year	
12	Investment required (including recurring cost of critical components for a period of 6 months)	INR 10 lakh	
13	Simple pay-back period	6.3 months	
14	Annual energy savings	151.2 toe/y	
14	Annual GHG saving	675 tCO_2/y	

5.6 Technology summary

The technology impacts for energy efficient pulverizer are summarized below.

- Annual energy saving : 110–180 toe/y
- Annual GHG emission reductions : 600–800 tCO_2/y
- Annual monetary saving : INR 14–23 lakh/y
- Investment : INR 8–20 lakh
- Payback : 6–15 months

Tech 6: Installation of Modified Pulverized Coal Handling and Feeding System

6.1 Baseline scenario

Conventionally, the pulverized coal is conveyed with cold combustion air, without the provision of a recuperator, and fired by a four-inch pipe. As there is no proper control on the fuel and air, the process results in improper combustion resulting in unburnt coals. Also, the pulverizer in most cases is inefficient.

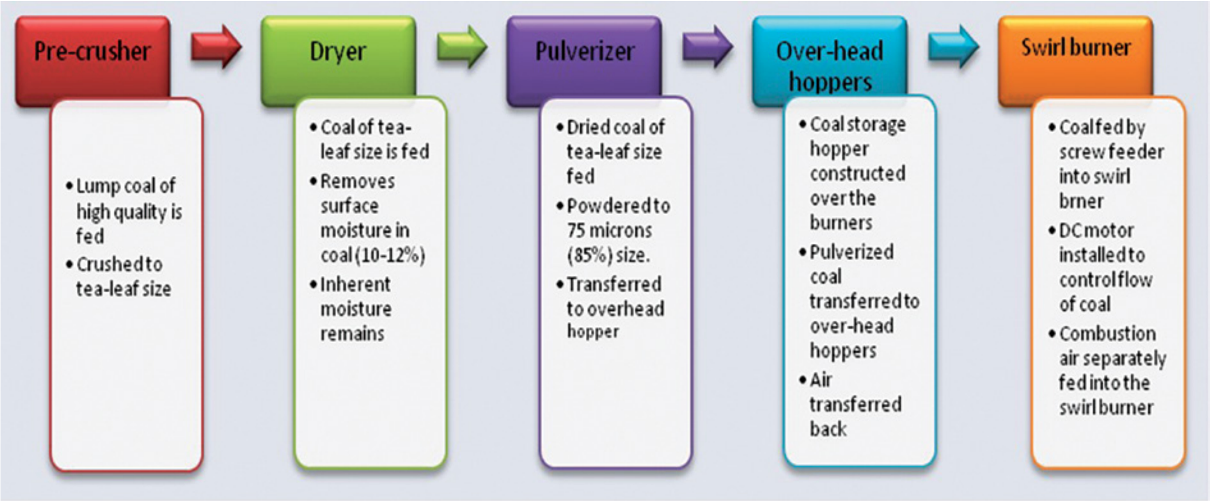
6.2 Energy efficient technology

In the energy efficient process, high quality lump coal is first fed into a pre-crusher, wherein coal is crushed to tea leaf size. The pre-crushed coal is passed through the dryer where the surface moisture of coal is removed using hot air from the recuperator. The coal is then fed into the pulverizer, where it is powdered to 75-micron size. Finer coal means more surface area available for combustion and hence, more heat output. Pulverized coal is transferred to the overhead furnace hopper, which allows storing of coal of required quantity at the furnace head. DC motor-run screw feeder controls the coal flow to the burner, based on the furnace temperature.

A swirl-type burner with annual arrangement for separate entry of coal and hot air and equipped with circumferential vanes is used in the system to ensure proper turbulence and mixing of air and fuel.

The process is completed by feeding pre-heated combustion air from the recuperator to the burner tip, which along with the swirling motion improves the combustion significantly leading to lower specific fuel consumption and burning loss.

The process flow of the modified coal handling and feeding system is shown in the figure below.



Process flow of pulverized coal handling and feeding system

A typical specification of the pulverized coal handling and feeding system for a 15-tph furnace is tabulated below.

Technical specification of pulverized coal handling and feeding system

Sl no.	Parts	Standard specification
1	Pre-crusher	Type: Primary crusher
		Processing capacity: up to 1.5 tph
		Feeding size: 10–30 mm
		Output size: 2–5 mm
		Motor: 10 hp/1440 RPM
2	Coal dryer	Type: Cyclone type
		Drying capacity: Up to 12% surface moisture
		Hot air input: from recuperator
		No. of conveyors for transferring dried coal: 2
		Additional feature: ID fan to throw away moisture laden air; air lock to restrict the entry of air into the conveyors.
		Conveyor motor: 5 hp/1440 RPM – 3 nos
		ID fan motor: 7.5 hp/1440 RPM – 1 no.
		Air lock motor: 2 hp/1440 RPM – 2 nos

Sl no.	Parts	Standard specification
3	Pulverizer	Type: Hammer type
		Hammer material: High chrome manganese liner material - EN-31 hardened steel plates
		Classifier: Minimum gap maintained with casing Feeding input: 2–5 mm crushed coal
		Output: 75 microns pulverized coal
		No. of pulverizing units: 2
		Size of pulverizing unit: 38"
		Motor: 75 hp/1440 RPM – 2 nos
4	Burner	Type: Swirl burner
		Numbers: 4
		Control: Screw feeder (DC motor-driven)
		Inputs: Separate entry for coal, primary and secondary air

6.3 Benefits of technology

The installation of modified pulverized coal handling and feeding system in the furnace leads to following benefits:

- Consistent and controlled heating
- Improved combustion efficiency
- Improved quality of material

6.4 Limitations of technology

There is no limitation for adoption of this technology.

6.5 Investment required, energy and GHG saving potential, and cost-benefit analysis

To understand the cost-benefit analysis, let us consider a re-heating furnace of 15-tonne capacity. The cost-benefit analysis of modified pulverized coal handling and feeding system in re-heating furnace is tabulated below.

Sl no.	Parameter	Value
1	Latent heat of evaporation of water vapour	542 kcal/kg
2	Amount of coal used in 15-t re-heating furnace operating for 16 hours per day (considering specific coal consumption of 75 kg/t)	18000 kg/d
3	Mass of 1% of moisture present in coal	180 kg/d
4	Heat taken away by this 1% of moisture through latent heat of evaporation	97560 kcal/d

Sl no.	Parameter	Value
5	Reduction in moisture by installing coal drying system	12%
6	Total heat saved due to reduction in moisture content by installing coal drying system	11707.2 kcal/d
7	Calorific value of coal used in re-heating furnace	5600 kcal/kg
8	Saving in coal consumption due to installation of coal drying system	2.1 kg/d
9	Increase in calorific value of coal due to reduction in moisture (assuming 10% increase)	560 kcal/kg
10	Coal consumption due to increased calorific value	16,364 kg/d
11	Total reduction in coal consumption	1638 kg/d
12	Saving in fuel consumption	9.1%
13	Annual coal saving	492 t/y
14	Coal saving due to swirl burner (3% reduction in coal consumption)	162 t/y
15	Monetary saving	INR 46 lakh
16	Investment incurred	INR 35 lakh
17	Simple payback period	9.2 months
18	Annual energy savings	366 Mtoe
19	Annual GHG emission reduction	1633.8 tCO_2/y

6.6 Technology summary

The technology impacts for modified pulverized coal handling and feeding system are summarized below.

- Annual energy saving : 300–450 toe/y
- Annual GHG emission reductions : 1500–2000 tCO_2/y
- Annual monetary saving : INR 40–50 lakh/y
- Investment : INR 30–50 lakh
- Payback period : 8–15 months

Tech 7: Installation of Coal Drying System

7.1 Baseline scenario

Coal is the predominantly used fuel in re-heating furnaces. Coal will normally have an inherent moisture of 8% and surface moisture of 10%. Such moisture content takes away substantial heat during the combustion process as latent heat of vapour. Such high moisture also leads to choking of coal storage hoppers leading to frequent breakdowns. Although many industries have attempted drying coal using crude methods (spreading coal on top of re-heating furnaces, in open areas, etc.), they have not been able to get the desired results.

7.2 Energy efficient technology

Flue gas comes out of the re-heating furnace at temperatures of 600–700 °C. Partial heat recovery is achieved in a recuperator for pre-heating combustion air. A bypass line from the pre-heated combustion air is fed into the cyclone dryer wherein it is mixed with the moisture-laden air. Dried coal is dropped into two conveyors. An ID Fan throws out the moisture-laden air. An air-lock system is provided to block the entry of air into the conveyors. The two conveyors are used to carry dried coal to the pulverizer. In this process, the cyclone dryer is used to remove the surface moisture of the coal, which is around 10%–12%. The inherent moisture in coal, however, remains intact.

The entire coal drying system works on the principle of removing the moisture content by using the waste heat available in flue gas.

7.3 Benefits of technology

The installation of coal drying system in the furnace leads to following benefits:

- Improved combustion efficiency
- Lower emissions
- Higher energy output
- Overall process optimization

7.4 Limitations of technology

There will be an additional operational and maintenance cost of the technology. Also, there is a requirement of space near the rolling mill for integration.

7.5 Investment required, energy and GHG saving potential, and cost-benefit analysis

To understand the cost-benefit analysis, let us consider a re-heating furnace of 15-tonne capacity. The cost-benefit analysis of coal drying system in re-heating furnace is tabulated below.

Sl no.	Parameter	Value
1	Latent heat of evaporation of water vapour	542 kcal/kg
2	Amount of coal used in 15-t re-heating furnace operating for 16 hours per day	18,000 kg/d
3	Mass of 1% of moisture present in coal	180 kg/d
4	Heat taken away by this 1% of moisture through latent heat of evaporation	97,560 kcal/d
5	Reduction in moisture by installing coal drying system	12%
6	Total heat saved due to reduction in moisture content by installing coal drying system	11,707.2 kcal/d
7	Calorific value of coal used in re-heating furnace	5600 kcal/kg
8	Saving in coal consumption due to installation of coal drying system	2.1 kg/d
9	Increase in calorific value of coal due to reduction in moisture	560 kcal/kg
10	Coal consumption due to increased calorific value	16,364 kg/d
11	Total reduction in coal consumption	1638 kg/d
12	Saving in fuel consumption	9.1%
13	Annual coal saving	492 t/y
14	Monetary saving	INR 34 lakh
15	Investment required	INR 21 lakh
16	Simple payback period	7.3 months
17	Annual energy saving potential	275.3 toe/y
18	Annual CO_2 emission reduction potential	1228.8 tCO_2/y

7.6 Technology summary

The technology impacts for coal drying system are summarized below.

- Annual energy saving : 200–350 toe/y
- Annual GHG emission reductions : 800–1600 tCO_2/y
- Annual monetary saving : INR 25–40 lakh/y
- Investment : INR 15–35 lakh
- Payback period : 5–12 months

Tech 8: Swirl Burner Used for Pulverized Coal Firing

8.1 Baseline scenario

Pulverized coal is the most preferred fuel used in re-heating furnaces because of its easy availability, low cost, and ease of operation. Combustion depends on three 'Ts', namely 'Time, Temperature, and Turbulence'. Efficient burning of coal depends on proper air-fuel mixture.

In most SRRM units, a 4-inch pipe is used as a burner for pulverized coal. This 4-inch pipe is inserted into the front and side walls of the re-heating furnace. Only primary air in ambient temperature is used for combustion in such conventional burners and the air-fuel ratio is neither monitored or controlled. This crude practice of using 4-inch pipe as a burner leads to incomplete combustion, inefficient heat transfer to ingot/billet/scrap, and higher fuel consumption.

8.2 Energy efficient technology

To have proper control of the air-fuel mixture in a re-heating furnace and also to ensure optimum combustion of coal, swirl burners for pulverized coal-fired re-heating furnaces can be used. The purpose of using a swirl burner is to achieve a stable flame and to ensure proper mixing of air and fuel. In a swirl burner, secondary air is supplied along with primary air in an annular arrangement. Both primary air and secondary air are hot air drawn from the recuperator. The swirl burner typically has three inputs: (a) the closest input towards the furnace is for primary air, which is directly fed from the recuperator; (b) coal is fed from the next input in a controlled manner from the screw feeder attached to the overhead hopper; and (c) the third input is for the secondary air, which pushes the coal into the burner. The hot secondary air is also utilized for complete combustion of powder coal. This burner works on the basis of three Ts of combustion:

- Time: Sufficient time for burning
- Temperature: Ignition temperature must be achieved
- Turbulence: Proper mixing of fuel and air, which is achieved by swirler

Swirl burner

Source: https://powerz.co/en/products/burners/pulverized-coal-burners/

8.3 Benefits of technology

The installation of swirl burner for pulverized coal firing in the furnace leads to following benefits:

- Improved combustion efficiency leads to enhanced flame stability
- Lower unburned carbon and reduced NOx emissions
- Reduced slagging and fouling
- Lower operating costs

8.4 Limitations of technology

It will add a degree of complexity in the combustion system, also combustion instability on lower loads, requirement of skilled operators or proper training should be provided to operators.

8.5 Investment required, energy and GHG saving potential, and cost-benefit analysis

To understand the cost-benefit analysis, let us consider a reheating furnace of 15-tonne capacity. The cost-benefit analysis of swirl burner used for pulverized coal firing in a re-heating furnace is tabulated below.

Sl no.	Parameter	Furnace with pipe burner	Furnace with swirl burner
1	Productivity	15 t/h	15 t/h
2	Operating hours per day	16	16
3	Operating days per year	300	300
4	Specific fuel consumption	75 kg/t	72.75 kg/t
5	Annual fuel consumption	5400 t/y	5238 t/y
6	Saving in fuel consumption	162 t/y	
7	Annual monetary saving due to fuel savings	INR 11.34 lakh	
8	Investment required (6 nos. of swirl burners with required accessories	INR 9 lakh	
9	Simple payback period	9.52 months	
10	Annual energy saving potential	90.72 toe/y	
11	Annual GHG emission reduction potential	405 tCO_2/y	

8.6 Technology summary

The technology impacts for swirl burner are summarized below.

- Annual energy saving : 60–110 toe/y
- Annual GHG emission reductions : 300–500 tCO_2/y
- Annual monetary saving : INR 8–15 lakh/y
- Investment : INR 7–14 lakh
- Payback period : 8–16 months

Tech 9: Replacement of Fossil Fuel Firing to Coal-bed Methane (CBM) Firing in Re-heating Furnace

9.1 Baseline scenario

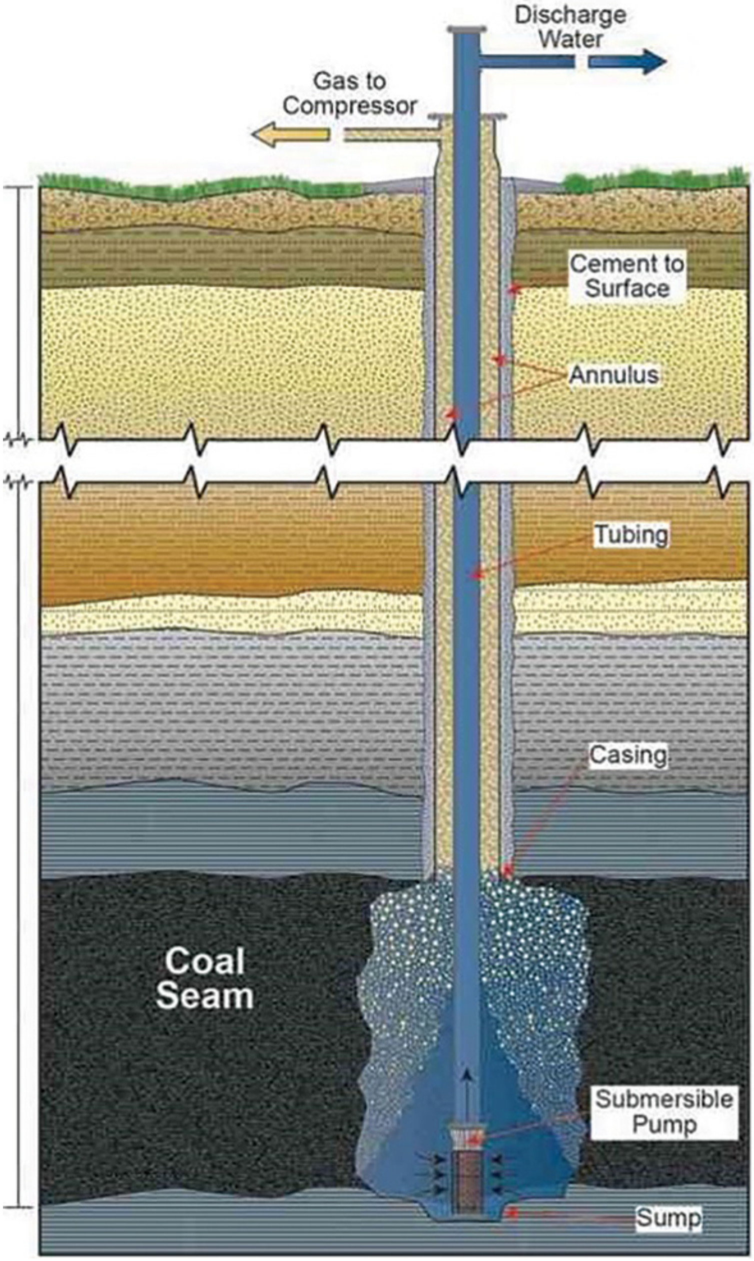
Traditionally, fossil fuels in the form of lump coal, pulverized coal, furnace oil, natural gas or producer gas have been the commonly used fuel to fire a re-heating furnace. The use of fossil fuels not only adds to the country's worries but also emits greenhouse gases (GHGs), which are a proven threat to the universe. Under such a scenario, there is a quest for alternative sources of energy worldwide to combat the harmful threats of global warming.

9.2 Energy efficient technology

Coal-bed methane (CBM), coal-bed gas, coal-seam gas (CSG), or coal-mine methane (CMM) is a form of natural gas extracted from coal beds. Methane adsorbed into a solid coal matrix (coal macerals) is released if the coal seam is de-pressurized. Methane is extracted by drilling wells into the coal seam. The goal is to decrease the water pressure by pumping water from the well. The decrease in pressure allows methane to desorb from the coal and flow as a gas up the well to the surface. Methane is then compressed and piped to market.

The objective is to avoid putting methane into the water line, but allow it to flow up the backside of the well (casing) to the compressor station. If the water level is pumped too low during dewatering, methane may travel up the tubing into the water line causing the well to become 'gassy'. Although methane may be recovered in a water-gas separator at the surface, pumping water and gas is inefficient and can cause pump wear and breakdown. Extraction of coal-bed methane in large quantities is being currently done in areas of West Bengal in and around Raniganj-Panagarh, etc.

Coal-bed methane (CBM) can be used in rolling mills as a piped gas and has features similar to that of natural gas. Use of CBM is considered as a carbon-neutral fuel as the main component of the gas is methane (CH_4), which is a GHG, which is burnt in the combustion process.



Coal-bed methane well

9.3 Benefits of technology

The replacement of fossil fuel firing to CBM firing in re-heating furnace leads to following benefits:

- Lower air pollutant emissions and reduced GHG emissions
- Fast ignition and heating lead to consistent heating performance
- Potential for co-firing

9.4 Limitations of technology

Replacement of fossil fuel firing to CMB firing in re-heating furnace is capital-intensive and extra safety measures needed.

9.5 Investment required, energy and GHG saving potential, and cost-benefit analysis

To understand the cost-benefit analysis, let us consider a reheating furnace of 15-tonne capacity. The cost-benefit analysis of replacement of fossil fuel firing to CBM firing in a re-heating furnace is tabulated below.

Sl no.	Parameter	Furnace oil fired re-heating furnace	CBM-fired re-heating furnace
1	Productivity	15 t/h	15 t/h
2	Operating hours per day	20	20
3	Operating days per year	300	300
4	Specific fuel consumption	35 l/t; Nm^3/t	31 l/t; Nm^3t
5	Cost of fuel	30 INR/l; INR/Nm^3	25 INR/l; INR/Nm^3
6	Annual fuel consumption	3150 kl/y; Nm^3/y	27,90,000 kl/y; Nm^3/y
7	Annual cost of fuel	INR 945 lakh	INR 697.5 lakh
8	Annual monetary savings	INR 247.5 lakh	
9	Investment required	INR 170 lakh	
10	Simple payback period	8.2 months	
11	Annual energy saving potential	712 toe/y	
12	Annual GHG emission reduction potential	2367 tCO_2/y	

9.6 Technology summary

The technology impacts for CBM firing are summarized below.

- Annual energy saving : 600–1100 toe/y
- Annual GHG emission reductions : 1800–2700 tCO_2/y
- Annual monetary saving : INR 200–300 lakh/y
- Investment : INR 140–250 lakh
- Payback period : 7–14 months

Tech 10: Replacement of Fossil Fuel Firing to Biomass-based Producer Gas in Re-heating Furnace

10.1 Baseline scenario

Traditionally, fossil fuels in the form of lump coal, pulverized coal, furnace oil, natural gas or producer gas have been the commonly used fuel to fire a re-heating furnace. The use of fossil fuels not only adds to the country's worries but also emits GHGs, which are a proven threat to the universe. Under such scenario, there is a quest for alternative source of energy worldwide to combat the harmful threats of global warming.

10.2 Energy efficient technology

Biomass generated from agricultural waste such as groundnut shell, coconut shell, and bagasse – formed into briquettes by a suitable binding medium – can be used as input to a biomass-based producer gas plant; the producer gas, in turn, can be used as a fuel for the re-heating furnace. Gasification is a thermo-chemical process where biomass is converted into a combustible producer gas. The main components in producer gas are N_2, H_2 CO, CO_2, and CH_4. Producer gas from biomass gasification is available in two forms: (i) hot raw gas and (ii) cleaned cold gas.

A biomass-based producer gas plant

Source: http://radhegroup.com/green-technologies/biomass-coal-gasification/

The hot raw gas is obtained by tapping from an appropriate point of the reactor, where the gas is at a temperature of about 500 °C. In this gas, all tar and naptha will be in vapour form. Therefore, the calorific value (CV) is high (1350–1400 kcal/Nm^2). Also, as this gas is at high temperature, adiabatic flame temperature by combustion of this gas with air at 350 °C will be above 1800 °C, which is adequate for re-heating furnaces. However, the raw gas will be available at low pressures, about 50-mm water column (WC), which is just sufficient for typical burners. This means it is not possible to introduce any measurement and auto control system with hot raw gas, as the pressure is not adequate. With lack of flow measurement and flow control, furnace temperature control cannot be maintained at optimum levels. Boosting the hot raw gas with tar to the required pressure level by a booster is not practical. Biomass-based producer gas can be effectively used in a rolling mill using suitable producer gas burners.

Cold gas is tapped from top of the reactor after the heat content of the gas is recovered for drying and pre-heating of the coal charge. The gas is further processed for removal of tar and naphtha in scrubbers, and ultimately the gas will be free from tar. As the gas is free from tar, this can be boosted to the desired pressure. However, as tar has been removed, the CV of the gas will be in the range of 1050–1100 kcal/Nm^2. Adiabatic flame temperature of cold gas with this CV and with combustion air temperature of 350 °C, will be about 1600 °C. With this adiabatic flame temperature, the furnace cannot be heated to 1280 °C, which is required in the re-heating furnaces. Therefore, when this gas is used, support of high CV fuel like furnace oil is required.

GHG (CO_2) emissions from the biomass are high as compared to the other fuels in the re-heating furnace but it cannot be considered as GHG emission because CO_2 emission from biomass is considered as a part of the natural carbon cycle. Thus, the use of biomass-based producers in the re-heating furnace is a carbon-neutral process.

10.3 Benefits of technology

The replacement of fossil fuel firing to biomass-based producer gas for firing in a re-heating furnace leads to following benefits:

- Lower air pollutant emissions and reduced GHG emissions
- Fast ignition and heating lead to consistent heating performance
- Potential for co-firing

10.4 Limitations of technology

Replacement of fossil fuel firing to biomass-based producer gas in re-heating furnace is capital-intensive and extra safety measures are needed.

10.5 Investment required, energy and GHG saving potential, and cost-benefit analysis

To understand the cost-benefit analysis, let us consider a re-heating furnace of 15-tonne capacity. The cost-benefit analysis of replacement of fossil fuel firing to biomass-based producer gas for firing in re-heating furnace is tabulated below.

Sl no.	Parameter	Furnace oil fired re-heating furnace	Biomass-based producer gas-fired re- heating furnace
1	Productivity	15 t/h	15 t/h
2	Operating hours per day	16	16
3	Operating days per year	300	300
4	Specific fuel consumption	40 l/t; kg/t	120 l/t; kg/t
5	Cost of fuel	INR 30/litre; INR/kg	-
6	Annual fuel consumption	2880 kl/y; t/y	8640 kl/y; t/y
7	Annual cost of fuel	INR 1152 lakh	INR 604.8 lakh
8	Annual monetary savings	INR 547 lakh	
9	Investment required	INR 170 lakh	
10	Simple payback period	3.73 months	
11	Annual energy saving potential	99 Mtoe	
12	Annual GHG emission reduction potential	288 tCO_2/y	

10.6 Technology summary

The technology impacts for biomass-based producer gas firing are summarized below.

- Annual energy saving : 70–140 toe/y
- Annual GHG emission reductions : 220–350 tCO_2/y
- Annual monetary saving : INR 400–600 lakh/y
- Investment : INR 150–250 lakh
- Payback period : 3–8 months

Tech 11: Replacement of Coal Firing to Natural Gas Firing in Re-heating Furnace

11.1 Baseline scenario

Coal has been traditionally used as the most common form of energy used in re-heating furnaces. However, firing coal into the re-heating furnace is a dirty process and also causes a threat to the health of the workers due to the local level pollution. Coal also increases the suspended particulate matter (SPM) level of the factory's environment thus causing threat to the nearby locality. Also, burning of coal leads to formation of accretion in the furnace walls, primarily due to unburnt coal and formation of soot.

11.2 Energy efficient technology

Use of natural gas as fuel as replacement of coal leads to cleaner and healthier production. Piped gas lines are available in some parts of the country, which can be used as fuel for the re-heating furnace. Natural gas as fuel not only allows a better environment for the unit, but also provides significant improvement in the internal environment of the furnace. Natural gas firing, if controlled in a proper fashion, can lead to optimum specific fuel consumption and burning loss. Also, the efficiency of the furnace improves significantly, leading to a longer furnace life.

11.3 Benefits of technology

The replacement of coal firing to natural gas firing in a re-heating furnace leads to following benefits:

- Lower air pollutant emissions and reduced GHG emissions
- Fast ignition and heating lead to consistent heating performance
- Lower maintenance and cleaning costs
- Low scaling losses

11.4 Limitations of technology

Replacement of coal firing to natural gas firing in re-heating furnaces is capital-intensive and extra safety measures are needed due to the use of natural gas, which is highly inflammable.

11.5 Investment required, energy and GHG saving potential, and cost-benefit analysis

To understand the cost-benefit analysis, let us consider a re-heating furnace of 15-tonne capacity. The cost-benefit analysis of replacement of coal firing to natural gas firing in a re-heating furnace is tabulated below.

Sl no.	Parameter	Coal-fired re-heating furnace	Natural gas-fired re-heating furnace
1	Productivity	15 t/h	15 t/h
2	Operating hours per day	20	20
3	Operating days per year	300	300
4	Specific fuel consumption	120 kg/t; Nm^3/t	29 kg/t; Nm^3/t
5	Cost of fuel	INR 7/kg; INR/Nm^3	INR 28/kg; INR/Nm^3
6	Annual cost of fuel	INR 756 lakh	INR 730 lakh
7	Annual monetary savings	INR 25 lakh	
8	Investment required	INR 100 lakh	
9	Simple payback period	47.6 months	
10	Annual energy saving potential	3803 Mtoe/y	
11	Annual GHG emission reduction potential	21,519 tCO_2/y	

11.6 Technology summary

The technology impacts for natural gas-based firing are summarized below.

- Annual energy saving : 3000–4000 toe/y
- Annual GHG emission reductions : 18,000–23,000 tCO_2/y
- Annual monetary saving : INR 20–40 lakh/y
- Investment : INR 80–120 lakh
- Payback period : 40–50 months

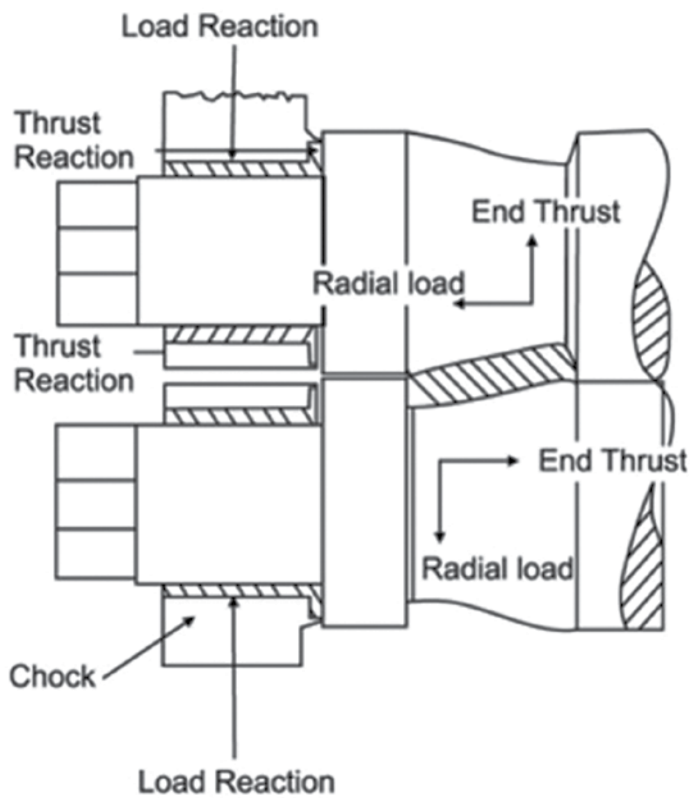
Tech 12: Installation of Anti-friction Roller Bearing in Rolling Mill Strands

12.1 Baseline scenario

Bearings are one of the most critical equipment in a rolling mill and they perform three basic functions:

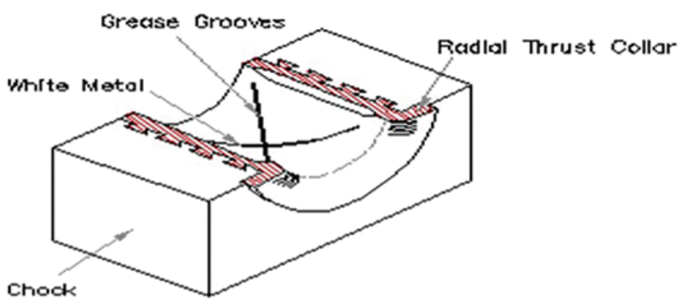
- Carrying a load
- Reducing friction
- Positioning moving machine parts

Rolling mill bearings are required to withstand extremely severe operating conditions, including heavy shock loads, varying speeds, and extreme temperature variations. In most of the cases, the bearing has to withstand both the radial roll separating force and the roll end thrust as illustrated in the figure below.

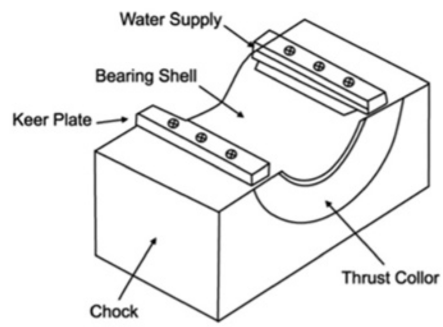


Various load on bearing

The proposition of end thrust varies considerably, being quite low in flat rolling but high in section rolling. Traditionally, many types of bearings are used in a rolling mill. The plain metal bearings (e.g., bronze and white metal) have been used extensively in the past, but is now being superseded by the other bearings although examples can still be found to-day, which are giving very satisfactory performance. The bearing is formed by running the white metal, etc. into the recesses of cast chocks, which are then machined to profile and drilled for grease grooves. The recesses hold metal for radial and thrust loads as illustrated in the above figure. Lubrication is normally by grease or oil, which is either automatically or manually applied.



Plain metal bearing



Fabric bearing

Fabric bearings have in many cases replaced the plain metal bearing and often represent the most economical bearing for particular equipment. They are composed of a fabric such as cotton impregnated with a resin and are manufactured by moulding or wrapping according to the type of resin used. Consequently, they take the form of shell bearings, which are fitted into chocks and retained by keep plates. Usually, the thrust collars are made and fitted separately. Water is used as a lubricant and as the bearing is a poor conductor of heat, copious supplies of clean cool water are required.

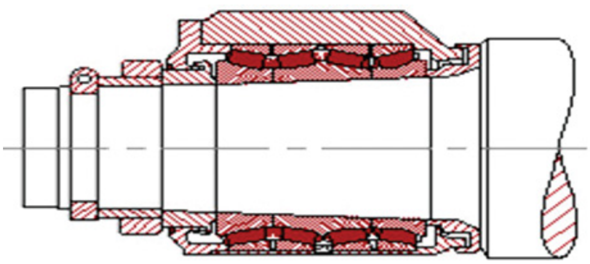
A fabric bearing is subjected to a linear contact with the rotating rolls. Thus, these bearings lead to more friction thereby leading to significant mechanical losses and lead to comparatively higher power consumption

12.2 Energy efficient technology

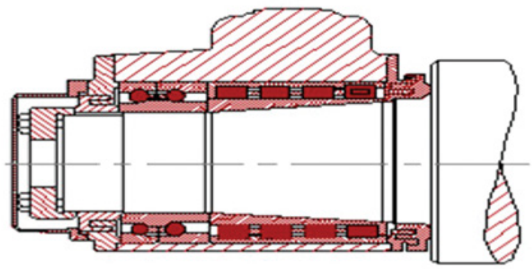
As an alternative to the conventional metal and fabric, bearing is an anti-friction roller bearing.

A typical roller bearing consists of rolling elements or rollers, an inner ring, an outer ring, and a retainer. In a typical installation, the outer ring is fixed and does not move and the inner ring is fitted to the shaft. As the shaft rotates, the inner ring also rotates. The rollers are held into position by the retainer, which positions the rollers equally around the rings and ensures that the load is distributed equally on each roller when the shaft is rotating.

Ball and roller bearings are finding wide use in all types of mills due their close tolerance and low power loss. Parallel, taper, and spherical taper races are available and even ball races vary considerably in form – angular contact and deep-seated types being used for thrust races. Taper rollers can take thrust as well as radial loads but parallel rollers require a separate thrust race. Two typical arrangements are shown in the figure below. The method of mounting the inner races varies with the duty – for slow-speed applications, a loose fit on the roll neck might suffice whereas in high-speed application a shrink fit on a parallel or taper neck may be required. Lubrication may be by grease pack or automatic feed of grease, oil or oil mist.



Taper roller bearing for radial load and thrust



Parallel roller for radial load and angular contact ball bearing for thrust

12.3 Benefits of technology

Installation of anti-friction roller bearing in rolling mill strands leads to following benefits:

- Reduced friction and energy consumption
- Increased rolling speed
- Improved product quality
- Longer bearing life and less maintenance

12.4 Limitations of technology

Installation of anti-friction roller bearings in rolling mill strands is capital-intensive and has some retrofitting challenges along with load capacity limitations.

12.5 Investment required, energy and GHG saving potential, and cost-benefit analysis

To understand the cost-benefit analysis, let us consider a 15-tonne capacity rolling mill. The cost-benefit analysis of installation of anti-friction roller bearing in rolling mill strands is tabulated below.

Sl no.	Parameter	With conventional bearings	With roller bearings
1	Productivity	15 t/h	15 t/h
2	Annual operational hours	6000	6000
3	Mill utilization	85%	90%
4	Annual production	76,500 t	81,000 t
5	Specific power consumption (average)	120 kWh/t	105 kWh/t
6	Saving in specific power consumption	15 kWh/t	
7	Annual power savings	12,15,000 kWh/t	
8	Power tariff	INR 7.16/kWh	
9	Annual monetary saving due to power saving	INR 87 lakh	
10	Annual monetary profit due to increase in productivity	INR 67.5 lakh	
11	Total annual saving	INR 154 lakh	
12	Investment for replacement of conventional bearing with roller bearing	INR 70 lakh	
14	Payback period	5.4 months	
15	Annual energy saving potential	104 Mtoe/y	
16	Annual GHG emission reduction potential	862 tCO_2/y	

12.6 Technology summary

The technology impacts of installation of anti-friction roller bearing in rolling mill strands are summarized below.

- Annual energy saving : 70–150 toe/y
- Annual GHG emission reductions : 600–1100 tCO_2/y
- Annual monetary saving : INR 110–170 lakh/y
- Investment : INR 60–100 lakh
- Payback period : 5–12 months

Tech 13: Installation of Universal Couplings/Spindles in Rolling Mill

13.1 Baseline scenario

Couplings are devices used to connect two pieces of rotating equipment or shafts together. Couplings are used for transmitting power. Spindles are used for transmitting rotation to the rolls from pinion stands or from electric motors. Careful selection, installation, and maintenance of couplings and spindles will ensure substantial savings. The savings will be in terms of reduced power consumption, reduced maintenance costs, and downtime.

Traditionally, wobblers are the most commonly used couplings in SRRM units. These wobbler couplings are made of cast iron, either three-fluted or four-fluted, and are used in un-machined condition. These couplings are usually used with nylon or wooden packings. The roughness or improper pairing gives rise to low metal-to-metal contact. Further, the wobbler connections do not allow flexibility towards inclination from the roll axis beyond 1–20 degrees The disadvantages of using wobbler couplings are:

- Jerking loads on drive motor due to wear out of nylon/wooden pads owing to repeated biting of rolling stocks in various parts
- Higher load on drives due to limited flexibility of inclination of the spindles owing to differential wear diameter of the rolls
- Higher mill downtime and lower mill utilization

13.2 Energy efficient technology

As an alternative to the wobbler couplings and spindles, the energy efficient way is to use universal couplings and spindles.

Universal spindles allow rotation to be translated to the rolls at considerable angles, up to 8–100 degrees between the axis of the spindle and the axes of the rolls or pinion of a pinion stand. The horizontal projection of the spindle's length alters in accordance with the angle of inclination. For this reason, one of the hinges of a spindle is usually fixed at the end of the driving shaft and the other at the roll end; if not fixed, it floats in an axial direction.

An improvised form for a universal coupling is the cardon shaft coupling and spindles. In case of cardon shaft, the flexibility of inclination is even more.

13.3 Benefits of technology

The advantages of Universal couplings over wobbler couplings are listed below.

- They have high torque transmission capacity.
- Their simplicity of design results in easy maintenance. This reduces the down time.
- They have negligible backlash and radial clearance.
- They have high operational life and low operational costs.
- They lead to uniform loading on drive motors.
- They lead to increased roll life due to the higher flexibility of the spindle inclination.
- They reduce power consumption and increase mill utilization.

13.4 Limitations of technology

Limitations of installation of universal couplings / spindles in a rolling mill are the initial investment and increased maintenance complexity.

13.5 Investment required, energy and GHG saving potential, and cost-benefit analysis

To understand the cost-benefit analysis, let us consider a rolling mill of 15-tonne capacity. The cost-benefit analysis of installation of universal couplings / spindles in a rolling mill is tabulated below.

Sl no.	Parameter	With wobbler couplings / spindles	With universal couplings / spindles
1	Productivity	15 t/h	15 t/h
2	Annual operational hours	6000	6000
3	Mill utilization	85%	90%
4	Annual production	76,500 t/a	81,000 t/a
5	Specific power consumption (SPC) (average)	120 kWh/t	105 kWh/t
6	Saving in SPC	15 kWh/t	
7	Annual power savings	12,15,000 kWh/y	
8	Power tariff	INR 7.16/kWh	
9	Annual monetary saving due to power saving	INR 87 lakh	
10	Annual monetary profit due to increase in productivity**	INR 67 lakh	
11	Total annual saving	INR 154 lakh	
12	Investment required	INR 80 lakh	

Sl no.	Parameter	With wobbler couplings / spindles	With universal couplings / spindles
14	Payback period	6.2 months	
15	Annual energy saving potential	104 toe/y	
16	Annual GHG emission reduction potential	862 tCO_2/y	

13.6 Technology summary

The technology impacts for installation of universal couplings / spindles in a rolling mill are summarized below.

- Annual energy saving : 80–130 toe/y
- Annual GHG emission reductions : 700–1200 tCO_2/y
- Annual monetary saving : INR 40–90 lakh/y
- Investment : INR 60–110 lakh
- Payback period : 5–15 months

Tech 14: Installation of Y-table/Tilting Table/ Repeaters in a Rolling Mill

14.1 Baseline scenario

Thus, to improve upon the efficiency of operation of a rolling mill, one has to improve upon the mill utilization factor, which can be done through combating mill delays. A large portion of mill delays can be avoided by minimizing manual intervention and adoption of automatic material handling machines. The 3-Hi-Roughing Mill stand forms the major bottleneck towards increased mill speed of a rolling mill. The roughing mill is generally used for heavy reduction of charge. The hot charge is alternatively processed between middle-bottom and top-middle rolls.

Conventionally, after a pass rolling, the charge is transferred to the next pass using a guide through manual intervention. The manual handling is done by a tongues man, who usually holds the rear end of the hot charge and enters it into the next pass. Delays in the process of charging also sometimes lead to cooling of the charge, which, in turn, reduces the life of the machine.

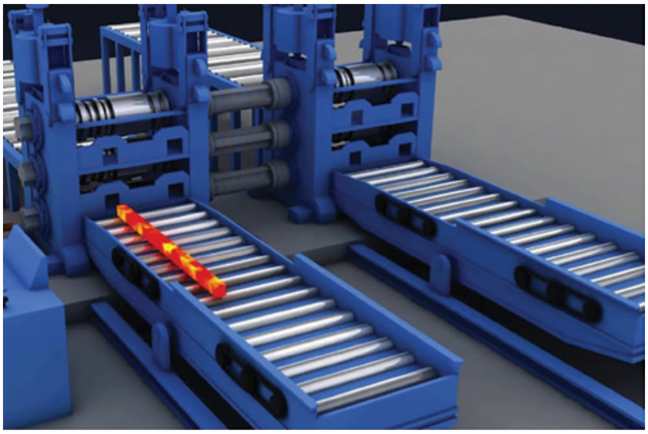
Traditionally, manual intervention can also be seen in cross-country mills, wherein unskilled workers use tongues to hold a hot charge and put it into the next pass. Manual handling of charge is an unsafe process, which can lead to threats on one's life.

14.2 Energy efficient technology

Automatic material handling systems are an energy efficient alternative for manual handling systems. For automatic handling of hot charge in the 3-Hi-Roughing Mill stand, a Y-table or Tilting Table are used. Y-tables are usually used for material weights of less than 150 kgs A Y-table is a steel-fabricated structure in the shape of a Y. The structure is made of roller conveyors. A metal lid is used in the Y-joint, which allows only one-way travel of the charge. The charge after rolling from the bottom-middle rolls passes through the rear end of the table; the metal lid falls once the charge has completely passed through. During return, the metal charge passes through the top end, thus facilitating the transfer of the billet to the next pass. A Y-table is common in TMT mills, wherein on one side of the stand, Y-tables are installed and on the opposite side, drop tilters are present.

Tilting machine is quite similar to the Y-table and used for higher cross-sections, especially in structure mills. Here the steel structure, fitted with a roller conveyor, is mounted to a motor. The structure is operated by an operator; and on his instruction the entire steel structure moves up and down as per requirement.

Repeaters are steel-fabricated pathways connected between two consequent rolling stands. The repeaters are fitted to guides and allow free movement of hot charge between two rolling mill stands. Twisting of charge, if required, can also be facilitated by the design of a recuperator.



Y-table in a rolling mill

Tilting table in a rolling mill

14.3 Benefits of technology

The advantages of installing Y-table / tilting table / repeaters in a rolling mill are as listed below.

- Improved material handling
- Enhanced productivity
- Reduction of material waste
- Reduced operator fatigue and enhanced safety
- Space optimization

14.4 Limitations of technology

Limitations of installing Y-table / tilting table / repeaters in a rolling mill are (a) the initial investment, (b) complexity of integration, and (c) space constraints.

14.5 Investment required, energy and GHG saving potential, and cost-benefit analysis

To understand the cost-benefit analysis, let us consider a reheating furnace of 15-tonne capacity. The cost-benefit analysis of installation of Y-table / Tilting table / repeaters in a rolling mill is tabulated below.

Sl no.	Parameter	Rolling mill with manual handling	Rolling mill with automatic handling
1	Design capacity of rolling mill	15 t/h	15 t/h
2	Mill utilization	80%	85%
3	Operating hours per day	20	20
4	Operating days per year	300	300
5	Annual production	72,000 t/y	76,500 t/y
6	Additional production due to increased mill utilization	4500 t/y	
7	Annual monetary benefit due to increased production	INR 67 lakh	
8	Specific fuel consumption	75 kg/t	70 kg/t
9	Annual saving in coal consumption	337.5 t/y	
10	Monetary saving due to fuel saving	INR 23.6 lakh	
11	Specific power consumption	110 kWh/t	103 kWh/t
12	Annual saving in power consumption	535 MWh/y	
13	Monetary saving due to power saving	INR 38 lakh	
14	Total monetary saving	INR 129 lakh	
15	Investment required	INR 70 lakh	
16	Simple payback period	6.5 months	
17	Annual energy saving potential	235 toe/y	
18	Annual GHG emission reduction potential	1223 tCO_2/y	

14.6 Technology summary

The technology impacts of installing Y-table / tilting table / repeaters in a rolling mill are summarized below.

- Annual energy saving : 200–300 toe/y
- Annual GHG emission reductions : 900–1500 tCO_2/y
- Annual monetary saving : INR 80–150 lakh/y
- Investment : INR 50–100 lakh
- Payback period : 6–12 months

Tech 15: Revamping of Rolling Mill

15.1 Baseline scenario

Layout of a rolling mill is significant while determining the mill's productivity, energy consumption, and efficiency. In earlier days, the rolling mill was haphazardly built without proper layout design. Also, most of the units were driven by manual material handling and equipped with old, outdated machines. These, in turn, led to increase in mill downtime, cobble formation, and high energy consumption. Also, productivity of such mills was low. As and when a rolling mill unit decided to enhance the production, the required numbers of stands were added haphazardly, without giving due consideration to the overall layout. Thus, these units usually have high energy consumption.

15.2 Energy efficient technology

Energy efficient design of a rolling mill consists of design of proper layout, selection of proper size of equipment, and correct roll pass design, including temperature profile across stands. Following are some of the general considerations for revamping a rolling mill into an energy efficient one:

- Maintaining the correct temperature profile in the furnace.
- Reducing the distance between furnace discharges and roughing mill stand; in case of long distance, use an automatic roller conveyor.
- Uniform feeding of raw material, i.e., installation of ingot turning table.
- Proper distribution of draft across roughing, intermediate, and finishing mill
- Maintaining angle of bite to the optimum level (around 21 degrees)
- Conversion of cross-country mill configuration to continuous configuration.
- Adoption of automatic material handling.
- Increasing speed of rolling.
- Addition of roughing mill continuous side.
- Reduction of mill downtime by adoption of cantilever stands and housing less stands.

15.3 Benefits of technology

The advantages of revamping of a rolling mill are:

- Improved material handling
- Enhanced productivity
- Reduction of material waste

15.4 Limitations of technology

Limitations of revamping a rolling mill is the initial investment and complexity of integration.

15.5 Investment required, energy and GHG saving potential, and cost-benefit analysis

To understand the cost-benefit analysis, let us consider a rolling mill of 15-tonne capacity. The cost-benefit analysis of revamping a rolling mill is given below.

Sl no.	Parameter	Manual rolling mill	Revamped rolling mill
1	Design capacity of rolling mill	15 t/h	15 t/j
2	Mill utilization	80%	85%
3	Operating hours per day	16	16
4	Operating days per year	300	300
5	Annual production	57,600 t/y	61,200 t/y
6	Additional production due to increased mill utilization	3600 t/y	
7	Annual monetary benefit due to increased production	INR 54 lakh	
8	Specific fuel consumption (SFC)	75 kg/t	70.59 kg/t
9	Annual saving in coal consumption	270 t/y	
10	Monetary saving due to fuel saving	INR 18 lakh	
11	Specific power consumption	110 kWh/t	103 kWh/t
12	Annual saving in power consumption	428 MWh/y	
13	Monetary saving due to power saving	INR 30 lakh	
14	Total monetary saving	INR 103 lakh	
15	Investment required	INR 70 lakh	
16	Simple payback period	8 months	
17	Annual energy savings	188 toe/y	
18	Annual GHG emission reduction	979 tCO_2/y	

15.6 Technology summary

The technology impacts of revamping a rolling mill are summarized below.

- Annual energy saving : 150–250 toe/y
- Annual GHG emission reductions : 700–1200 tCO_2/y
- Annual monetary saving : INR 70–130 lakh/y
- Investment : INR 60–100 lakh
- Payback period : 6–12 months

Tech 16: Combustion Air Flow Regulation Using Variable Voltage Variable Frequency Drives

16.1 Baseline scenario

In the SRRM sector, centrifugal fans are used as forced draft (FD) fans in re-heating furnaces with the main aim of supplying ambient air for the combustion of fuel. Performance of centrifugal fans depends on various factors such as type of fan, proper sizing of the fan, and the specification and design of ducting for the fan.

Generally, air flow to a re-heating furnace is kept constant irrespective of temperature, draft, and excess air in the reheating furnace. It has been observed that due to inadequate draft and supply of excess air, the flame continuously gushes out of various openings of the re-heating furnace, which poses a threat to the safety of men and machines working near the re-heating furnace.

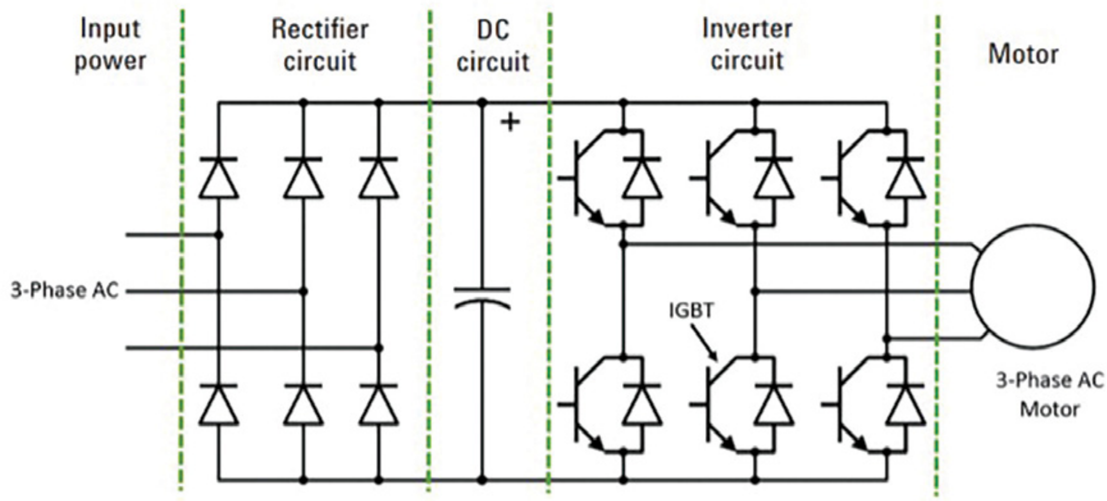
The most general practices of the flow regulation mechanisms in FD fans currently employed in the SRRM sector include damper control, suction control or change of pulley. All of the above methods for controlling the air flow require manual interventions. Thus, most of the time, combustion air flow is not monitored and controlled under the conventional system leading to higher energy consumption and high burning loss.

16.2 Energy efficient technology

As an energy efficient alternative, it is recommended to regulate the air flow of the combustion air blower by variable frequency drives (VFDs). VFDs reduce the speed of the fan for reduced air-flow demand, and this speed reduction is achieved by altering the frequency of input power. Hence, the power consumption of FD fans will be proportional to the air flow being delivered to the re-heating furnace. The feedback for VFDs can be taken from an oxygen analyzer installed in the flue gas line. This analyzer will measure the excess air content in the flue gas. Along with stoichiometric air required for combustion, a certain amount of excess air needs to be supplied and this excess air varies based on the type of fuel used in the re-heating furnace.

VFD is a device introduced in 1980s to effectively run a 3-phase AC motor at variable speed. A VFD consists of three diodes, which allows the flow of current only in the direction of the arrows. So, we have a convertor that converts the 3-phase AC power into DC. The DC that comes out of this is not very smooth; so a capacitor is used to clean that DC up. The capacitor works as a reservoir in the plumping circuit, which smoothens everything out and gives a nice clean DC. Then going to the right, we see six switches. These switches have a

DC-to-AC inverter; so by switching these switches on and off, we can create any frequency that we like and that frequency would regulate the speed of the motor.



Circuit of a typical VFD unit

The technical specifications of a variable voltage variable frequency drive (VVVFD) for a 40-hp blower are presented below.

Sl no.	Parameter	Value
1	Power rating	0.18–4.00 kW
2	Voltage supply	120 V (single phase) 240 V (single phase or three phase
3	Fan management	Required above 0.75 kW
4	Noise level	< 50 Dba
5	Commissioning	Plug and play type
6	Power factor	0.8
7	Frequency	50 Hz
8	Operating ambient temperature	–10 to +40 °C (without derating) up to 60 °C with a derating

16.3 Benefits of technology

The advantages of combustion air flow regulation using VVVFDs are listed below.

- Improved combustion control
- Reduced mechanical stress
- Lower power consumption
- Remote monitoring and control

16.4 Limitations of technology

There is no limitation for adoption of this technology.

16.5 Investment required, energy and GHG saving potential, and cost-benefit analysis

The following section provides the details of optimum air flow regulation using VFD and on-line oxygen analyzer in terms of energy and GHG saving potential, investment required, and cost-benefit analysis. The calculations have been provided considering a 15 t/h rolling mill.

Sl no.	Parameter	Without control	With control
1	Productivity	15 t/h	15 t/h
2	No. of operating hours	16	16
3	No. of working days	300	300
4	Specific fuel consumption	75 kg/t	71.25 kg/t
5	Annual production	72,000 t/y	72,000 t/y
6	Annual fuel consumption	5400 t/y	5130 t/y
7	Annual fuel savings	270 t/y	
8	Cost of fuel	INR 7000/t	
9	Annual monetary saving	INR 18 lakh	
10	Investment required	INR 9 lakh	
11	Simple payback period	5 months	
12	Annual energy saving	151 toe/y	
13	Annual GHG emission reduction	675 tCO_2/y	

16.6 Technology summary

The technology impacts of combustion air flow regulation using VVVFDs are summarized below.

- Annual energy saving : 120–180 toe/y
- Annual GHG emission reductions : 500–800 tCO_2/y
- Annual monetary saving : INR 12–25 lakh/y
- Investment : INR 8–15 lakh
- Payback period : 5–12 months

Tech 17: Adoption of Direct Rolling in TMT Mills

17.1 Baseline scenario

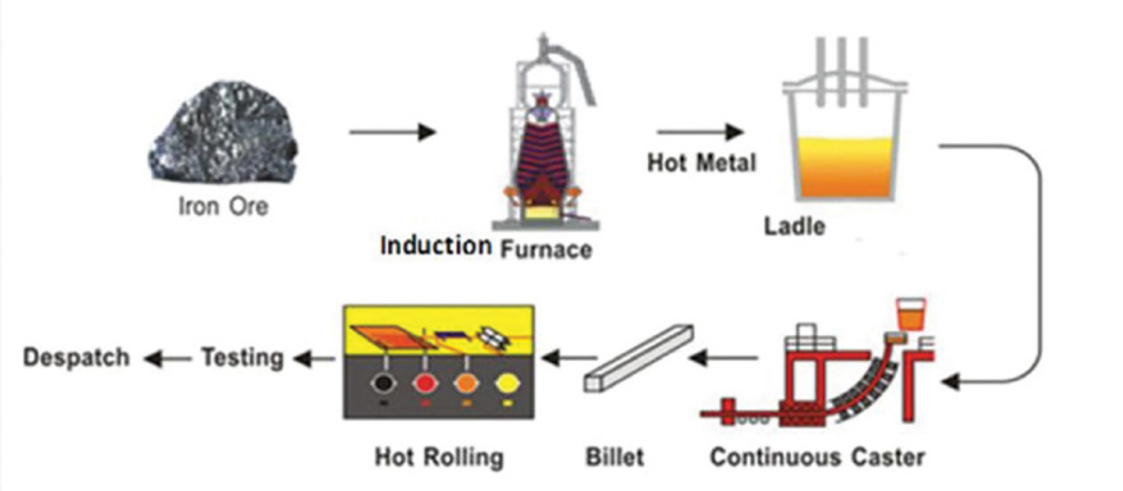
A composite unit consists of a rolling mill and an induction furnace in the same premises. Sponge iron or scrap sourced from the market is fed into an induction furnace, where electricity is used for melting of steel at 1600 °C. The molten steel is casted into moulds to form ingots or through a continuous casting machine (CCM) to form billets or blooms. The casted ingot/billet or bloom is cooled to ambient temperature and stored in the billet yard. For the rolling process, the ingot, billets or blooms are used as raw material. They are charged into the pusher-type re-heating furnace. The raw materials are re-heated to the recrystallization temperature of steel, which is around 1200 °C. The red-hot charge is then processed in a rolling mill to the desired shape and cross-section.

A large number of composite units in the country followed the above process till the introduction of direct rolling. In this conventional process; a significant portion of energy was lost in the process of cooling the billets in the CCM cooling bed and then again re-heating the same in the re-heating furnace.

17.2 Energy efficient technology

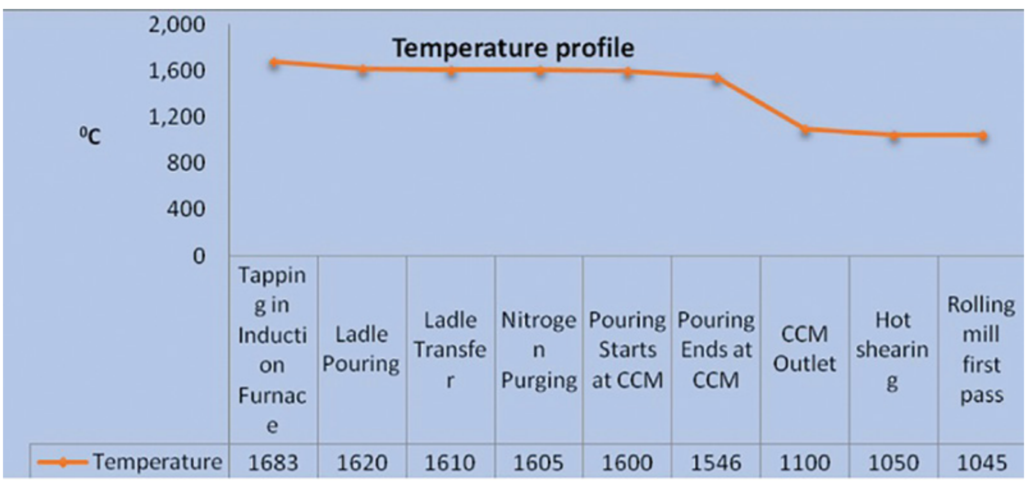
The energy efficient way of rolling in the case of composite units has been dictated by a revolutionary technology in the last few years. Hot charging or direct rolling of hot billets from CCMs to rolling mill, which eliminates the re-heating furnace in the process, has transformed the entire sector to a new dimension of energy saving. The process of direct rolling/hot charging of billets is shown in the process flow diagram.

The process flow for direct rolling starts with tapping of molten metal from the induction furnace at a slightly higher temperature (around 1650 °C) compared to conventional systems. Due care is taken for minimum heat loss during ladle transfer. Hot metal at 1600 °C is poured into the tundish of the CCM. Secondary cooling at CCM is controlled with a programmable logic controller (PLC) system to maintain billet temperature at CCM outlet at 1100 °C. Subsequently, there is a slight temperature loss during the shearing process. Preferably, hot billet shearing should be in place of gas cutting for minimum temperature loss.



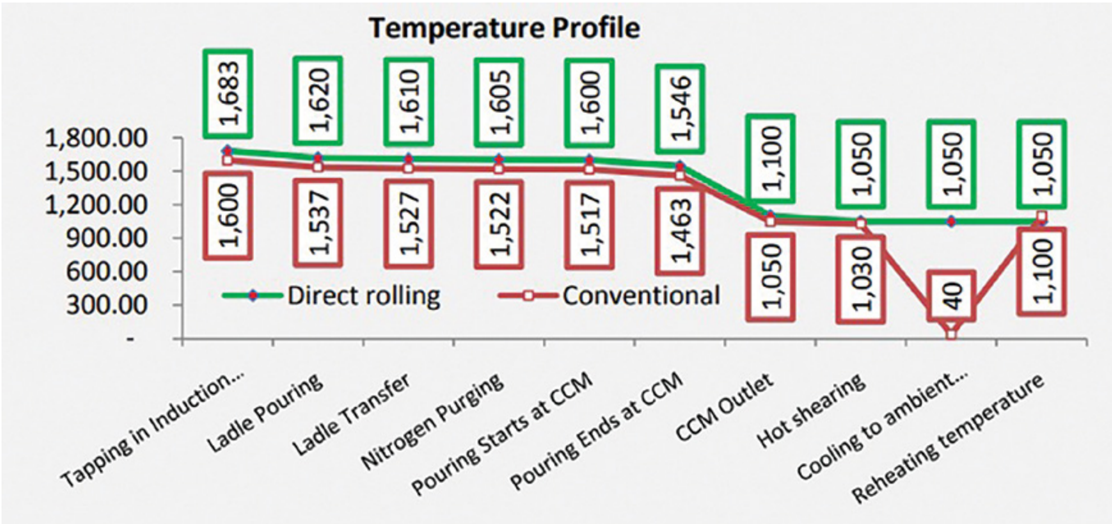
Process flow diagram of direct rolling mill

Once the hot billet is cut into pieces, the next step involves transferring of the billet in a high-speed conveyor to the rolling mill first stand. It should be ensured that minimum heat loss occurs during the process. For this, refractory made canopy covers should be used in the conveyors. Also, high rpm motors are to be used for the conveyors for minimum time travel of the billets. Bends should be avoided in the conveyor to the extent possible. Billets reaching the first pass will be processed at a temperature of 1045 °C. In the direct rolling process, the core of the billet is at higher temperature than the surface. During 2–3 passes of the rolling, the charge attains a uniform temperature at the core and is exposed in such cases. The roll pass design needs to be revamped in case of switchover to direct rolling. Also, if the temperature drop is high, it should be ensured that the gear box for the first stand should be of heavier capacity. The temperature maintained at different processes of a direct rolling unit is shown in the figure below.



Temperature profile for different processes of direct rolling

Conventional process of melting and casting differs with the direct rolling process mainly on the temperature profile. As the metal coming out of the cooling bed should be solidified, the temperature profile needs to be precisely maintained. A PLC-based control system is suggested for the purpose. The temperature difference in the various processes for conventional melting and casting with direct rolling is shown in the figure below.



Conventional vs direct rolling

Transfer of hot billets in direct rolling

Source: https://www.electrotherment.com/our-application

17.3 Benefits of technology

The advantages of direct rolling in TMT mills are listed below.

- Reduced scale loss
- Improved mechanical properties
- Enhanced process control
- Improvement in overall efficiency of plant
- Lower specific energy consumption

17.4 Limitations of technology

Implementation of direct rolling in TMT mills needs high initial investment. Also, induction furnaces should be near to rolling mills to maintain proper temperature of billet at the time of rolling.

17.5 Investment required, energy and GHG saving potential, and cost-benefit analysis

To understand the cost-benefit analysis, let us consider a rolling mill of 15-tonne capacity. The cost-benefit analysis of hot rolling in a TMT mill is tabulated below.

Sl no.	Parameter	Conventional mill	Direct rolling
1	Productivity	15 t/h	15 t/h
2	Operating hours per day	16	16
3	Operating days per year	300	300
4	Specific fuel consumption	80 kg/t	-
5	Specific power consumption	110 kWh/t	120 kWh/t
6	Annual savings in terms of coal	5760 t/y	
7	Annual increase in power consumption	7,20,000 kWh/t	
8	Net monetary savings	INR 352.8 lakh	
9	Investment required	INR 180 lakh	
10	Simple payback period	6 months	
11	Annual net energy saving potential	3163.68 toe/y	
12	Annual GHG emission reduction potential	13,888.8 tCO_2/y	

17.6 Technology summary

The technology impacts of adoption of hot rolling in a TMT mill are summarized below.

- Annual energy saving : 2500–3500 toe/y
- Annual GHG emission reductions : 12,000–16,000 tCO_2/y
- Annual monetary saving : INR 300–400 lakh/y
- Investment : INR 160–220 lakh
- Payback period : 5–12 months

Tech 18: Adoption of Direct Rolling in Structural Mills

18.1 Baseline scenario

In composite units, billets/blooms that are suitable for rolling of structures are casted in a CCM. The billets/blooms are cut into required size using a gas cutter and cooled to ambient temperature. The cold billet/bloom is transferred to the rolling mill bay, wherein the same is re-heated using a fuel-fired re-heating furnace. Rolling of structures requires heating to 1200 °C or more. The heated billets are then rolled to desired shape and size. Due to the requirement of higher rolling temperature, direct rolling or hot charging of billets/blooms directly from the CCM to the rolling mill has not been preferred. While, the concept of direct rolling was touching new heights in TMT rolling during the past few years, the same remained unattended in structural rolling, especially in the case of medium and heavy structures.

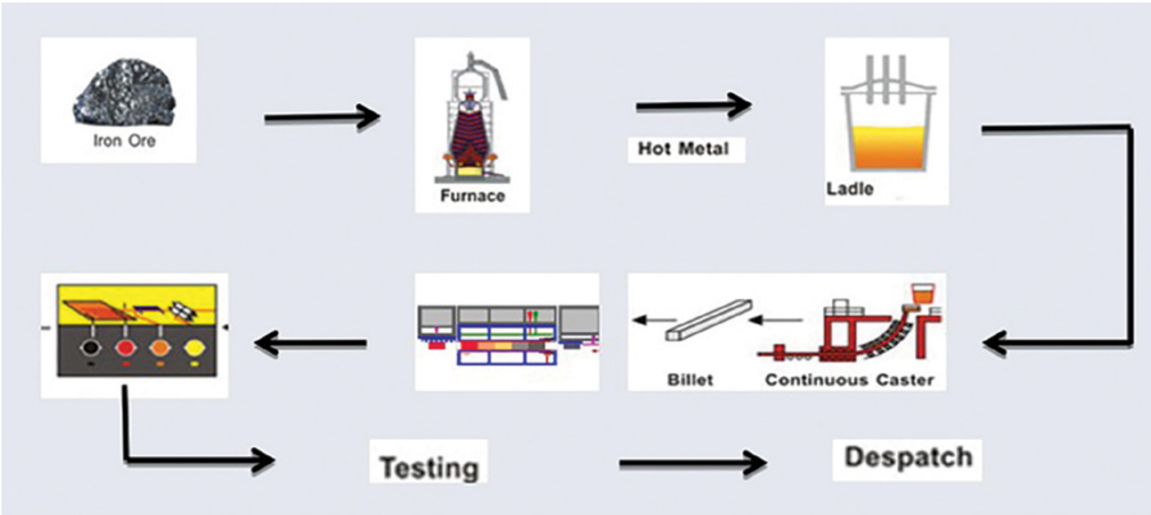
18.2 Energy efficient technology

The energy efficient way of rolling in composite units has been dictated by a revolutionary technology in the past few years. Hot charging or direct rolling of hot billets from CCM to rolling mill, which eliminates the re-heating furnace in the process, has transformed the entire sector to a new dimension of energy saving.

Direct rolling

Source: https://www.lmmgroupcn.com/more-and-more-application-of-direct-rolling-technology%EF%BC%81/

The process of direct rolling/hot charging of billets is shown in the process flow diagram below.



Process flow diagram of direct rolling in structural mill

The technical specifications of induction heater required for intermittent heating are tabulated below:

Sl no.	Parameter	Value
1	Equipment type	In-line induction heating for hot rolling
2	Frequency	50–6000 Hz
3	Power	500–10,000 kW
4	Heating time	Instantaneous
5	Rated voltage	415 V
6	Power factor	0.8
7	Efficiency	60%–65%

18.3 Benefits of technology

The advantages of direct rolling in structural mills are listed below.

- Reduced scale loss
- Improved mechanical properties
- Enhanced process control
- Improvement in overall efficiency of plant
- Lower specific energy consumption

18.4 Limitations of technology

Implementation of direct rolling in structural mills needs high initial investment.

18.5 Investment required, energy and GHG saving potential, and cost-benefit analysis

To understand the cost-benefit analysis, let us consider a rolling mill of 15-tonne capacity. The cost-benefit analysis of hot rolling in a structural mill is tabulated below.

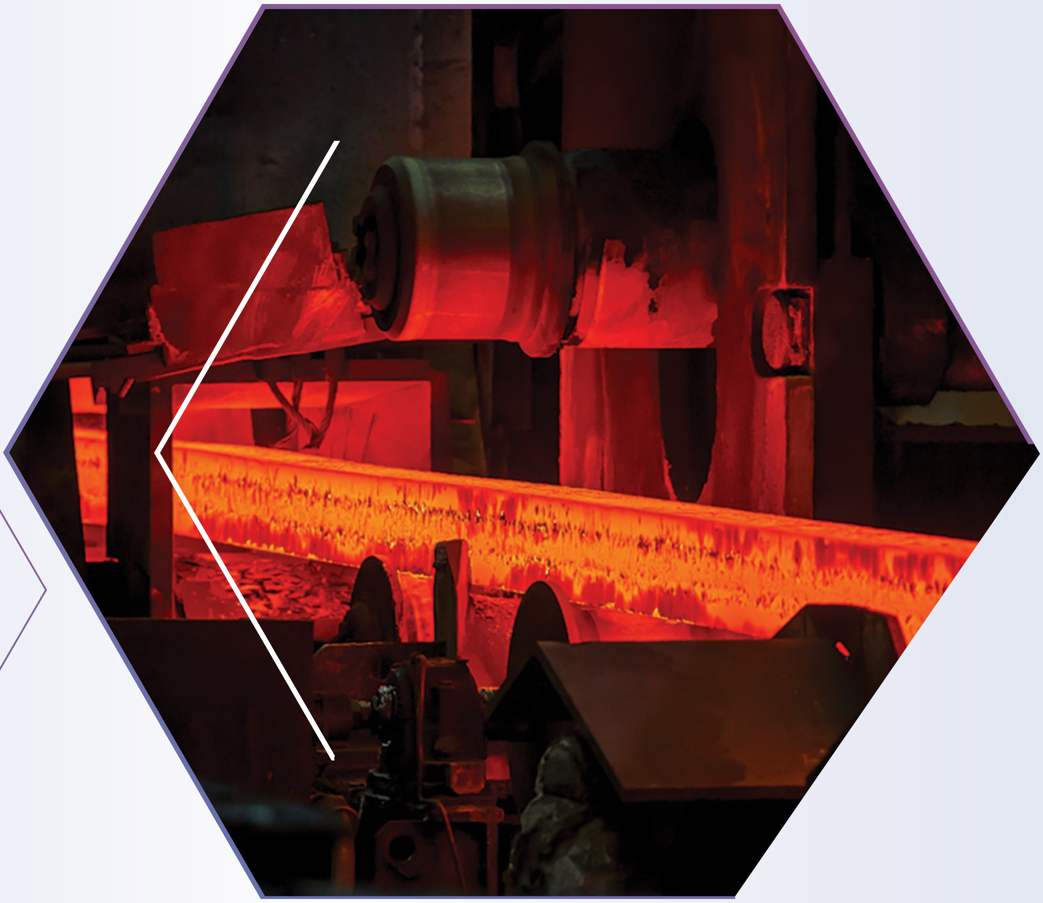
Sl no.	Parameter	Conventional mill	Direct rolling
1	Productivity	15 t/h	15 t/h
2	Operating hours per day	16	16
3	Operating days per year	300	300
4	Specific fuel consumption	80 kg/t	-
5	Specific power consumption	110 kWh/t	130 kWh/t
6	Annual savings in terms of coal	5760 t/y	
7	Annual increase in power consumption	14,40,000 kWh/t	
8	Net monetary savings	INR 302 lakh	
9	Investment required	INR 200 lakh	
10	Simple payback period	8 months	
11	Annual energy saving potential	3101 toe/y	
12	Annual GHG emission reduction potential	13,377 tCO_2/y	

18.6 Technology summary

The technology impacts of adoption of hot rolling in a structural mill are summarized below.

- Annual energy saving : 2500–3500 toe/y
- Annual GHG emission reductions : 11,000–16,000 tCO_2/y
- Annual monetary saving : INR 250–350 lakh/y
- Investment : INR 170–250 lakh
- Payback period : 7–14 months

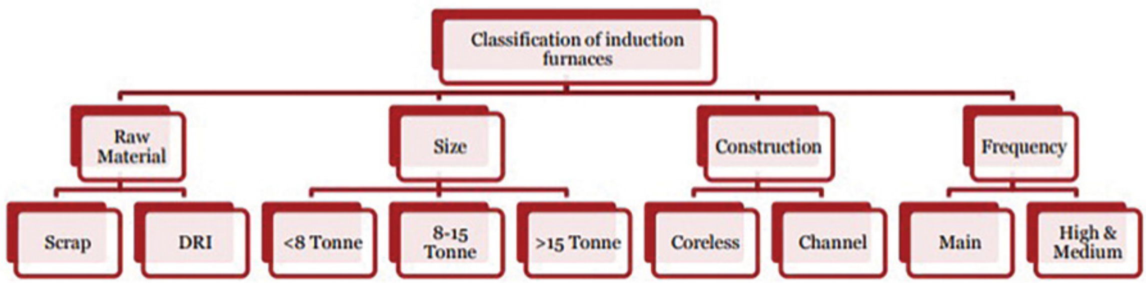
SECTION 2:
Electric Induction Furnace



Electric Induction Furnace: A Process Overview

Electric induction furnace (EIF) is a type of furnace for steelmaking, which uses electrical energy for its operation. The principle of melting in an induction furnace (IF) is that a high-voltage electrical source from a primary coil induces a low voltage, high current in the metal or secondary coil. IF uses the heat produced by the eddy currents generated by a high frequency alternating field. The alternating magnetic field produced by the high frequency current induces powerful eddy currents in the charge resulting in very fast heating.

In today's scenario, induction furnaces can be classified based on raw material, size, construction, and operating frequency of furnaces. The figure below captures the detailed classification of induction furnaces.



Typically, an induction furnace plant consists of a furnace, ladle, ingot mould/continuous casting machine (CCM), and raw material yard with cooling water system, cranes, etc. The figure below captures the typical process flow of an induction furnace unit.

There are mainly two types of induction furnaces: (a) channel induction furnace and (b) coreless induction furnace.

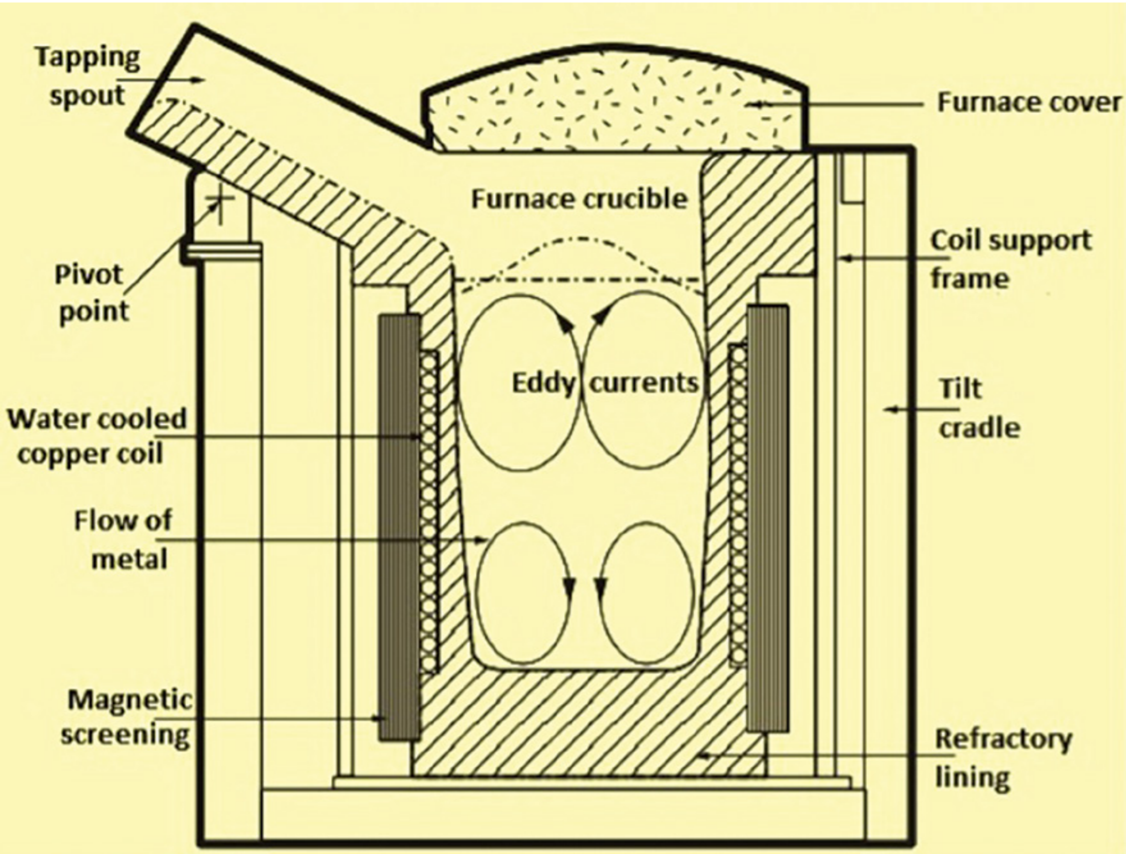
Channel induction furnace

The channel IF consists of a refractory lined steel shell, which contains the molten metal. Attached to the steel shell and connected by a throat is an induction unit that forms the melting component of the furnace. The induction unit consists of an iron core in the form of a ring around which a primary induction coil is wound. This assembly forms a simple transformer in which the molten metal loops comprise the secondary component. The heat generated within the loop causes the metal to circulate into the main well of the furnace. The circulation of the molten metal causes a useful stirring action in the melt. The channel IF is normally used for melting low melting point alloys, or as a holding and superheating unit for higher melting point alloys such as cast iron. The furnace can be used as a holder for metal melted off peak in coreless IF thereby reducing total melting costs by avoiding peak demand charges. Channel IF is not generally used for steelmaking.

Coreless induction furnace

The coreless IF has a fairly simple construction. It basically consists of a refractory vessel and the surrounding coil borne by a steel frame. When an alternating current (AC) flows through the coil, it creates an electromagnetic field, which, in turn, induces eddy currents in the charged material. This charge material gets heated up as per Joule's law and with further heat the charge material melts.

A coreless IF consists of a crucible, a power supply unit consisting of transformer, inverter and capacitor bank, the charging arrangement, the cooling system for the power supply and furnace coil, process control system, and the fume extraction equipment. The schematic diagram of a coreless IF is shown below.

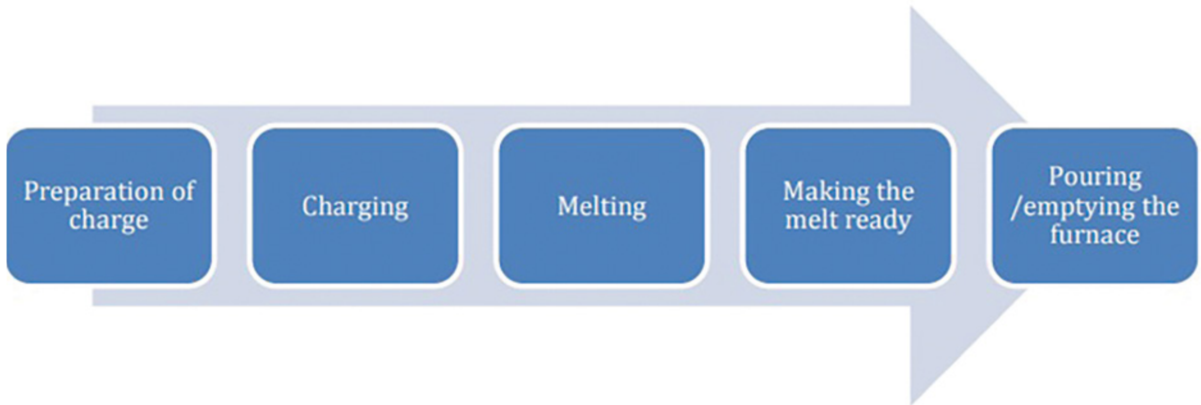


Schematic diagram of coreless induction furnace

Source: IspatGuru

The steps involved in the operation of an induction furnace include:

1. Charge preparation
2. Charging
3. Melting
4. Making the melt ready
5. Tapping of the heat



Induction furnace process

Charge preparation and charging: The raw materials are weighed and kept near the furnace on the furnace charging floor before starting the melting. The charge is to be free from all the foreign materials, including sand, dirt, and oil/grease. Rusty scrap not only takes more time to melt but also contains less metal per charging. For every 1 % slag formed at 1500 °C, the energy loss is 10 kWh/t. The scrap is to be cleaned. Exact weight of the ferro-alloys is to be kept ready, since the ferro-alloys are expensive and their proper handling not only reduces wastage but also reduces the time lost in their addition.

The maximum size of a single piece of metal/scrap is not to be more than one-third of the diameter of the furnace crucible. It avoids the problem of bridging. Moreover, each charge is to be around 10% of the crucible volume. Also, there are not to be any sharp edges, particularly in case of heavy and bulky scrap, as this can damage the refractory lining of the furnace. Further, the furnace is not to be charged beyond the coil level, i.e., charging the furnace to its capacity. It is to be understood that as furnace lining wears out, the charging can slightly increase.

Proper charge sequence is to be followed. Bigger size metal is to be charged first followed by charging the smaller size and gaps are to be filled by turnings and boring. The use of baled steel scrap and loose borings (machining chips) is to be controlled. Charge driers and pre-heaters are to be used to remove moisture, pre-heat the charge, and remove any oil or grease. Introduction of wet or damp scrap in the melt is to be avoided as this can cause an explosion.

Melting and making ready the heat: It is essential that the furnace is always run with full power. This not only reduces batch duration but also improves energy efficiency. By the use of furnace cover, the radiation heat loss can be reduced substantially. The build-up of slag on furnace walls is to be avoided. Typical slag build-up takes place near the neck, above coil level where agitation effect is less. Quantity of flux used for slag removal is important. Typically flux consumption is less than 1 kg per ton of steel. Proper tools are to be used for de-slagging. Tools with a flat head are to be used instead of rod or bar for de-slagging. They are more effective and take very less time.

Process control through a melt processor leads to less interruptions. Typically process control reduces interruptions by 2–4 minutes. Spectral testing laboratory is to be located near the steel melting shop to avoid waiting time for the chemical analysis of the heat and slag samples. Unnecessary superheating of the liquid steel is to be avoided. Superheating by 50 °C can increase furnace specific energy consumption by 25 kWh/t.

Tapping of the heat: The plant layout plays an important role in determining the distance travelled by the liquid steel in the ladle and the temperature drop. The ladle size is to be optimized to minimize the heat losses and to empty the furnace in the shortest possible time. Melting is needed to be synchronized with the casting of the liquid steel. Liquid steel is not to wait in the furnace. The ladle pre-heater is to be used to avoid drop of the temperature. Use of liquid steel to pre-heat the ladle is quite energy intensive and expensive. The quantity of liquid steel left in the ladle is to be as low as possible. Ladle covering compound is to be used to minimize the temperature drop due to the radiation losses from the ladle top.

Tech 1: Installation of Insulated Gate Bipolar Transistor Technology-based Induction Furnace

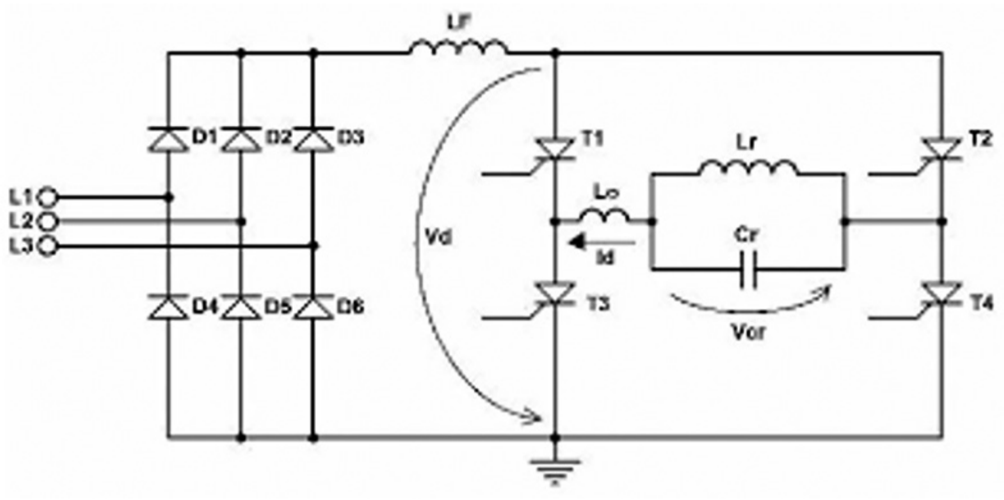
1.1 Baseline scenario

An induction furnace is an electrical furnace in which the heat is applied by induction heating principle to the metal. Capacity of an induction furnace ranges from less than one kilogram to one hundred tonne capacity and is used to melt iron and steel, copper, aluminum, and other precious metals. Induction melting furnaces are widely used in the metal industry for melting or heating because of good heating efficiency, high production rate, and clean working environment. Induction furnaces have high power consumption and non-linear characteristics. A typical parallel resonant inverter circuit for an induction melting furnace has a phase-controlled rectifier that provides a constant DC current source. The inverter consists of four thyristors and a parallel resonant circuit comprising capacitor bank and heating coil. Thyristors are naturally commutated by AC current flowing through the resonant circuit. Major problems with thyristor-based induction furnaces are (a) insufficient output power and (b) frequent damage of the capacitor bank. Conventionally, most of the electric induction furnaces in the secondary steel sector use thyristor-based power systems.

1.2 Energy efficient technology

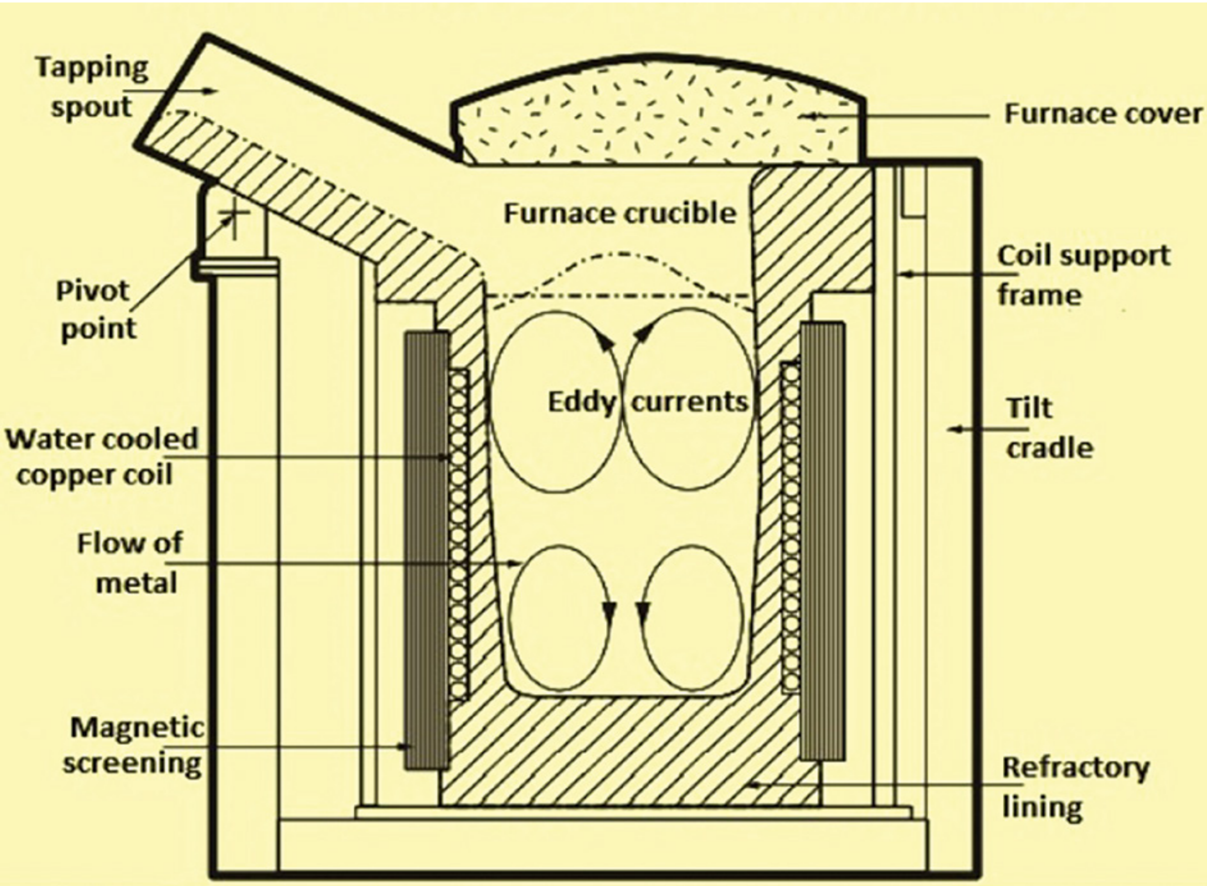
Industry commonly uses induction heating units that are fed by current source inverter (CSI). Most of these CSIs are thyristor-based. For high power and low frequency induction heating operation (where operating frequencies are less than 1 kHz), thyristor is good. However, for medium power and high frequency induction heating (where operating frequencies are up to 10 kHz), an Insulated Gate Bipolar Transistor Technology (IGBT) may be used to get better performance. IGBT is the most effective and efficient induction melting technology. IGBT has high pulse rate. This high pulse rate allows the technology to generate large power pulses. Large power pulses are necessary stirring action, which helps in melting the metal.

Melting by induction is cost-effective with use of IGBT. Compared to a thyristor-based induction furnace, an IGBT induction furnace is more efficient and easier to operate. Energy losses are reduced in IGBT induction furnaces, as the furnace temperature can be controlled easily and furnaces will never heat the material higher than required temperature. The power factor maintained in IGBT is in the range of 0.95–0.98 as compared to less than 0.80 in the case of thyristor-based induction. In IGBT, the output capacitors are installed inside the generator itself, whereas in thyristor-based furnace, the output capacitors are installed near the transformer.



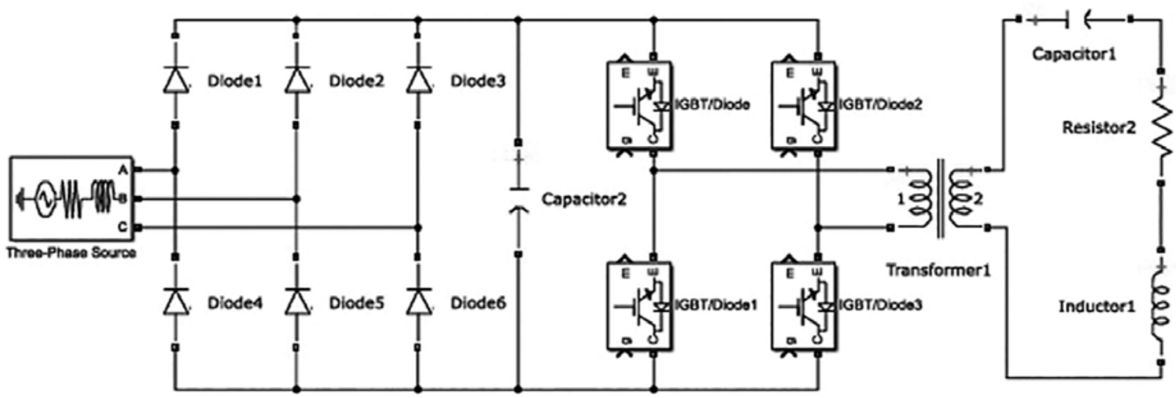
Circuit diagram of thyristor-based induction furnace

Source: https://www.power-mag.com/pdf/feature_pdf/1410340545_ABB_0514%289%29_Layout_1.pdf



Schematic diagram of coreless induction furnace

(Source: https://www.ispatguru.com/steelmaking-by-induction-furnace/)



Circuit diagram of IGBT-based induction furnace

Source: https://www.researchgate.net/figure/Main-circuit-of-induction-heating-power-supply_fig1_336202799

1.3 Benefits of technology

The replacement of thyristor-based induction furnace with IGBT induction furnace leads to following benefits:

- Compensation-free in every operating condition, so there is no installation and maintenance costs
- Upgradable converter power with parallel module technology
- Simple replaceable power modules in case of trouble and service requirement
- Excellent coil protection system
- Probe-less automatic sintering
- Automatic crucible preheating
- Energy monitoring and consumption reporting via remote connection

1.4 Limitations of technology

Investment in an IGBT furnace is much higher than that in a thyristor-based furnace. Also, the system upgrades will call for skilled manpower for operations.

1.5 Investment required, energy and GHG saving potential, and cost-benefit analysis

To understand the cost-benefit analysis, let us consider a thyristor-based furnace of 10-tonne melting capacity. The cost-benefit analysis for replacement of the present furnace with an IGBT furnace is tabulated below.

Sl no.	Parameters	Value
1	Average production per heat	9.1 t/heat
2	Average heat time	2 h
3	Average number of heats in a day	10
4	Specific energy consumption (SEC) of induction furnace (present)	645 kWh/t
5	SEC for IGBT	574 kWh/t
6	Electricity saving potential	1,936,935 kWh/y
7	Electricity charges	INR 7/kWh
8	Annual monetary saving in INR	INR 135 lakh/y
9	Investment required (for upgradation of power system)	INR 120 lakh
10	Simple payback	11 months
11	Annual energy saving potential	167 toe/y
12	Annual GHG emission reduction potential	1375 tCO_2/y

1.6 Technology summary

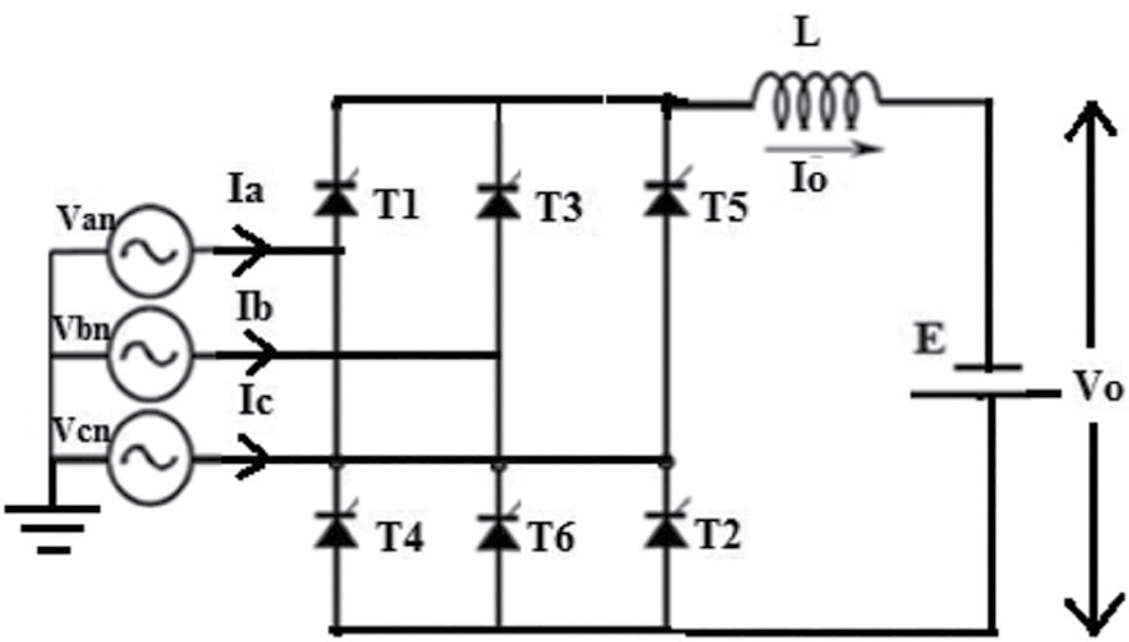
The technology impacts for a typical 10-tonne induction furnace are summarized below.

- Annual energy saving : 120–200 toe/y
- Annual GHG emission reductions : 1200–1800 tCO_2/y
- Annual monetary saving : INR 120–130 lakh/y
- Investment : INR 100–150 lakh
- Payback : 10–18 months

Tech 2: Conversion from 6-Pulse to 12-Pulse/ 24-Pulse Power System

2.1 Baseline scenario

One of the major challenges of using an electric induction furnace from an electrical point of view is the inductive and nonlinear nature of the furnace load. This is responsible for the generation of considerable harmonic distortion and pollution in the supply system. The cause is within the induction furnace design and operation itself, because it is a known fact that the order of harmonics and hence the magnitude of distortion depends upon the number of converter pulses used in the furnace power supply system. For controlling and preventing the harmonics/waveform distortion problems, rules and norms concerning permissible limits of voltage and current harmonic distortion do exist. However, to comply with these legislations and reduce harmonic distortion below the established permissible level, proper corrective actions have to be taken. Most of the industries generally have a 6-pulse converter system, which results in high harmonic distortion, leading to higher specific energy consumption.



Circuit diagram of 6-pulse converter

Source: https://www.researchgate.net/figure/Circuit-diagram-of-three-phase-6-pulse-converter_fig1_311986855

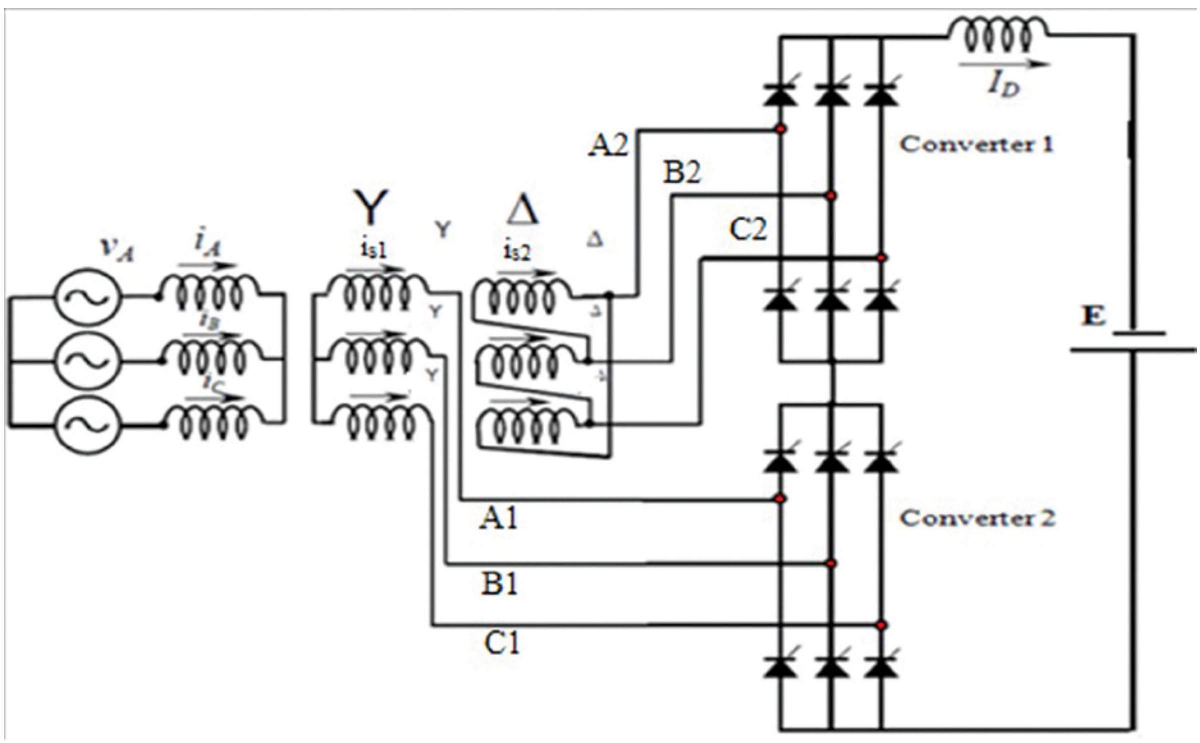
2.2 Energy efficient technology

Total harmonic distortion (THD) is a common measurement of the level of harmonic distortion present in power systems. With the 6-pulse power supply system, the 5th and 7th order harmonics are significant, and filtering is often needed. Harmonic current in the system increases hysteresis losses and eddy current losses. These losses raise the system's operating temperature, which can derate performance and reduce the life of the system.

A 12-pulse rectifier uses two 6-pulse rectifiers in parallel (12 diodes) to feed a common DC bus. A transformer with one primary and two secondary windings creates a 30-degree phase shift between the two current waveforms, which eliminates the 5th and 7th harmonics and reduces current THD to between 10% and 15%.

Eliminating virtually all harmonics requires a 24-pulse rectifier, which consists of two 12-pulse rectifiers in parallel and two 3-winding transformers. The transformers provide a voltage waveform offset of 15 degrees, which cancels most low-frequency harmonics.

Conversion of the existing 6-pulse to 12-pulse/24-pulse power supply system thus leads to significant reduction in THD for the induction furnace system. It also improves the power factor improving the system efficiency and reducing the specific energy consumption.



Circuit diagram of 12-pulse converter

Source: https://www.researchgate.net/figure/Circuit-Diagram-of-Three-Phase-12-Pulse-Converter_fig3_311986855

2.3 Benefits of technology

The replacement of 6-pulse induction furnace with 12/24-pulse induction furnace leads to following benefits:

- Reduction in THD
- Increase in power factor
- Better life of equipment
- Improved system efficient, lesser losses

2.4 Limitations of technology

The conversion to 12-pulse and 24-pulse power supply system is a capital-intensive process. In most cases, the entire furnace including the crucible needs to be replaced. Installation of a new 12-pulse/24-pulse induction furnace is economically more viable compared to upgradation of the existing power system in most cases.

2.5 Investment required, energy and GHG saving potential, and cost-benefit analysis

To understand the cost-benefit analysis for conversion of 6-pulse to 12-pulse power supply system, let us consider a 10-tonne induction furnace.

Sl No.	Parameters	Value
1	Average production per heat	9.1 t/heat
2	Average number of heats in a day	10
3	Annual production	27,300 t/y
4	Specific energy consumption (SEC) of induction furnace (present)	654 kWh/t
5	New SEC of induction furnace (with pre-heated ladle)	581 kWh/t
6	Electricity saving potential	10%
7	Electricity saving potential	5869.5 kWh/d
8	Number of operating days in a year	300
9	Electricity saving potential	17,60,850 kWh/y
10	Electricity charges	INR 7/kWh
11	Annual monetary saving	INR 123.3 lakh/y
12	Investment required (for upgradation of power system)	INR 60 lakh
13	Simple payback period	6 months
14	Annual energy saving potential	151 toe/y
15	Annual GHG emission reduction potential	1250 tCO_2/y

2.6 Technology summary

The technology impacts for a typical 10-tonne induction furnace are summarized below.

- Annual energy saving : 130–180 toe/y
- Annual GHG emission reductions : 1000–1500 tCO_2/y
- Annual monetary saving : INR 100–120 lakh/y
- Investment : INR 50–80 lakh
- Payback : INR 6–12 months

Tech 3: Installation of Shredding Machine and Scrap Charging Through Bucket or Vibro-feeder

3.1 Baseline scenario

The primary raw source for induction furnace units in India is scrap. About 70% of the scrap is often utilized. According to current usage, most induction furnace units appear to feed unprocessed scrap. The charge mix is fed with the unprocessed or unshredded scrap either by magnet or through a manually operated charging system. This charging procedure causes the scrap charge's bulk density to be low, which causes air pockets (voids) between the scrap pieces and, in turn, low power density, which lengthens the heat/cycle time. For non-shredded scrap, best charging practices like bucket charging or charging through a vibro-feeder are also not an option, resulting in low furnace efficiency.

3.2 Energy efficient technology

The size and shape of scrap plays an important role in running the EIF at full power/load, which is the best operating practice. The more the EIF runs at full power, the lower will be total energy losses leading to lower specific energy consumption. The best practice is to use dense scrap charge for a faster melt rate and lower energy consumption. Small and dense scrap pieces are preferred for optimum results. To adopt this best practice, it is proposed to use shredded scrap in an induction furnace. Thus, a 'shredding machine with bucket/vibro-feeder' is an important technology package for induction furnace units. A shredder is a machine that cuts large scrap pieces into smaller pieces and compresses them into pieces with higher bulk density. The shredder also removes rust and dust from the scrap. In the shredder, the scrap is cut into small pieces by specially designed hammers. The shredded scrap, because of its higher bulk density, increases the charging rate and also helps in better power coupling (means maximum power input which increases the melt rate) thus reducing heat/cycle time.

Vibro-feeder

Source: https://www.electrotherment.com/iron-steel-making/scrap-processing/vibro-feeder-scrap-charging-vibratory-car

Scrap shredding machine

Source: https://jmcrecycling.com/portfolio_category/shredders/

3.3 Benefits of technology

The benefits of using shredded scrap in induction furnace are as follows:

- Reduction in specific power consumption
- Higher productivity
- Lower cycle time
- Improved system efficiency, lesser losses

3.4 Limitations of technology

The technology calls for additional infrastructure in terms of installation of shredding machines, which will require additional capital and space. Alternatively, common facilities for scrap processing can be set up at cluster level.

3.5 Investment required, energy and GHG saving potential, and cost-benefit analysis

To understand the cost-benefit analysis after installation of shredding machine and scrap charging through bucket or vibro-feeder, let us consider a 10-tonne induction furnace.

Sl no.	Parameters	Value
1	Average production per heat	9.1 t/heat
2	Average slag generation per heat	5%
3	Average charge input per heat	9.6 t/heat
4	Scrap quantity in charge mix per heat	90%
5	Out of the total quantity of scrap feeding in charge mix, scrap that can be fed after shredding	40%
6	Quantity of shredded scrap	3448 kg/heat
7	Average electricity consumption per heat	5870 kWh/heat
8	Average heat time	2 hours
9	Average number of heats in a day	10
10	Specific energy consumption (SEC) of induction furnace (present)	645 kWh/t
11	Cycle time reduction	11 min
12	Reduction in cycle time after shredder installation	9.17%
13	New cycle time after using shredded scrap with bucket	1.82 hours
14	New average electricity consumption per heat	5331 kWh/heat
15	New SEC of induction furnace	586 kWh/t
16	Electricity saving potential	9.17%
17	Electricity saving potential	5385 kWh/d
18	Electricity consumption in the shredding machine	1480 kWh/d

Sl no.	Parameters	Value
19	Net electricity savings due to shredding machine	3905 kWh/d
20	Number of operating days in a year	300
21	Electricity saving potential	11,71,500 kWh/y
22	Electricity charges	INR 7/kWh
23	Annual monetary saving	INR 82.01 lakh/y
24	Capacity of shredding machine having 250 hp motor	3.5 t/h
25	Price of shredding machine	INR 90 lakh
26	Price of bucket and vibro feeder for scrap feeding in INR	INR 17 lakh
27	Investment required	INR 107 lakh
28	Simple payback period	15.7 months
29	Annual energy saving potential	101 toe/y
30	Annual GHG emission reduction potential	832 tCO_2/y

3.6 Technology summary

The technology impacts for installation of scrap processing and charging system for a typical 10-tonne induction furnace are summarized below.

- Annual energy saving : 80–120 toe/y
- Annual GHG emission reductions : 700–1200 tCO_2/y
- Annual monetary saving : INR 50–100 lakh/y
- Investment : INR 90–140 lakh
- Payback : 14–20 months

Tech 4: Replacement of Coil Cradle of Old Furnace

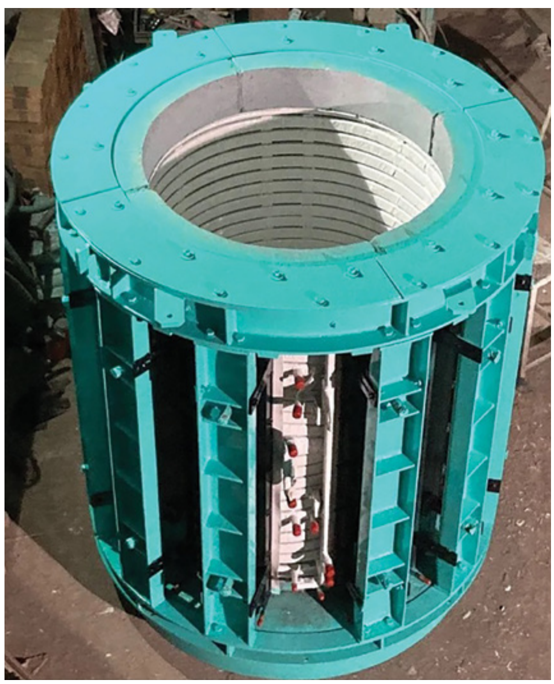
4.1 Baseline scenario

In some induction furnace plants, furnaces are more than 8–10 years old. These furnaces have outdated coil cradle assembly while the latest furnaces have far more energy-efficient coil cradle assembly. Over time, the efficiency of the old coil reduces as its shape gets distorted. Energy losses are high for old coil cradle assembly due to the following possible reasons:

- Non-uniform temperature gradient throughout the refractory
- Non-efficient shunt coverage
- Low current-carrying efficiency of the coil

4.2 Energy efficient technology

Replacement of an old coil cradle assembly of the induction furnace unit with a new and efficient design assembly can reduce electricity consumption during melting operation. Latest coil cradle assembly is equipped with specially designed curved magnetic shunts and covers around 80% of coil periphery, which minimizes stray losses and improves efficiency besides providing rigidity to coil cradle assembly. The shunts are carefully designed to provide a positive support to the coil. Cushioned insulating pads reduce noise and vibration and hence enhance overall efficiency of the shunts. The coil cradle assembly with the latest design maintains uniform temperature gradient throughout the refractory, preventing overheating and enhances life of refractory.



Coil cradle

4.3 Benefits of technology

Major benefits of using new efficient coil cradle system are:

- Better furnace efficiency
- Lower energy consumption
- Enhanced lining life.

4.4 Limitations of technology

Design of coil cradle needs to be customized based on the furnace capacity, loading pattern, and type of processed material.

4.5 Investment required, energy and GHG saving potential, and cost-benefit analysis

To understand the benefits of the technology, let us consider an induction furnace unit of 10-tonne capacity.

Sl no.	Parameters	Value
1	Average electricity consumption per heat	5870 kWh/heat
2	Average production per heat	9.1 t/heat
3	Average heat time	2 hours
4	Average number of heats in a day	10
5	Specific energy consumption (SEC) of induction furnace (present)	645 kWh/t
6	Reduction in electricity consumption due to new coil cradle	16 kWh/t
7	New SEC of induction furnace	629 kWh/t
8	Electricity saving potential	2.50%
9	Electricity saving potential	1467.37 kWh/d
10	Number of operating days in a year	300
11	Electricity saving potential	4,40,212.5 kWh/y
12	Electricity charges	INR 7/kWh
13	Annual monetary saving	INR 30.81 lakh/y
14	Investment required (Replacement of coil cradle)	INR 25 lakh
15	Simple payback period	9.7 months
16	Annual energy saving potential	38 toe/y
17	Annual GHG reduction potential	313 tCO_2/y

4.6 Technology summary

The impacts for replacement for coil cradle of old furnace are summarized below.

- Annual energy saving : 30–50 toe/y
- Annual GHG emission reductions : 300–500 tCO_2/y
- Annual monetary saving : INR 25–35 lakh/y
- Investment : INR 20–40 lakh
- Payback period : 8–14 months

Tech 5: Installation of Continuous Casting Machine for Billet Making

5.1 Baseline scenario

A majority of smaller capacity induction furnace units use 'mould' to cast the molten metal into ingots. The 'mould' filling using the runner and gate system is the traditional practice of converting molten metal to ingots, although the system does not require any extra energy consumption except for the crane operation for every heat/cycle. It has associated energy loss of melting, which is almost 500–600 kg of molten metal (for a 10-tonne capacity furnace) in the runner and gates resulting in increased specific energy consumption. However, the waste metal of 500–600 kg is reused into the furnace as charge for melting.

5.2 Energy efficient technology

The proposed technology option to avoid these losses and increase productivity is by installing a continuous casting machine (CCM). This technology removes the traditional 'mould' filling using the 'runner and gate system' and saves the energy loss of melting 500–600 kg of steel per heat thereby reducing the specific energy consumption at the final output. Output of CCM is billets of 100 × 100 mm and above. Compared to pencil ingots, billets have better quality and less rejection at the rolling end. Installing a CCM enhances the production and profit margin (as the market selling price of billet is higher by INR 400–500 per tonne as compared to billet). Therefore, the installation of a CCM can be a possible technology package to improve production and reduce the specific energy consumption at finished product in induction furnace units.

5.3 Benefits of technology

Major benefits of using continuous casting machine are:

- Higher productivity
- Reduction in specific power consumption
- High yield

5.4 Limitations of technology

Installation of CCM for billet making is capital-intensive. Also, a proper layout is required for installation of the system.

Continuous casting machine

5.5 Investment required, Energy and GHG saving potential, and Cost- Benefit Analysis

To understand the benefits of CCM, let us consider an induction furnace unit of 10-tonne capacity.

Sl no.	Parameters	Value
1	Average electricity consumption per heat	5870 kWh/heat
2	Average production per heat	9.1 t/heat
3	Average heat time	2 hours
4	Average number of heats in a day	10
5	Specific energy consumption (SEC) of induction furnace (present): Scrap-based	645 kWh/t
6	Recommended CCM size	4/7 m radius
7	No. of stands in the proposed CCM	2
8	Price of CCM	INR 120 lakh
9	Expenses in civil and other work	INR 150 lakh
10	Investment required (Total cost of CCM)	INR 270 lakh
11	Reduction in wastage of metal per heat due to CCM	0.5 tonne/heat

Sl no.	Parameters	Value
12	Total reduction in wastage in a year without CCM	1500 t/y
13	Average tapping temperature	1645 °C
14	Initial temperature of charge	40 °C
15	Heat loss due to wastage in running system per heat	1,89,929 kcal/heat
16	Energy loss due to wastage in running system per heat	221 kWh/heat
17	Electricity consumption in CCM and extra furnace operation due to high tapping temperature required	209 kWh/heat
18	Net electricity saving due to CCM operation	12 kWh/heat
19	Electricity charges	INR 7/kWh
20	Annual monetary saving due to CCM	2.49 lakh/y
21	Additional price on billets made through CCM	INR 400/t
22	Additional profit due to CCM	INR 101 lakh
23	Total profit due to CCM	INR 103 lakh
24	Number of operating days in a year	300
25	Simple payback period	31.31 months
26	Annual energy saving potential	3 toe/y
27	Annual GHG emission reduction potential	25 tCO_2/y

5.6 Technology summary

The impacts of installation of continuous casting machine are summarized below.

- Annual energy saving : 2–5 toe/y
- Annual GHG emission reductions : 20–30 tCO_2/y
- Annual monetary saving : INR 70–100 lakh
- Investment : INR 240–300 lakh
- Payback period : 30–36 months

Tech 6: Installation of Sintering Panel for Sintering Heat

6.1 Baseline scenario

Refractory or ramming mass plays an important role as refractory/insulation material in the induction furnace. The thickness of refractory lining keeps on reducing with furnace operation. After every 15–20 heats, the ramming mass needs resetting or replacement to avoid furnace breakdown. The first heat after ramming mass resetting is called sintering heat and takes almost double the heat time compared to normal heat time (as it requires slow heating from ambient temperature to approximately 1660 °C). The sintering heat consumes much more energy, ultimately reducing the overall SEC. The present status suggests that none of the units have given due importance to this aspect and have been losing on energy and production.

6.2 Energy efficient technology

The installation of a sintering panel can overcome the limitations associated with sintering heat. The sintering panel is a dedicated power panel applicable during sintering heat. During the sintering heat, it can share the load between the induction furnace under operation and the newly ready crucible that needs pre-heating before the charge feed. The load sharing can be done in a certain ratio, so that it does not affect the melting process under the furnace and simultaneously pre-heats the newly ready crucible up to 500–700 °C. With the installation of the sintering panel, the utilization index will go up by 25%–30% It reduces the heat time of sintering heat to normal heat time and will increase productivity. Also, it does not consume any extra power. The end result is reduced SEC, enhanced production, and better power quality and utilization during the sintering heat.

6.3 Benefits of technology

Major benefits of using sintering panel system are:

- Higher productivity
- Reduction in specific power consumption
- High yield
- Lower operational cost

Sintering panel

Source: https://www.exportersindia.com/product-detail/e-50-induction-furnace-5056089.htm

Sintering panel

6.4 Limitations of technology

The sintering panel's coil design is critical to achieving uniform and controlled heating across the sintering material. The coil is typically custom-designed to match the specific dimensions and shape of the sintering material being processed. Also, precise temperature control during sintering is essential to achieve the desired material properties.

6.5 Investment required, energy and GHG saving potential, and cost-benefit analysis

To understand the cost-benefit analysis, let us consider an induction furnace of 10-tonne melting capacity. The cost-benefit analysis for installation of sintering panel for sintering heat is tabulated below.

Sl no.	Parameters	Value
1	Extra time consumed for sintering heat	120 min
2	Frequency of sintering	15 heats
3	Average production per heat	9.1 t/heat
4	Average number of heats in a day	10
5	Average heat time	2 hours
6	Average electricity consumption per heat	5870 kWh/heat
7	Specific energy consumption (SEC) of induction furnace (present)	645 kWh/t
8	Number of operating days in a year	300
9	Total heats in a year	3000 heats/y
10	Total sintering heat in a year	200 heats/y
11	Extra available time for production due to installing sintering panel	400 hours
12	Extra number of heats in a year	200 heats/y
13	Extra production	1820 t/y
14	Profit margin on extra production	INR 1000/t
15	Electrical savings due to reduction in SEC (reduction in SEC by 20% for extra production)	2,34,780 kWh
16	Annual monetary saving	INR 35 lakh/y
17	Investment required (installation of sintering panel)	INR 35 lakh
18	Simple payback period	12 months
19	Annual energy saving potential	20 toe/y
20	Annual GHG emission reduction potential	167 tCO_2/y

6.6 Technology summary

The impacts for installation of sintering panel for a typical 10-tonne induction furnace are summarized below.

- Annual energy saving : 15–25 toe/y
- Annual GHG emission reductions : 140–190 tCO_2/y
- Annual monetary saving : INR 30–50 lakh/y
- Investment : INR 25–50 lakh
- Payback period : 10–18 months

Tech 7: Scrap Pre-heating

7.1 Baseline scenario

Pre-heating of scrap is considered an energy-saving option to save energy. Market understanding suggests that units had tried scrap pre-heating in induction furnaces, but with limited success. At present, normal scrap at ambient temperature is fed to the furnace, ultimately consuming more energy (electricity) for melting, resulting in more heat/cycle time. Therefore, scrap pre-heating could be a better option if we have any waste heat available in the plant or even if any cheap source of energy is available. Using any cheap source of energy for scrap pre-heating can result in monetary savings as well as reduction in carbon emissions.

7.2 Energy efficient technology

Scrap heating is proposed as one of the technology packages. By using a scrap pre-heater, scrap can be pre-heated from ambient temperature to 400–450 °C. A scrap pre-heating system consists of a high velocity burner, blower, scrap basket, swiveling, and temperature control mechanism. It is fabricated from mild steel plates of suitable thickness with two hoods fitted on its structural arm: one for firing and the other to collect the flue gases after routing through the charged basket kept for pre-heating, under the hood. The hood will be lined with ceramic fibre of suitable thickness. With the installation of a scrap pre-heater, the work of the induction furnace will be reduced as the power will be required to raise the temperature of the raw material from 500 °C to 1600 °C instead of 35 °C to 1600 °C. Thus, the overall heat/cycle time will be reduced, thereby reducing the SEC.

If waste heat is not available in the plant, then furnace oil is used as a fuel in the scrap pre-heating system. The running cost of scrap pre-heating using furnace oil vis-à-vis electricity is calculated making the viability of this system dependent on the electricity tariff.

7.3 Benefits of technology

Major benefits of using scrap pre-heating system are:

- Reduction or removal of moisture content in scrap
- Possibility of energy cost savings
- Productivity improvement by reduction in heat/cycle time of induction furnace

Scrap pre-heating arrangement
Source: https://www.foundryprojects.com/foundry-equipment-products/scrap-drying-preheating

7.4 Limitations of technology

Availability of waste heat or cheaper alternative option for pre-heating in the plant.

7.5 Investment required, energy and GHG saving potential, and cost-benefit analysis

To understand the cost-benefit analysis, let us consider an induction furnace of 10-tonne melting capacity. The cost-benefit analysis for installation of scrap pre-heating management system is tabulated below.

Sl no.	Parameters	Value
1	Scrap quantity used in charge mix per heat	90%
2	Scrap quantity used in charge mix per heat	8645 kg/heat
3	Average electricity consumption per heat	5870 kWh/heat
4	Average production per heat	9.1 t/heat
5	Average heal time	2 hours

Sl no.	Parameters	Value
6	Average number of heats in a day	10
7	SEC of induction furnace (present)	645 kWh/t
8	Weight of scrap to be pre-heated	8645 kg/heat
9	Pre-heating temperature of the scrap	450 °C
10	Raw material temperature	40 °C
11	Fuel to be used in scrap pre-heater	Furnace oil
15	Equivalent quantity of FO required	47.90 litres
16	Cost of furnace oil	INR 40/litre
17	Electricity charges	INR 7/kWh
18	Cost of furnace oil in pre-heating per heat	INR 1916/heat
19	Electricity consumption in blower of pre-heater	16.6 kWh/heat
20	Cost of electricity in pre-heating of scrapper heat	INR 116.20/heat
21	Total running cost in scrap pre-heating using FO-based pre-heater	INR 2032/heat
23	Electricity required	612.5 kWh/heat
24	Annual electricity consumption	INR 4287.3/heat
25	Saving	INR 2254.9/heat
26	Annual monetary savings	INR 67.6 lakh/y
27	Investment required (installing scrap pre-heating)	INR 30 lakh
28	Simple payback period	5.3 months
29	Annual energy saving potential	23.7 toe/y
30	Annual GHG emission reduction potential	300.7 tCO_2/y

7.6 Technology summary

The impacts for the technology of scrap pre-heating are summarized below.

- Annual energy saving : 15–30 toe/y
- Annual GHG emission reductions : 250–400 tCO_2/y
- Annual monetary saving : INR 50–70 lakh/y
- Investment : INR20–35 lakh
- Payback period : 5–10 months

Tech 8: Ladle Pre-heating

8.1 Baseline scenario

Induction furnaces are used to melt metal in many foundry and steel industries. In metallurgy, a ladle is a vessel used to transport and pour out molten metals. Ladles range in size from small hand-carried vessels that resemble a kitchen ladle and hold 20 kg (44 lb) to large steel mill ladles that hold up to 300 tonnes (330 tons). Many non-ferrous foundries also use ceramic crucibles for transporting and pouring molten metal and will also refer to these as ladles. Ladle forms an important media to transfer energy.

Ladles are pre-heated slowly to remove the moisture from its lining and also to ensure that no cracks are developed. Ladle pre-heating is also necessary to withstand the temperature of the molten metal. Conventionally, ladles are dried using wood, coal, plastics, waste materials, etc. Furthermore, the ladles are pre-heated using light diesel oil using crude method leading to lots of energy loss.

The partially heated ladle is filled with molten metal after tapping. This results in heating up of the lining of the ladle. This lowers the temperature of the molten metal. Therefore, the tapping temperature needs to be increased to get the required temperature at the time of pouring the metal into ingot molds or CCM. Due to this, the cycle time is increased resulting in more electricity consumption per tonne of production.

8.2 Energy efficient technology

The inefficiency in the conventional system can be reduced by using an energy-efficient (EE) ladle pre-heater. An EE ladle pre-heater is equipped with a complete lid cover, EE high velocity burners, air-fuel ration controller, and an inbuilt recuperator. The height of the lid is adjusted using a motorized or hydraulically operated system. Once the ladle is placed, the swinging lid and height of lid are adjusted to completely cover the ladle. The lid is properly insulated to avoid any heat loss. The burner has an auto ignition system and an on-off control system, which is controlled by a PIC controller. The drying and pre-heating of the ladle is programmed based on requirement. The air-fuel ratio is automated to ensure optimized fuel consumption.

The burner is dual-fuel type and suitable for liquid and gaseous fuels. Several interlocks are provided to ensure quality and safety of the ladle pre-heating process. This EE ladle pre-heating ensures quick pre-heating up to 10,000 °C instantly.

A ladle pre-heater allows maintaining the bottom temperature of the ladle slightly higher than the top. The ladle is kept below the pre-heater by the overhead crane or forklift. Then, the lid is placed on top of the ladle and the burner is lit with the help of natural gas. A high velocity flame makes sure there are no cold zones in the ladle.

The process takes about 15–20 minutes just before the tapping process.

Ladle preheating system

Source: https://acetarc.co.uk/ladle-pre-heaters/

8.3 Benefits of technology

The advantages of ladle pre-heating are as listed below.

- Reduction in cycle time
- Better lining life of ladle
- Reduction in heat losses during transferring of ladle
- Better solidification of metal during pouring and casting

All these help reduce the tapping temperature by 15–20 °C in the furnace.

8.4 Limitations of technology

It is important to place the ladle pre-heater close to the induction furnace to reduce the time of transfer.

8.5 Investment required, energy and GHG saving potential, and cost-benefit analysis

To understand the cost-benefit analysis, let us consider an induction furnace of 10-tonne melting capacity. The cost-benefit analysis for installation of ladle preheating system is tabulated below.

Sl no.	Parameters	Value
1	Tapping temperature	1645 °C
2	Temperature at pouring	1620 °C
3	Temperature of ladle before tapping	800 °C
4	Ladle pre-heat by using burner	1100 °C
5	Temperature gains due to pre-heating of ladle	300 °C
6	Average production per heat	9.1 t/heat
7	Average number of heats in a day	10
8	Average heat time	2 hours
9	Average electricity consumption per heat	5870 kWh/heat
10	SEC of induction furnace (present)	645 kWh/t
11	Due to pre-heating of ladle, tapping temperature reduced by	20 °C
12	Due to pre-heating of ladle tapping temperature	1625 °C
13	Reduction in cycle time due to ladle pre-heating	2.5 min
14	Reduction in cycle time	2.08%
15	New cycle time after ladle pre-heating	1.96 hours
16	New average electricity consumption per heat	5747 kWh/heat
17	New SEC of induction furnace	632 kWh/t
18	Electricity saving potential	2.08%
19	Electricity saving potential	1223 kWh/d
20	Number of operating days in a year	300
21	Electricity saving potential	3,66,844 kWh/y
22	Electricity charges	INR 7/kWh
23	Annual monetary saving	INR 25.68 lakh/y
24	Investment required (burner installation with cover)	INR 12 lakh
25	Quantity of diesel consumption	6 litres/heat
26	Quantity of diesel consumption	60 litres/day

Sl no.	Parameters	Value
27	Quantity of diesel consumption	18,000 litres/y
28	Cost of diesel	INR 95/litre
29	Annual expenses of diesel consumption	INR 17.1 lakh/y
30	Electricity consumption of blower in pre-heating ladle	2 kWh/heat
31	Electricity consumption of blower in pre-heating ladle	6000 kWh/y
32	Expense of electricity in blower	INR 0.42 lakh/y
33	Annual expense in pre-heating of ladle	INR 17.5 lakh/y
34	Net annual monetary savings	INR 8.16 lakh/y
35	Simple payback period	18 months
36	Savings per year	16 toe/y
37	GHG reduction potential	209 tCO_2/y

8.6 Technology summary

The impacts of installing a ladle preheating technology are summarized below.

- Annual energy saving : 10–20 toe/y
- Annual GHG emission reductions : 150–250 tCO_2/y
- Annual monetary saving : INR 5–15 lakh/y
- Investment : INR 8–15 lakh
- Payback period : 15–25 months

Tech 9: Avoid Super-heating of the Metals

9.1 Baseline scenario

The majority of the units use super heating of the metal/melt to ensure the optimum temperature at CCM considering the travel time. When CCM is engaged, super heating is conducted considering the waiting and travel time. The operator working on the furnace may not be confident about the temperature shown by the transducer, so the operator keeps providing extra heat to the melt till the CCM is ready to take up the melt for billet making.

Ladles are pre-heated slowly to remove the moisture from its lining and also to ensure that no cracks are developed. Ladle pre-heating is also necessary to withstand the temperature of the molten metal. Conventionally, ladles are dried using wood, coal, plastics, waste materials, etc. Furthermore, the ladles are pre-heated using light diesel oil using crude methods leading to energy loss.

The partially heated ladle is filled with molten metal after tapping. This results in heating up of the lining of the ladle. This lowers the temperature of the molten metal. Therefore, the tapping temperature needs to be increased to get the required temperature at the time of pouring the metal into ingot molds or CCM. Due to this, the cycle time is increased resulting in more electricity consumption per tonne of production.

9.2 Energy efficient technology

There is no technology involved here, but it is all about the operating practice. The operating practice needs to be checked to avoid superheating of the metal/melt. The operator working on the induction furnace needs to be trained, so that he/she effectively utilizes the power for melting the metal.

9.3 Benefits of technology

The advantages of avoiding superheating of the metals are as follows:

- Reduction in heat losses due to overheating
- Lower specific energy consumption

9.4 Limitations of technology

A skilled operator is required for the operation. Also, the installation of an online temperature measurement system is a must.

9.5 Investment required, Energy and GHG saving potential, and Cost-benefit Analysis

To understand the cost-benefit analysis, let us consider an induction furnace unit of 10-tonne capacity.

Sl no.	Parameters	Value
1	Tapping time	5 min
2	Average power input at the time of tapping	2500 kW
3	Average electricity consumption per heat	5870 kWh/heat
4	Average production per heat	9.1 t/heat
5	Average heat time	2 hours
6	Average number of heats in a day	10
7	SEC of induction furnace (present)	645 kWh/t
8	Power consumption in superheating	127.4 kWh/heat
9	New average electricity consumption per heat	5742 kWh/heat
10	New SEC of induction furnace	631 kWh/t
11	Electricity saving potential	2.17%
12	Electricity saving potential	1274 kWh/d
13	Number of operating days in a year	300
14	Electricity saving potential	3,82,104 kWh/y
15	Electricity charges	INR 7/kWh
16	Annual monetary saving	INR 27 lakh/y
17	Price to avoid superheating	Nil
18	Simple payback period	Immediate
19	Annual energy saving potential	33 toe/y
20	Annual GHG emission reduction potential	271 tCO_2/y

9.6 Technology summary

The impacts for avoid superheating of material for a typical 10-tonne induction furnace are as listed below.

- Annual energy saving : 25–40 toe/y
- Annual GHG emission reductions : 250–350 tCO_2/y
- Annual monetary saving : INR 25–40 lakh/y
- Investment : Nil
- Payback period : Immediate

Tech 10: Avoiding Overfilling (Metal Above the Coil Level) of Furnace During Melting

10.1 Baseline scenario

Most of the units overfill the furnace above the coil height, to get increased production. Overfilling the feed above the coil height has its own disadvantages. The heat transfer mechanism takes place from coil to melt via conduction till the coil height. Above the coil height, heat transfer is from melt to melt (or metal to metal) instead of coil to metal. It takes some extra time for the heat and affects the SEC of the furnace. Improper filling and melting also leads to voids in the furnace.

10.2 Energy efficient technology

This is an operating practice that needs to be checked to avoid overfilling of the furnace during melting. The operator working on the induction furnace needs to be trained, so that he or she fills the furnace up to the desired coil height for effective and faster heat transfer. Although overfilling is associated with extra production, extra production can also be achieved if the furnace is filled to the desired coil height. It will result in reduced heat time, thus allowing more heat per day to ultimately result in more production. Apart from more production, it will also reduce the SEC of the operation as compared to the SEC during the overfilling.

10.3 Benefits of technology

The benefits of the technology are as follows.

- Reduction in energy consumption
- Better lining life of ladle
- Safer working environment

10.4 Limitations of technology

There is no limitation for adoption of this practice.

10.5 Investment required, Energy and GHG saving potential, and Cost- Benefit Analysis

To understand the cost-benefit analysis, let us consider an induction furnace unit of 10-tonne capacity.

Sl no.	Parameters	Value
1	Average production per heat	9.1 t/heat
2	Average heat time	2 hours
3	Average number of heats in a day	10
4	SEC of induction furnace (present)	645 kWh/t
5	New SEC of induction furnace (by maintaining charge till coil height)	632.1 kWh/t
6	Electricity saving potential	2%
7	Electricity saving potential	1173.9 kWh/d
8	Number of operating days in a year	300
9	Electricity saving potential	352,170 kWh/y
10	Electricity charges	INR 7/kWh
11	Annual monetary saving	INR 24.7 lakh/y
12	Annual energy saving potential	30 toe/y
13	Annual GHG emission reduction potential	250.04 tCO_2/y

10.6 Technology summary

The impacts of avoiding overfilling of metal above coil level during melting for a typical 10-tonne induction furnace are summarized below.

- Annual energy saving : 20–40 toe/y
- Annual GHG emission reductions : 200–300 tCO_2/y
- Annual monetary saving : INR 15–30 lakh/y
- Investment : Nil
- Payback period : Immediate

Tech 11: Lid Mechanism in Induction Furnace Melting

11.1 Baseline scenario

Induction furnaces are mainly of two types, i.e., coreless furnace and channel furnace.

A coreless furnace, as the name suggests, has a highly conducting copper tube wound in the form of a helical coil. The coil is water-cooled and circulated, the water being recirculated and cooled in a cooling tower. It should be ensured that the lid fits properly and one should look out for maintenance issues. Regular maintenance must be done to ensure correct lid fit, therefore, it will save energy that can be used otherwise. Radiation losses rise exponentially with the metal temperature. For example,a 10% increase in molten metal temperature results in 33% increase in radiation losses; hence the installation of a lid mechanism would lead to a genuine decrease in power costs.

11.2 Energy efficient technology

If one tonne of iron is heated to 1500 °C, the electrical energy required is 396 kWh. Losses in an induction furnace include thermal furnace losses, transmission losses, radiation losses, etc. The furnace efficiency accounts to 65%–70%. 100–130 kWh of energy is lost in such losses. Installation of a lid mechanism alone saves energy up to 25 kWh per ton that accounts to 4%–6% of energy input.

11.3 Benefits of technology

The benefits of the technology are as follows.

- Saves radiation losses, improves furnace efficiency by 6%
- Promotes operational safety

11.4 Limitations of technology

There is no limitation for adoption of this practice other than one-time capital investment.

Induction furnace lid mechanism

Source: https://www.electrotherment.com/foundry-furnace-equipment/special-features/special-features

11.5 Investment required, Energy and GHG saving potential, and Cost- Benefit Analysis

To understand the technology benefits, let us consider an electric induction furnace of 10-tonne capacity.

Sl no.	Parameters	Value	
1	Temperature of the opening	1500 °C	465 °C
2	Ambient temperature	33.6 °C	35.2 °C
3	Total heat loss per heat	24.45 kWh/heat	11.16 kWh/heat
4	Saving potential per heat	13.29 kWh/heat	
5	Total heats per day	10	
6	Operational days in a year	300	
7	Annual saving potential	39,870 kWh/y	
8	Annual monetary savings in a year	INR 2.8	

Sl no.	Parameters	Value
9	Investment required	INR 4 lakh
10	Simple payback	17.2 months
11	Annual energy saving potential	3.4 toe/y
12	Annual GHG emission reduction potential	28.3 tCO_2/y

11.6 Technology summary

The technology impacts for lid mechanism for a typical 10-tonne induction furnace is summarized below.

- Annual energy saving : 2.5–4.0 toe/y
- Annual GHG emission reductions : 20–35 tCO_2/y
- Annual monetary saving : INR 2–4 lakh/y
- Investment : INR 3.5–5.0 lakh
- Payback period : 15–28 months

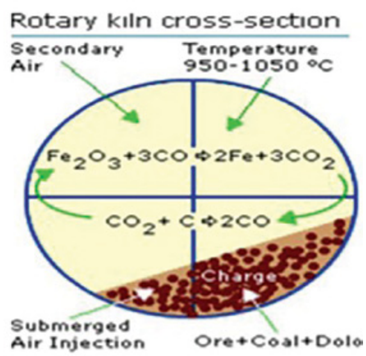
SECTION 3:
Direct Reduced Iron

Direct Reduced Iron (DRI): A Process Overview

The process of sponge iron (SI) manufacturing involves removal of oxygen from iron ore. Also called as direct reduced iron (DRI), SI is produced from direct reduction of iron ore (in the form of lumps, pellets, or fines) by a reducing gas using fuel, i.e., natural gas or coal. The reducing gas is a mixture of carbon monoxide (CO) and hydrogen (CO is more and hydrogen is less), which acts as a reducing agent. In this process, coal is used for producing reducer gas and the process is carried out in a horizontal rotary kiln. The finished product, i.e., SI observed under a microscope, resembles a honeycomb structure, which looks spongy in texture; hence, the name SI. The reduction of iron ore can be achieved by using either carbon-bearing material, such as coal or a suitable reducing gas in the form of reformed natural gas. The processes employing coal are known as solid-reductant or coal-based processes while those employing reducing gases are known as gas-based processes. Generally, non-coking coal is used in kiln-based DRI process and coking coal for more efficient coke oven—Blast Furnace (BF) – Basic Oxygen Furnace (BOF) route steelmaking process.

The basic reactions in this process are as follows:

$$C + O_2 = CO_2$$
$$CO_2 + C = 2CO$$
$$Fe_2O_3 + CO = Fe_3O_4 + CO_2$$
$$Fe_3O_4 + CO = FeO + CO_2$$
$$FeO + CO = Fe + CO_2$$



The majority of the DRI units in India are coal-based. In a coal-based DRI unit, non-coking coal and iron ore, along with limestone or dolomite, in the required size range and quantity are continuously fed into the feed-end of an inclined rotary kiln through a feed pipe. The materials move along the length of the kiln due to its inclination and rotation. Air is blown in through the required number of air tubes suitably located along the length of the kiln. At the feed-end of the kiln, air is blown in through nozzles for drying and pre-heating of the charge. Initial heating of the kiln is carried through a central oil burner located at the discharge end. As the charge moves through the kiln, it is heated by the hot gases, which flow in the opposite direction to the charge (i.e., counter-current flow). The initial part of the kiln (about 30%) is called the pre-heating zone, where the volatiles in the coal burns and liberates heat for pre-heating and removal of moisture present in the raw materials. The remaining portion of the kiln is called the reduction zone. In this zone, oxygen in the iron ore is removed leaving metallic iron as per the following chemical reaction:

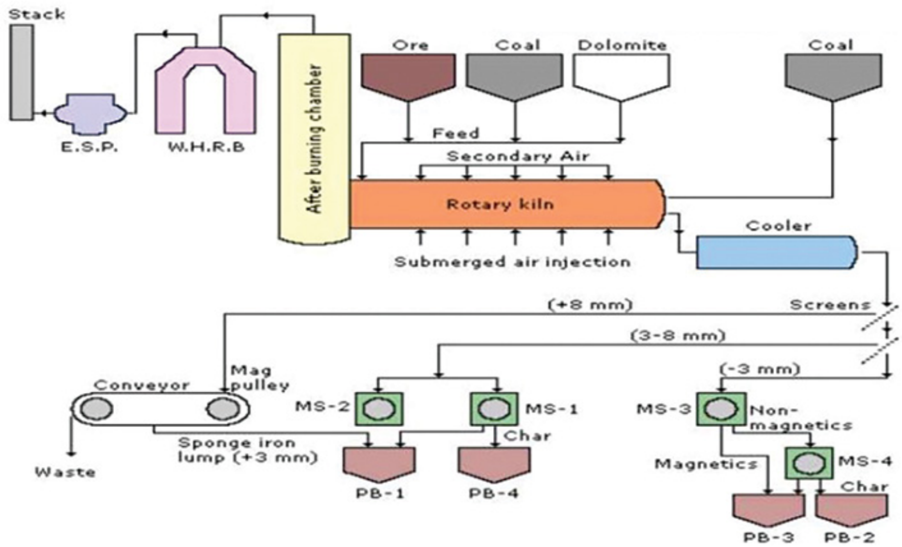
$$3\,Fe_2O_3 + CO \text{ -------------------> } 2\,Fe_3O_4 + CO_2$$

$$Fe_3O_4 + CO \text{ -------------------> } 3\,FeO + CO_2$$

$$FeO + CO \text{ -------------------> } Fe + CO_2$$

Fe_2O_3 is magnetite and is a combination of FeO and Fe_3O_4 with a weak bond. Carbon monoxide (CO) is generated for the above reaction according to $CO_2 + C > 2\ CO$, at temperature above 900 °C, carbon monoxide (CO) will combine with the oxygen in the iron ore forming carbon dioxide and thus reduce the ore to metallic state.

Higher the temperature, the faster would be the oxygen removal. There is a limiting temperature and iron oxide is not allowed to soften. If it softens, accretion occurs, which leads to disruption in production. With the removal of oxygen, there will be metallization of SI. Metallization levels can roughly be checked by measuring the density of SI. It can also be judged by the metallic luster if a sample is rubbed against a rough surface.



Process flow diagram for coal-based sponge iron

Source: https://www.semanticscholar.org/paper/REOXIDATION-OF-SPONGE-IRON-IS-AN-EXOTHERMIC-PROCESS-Sharma-Rajput/368a6caf5d-f54c9bf754454879c83b22c19bb9f2

The overall process extends to a period of five to nine hours, depending upon the length of the kiln. During this time, iron ore is optimally reduced and the hot-reduced SI along with semi-burnt coal is discharged to a rotary cooler for indirect cooling by water spray to a temperature of about 120 °C. SI being magnetic in nature, the discharge from cooler consisting of SI, chars, and other impurities, if any, are routed through magnetic separators, which are installed to preserve its quality, reduce re- oxidation, and facilitate faster loading onto the trucks.

Tech 1: Waste Heat Recovery Boiler-based Power Plant

1.1 Baseline scenario

In a coal-based direct reduced iron (DRI) plant, the raw materials (iron ore and coal) are fed into the rotary kiln from the feed end. As the material travels towards the discharge end of the kiln, the gases generated travel in the counter-current direction. The temperature of the kiln waste gases would be between 850 °C and 900 °C. At times it may go up to 950 °C.

These gases first enter into the Dust Settling Chamber (DSC) where heavier particles of dust settle down. From the DSC, the gases pass to the After Burning Chamber (ABC), where CO, if any present, is burnt to CO_2 with the supply of external air by a blower. Then these gases are cooled below 200 °C to enable the Electrostatic Precipitator (ESP) to handle the gases.

In normal conditions, these gases are cooled with the help of a wet scrubber/gas-conditioning tower/forced-draught (FD) cooler. Nowadays, most plants are provided with (FD) coolers only as it works with natural air while the other two require water. Cooling of gases is essential to enable the ESP to handle the removal of laden dust. Extra energy is required for operating the FD cooler for cooling the gases.

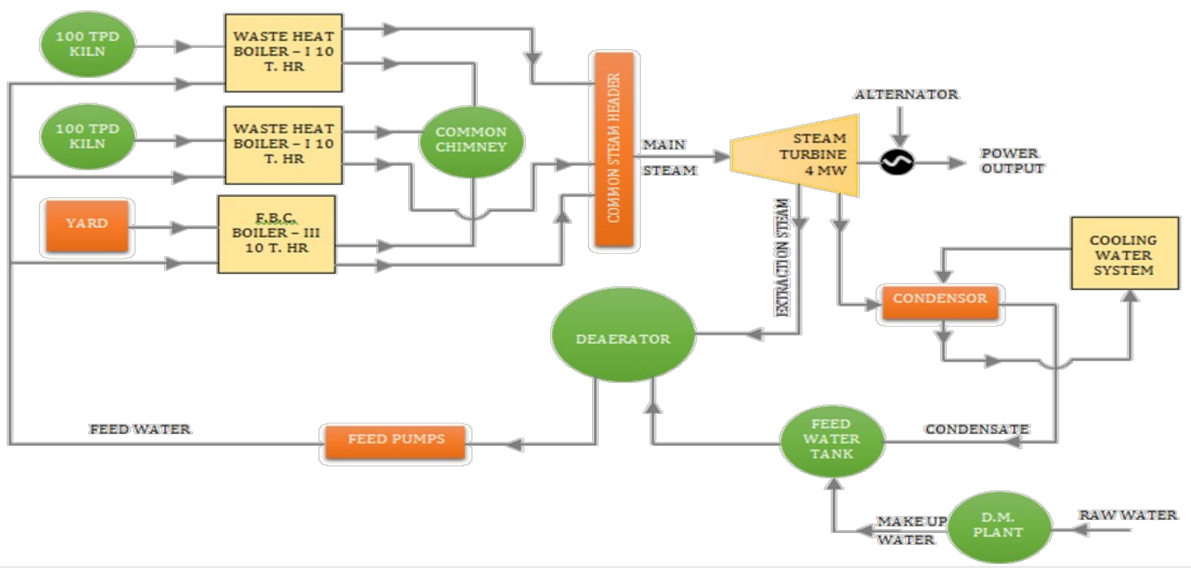
The clean gases are let out to the atmosphere through a chimney with the help of an induced draught (ID) fan. One of the most popular options to utilize sensible heat carried away by the waste gases is to establish a Waste Heat Recovery Boiler (WHRB)-based power plant through which maximum recovery of the thermal energy is possible.

1.2 Energy efficient technology

About 6000 Nm^3 of waste gases are generated per tonne of sponge iron (SI) produced. For example, in a 100-tpd SI plant, about 25,000 Nm^3/h of gases are generated. It is estimated that with this quantity of gases at 900 °C about 8–10 tph of steam at 66 kg/cm^2 and 490 °C could be produced. With 2 × 100 tpd kilns, 3.5–4.0 MW of power could be generated.

For the recovery of thermal energy, each kiln is to be provided with one 10-tph capacity WHRB. To meet the requirement of steam during the shutdown of any one of the two SI units for accretion removal, an FBC boiler of 10 tph is also provided. As the gases are automatically cooled down to below 200 °C, they are passed directly through ESP. The boiler system will eliminate/bypass the FD cooler.

A typical configuration based on 2 × 100 tpd DRI plant for a WHRB-based power plant with two waste heat boilers of 10 tph each and a char-based fluidized bed boiler (FBC) is depicted in the figure below.



Configuration for a 4-MW WHRB-based power plant

Technical specifications of a WHRB-based power plant

Sl no.	Parameter	Value
1	Steam pressure	66 kg/cm^2
2	Steam temperature	490 °C
3	Steam flow	18 tph
4	Flue gas temperature	950 °C
5	Installed capacity of sponge iron plant	2 ×100 tpd
6	Flue gas flow	48,000 Nm^3/h
7	Flue gas outlet temperature	180 °C
8	Feed water temperature inlet to economizer	126 °C
9	Cooling water temperature	40 °C

Type of boiler: Four pass, horizontal, water tube, natural circulation, single drum boiler

Snapshot of DRI plant with WHRB

Source: https://www.thermaxglobal.com/boilers-heaters/waste-heat-recovery-boilers/whrb-for-sponge-iron-plant/

1.3 Benefits of technology

The installation of WHRB-based power plant in a DRI Unit leads to the following benefits:

- Utilization of waste flue gases for in-house power generation
- Reduction in overall plant specific energy consumption

1.4 Limitations of technology

Installation of a WHRB -based power plant in DRI unit has high initial investment. Also, a WHRB-based power plant requires adequate water and the power generated cannot be stored, it should be either utilized internally or exported.

1.5 Investment required, energy and GHG saving potential, and cost-benefit analysis

To understand the cost-benefit analysis, let us consider a 2 ×100 tpd DRI plant generating 4 MW power. The cost-benefit analysis for a WHRB -based power plant in a DRI unit is tabulated below.

Sl no.	Parameter	Without power plant	With power plant
1	Rotary kiln capacity	100 t/d	100 t/d
2	Number of kilns in the plant	2	2
3	Total installed capacity	200 t/d	200 t/d
4	Iron ore consumption (considering consumption in two kilns)	11.3 t	11.3 t
5	Iron ore consumption (considering consumption in two kilns)	271.2 t/d	271.2 t/d

Sl no.	Parameter	Without power plant	With power plant
6	Coal calorific value	5600 kcal/kg	5600 kcal/kg
7	Lump coal consumption (considering consumption in two kilns)	3.44 t/h	3.44 t/h
8	Fine coal consumption (considering consumption in two kilns)	3.6 t/h	3.6 t/h
9	Total coal consumption (considering consumption in two kilns)	7.04 t/h	7.04 t/h
10	Total coal consumption (considering consumption in two kilns)	169 t/d	169 t/d
11	Dolomite consumption (considering consumption in two kiln)	1 t/h	1 t/h
12	Flue gas generated by kiln	23,865 Nm^3/h	23,865 Nm^3/h
13	Total flue gas generated at installed capacity (2×100 tpd)	47,730 Nm^3/h	47,730 Nm^3/h
14	Density of flue gas	1.3 kg/m^3	1.3 kg/m^3
15	Actual gas flow	62,049 kg/h	62,049 kg/h
16	Flue gas temperature at outlet of kiln	950 °C	950 °C
17	Enthalpy of flue gas at kiln outlet @ 950 °C	261.92 kcal/kg	261.92 kcal/kg
18	Enthalpy of gas at boiler outlet @ 170 °C	39.15 kcal/kg	
19	Flue gas temperature at inlet of ESP	170 °C	
20	Heat value available in flue gas	13,822,656 kcal/h	
21	Radiation heat loss (1%)	138,227 kcal/h	
22	Blow down loss (2%)	276,453 kcal/h	
23	Actual heat available after loss	13,407,976 kcal/h	
24	Steam enthalpy or total heat at 66 kg/cm^2, 490 °C	800 kcal/kg	
25	Feed water temperature	126 °C	
26	Enthalpy of feed water	127 kcal/kg	
27	Generated steam @66 kg/cm^2, 490 °C	19,923 kg/h	
28	Power generation by generated steam	4 MW	
29	Power generation	96,000 kWh/d	
30	Auxiliary power consumption	9,600 kWh/d	
31	Captive power consumption	22,000 kWh/d	
32	Power available for grid	19,320,000 kWh/y	
33	Power export cost	INR 2.8/kWh	
34	Annual income from exported power	INR 541 lakh/year	
35	Annual monetary saving due to captive power use	INR 462 lakh/year	
36	Total monetary gain	INR 1003 lakh/year	
37	Investment required	INR 2900 lakh	
38	Payback period	35 months	
39	Annual energy saving potential	2476 toe/y	
40	Annual GHG emission reduction potential	20,448 tCO_2/y	

1.6 Technology summary

The technology impacts of a WHRB -based power plant are summarized below.

- Annual energy saving : 2000–2800 toe/y
- Annual GHG emission reductions : 17,000–25,000 tCO_2/y
- Annual monetary saving : INR 750–1350 lakh/y
- Investment : INR 2600–3500 lakh
- Payback period : 33–40 months

Tech 2: Pre-heating Kiln for Iron Ore Pre-heating

2.1 Baseline scenario

In the conventional coal-based DRI plant, raw materials in the form of iron ore, coal, and dolomite are separately fed directly into the rotary kiln using separate hoppers. During the process, the volatile matter present in the coal burns and liberates thermal energy to pre-heat the iron ore and carbon bearing material. This happens in the initial one-third length of the kiln. By the time the mixture reaches one-third the length of the kiln, it attains a temperature of 900 °C to support 'Boudouard' reaction. Thereafter, the stage-wise reduction of iron ore to metallic iron begins. The process of reduction continues and is completed till the time iron ore travels to the discharge end of the kiln. While the material travels in downward direction by gravity due to inclination of the kiln and its continuous rotation, the gases generated travel in the counter-current direction to the material flow. These gases after leaving the kiln first enter the DSCs where all heavier particles of dust settle down. Next, the gases enter the ABC. In the ABC, carbon-monoxide (CO) present in the gas, if any, is burnt to carbon dioxide (CO_2) with the help of some extra air supplied by a combustion air fan. This reaction further increases the temperature and volume of the gases. About 6000 Nm^3 of gases in between 850–950 °C is generated per tonne of SI produced.

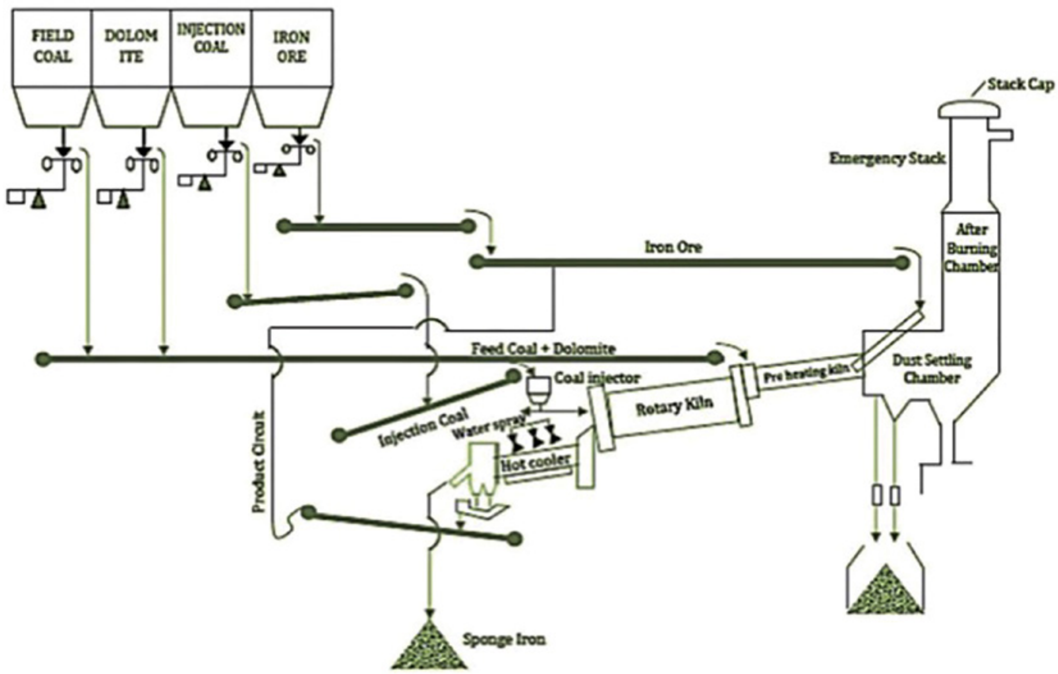
Under conventional practice, these gases are cooled down to a temperature below 200 °C with the help of an FD cooler and later passed through an ESP for complete elimination of dust particles before letting it out through the chimney. In the process, not only a considerable amount of sensible heat is wasted but also extra energy is being used for the cooling of gases.

The total thermal energy input for a rotary kiln is about 22.5 GJ per tonne of SI produced, out of which, about 8–9 GJ of energy is carried out by the kiln off gases. This thermal energy available in the waste gas can be re-utilized by any one of the following options:

- Utilize waste heat using a WHR-based boiler to form steam, which can be used to generate electric power
- Utilize the waste heat for pre-heating of iron ore in a separate rotary kiln
- In the case of plants with two or more kilns, provisions for both WHR-based power plant and pre-heating kiln can be made.

2.2 Energy efficient technology

The waste heat contained in the kiln's off gases can be re-utilized by introducing a pre-heating kiln where the thermal energy can be used to pre-heat the iron ore before feeding it into the rotary kiln. While iron ore is processed through the pre-heating kiln, coal and dolomite are directly fed to the main kiln, as usual. The process flow diagram of the pre-heating kiln is shown in the figure below.



Process flow for pre-heating kiln technology

In this system, a separate rotary kiln is introduced prior to the feed end of the main kiln. Iron ore is fed into the pre-heating kiln instead of the main kiln. As the iron ore travels from the feed end of the pre-heating kiln towards the discharge end of the kiln, the gases from the main kiln pass in a counter-flow direction through the pre-heating kiln. The sensible heat in the gases is transferred to iron ore in the pre-heating kiln. By the time iron ore leaves the pre-heating kiln, the temperature from ambient rises to above 650 °C before entering into the main kiln. In the normal plant without pre-heating kiln, the first one-third length of the kiln is used for heating the raw materials. By introducing the pre-heating kiln, the iron ore is heated to about 650 °C, before it enters into the main kiln. Hence, almost the entire length of the main kiln is available for the reduction of iron ore.

2.3 Benefits of technology

The installation of the pre-heating kiln will lead to some advantages as listed below.

- **Consistency in the product quality:** Iron ore enters into the main kiln at about 650 °C and attains 900 °C within a shorter time in a pre-heating-based kiln compared to a normal kiln. This helps to start the reduction process early leading to a higher degree of metallization.

- **Saving in coal consumption:** Pre-heating of iron ore prior to charging to the main kiln leads to significant savings in coal consumption. The details have been provided later.
- **Increase in production:** As the heating process in the main kiln is reduced to a large extent, the entire kiln can be used for the reduction process, thus leading to an increase in production by 20%–30% more than the rated capacity.
- **Reduction in fixed cost:** In coal-based DRI plants, the fixed-cost component comprising interest on loans, depreciation, overheads, etc. comes to approximately Rs 2000/tonne of SI. Considering a 30% increase in production, the fixed cost would reduce by about Rs 400/tonne of SI.

2.4 Limitations of technology

The DRI process is sensitive to the pressure and temperature in the kiln. The operating conditions from the waste gas ID fan up to the cooler discharge point should be maintained consistently for ensuring consistency in the quality and quantity of the SI produced. Hence, any introduction of new equipment in between the system is to be made without affecting the basic operating conditions. With due considerations of the above, a pre-heating kiln needs to be introduced in the waste gas path in between the main kiln and the DSC. Even with a pre-heating kiln, the available entire thermal energy is not recoverable, only a part is recovered. Also, in case a WHRB-based power plant is to be added later, the lower waste gas temperature of 600–700 °C may be of disadvantage.

2.5 Investment required, energy and GHG saving potential, and cost-benefit analysis

The calculations have been provided considering a 100-tpd DRI plant. The cost-benefit analysis of a pre-heating kiln for iron ore pre-heating in a DRI unit is tabulated below.

Sl no.	Parameter	Without pre-heating kiln	With pre-heating kiln
1	Total iron ore fed into the rotary kiln per day	135.6 t/d	163.67 t/d
2	Total coal fed into the rotary kiln per day	85.92 t/d	88.15 t/d
3	Sponge iron (SI) produced per day	93.36 t/d	112.69 t/d
4	Specific coal consumption per tonne of SI produced	0.92 t/t	0.78 t/t
5	Specific iron ore consumption per tonne of SI produced	1.45 t/t	1.45 t/t
6	Yield of SI/tonne of iron	68.85%	68.85%
7	Percentage reduction in specific fuel consumption	15%	
8	Percentage increase in production	20.7%	
9	Annual coal savings by installation of pre-heating kiln	4667 t/y	

Sl no.	Parameter	Without pre-heating kiln	With pre-heating kiln
10	Annual production considering 20.7% production increase due to installation of pre-heating kiln	33,807 t/y	
11	Fixed cost to produce one tonne of SI in normal kiln	INR 2000/t	
12	Reduction in fixed cost due to increase in productivity	INR 343/t	
13	Annual monetary saving due to reduction in coal consumption (in lakh)	INR 233 lakh	
14	Annual monetary saving due to reduction of fixed cost	INR 116 lakh	
15	Amount spent towards operation & maintenance of preheating kiln annually	INR 15 lakh	
16	Total monetary saving per year	INR 334 lakh	
17	Investment required	INR 495 lakh	
18	Payback period	17.8 months	
19	Annual energy saving potential	2614 toe/y	
20	Annual GHG emission reduction potential	11,670 tCO_2/y	

2.6 Technology summary

The technology impacts of installing a pre-heating kiln for iron ore pre-heating are summarized below.

- Annual energy saving : 2200–3000 toe/y
- Annual GHG emission reductions : 8000–14000 tCO_2/y
- Annual monetary saving : INR 280–360 lakh/y
- Investment : INR 400–500 lakh
- Payback period : 15–24 months

Tech 3: Raw Material Pre-heating Using Fuel Economizer

3.1 Baseline scenario

In the conventional coal based DRI plant, raw materials in the form of iron ore, coal, and dolomite are separately fed directly into the rotary kiln using separate hoppers. During the process, the volatile matter present in the coal burns and liberates thermal energy to pre-heat the iron ore and carbon-bearing material. This happens in the first one-third length of the kiln. By the time the mixture reaches one-third the length of the kiln, it attains a temperature of 900 °C to support Boudouard reaction. Thereafter, stage-wise reduction of iron ore to metallic iron starts. The process of reduction continues and is completed by the time the iron ore travels to the discharge end of the kiln. While the material travels in downward direction by gravity due to inclination of the kiln and its continuous rotation, the gases generated travel in the counter-current direction to the material flow. These gases after leaving the kiln first enter the DSCs where all heavier particles of dust settle down. Next, the gases enter the ABC. In the ABC, carbon-monoxide (CO) present in the gas, if any, is burnt to carbon dioxide (CO_2) with the help of some extra air supplied by a combustion air fan. This reaction further increases the temperature and volume of the gases. About 6000 Nm^3 of gases in between 850–950 °C are generated per tonne of SI produced.

Under conventional practice, these gases are cooled down to a temperature below 200 °C with the help of a FD cooler and later passed through an ESP for complete elimination of the dust particles before letting it out through the chimney. In the process, not only a considerable amount of sensible heat is wasted but also extra energy is being used for cooling the gases.

The total thermal energy input for a rotary kiln is about 22.5 GJ per tonne of SI produced, out of which, about 8–9 GJ of energy is carried out by the kiln off gases. The main process of producing DRI can be split into three parts:

- Pre-heating the raw materials (iron ore and dolomite)
- Reducing the iron ore
- Cooling the DRI in a controlled process

The idea behind development of a fuel economizer is to carry out the pre-heating process outside the rotary kiln with the help of hot flue gases coming out of the rotary kiln to re-utilize it and not to disturb the operation of WHRB-based power generation.

3.2 Energy efficient technology

In this process, a fuel economizer is suggested to be installed parallel to ABC on top of the feed chute of SI kiln. The iron ore passes through the fuel economizer and enters into the kiln at a temperature of around 700 °C, whereas the mixture of coal and dolomite follows the conventional route. The hot gases, induced from ABC, blow into the iron ore chamber, resulting in the exchange of heat from the hot gases while passing through the fuel economizer raises the temperature of the iron ore before entering into the kiln. It is known that heat transfer is directly proportional to the surface area exposed to hot gases.

In this fuel economizer, the iron ore is continuously fed through an in-built mechanism and travels through multi-deck platforms cum conveyor and, in the process, progresses towards metallization. Heat transfer takes place due to surface area exposed to hot gases and through this heat transfer almost 85% efficiency is achieved. The pre-heated iron ore enters into the main reduction kiln at about 700 °C and reduction of this preheated iron ore literally starts from the second zone of the main reduction kiln instead of the fourth zone, as in case of conventional kiln. Hence, retention time of kiln feed decreases and as a result the output rate increases. This leads to higher production of SI. In order to avoid any reaction of iron oxide, the following are maintained:

- Coal is not added in fuel economizer
- Iron ore is not heated beyond 700 °C in the fuel economizer

The difference between the preheating kiln technology and the fuel economizer is that while the preheating kiln is a rotary kiln similar to the construction of the main kiln, the economizer is a stationary chamber installed parallel to the ABC chamber on the top of the feed chute of the SI kiln. While iron ore travels downward due to gravity inside the chamber, hot gases induced from ABC are blown into the iron ore chamber. While passing through the fuel economizer, the hot gases cause a rise in temperature of the iron ore before it enters the kiln.

3.3 Benefits of technology

The installation of the fuel economizer will lead to the following advantages:

- Increase the output of the existing kiln to the extent of 20% minimum.
- Reduces the coal consumption to the extent of 4.5% minimum.
- Reduces the power consumption per million tonne of SI produced in comparison to conventional SI kiln.
- Generation of (–) 3 mm fines in the product is less as slow heating has been avoided.
- Requires no additional space to be installed.

3.4 Limitations of technology

The DRI process is sensitive to pressure and temperature in the kiln. The operating conditions from the waste gas ID fan up to the cooler discharge point should be maintained consistently to ensure consistency in the quality and quantity of the SI produced. Hence, any introduction of new equipment in between the system is to be made without affecting the basic operating conditions.

3.5 Investment required, energy and GHG saving potential, and cost-benefit analysis

The calculations have been provided considering a 100-tpd DRI plant. The cost-benefit analysis for fuel economizer in a DRI unit is tabulated below.

Sl no.	Parameter	Without fuel economizer	With fuel economizer
1	Total iron ore fed into the rotary kiln per day	135 t/d	155 t/d
2	Total coal fed into the rotary kiln per day	85 t/d	93 t/d
3	Sponge iron (SI) produced per day	93 t/d	107 t/d
4	Specific coal consumption per tonne of SI produced	1 t/t	1 t/t
5	Specific iron ore consumption per tonne of SI produced	1 t/t	1 t/t
6	Yield of SI per tonne of iron	69%	69%
7	Reduction in specific fuel consumption	5%	
8	Increase in production	15%	
9	Annual coal savings by installation of fuel economizer	1489 t/y	
10	Annual production considering 15% production increase due to installation of pre-heating kiln	32,208 t/y	
11	Fixed cost to produce 1 tonne of SI in normal kiln	INR 2000/t	
12	Reduction in fixed cost due to increase in productivity	INR 261/t	
13	Annual monetary saving due to reduction in coal consumption (in lakh)	INR 74 lakh	
14	Annual monetary saving due to reduction of fixed cost	INR 84 lakh	
15	Amount spent towards operation and maintenance of fuel economizer annually	INR 15 lakh	
16	Total monetary saving per year	INR 143 lakh	
17	Investment required	INR 305 lakh	
18	Payback period	25 months	
19	Annual energy saving potential	834 toe/y	
20	Annual GHG emission reduction potential	3723 tCO_2/y	

3.6 Technology summary

The technology impacts for fuel economizer are summarized below.

- Annual energy saving : 700–1200 toe/y
- Annual GHG emission reductions : 3000–4500 tCO_2/y
- Annual monetary saving : INR 120–170 lakh/y
- Investment : INR 250–320 lakh
- Payback period : 20–30 months

Tech 4: Replacement of Coal Firing with Coal-based Producer Gas Firing for Heating of Charge

4.1 Baseline scenario

Most DRI units in India are coal-based. In a coal-based DRI unit, non-coking coal, and iron ore along with limestone or dolomite in the required size range and quantity are continuously fed into the feed end of an inclined rotary kiln through a feed pipe. The materials move along the length of the kiln due to its inclination and rotation. Air is blown in through the required number of air tubes suitably located along the length of the kiln. At the feed end of the kiln, air is blown in through nozzles for drying and pre-heating of the charge. Initial heating of the kiln is carried through a central oil burner located at the discharge feed end. As the charge moves through the kiln, it is heated by the hot gases, which flow in the opposite direction to the charge (i.e., counter-current flow). The initial part of the kiln (about 30%) is called the pre-heating zone, where moisture in the charge and volatiles in the coal are removed/burnt off as waste gases. The required heat in this zone is provided by the combustion of the feed coal. The remaining portion of the kiln is called the reduction zone.

Availability of good quality non-coking coal is scarce in the Indian market. Most units are importing coal from other countries. However, increasing the cost of the same is a challenge for the industry.

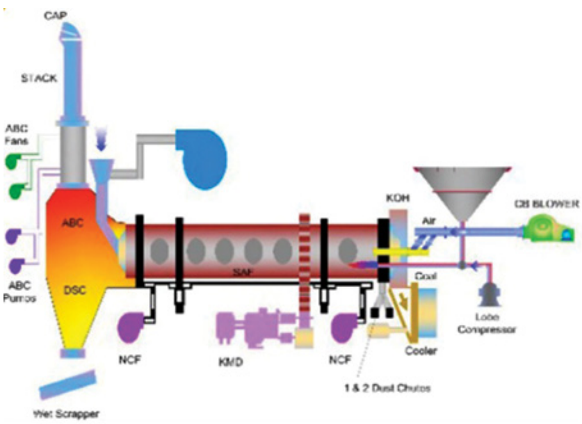
4.2 Energy efficient technology

The producer gas generated by the process of gasification is made useful in the rotary kiln as a partial replacement of coal within the kiln can be achieved. The gas is injected into the kiln from the outlet side of the central burner section. Figures show a conventional kiln with and without a gasifier.

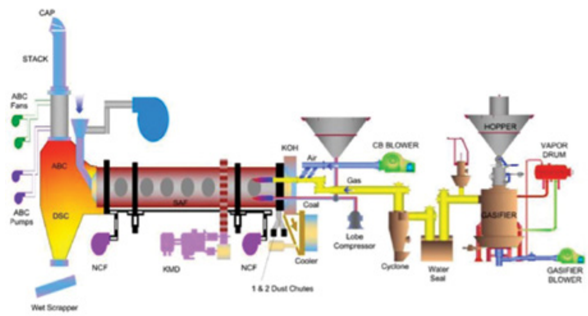
To effectively use producer gas instead of coal for heating purpose in a DRI kiln, the following should be ensured:

- **High gas temperature:** High gas temperature over 450 °C is to be maintained to ensure that the volatile matter of coal remains in gaseous form and burns along with the gas within the kiln as a fuel. This property of high temperature gas also ensures that there is no deposition of volatile matter inside the gas pipe line (gas transportation system).

- **High gas pressure:** High gas pressure makes sure that the required amount of gas is transported to the kiln at all times. The kiln itself has its own atmosphere of temperatures and pressure, so in order to make the coal gas sync with the kiln, high pressure gas is needed for effective gas injection.
- **Automation and instrumentation:** With the incorporation of high-leveled instrumentation and automation, the gasifier can run without any human interference. This makes operation errors minimal thus resulting in consistency and performance. Also, required safety norms should be maintained.



Conventional kiln without a gasifier



Conventional kiln with a gasifier

4.3 Benefits of technology

The installation of the coal-based producer gas plant for heating of charge will lead to the following advantages:

- Reduction in specific coal consumption by 7%–12%
- Increase in production by 5%–10%
- Extended campaign life by 10% due to reduction in formation of accretions
- Consistency in the quality of the gas unlike coal fines, which may fluctuate
- Increase in generation of steam by 10%
- Reduction in GHG emissions

Also, the gasifier is not required to be run continuously. If the kiln is under stoppage for any reason, the gasifier is also made to stop and during that period there is no gas generation and there is no by-pass of gas.

4.4 Limitations of technology

The producer gas plant is a separate entity, which requires additional maintenance.

4.5 Investment required, energy and GHG saving potential, and cost-benefit analysis

The calculations have been provided considering a 100-tpd DRI plant. The cost-benefit analysis for coal-based producer gas technology in a DRI unit is tabulated below.

Sl no.	Parameter	Without gasifier	With gasifier
1	Iron ore feed rate	7.7 t/h	8.09 t/h
2	Fe (Total) of iron ore	64%	64%
3	Coal feed rate	4.1 t/h	3.62 t/h
4	Coal feed from inlet (8–20 mm)	2.1 t/h	1.68 t/h
5	Fixed carbon of coal	53%	53%
6	Coal feed from injection	2 t/h	1.6 t/h
7	Coal used in gasifier	-	0.34 t/h
8	Fixed carbon in coal of gasifier	-	53%
9	C/Fe ratio	0.44	0.36
10	Yield	0.6	0.6
11	DRI produced	4.62 t/h	4.85 t/h
12	DRI produced	110 t/d	116 t/d
13	Specific consumption of coal per tonne of SI	0.89 t/t	0.75 t/t
14	Coal consumption per day	98.40 t/d	86.88 t/d
15	Savings on coal per day	11.52 t	
16	Price of coal	INR 5000/t	
17	Savings on coal	INR 57,600/d	
18	Production increase per day	5.6 t/d	
19	Profit margin on production	INR 2000/t	
20	Savings due to increase on production	INR 11,232/d	
21	Total savings per day	INR 68,832/d	
22	Annual monetary savings	INR 206 lakh	
23	Investment required	INR 135 lakh	
24	Payback	7.8 months	
25	Annual energy saving potential	1935 toe/y	
26	Annual GHG emission reduction potential	8640 tCO_2/y	

4.6 Technology summary

The technology impacts for coal-based gasifier plant are summarized below.

- Annual energy saving : 1600–2350 toe/y
- Annual GHG emission reductions : 7500–9480 tCO_2/y

- Annual monetary saving : INR 185–231 lakh/y
- Investment : INR 120–160 lakh
- Payback period : 7–12 months

Coal gasifier

Source: https://www.indiamart.com/proddetail/coal-gasifier-plant-in-ceramic-9658536630.html

Tech 5: Pelletization of Iron Ore

5.1 Baseline scenario

Iron ore forms the key raw material for the DRI plant, which is fed into the kiln along with coal and dolomite. In a DRI process, the iron ore is reduced to SI in the presence of coal and dolomite. Most industries in India use iron ore in lump form from the local mines. The quality of iron ore available is an issue that predominantly affects the quality of SI generated. Availability of good quality iron ore lumps is restricted to a few designated mines in the country. Also, feeding of lump iron ore leads to increased consumption of the raw material due to its relatively poor metal content.

Iron ore after mining is crushed to the required size for further processing in a blast furnace or in a DRI plant or in a submerged arc furnace. While crushing the iron ore, a considerable amount of fines is generated. Depending upon the size of the directly useful material, the balance quantity is termed as under size or fines. Large quantities of these fines are accumulated at the crushing plants. These fines are generally considered waste material.

5.2 Energy efficient technology

Pelletization is one of the agglomeration processes, employed for converting the fines, otherwise waste material, into pellets of spherical shape, which can be processed further, like its original material. Thus, the fines, which are available in large quantities at relatively cheaper price, can be utilized in the DRI plant after processing. These fines are better in quality compared to lump ore due to its richness in terms of quality. Depending upon the quality of the fines, it is generally decided whether these fines can go directly for pelletization or beneficiation is required before pelletization.

Pelletization is recommended for the following conditions:

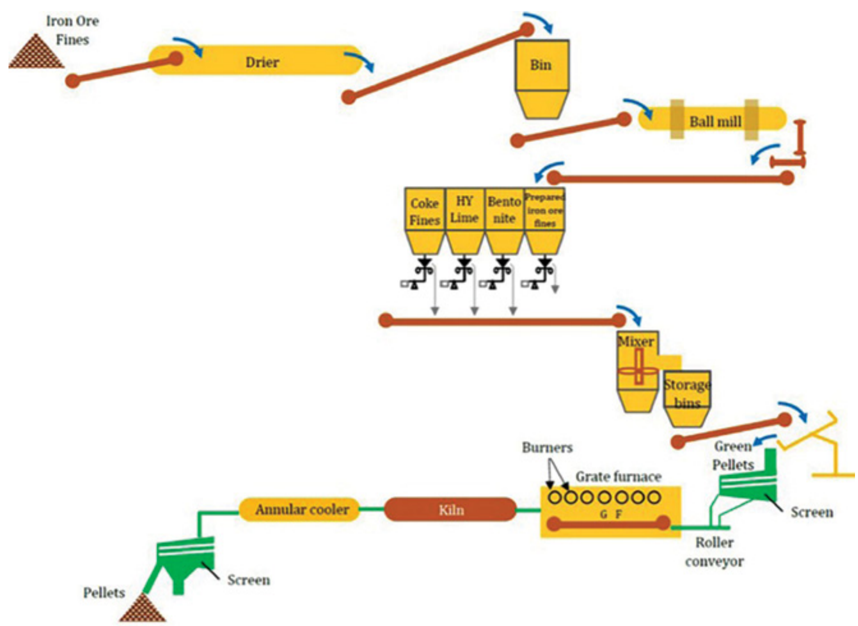
- After crushing of iron ore, fines are of good quality
- High-grade iron ores, which cannot be processed directly being soft in nature
- Low-grade iron ores, which are not suitable for direct processing

In the case of the last two conditions mentioned above, the iron ore fines are to be beneficiated to upgrade the Fe content before going for pelletization. The physical and chemical properties of the iron ore are to be taken into account for deciding the type of beneficiation to be adopted. Normally, one or both of the following methods are used for beneficiation:

- Washing or scrubbing
- Electric/magnetic concentration method

The iron ore fines are dried in a dryer for the removal of the moisture. The dried fines are passed through a ball mill to grind to a pre-determined size, which is normally (–) 200, mesh and stored in a bin. Hydrated lime and bentonite are used as additives. All these three materials are stored in separate stock bins. Sometimes coke fines are also to be added. Provision is to be created for the same. With the help of the dosing equipment, i.e., weight feeders, the required amount of these materials are drawn and conveyed to a mixer where the essential quantity of water is added. The moist mixed material is stored in a bin, from which through a screw feeder the mixed material is fed into a disc pelletizer for the formation of green pellets. The green pellets are screened (green ball screen) for the removal of the fines. Through a roller conveyor, the green pellets are passed into a travelling furnace and rotary kiln or a straight grate furnace. Here drying, pre-heating, firing, and cooling activities are performed to attain sintering and fusion of macro and micro particles in attaining the required hardness.

In this furnace with an oil burner the temperature is taken up to 1300 °C for heat endurance. As the grate travels from one end to the other end, heat endurance will be completed. Cooling of the pellets is carried out in an annular cooler. By this period the pellets are expected to attain 200–220 kg strength. The fired pellets are screened for the removal of any fines generated during the heat endurance process. The process flow diagram for iron ore Pelletization is shown below.



Process flow diagram of a pelletization plant

For optimum energy savings, it is proposed to install an online pelletization plant of lower capacity. Unlike the traditional pelletization plant, the online plants are of smaller capacity suitable for use in 100-tpd DRI plants and above. In this process, the iron ore pellets in hot conditions are directly transferred to the DRI kiln. The sensitive heat in the pellets is used in the DRI kiln, thus eliminating the requirement of additional coal for heating purposes. As the iron ore pellets are pre-heated during charging, one-third the length of the kiln can now be partly used for heating and partly for additional production. Thus, the process of having an online pelletization plant not only reduces specific fuel consumption in the kiln but also increases production by at least 10%–15%. These benefits of reduced fuel consumption and increased production are over and above the benefits of using pellets as a replacement to lumps.

A typical pelletization plant

Source: https://nhisales.com/ankit-0-6-mtpa-pellet-plant-project/

5.3 Benefits of technology

Use of pellets for SI production has multifold benefits compared to lumps. Some of the benefits are listed below.

- SI produced by use of pellets will be uniform in size unlike the use of lumps where the SI size varies from '0' to the maximum feed size.

- Generation of fines by use of pellets ranges from 0 to 5% whereas in the case of lumps, the same varies from 20% to 30% depending on the Tumble Index (TI).
- Fe (metallic), in the case of use of pellets, will be consistent as Fe (total), in the case of pellets, is high; whereas in the case of lumps, Fe (metallic) will fluctuate in line with the Fe (total) fed.
- In the case of pellets, due to higher Fe (metallic), the yield of steel per tonne of SI will be high compared to lumps where the Fe (metallic) is low and hence the yield of steel per tonne of SI is low.
- Specific consumption of pellets is around 1.40–1.45 tonnes per tonne of SI, which allows to feed a higher quantity of pellets resulting in an increase in the production by 20%– 25%. In the case of lumps, the specific consumption varies from 1.7 to 2.2 tonnes per tonne of SI, depending on the contaminants fed in the iron ore.

5.4 Limitations of technology

The cost of iron ore fines will go up with demand. Also, the market price of pellets may decrease with scalability. In such cases, using pellets instead of lumps will not be economically viable.

5.5 Investment required, energy and GHG saving potential, and cost-benefit analysis

The calculations have been provided considering a 100-tpd DRI plant. The cost-benefit analysis for a pelletization plant in a DRI unit is tabulated below.

Sl no.	Parameter	Use of lump iron ore	Use of pellets
1	Annual production of SI lumps	22,750 t/y	-
2	Annual production of SI pellets	-	34,200 t/y
3	Annual production of SI fines	7500 t/y	1800 t/y
4	Specific consumption of iron ore per tonne of SI (in case of lump feeding)	1.8 t/t	-
5	Specific consumption of coal per tonne of SI (in case of lump feeding)	1 t/t	-
6	Specific consumption of iron ore per tonne of SI (in case of pellets feeding)	-	1.4 t/t
7	Specific consumption of coal per tonne of SI (in case of pellets feeding)	-	0.85 t/t
8	Price of iron ore lumps	INR 4500/t	-
9	Price of coal	INR 5000/t	INR 5000/t
10	Price of iron ore pellets	-	INR 6500/t
11	Fixed cost component for production (in case of lump feeding)	INR 2000/t	-

Sl no.	Parameter	Use of lump iron ore	Use of pellets
12	Fixed cost component for production due to increased production (in case of pellets feeding)	-	INR 1667/t
13	Total cost of production	INR 15,100/t	INR 15,017/t
14	Annual production of SI	30,250 t/y	36,000 t/y
15	Annual production cost	INR 4568 lakh	INR 5406 lakh
16	Selling price of SI (lump/pellets)	INR 16,000/t	INR 16,000/t
17	Selling price for SI fines	INR 15,000/t	INR15,000/t
18	Annual sales realization	INR 4765 lakh	INR 5,742 lakh
19	Annual gross profit	INR 197 lakh	INR 336 lakh
20	Annual coal savings	-	5400 t/y
21	Annual monetary saving due to reduction in specific consumption of coal	-	INR 270 lakh
22	Investment required (installation of pelletization plant)		INR 900 lakh
23	Payback		40 months
24	Annual energy saving potential	-	3024 toe/y
25	Annual GHG emission reduction potential	-	13,500 tCO_2/y

5.6 Technology summary

The technology impacts for pelletization of Iron ore are summarized below.

- Annual energy saving : 2500–3500 toe/y
- Annual GHG emission reductions : 12,500–14,200 tCO_2/y
- Annual monetary saving : INR 250–300 lakh/y
- Investment : INR 800–1200 lakh
- Payback period : 36–48 months

Tech 6: Replacement of Conventional Lining with Mullite-based Lining in Rotary Kiln

6.1 Baseline scenario

The rotary kiln is lined inside with a high alumina refractory to protect the kiln shell when operated at high temperatures. The thickness of the lining varies from 6 to 10 inches depending on the kiln module. The selection of the refractory is based on various factors like the maximum service temperature, refractoriness under load, pyrometric cone equivalent (PCE), abrasion resistance, cold crushing strength, thermal conductivity, thermal shock resistance, CO resistance, etc. Normally, high alumina (85%) low cement castable is used in the kiln hot zones. The thermal conductivity of the castable with fused alumina base is high, i.e., about 2.78 W/mK at operating temperature. The total heat input for a typical DRI plant is 24,537 MJ, out of which radiation losses from the surface of the rotary kiln is found to be 8%–10%. Heat losses in case of LC castables is found to be approximately 5000 W/m^2. The major cause of energy losses in case of conventional refractory system are listed below.

- Damages during accretion removal
- Gradual increase in shell temperature leading to energy loss
- Higher shell temperature due to high thermal conductivity leading to radiation loss

6.2 Energy efficient technology

It is proposed to replace the high alumina low cement castables with mullite-based high alumina castables. When the same is substituted with the mullite-based high alumina castable, the thermal conductivity is 1.69 W/mK. This helps the shell temperature to drop by about 50–80 °C, thereby reducing radiation heat loss through the kiln shell. A comparison of the heat loss in case of mullite-based castable vis-à-vis conventional castable is shown in the table below.

Mullite-based castable versus conventional castable: a comparison

Sl no.	Parameter	LC–80 castable	Mullite-based castable
1	Shell diameter	3000 mm	3000 mm
2	Hot-face temperature	1200 ℃	1200 ℃
3	Ambient temperature	30 ℃	30 ℃
4	Wind velocity	1 m/sec	1 m/ sec

Sl no.	Parameter	LC–80 castable	Mullite-based castable
5	Refractory lining thickness	200 mm	200 mm
6	Thermal conductivity @ 1200 °C	2.7 W/mK	1.69 W/mK
7	Skin temperature of kiln	285 °C	244 °C
8	Heat loss	5380 W/m^2/K	3796 W/m^2/K

Thus, using mullite-based castables in place of low cement castables can lead to a saving of 14% in the skin temperature and about 30% savings in radiation heat loss from surface. The comparison of the physical and thermal properties of mullite-based vis-à-vis LC 80 castables is summarized in table below.

Comparison of the physical and thermal properties of mullite-based castable vis-à-vis LC 90 castable

Sl no.	Properties	LC-90 castable	Mullite-based castable
1	CCS (N/mm^2) At 110 °C/24 hours At 1100 °C/24 hours	75 min 100 min	80 min 100 min
2	PLC in % At 1500 °C /24 hours	–0.6	–0.5
3	Thermal Conductivity kCal.m.hr/°C AT 800 °C /24 hours	1.2	1.84
4	Abrasion losses (ASTMC 704)	3.5 cc	6 cc
5	HMOR (N/mn3 at 1200 °C	9	5

6.3 Benefits of technology

The installation of the mullite-based refractory will lead to the following advantages:

- Easy accretion removal – less damages to lining
- 20% lower thermal conductivity – lower shell temperature and heat loss
- High abrasion resistance – 3.5 cc (ASTM C 704 at 1000 °C) against 5 to 6 cc of LC 80 castable
- Very good hot MOR – 90 kg/cm^2 at 1200 °C against 50–60 k/cm^2.
- Low FE2O3 – improved behaviours under reducing conditions
- Reduces the coal consumption to the extent of 4.5% minimum

6.4 Limitations of technology

The installation of mullite-based castables has no limitations. However, the replacement from conventional lining to mullite-based lining requires complete overhauling of the plant, which will result in loss of production.

6.5 Investment required, energy and GHG saving potential, and cost-benefit analysis

The calculations have been provided considering a 100-tpd DRI plant. The cost-benefit analysis for replacement of conventional lining with mullite-based lining is shown below.

Sl no.	Parameters	LC castable	Mullite-based castable
1	Average temperature of the kiln	285 °C	244 °C
2	Ambient temperature	35 °C	35 °C
3	Length of the kiln	42 m	42 m
4	Radius of the kiln	1.5 m	1.5 m
3	Total wall area	396 m^2	396 m^2
4	Heat loss from surface	1,714,282 kcal/h	1,294,493 kcal/h
5	Fuel consumed	306 kg/h	231 kg/h
6	Annual operating hours	7200 h/y	7200 h/y
7	Reduction in fuel consumption	-	540 t/y
8	Unit cost of fuel	-	INR 5000/t
9	Savings	INR 27 lakh/y	
10	Investment required	INR 81 lakh	
11	Payback period	36 months	
12	Annual energy saving potential	302 toe/y	
13	Annual GHG emission reduction potential	1349 tCO_2/y	

6.6 Technology summary

The technology impacts for mullite-based castables are summarized below.

- Annual energy saving : 250–350 toe/y
- Annual GHG emission reductions : 1200–1400 tCO_2/y
- Annual monetary saving : INR 22–35 lakh/y
- Investment : INR 70–90 lakh
- Payback period : 34–48 months

Kiln interiors lined with mullite-based casting

Installation of mullite-based castable in a rotary kiln

Tech 7: Installation of Automation and Control System for Maintaining Correct Temperature and Air Flow in the Rotary Kiln

7.1 Baseline scenario

At present, depending on the production capacity of the rotary kiln, the capacity and the number of shell air fans (SAF) are placed along the length of the kiln. These SAFs are controlled by a single variable voltage frequency drive (VFD), which drives all motors at the same speed.

The quantity of air required in each zone is further fine-tuned by the manual butterfly damper placed in front of the SAF. The amount of air depends on the temperature required in that zone, which is sensed by the corresponding thermocouple. The quantity of air required varies from 30% to 90% of the SAF capacity.

A two-kiln DRI plant

Source: https://seil.co.in/facility/steelplant

7.2 Energy efficient technology

Instead of having a single VFD drive for all the SAFs, it is advisable to have individual VFDs for each SAF thereby reducing the total power consumed by the SAFs.

This will further help in removing the switch gear protection mounted on the kiln shell where most of the faults occur. The automation looping can be done with respect to the air quantity required in that particular zone with the temperature interlock. This will eliminate the continuous manual intervention required for temperature control.

For the purpose of automation, feedback from the individual thermocouples will be taken and corresponding speed of SAFs will be noted.

This will form a close loop and the feedback will be received by a PID controller. For change of temperature for the particular zone, corresponding speed of SAF for that zone will be varied using a VFD. Thus, changing the speed of one of the SAFs will not affect the others. Also, this will allow operating the SAFs at varying capacity.

In the case of a 100-tpd DRI kiln, there are seven SAFs and seven thermocouples representing the seven zones.

The SAFs are with 11 kW, 2900 rpm induction motors and the VFD used is of 75 kW. All the SAFs are of the same capacity for interchangeability during the operation. With the installation of individual VFDs of 11 kW, we control each SAF independently and they can be individually changed as per the volume required.

As the power consumption is directly proportional to the volume of air delivered, there will be significant energy saving. The typical temperature and air profiles for different zones of a 100-tpd DRI plant has been presented in the table below.

Temperature and air profile for a 100-tpd kiln

Parameter	Zone 1	Zone 2	Zone 3	Zone 4	Zone 5	Zone 6	Zone 7	Central burner fan
Temperature (°C)	820	950	1000	1030	1060	1080	1100	-
Air volume (Nm^3/h)	1500	1850	2500	2700	2800	3000	3200	3150
SAF capacity (Nm^3/h)	5000	5000	5000	5000	5000	5000	5000	3500
Rated capacity (%)	30	37	50	54	56	60	64	90

All the blowers like shell air fans, nose cooling fans, sealing air fans, and ABC fans can be connected with individual VFDs and air volume can be controlled effectively as per requirement, thereby saving considerable electrical energy.

7.3 Benefits of technology

The installation of an automation and control system in the rotary kiln will lead to the following advantages:

- Control of temperature and shell fan speed on zonal basis
- Saving of power as different SAFs can be maintained at different speeds
- Improvement in product quality by ensuring better environment inside the kiln

7.4 Limitations of technology

The running of the automation and control system will require maintenance. For operation of the same, skilled manpower is recommended.

7.5 Investment required, energy and GHG saving potential, and cost-benefit analysis

The calculations have been provided considering a 100-tpd DRI plant. The cost-benefit analysis for automation and control system in a DRI unit is tabulated below.

Sl no.	Particulars	Value
1	Motor capacity	11 kW
2	Numbers of fans	7
3	Total capacity	77 kW
4	Power drawn at present	46.2 kWh
5	Saving potential	20%
6	Net reduction in power drawn	9.24 kWh
7	Working hour	7200 hours
8	Cost per unit	INR 7
8	Monetary benefit	INR 4.66 lakh/y
9	Investment required	INR 20 lakh
10	Payback period	52 months
11	Annual energy saving potential	5.72 toe/y
12	Annual GHG emission reduction potential	47.2 tCO_2/y

7.6 Technology summary

The technology impacts for automation and control system are summarized below.

- Annual energy saving : 4–7 toe/y
- Annual GHG emission reductions : 40–60 tCO_2/y
- Annual monetary saving : INR 4–6 lakh/y
- Investment : INR 18–30 lakh
- Payback period : 48–60 months

Tech 8: Removal of Coal Moisture Using Waste Heat

8.1 Baseline scenario

Coal is the predominantly used fuel in DRI units. Coal will normally have an inherent moisture of 8% and surface moisture of 10%. Such moisture content takes away substantial heat during the combustion process as latent heat of vapour. Such high moisture also leads to choking of coal storage hoppers leading to frequent breakdowns. Although many industries have attempted to dry coal using crude methods (spreading coal in open areas, etc.), they have not been able to get the desired results.

8.2 Energy efficient technology

About 6000 Nm^3 of gases in between 850–950 °C are generated per tonne of SI produced. Under conventional practice, these gases are cooled down to a temperature of below 200 °C ; with the help of a FD cooler and later passed through an ESP for complete elimination of dust particles before letting it out through the chimney.

An FD cooler generally consists of a number of passes or chambers for gradual decrease in the waste gas temperature. These passes are generally isolated from each other. Atmospheric air is circulated with FD fans in these chambers. The air is heated above 250–300 °C; hot air from the first and second chambers of the FD cooler can be used to pass through a rotary drum-type dryer, wherein coal will be fed in opposite direction to the hot air flow before entering the conveyor belts for transfer to the feeding bin. Hot gases in elevated temperature will come in contact with the coal in the rotary drum. In the process, the surface moisture can be removed from coal.

8.3 Benefits of technology

The installation of a coal drying system will lead to the following advantages:

- Removes surface moisture of coal completely.
- Reduces inherent moisture by retaining a minimum 5% moisture content to ensure that volatile matter is not vapourized.
- Every 1% reduction in moisture content of coal would lead to approximately at least a reduction of 2 kg of coal.
- Owing to reduction of coal moisture, choking of coal in coal hopper will be minimized.

8.4 Limitations of technology

Coal contains some amount of inherent moisture. The same cannot be removed through this process. Also, inherent moisture in coal should be maintained at a minimum of 5% to ensure that the volatile matter in the coal is not vapourized. Adequate care needs to be taken in the coal drying system itself to avoid self-ignition of coal due to hot air temperature. If not done carefully, the drying process may also take away the volatile matter in coal in case of over retention time resulting in the reduction of calorific value.

8.5 Investment required, energy and GHG saving potential, and cost-benefit analysis

The calculations have been provided considering a 100-tpd DRI plant. The cost-benefit analysis for removal of coal moisture using waste heat in a DRI unit is tabulated below.

Sl no.	Parameter	Value
1	Latent heat of evaporation of water vapour	542 kcal/kg
2	Amount of coal used in 100-tpd plant per day	85,000 kg/d
3	Mass of 1% of moisture present in coal	850 kg/d
4	Heat taken away by this 1% of moisture through latent heat of evaporation	4,60,700 kcal/d
5	Reduction in moisture by installing coal drying system	8%
6	Total heat saved due to reduction in moisture content by installing coal drying system	36,856 kcal/d
7	Calorific value of coal used in DRI Plant	5600 kcal/kg
8	Saving in coal consumption due to installation of coal drying system	6.58 kg/d
9	Increase in calorific value of coal due to reduction in moisture (assuming 10% increase)	560 kcal/kg
10	Coal consumption due to increased calorific value	77,273 kg/d
11	Total reduction in coal consumption	7727 kg/d
12	Saving in fuel consumption	9.1%
13	Annual monetary savings	INR 116 lakh
14	Investment required	INR 100 lakh
15	Simple payback period	10.4 months
16	Annual energy savings potential	1298 mtoe/y
17	Annual GHG emissions savings potential	5795 tCO_2/y

8.6 Technology summary

The technology impacts of removal of coal moisture using waste heat are summarized below.

- Annual energy saving : 1000–1500 toe/y
- Annual GHG emission reductions : 4800–6200 tCO_2/y
- Annual monetary saving : INR 80–150 akh/y
- Investment : INR 90–140 lakh
- Payback period : 10–16 months

SECTION 4:
Electric Arc Furnace

Electric Arc Furnace: A Process Overview

An electric arc furnace (EAF) is a furnace that heats material by means of an electric arc.

Industrial arc furnaces range in size from small units of approximately one-tonne capacity (used in foundries for producing cast iron products) up to about 400-tonne units used for secondary steelmaking. Arc furnaces used in research laboratories and by dentists may have a capacity of only a few dozen grams. Industrial electric arc furnace temperatures can reach 1800 °C (3300 °F), while laboratory units can exceed 3000 °C (5400 °F).

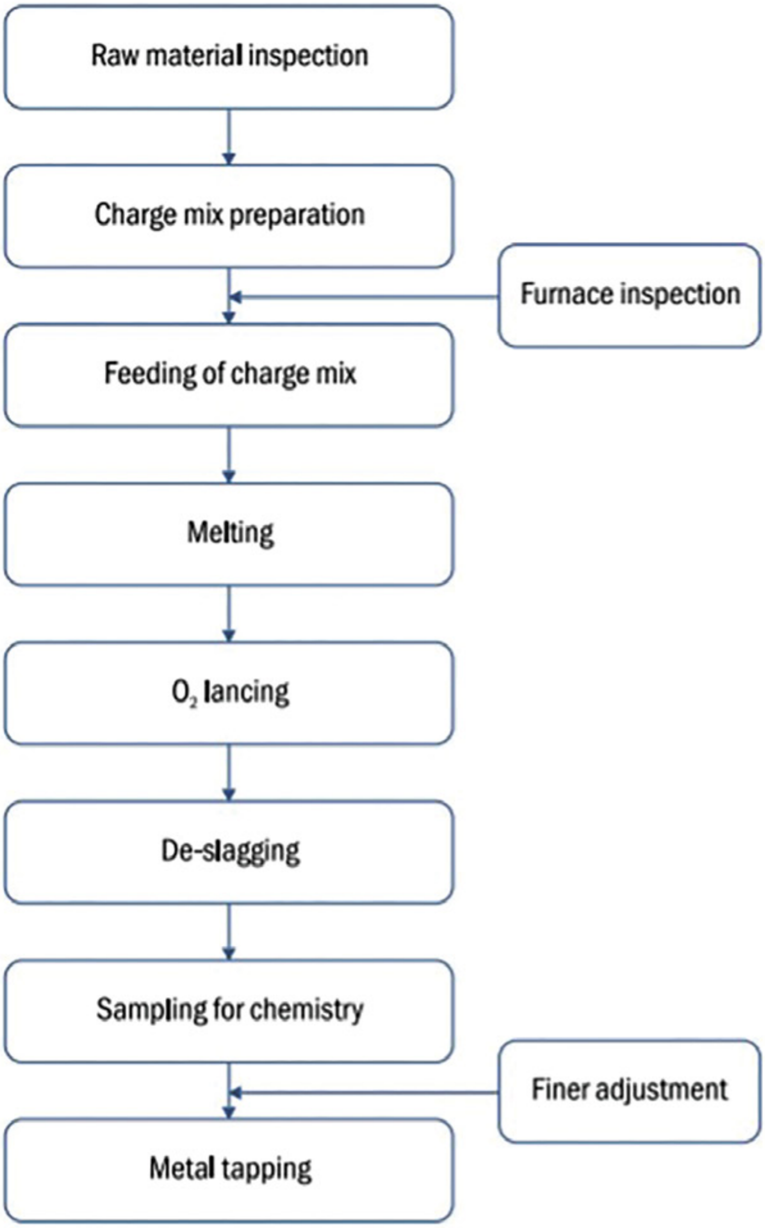
In electric arc furnaces, the charged material (the material entered into the furnace for heating, not to be confused with electric charge) is directly exposed to an electric arc, and the current from the furnace terminals passes through the charged material. Arc furnaces differ from induction furnaces, in which the charge is heated instead by eddy currents.

The alternating current (AC) electric arc furnace melts the charged material using an electric arc. The energy required for producing the melt is provided by the electric arc between each of the three electrodes and the metallic charge. Through the EAF route, it is possible to produce steel using 100% scrap mix, which would reduce the energy consumption for making steel as compared to primary steel-making through the blast furnace route. The construction of EAF encompasses an outer cylindrical steel shell internally lined with several layers of designated refractory materials, with the whole system mounted on a motorized tilting mechanism. The three electrodes enter the furnace from the roof through three cylindrical openings at an angle of 120 degrees. The roof is made of refractory brick, usually of high alumina. The vertical movement of electrodes is generally controlled automatically with a thyristor-based system. The crucible, roof, and electrodes are water-cooled to maintain the temperature and improve the service life. EAFs are generally provided with a door at the back to carry out alloying, oxygen lancing, and de-slagging. A pouring spout is present at the front in case of a launder pouring system and an opening is present at the bottom in case of an 'Eccentric Bottom Tapping' (EBT), which leads to slag-free tapping and shorter tap-to-tap times.

The steps involved in EAF operations include:

- charging;
- complete meltdown;
- oxidation and refining;
- de-oxidation; and
- tapping into the ladle.

The steps involved in the electric arc furnace (EAF) process is shown in the figure below.



Process flow diagram in EAF

The process steps are briefly explained below.

Charging: The first step in a batch furnace (tap-to-tap cycle) is the 'charging' of raw material into the furnace. Typically, a schedule is established by the EAF unit prior to each production shift and the charge is prepared in the charge buckets accordingly. The preparation of a charge bucket is a key step to: (1) ensure proper chemistry and (2) confirm good melting conditions. The scrap material is stacked in layers in the charging bucket according to size and density to facilitate quick melting while providing protection to the furnace from electric arc radiation. Typically, a 'steel melting shop' (SMS) is provided with two to three charging buckets, each of which is kept charged as soon as it becomes empty. Modern units in developed countries are equipped to charge the furnace at once so as to reduce idle time in operation, thereby ensuring productivity.

Complete meltdown: The melting is at the heart of the furnace operation. Energy for melting includes both electrical and chemical. Electrical energy is fed through three graphite electrodes, which is the major energy input. At the start, an intermediate voltage tap is selected until the electrodes bore into the scrap. Usually, light scrap is kept on top of the charge to quicken initial melting and create a molten metal pool. Approximately, 15% of scrap melts during the initial period.

The electrodes penetrate the scrap adequately a few minutes after the start. This ensures the usage of a long arc to reduce the damages to the roof structure. The long arc ensures maximum transfer of power to the scrap and a liquid metal pool is formed in the furnace hearth. In the beginning, the arc is generally erratic and unstable. As the furnace heats up, the arc becomes stable and the average power input rises. Upon the melting of a sufficient quantity of scrap, the charging process is repeated.

Oxidation and refining: EAF usually exhibits a pattern of hot spots and cold spots around the hearth perimeter, with cold spots generally located between electrodes. The state-of-the-art EAFs are provided with oxy-fuel burners on the sidewalls which ensure a more uniform heating of steel. Additional energy is provided through oxygen and carbon injection into the furnace. While this was being achieved through lances in the slag door in traditional furnaces, modern EAFs use multiple wall mounted injection arrangements. Once liquid steel is formed, oxygen can be directly lanced into the bath to accelerate the oxidation of solutes, starting with carbon in the bath followed by the oxidation of iron, silicon (Si), manganese (Mn), and phosphorus (P). These reactions are exothermic and provide additional energy in the melting process.

The carbon monoxide (CO) escapes as gas and produces 'carbon boil' in the melt. The carbon boil is an essential part of the refining process and helps in: (i) heat transfer by agitating the bath; (ii) cleansing the bath of the retained oxides as slag; (iii) accelerating reactions at the gas metal interface, and (iv) aiding the removal of H_2 and N_2.

Heat of reactions inside EAF

Exothermic reaction	Heat of reaction at 1650 °C (kWh per kg)
$Fe + ½ O_2$ (g) -----> FeO	1.275
$Si + O_2$ (g) ----->	9.348
$4Al + 3 O_2$ (g) -----> SiO_2	8.65
$C + ½ O_2$ (g) -----> $2 Al_2O_3$	2.739
CO (g) + ½ O_2 (g) -----> CO (g)	2.763
$C + O_2$ (g) -----> CO_2 (g)	9.184
$Mn + ½ O_2$ (g) -----> MnO	2.044
H_2 (g) + ½ O_2 (g) -----> H_2O (g)	34.614
CH_4 (g) + 2 O_2 -----> CO_2 (g) + 2 H_2O	13.994

Phosphorus is removed during the oxidizing period whereas sulphur is removed during the reducing period. The lime or dololime added in the process helps in de-slagging. The calcium oxide in lime reacts with silicon dioxide and forms calcium silicate slag:

$2 P + 5 FeO \longrightarrow (P_2O_5)_{SLAG} + 5 Fe$

$(P_2O_5)_{SLAG} + 3 (CaO)_{SLAG} \longrightarrow Ca3(PO4)2_{SLAG}$

$(CaO)_{SLAG} + [FeS]_{BATH} \longrightarrow (CaS)_{SLAG} + [FeO]$

$(CaC2)_{SLAG} + 3 [FeS]_{BATH} + 2 (CaO)_{SLAG} \longrightarrow 3 [Fe] + 3 (CaS) + 2 (CO)_{GAS}$

$2 CaO + 2 SiO_2 \longrightarrow 2 (CaO.SiO_2)_{SLAG}$

The composition of slag comprises SiO2 (55%–60%), MnO (12%–16%) CaO (7%–10%) and FeO (12%–20%). The slag typically floats over metal and acts as a thermal insulating layer reducing heat losses from the melt surface.

De-oxidation: The oxidized bath is de-oxidised before pouring into a transfer ladle. Otherwise, the oxides would form again and may go into the final products. Once the first slag is removed, the power is switched off. De-oxidation is carried out using specific deoxidisers with a high affinity towards oxygen in the bath as compared to iron. The most common deoxidisers include ferro-alloys, that is, ferro-manganese or ferro-silicon. Aluminum is typically added at the end, which is the most powerful de-oxidising agent as compared to the ferro alloys.

Tapping of liquid steel: Once the required temperature is achieved (usually about 1650 °C), a sample is drawn from the bath to ascertain the desired chemistry of the molten bath. Finer corrections are made to the chemistry, if required. The molten steel is poured into a pre-heated ladle either by tilting or by EBT mechanism. Any slag entering in the ladle is removed by adding adequate quantities of lime. On the completion of pouring, the slag door is cleaned of solidified slag, repairs, if any, are done, and electrodes are inspected for damages.

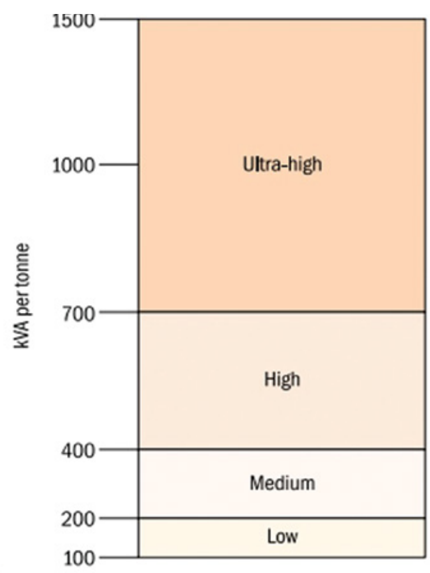
Tech 1: Ultra High-power Transformer

1.1 Baseline scenario

The power ratings of the transformers used in electric arc furnaces in India are limited to a maximum of 500 kVA per tonne resulting in longer tap-to-tap time and higher specific energy consumption levels. The overall energy loss due to use of low power rating transformers can be as high as 7%.

1.2 Energy efficient technology

Inefficient transformers can be replaced with ultra high-power (UHP) transformers, having ratings of 700 kVA per tonne or above. A transformer with an input power of above 700 kVA per tonne is defined as a UHP transformer. Although UHPs are typically available in the range 700–1500 kVA, transformers above 1000 kVA per tonne capacity are commonly used in developed countries.



Type of Power Transformers

(Source:UNDP Compendium: Energy Efficient Technology Packages for Electric Arc Furnace)

1.3 Benefits of technology

The advantages of using a UHP transformer are listed below.

- Substantial increase in productivity
- Improved energy efficiency
- Optimal voltage regulation
- Faster melting cycles
- Reduced electrode consumption

1.4 Investment required, energy and GHG saving potential, and cost-benefit analysis

The average energy savings with UHP transformers is estimated to be about 5%. Typically for a 50-tonne furnace, the investment requirement is about INR 400 lakh with a simple payback period of about 2 years. The greenhouse gas (GHG) emission reduction potential is about 3690 tonnes of CO_2 per year.

UHP transformers: Case study	
Parameter	**Value**
Existing transformer rating	50 MVA
Old transformer	500 kVA/t
New transformer	1000 kVA/t
Productivity enhancement	8.0%
Reduction in electrode consumption	10.0%
Reduction in energy consumption	5.5%
Investment	INR 400 lakh
Simple payback period	1–2 years

Source: Ernst Worrell, et.al. "Energy Efficiency Improvement and Cost Saving Opportunities for the U.S. Iron and Steel Industry", Oct 2010.

Tech 2: High-impedance System

2.1 Baseline scenario

The EAFs, which were using shorter arcs and high currents, switched over to long-arc operations with the use of foamy slag practices. Although EAFs were using lower operational currents and lower impedances that helped in minimizing electrode consumption, it had led to higher flickers and harmonics, particularly during the bore-down period leading to unstable operation. It further resulted in higher stress on mechanical components due to increased vibrations.

2.2 Energy efficient technology

High impedance operation helps in more stable and smooth operation of EAFs. With low current and long-arc operation, appropriate power factor and system reactance are selected for stable operation. High impedance system helps operate the furnace close to maximum power point of a given tap and lowers the sensitivity of power changes versus current changes through a series reactor on primary circuit and raising the voltage taps on secondary side.

2.3 Benefits of technology

The major advantages of the high impedance system include the following:

- Reduction in electrode tip consumption and breakage
- Less flickers, lower harmonics, and more stable arc operation
- Less mechanical forces on electrodes and electrode arms
- Potential to use lower electrode diameter to reduce oxidation losses.

2.4 Investment required, energy and GHG saving potential, and cost-benefit analysis

The average energy savings with high impedance operation is estimated to be about 1%–2%. Typically for a 50-tonne furnace, the investment requirement is about INR 170 lakh with a simple payback period of about 3 years. The GHG emission reduction potential is about 740 tonnes of CO_2 per year.

The effect of impedance can be illustrated by considering the following three cases: (a) traditional design; (b) same-arc power, but with lower electrode current; and (c) same-arc power and arc length, but with a slightly lower power factor to stabilize the arcing condition. The furnace can be operated with 'long arc' for about 75% of 'power ON' time, with this assumption the effect of high impedance on operating characteristics of an EAF is given in the following box. Although case 2 and case 3 indicate similar results, the advantage with case 3 is stable arcing operation.

Particular	Case 1	Case 2	Case 3
Secondary voltage	800 V	1025 V	1100 V
System reactance	3.3 mΩ	6.1 mΩ	7.1 mΩ
Electrode current	65.3 kA	50.4 kA	50.4 kA
Active power	73.7 MW	71.5 MW	71.4 MW
Arc power	67.8 MW	67.7 MW	67.6 MW
Power factor	0.84	0.83	0.78
Arc voltage	363 V	461 V	460 V
Electrode saving	-	15%	15%
Energy saving	-	1.5%	1.5%

Source: Kjell Bergman, Danieli CentroMet. "High impedance for stable and smooth EAF operation", Steel Times International May 1993, Vol. 17 No. 3.

Moreover, in the UHP transformer-based furnaces, there is an additional risk of tip breakage of electrodes due to high short circuit currents (ISC). The operation at high impedance with a slightly lower power factor reduces the short circuit currents by about one-third, thus reducing the tensile stress in the tip of the electrode by about 50%. The EAF units installing new transformers are mandated to use UHP transformers along with reactors. Therefore, the overall energy saving would be cumulative of both UHP and high impedance.

Furnace capacity, t	Transformer rating, MVA	Ratio, kVA/t
5	2	400
10	5	500
15	7.5	500
30	15	500

Source: Kjell Bergman, Danieli CentroMet, 'High impedance for stable and smooth EAF operation', Steel Times International May 1993, Vol. 17 No. 3.

Tech 3: Aluminium Electrode Arm

3.1 Baseline scenario

A mild steel support with water-cooled copper cables is the standard material used in EAFs. A copper clad, i.e., steel arm with copper bus tubes, is also being used by a few units. Though the copper system (Cu-system) offers high strength and conductivity, electromagnetic forces around copper bus and electrode clamping heads affect the system performance. This increases system resistance, leading to drop in power fed to the furnace.

3.2 Energy efficient technology

The aluminium system (Al-system) is lighter and non-magnetic. The Al-system comprises aluminium current-conducting electrode arms and columns with guide roll assemblies.

Source: http://www.hammersindustries.com/ea_furnace_components.html

Source: http://www.kark.de/cms/index.php/en/aluminiumelectrode-arms

3.3 Benefits of technology

The major advantages of aluminum electrode arm include the following:

- High arc power
- Increased productivity
- Reduction in maintenance downtime
- Low mechanical vibrations.

3.4 Investment required, energy and GHG saving potential, and cost-benefit analysis

The energy savings with aluminium electrode arm is about 0.7%. Typically for a 50-tonne furnace, the additional investment requirement is about INR 70 lakh with a simple payback period of 1.5 years. The GHG emission reduction potential is about 520 tonnes of CO_2 per year. A case study of an EAF unit located in the US, which replaced copper arm with aluminium electrode arm in a 100-tonne, 85-MVA furnace is reproduced in the following table.

Case study of an EAF unit, which replaced copper arm with aluminium electrode arm in a 100-tonne, 85-MVA furnace

Particular	Cu-system	Al-system	Change
Reactance (short circuit)	3.02 mΩ	2.88 mΩ	–4.6%
Reactance (foamy slag)	3.31 mΩ	2.93 mΩ	–11.5%
Power foamy slag	82.1 MW	82.6 MW	+0.6%
Power normal	76.6 MW	77.3 MW	+0.9%
Power melt down	75.5 MW	75.9 MW	+0.7%
Power ON time	41 min	39.7 min	–3.2%

Source: 'Operational experience with aluminium electrode arms', Metallurgical Plant and Technology International 2/2004

Tech 4: Improved Regulation Control

4.1 Baseline scenario

The degree of transformation of electrical power into thermal energy is pivotal for the efficient operation of the EAF. This depends on regulation of the transformer, which, traditionally, use following methods:

- changing the number of turns in primary winding
- star to delta switching in primary side of the transformer (this is not applicable for UHP transformers as regulation is done through on-load changer)
- use of auto transformers
- booster transformer.

One of the major issues with a conventional regulation system is that it is a complex-structure contact on-load changer, which increases the switching time (3–5 seconds). Further, the on-load changers operate in a high-intensity mode (frequent changes ~500–800 per day) leading to high wear and tear thereby decreasing the operational reliability.

4.2 Energy efficient technology

The shortcomings in conventional regulation systems can be addressed with 'high pressure hydraulic digital regulation' systems. The digital system allows minimum delays for switching from one melting stage to another. This system can be linked with 'Level-2 or 3' automation for dynamic production control.

4.3 Benefits of technology

The main advantages of digital-based regulation system are the following:

- Reduction in tap-to-tap time
- Increase in productivity
- Increase in operational reliability

4.4 Investment required, energy and GHG saving potential, and cost-benefit analysis

The average energy savings with improved electrode regulation is about 3%. Typically for a 50-tonne furnace, the investment requirement is about INR 75 lakh for hardware and software and associated hydraulic systems. The simple payback period is about 6 months. The GHG emission reduction potential is about 2,210 tonne of CO_2 per year.

The case study, as depicted in below table, of a 40-tonne, 36-MVA EAF illustrates the effects of using state-of-the-art electrode regulation systems. The units wherein digital regulation system is already in use can achieve additional energy saving with fine-tuning of the software with reference to their respective scrap quality.

Case study of a 40-tonne, 36-MVA EAF using state-of-the-art electrode regulation systems

Particular	Base case	EE technology
Furnace capacity	40 t	40 t
Transformer rating	36 MVA	36 MVA
SEC	426 kWh/t	412 kWh/t
Power ON time	49.7 min	48.9 min
Electrode consumption	3.51 kg/t	3.40 kg/t
Monetary benefit	-	INR 81/t
Investment cost	-	INR 250 lakh
Simple payback period	-	0.52 years

Source: TERI energy audit study in EAF unit, 2016

Tech 5: Oxy-fuel Burner

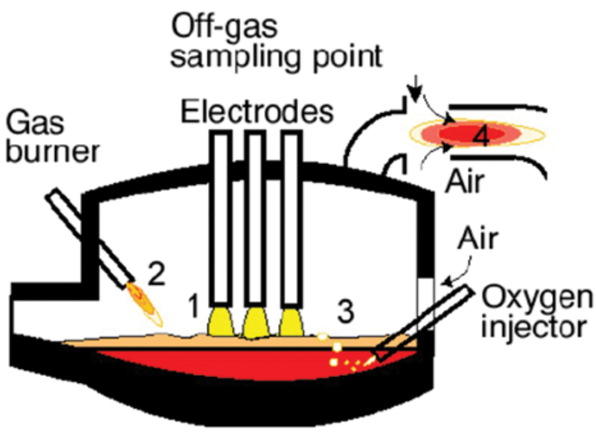
5.1 Baseline scenario

During EAF operation, cold spots form between electrodes on the peripheral areas of the furnace bottom. These cold spots within the EAF would lead to increase in tap-to-tap time thereby increasing the specific energy consumption. It is therefore important to eliminate cold spots from the furnace.

5.2 Energy efficient technology

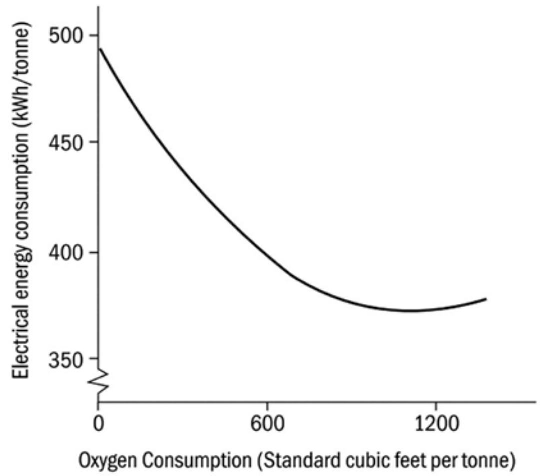
The state-of-the-art EAFs are equipped with oxy-fuel burners, which use fuels, such as natural gas and LPG, and provide chemical energy to cold spots, thereby ensuring more uniform melting and homogeneity of temperature of the molten metal bath.

Modern EAFs widely use stationary wall-mounted oxy-fuel burners and combination lance-burners, which operate in a burner mode during the initial part of the melting period.



Oxy-fuel Burner

Source: https://www.researchgate.net/figure/NO-x-sources-at-the-EAF-1-electric-arc-2-oxy-fuel-burner-3-4-CO-post-combustion_fig1_276394539



Electricity consumption vs. oxygen use (100 t EAF)

Source: http://infohouse.p2ric.org/ref/10/09047.pdf

5.3 Benefits of technology

The important advantages of oxy-fuel burner are the following:

- Low electricity consumption
- Reduced tap-to-tap time
- Enhanced yield.

5.4 Investment required, Energy and GHG saving potential, and Cost-Benefit Analysis

The average energy savings with use of oxy-fuel burners is about 3%. Typically for a 50-tonne furnace, the investment requirement is about INR 400 lakh with a simple pay-back period of about 2 years. The GHG emission reduction potential is about 2210 tonne of CO_2 per year.

Tech 6: Coherent Jet

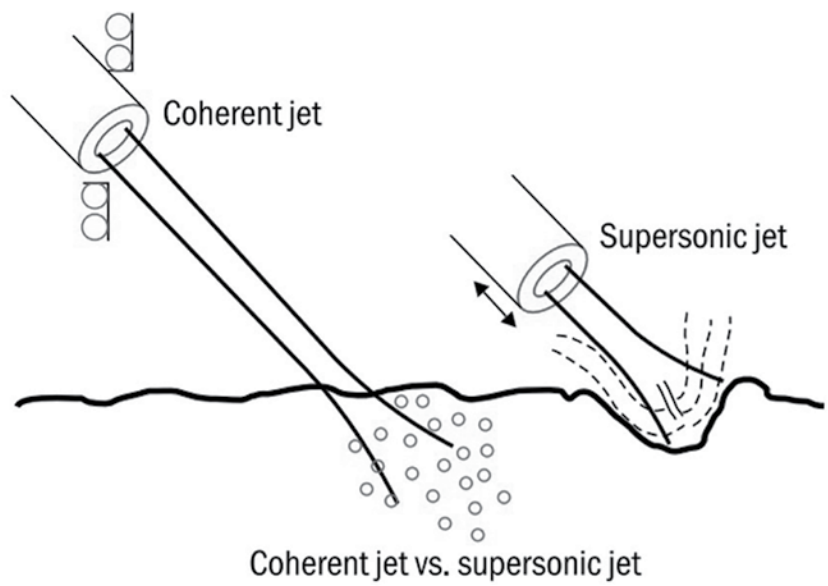
6.1 Baseline scenario

The oxygen injection system in traditional EAFs uses supersonic jet-based burners. However, the traditional method generates a splash and leads to formation of cavities in liquid metal. The penetration of oxygen is not effective in a conventional system and leads to high refractory consumption.

6.2 Energy efficient technology

The shortcomings in supersonic jet are overcome with use of coherent jet technology (CoJet). The coherent jet system comprises up to four numbers of CoJet injectors, which are mounted on furnace side walls, depending on the size and process requirement. These CoJet injectors are multi-purpose systems, which act as burner, lance, and also post-combustion device. The CoJet has the capability of compact lancing and decarburising without any splash. This is achieved by keeping the oxygen stream coherent, i.e., retaining its original diameter and velocity over longer distances.

Its performance can be further enhanced using programmable logic controllers.



Coherent jet vs. supersonic jet

Source: Praxair CoJetTM Technology

6.3 Benefits of technology

The major advantages of using CoJet system are the following:

- Better penetration of liquid metal bath
- Use of precise amount of oxygen
- Less splash and cavity formation
- Lower refractory consumption
- Improved slag foaming with less carbon
- Decreased air infiltration

6.4 Investment required, energy and GHG saving potential, and cost-benefit analysis

The average energy saving with use of CoJet injectors is about 2%. Typically for a 50-tonne furnace, the investment requirement is about INR 300 lakh with a simple payback period of about 2.5 years. The GHG emission reduction potential is about 1480 tonne of CO_2 per year. The case study of a 50-tonne, 40-MVA EAF unit using CoJet injectors is shown in the following table. The benefits include energy saving (6.4%), reduced electrode consumption (9.4%), and decreased tap-to-tap time (10.6%).

Case study of an EAF unit using CoJet injectors

Particular	Conventional	CoJet
Capacity	27.1 tph	28.8 tph
Tap-to-tap time	114 min	102 min
SEC	485 kWh/t	454 kWh/t
Electrode consumption	3.2 kg/t	2.9 kg/t
Investment	-	INR 100 lakh
Simple payback period		0.5 years

Source: Energy audits of EAF units supported by UNDP, 2017

Tech 7: Bottom Stirring: Inert Gas Purging

7.1 Baseline scenario

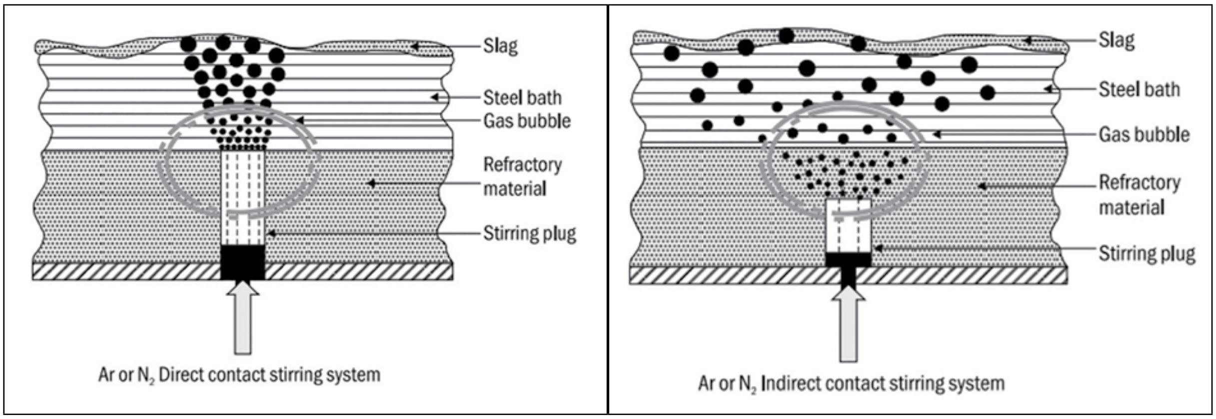
The molten metal in the arc furnace may not be of homogenous mass or uniform quality across the cross section. This may result in increased tap-to-tap (TTT) time and energy consumption. Moreover, it can lead to a high rejection level. Homogenization of the liquid metal bath is required to overcome the issues and enhance productivity.

7.2 Energy efficient technology

The bottom stirring of liquid bath in an EAF is a potential solution for better homogenization and ensures uniform quality. The mechanism used at present for bottom stirring is inert gas injection, mostly used in developed countries. In an inert gas-stirring system, the stirring of liquid metal is accomplished using inert gases such as argon or nitrogen. Bottom-stirring systems based on inert gas injection are available either as a single tube or multi-hole plugs. These plugs are either buried in the furnace hearth ramming mix or 'indirect purging' or in contact with steel melt or 'direct purging'. Indirect purging arrangement offers improved stirring arrangement due to better distribution10 of inert gases.

The bottom stirring using inert gases is more suitable for smaller furnaces. Bottom stirring further accelerates chemical reactions between steel and slag. The stirring helps in an increased heat transfer with an estimated energy saving of 12–24 kWh per tonne liquid steel. It further leads to increased metal yield of about 0.5%. However, the use of inert gas would require significant maintenance after every heat.

Bottom purging system in EAF



7.3 Benefits of technology

The advantages of inert gas-based bottom stirrer include the following:

- Improved control of the temperature and chemical composition
- Lower consumption of refractory and electrode
- Shorter TTT times
- Improvement in liquid metal yield

7.4 Investment required, energy and GHG saving potential, and cost-benefit analysis

The average energy saving with inert gas-based bottom stirring is estimated to be about 3%. Typically, for a 50-tonne furnace, the investment requirement is about 10 lakh and the payback is immediate. The GHG emission reduction potential is about 2210 tonne of CO_2 per year.

Tech 8: Bottom Stirring: Electro-magnetic System

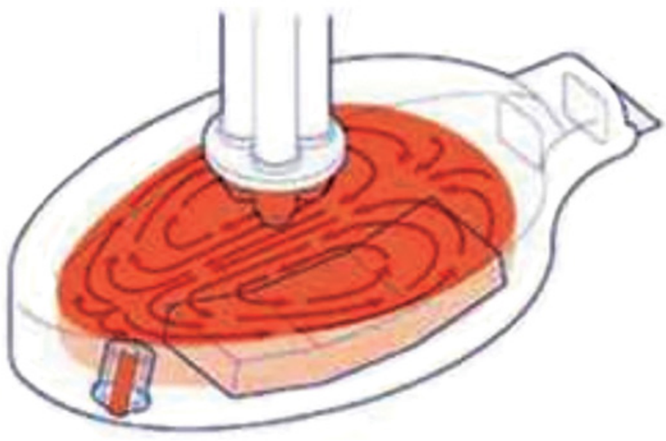
8.1 Baseline scenario

The molten metal in EAFs may not be of homogenous mass or of uniform quality across the cross section and depth of the furnace, which results in increased tap-to-tap time and specific energy consumption. Moreover, it can lead to a high rejection level.

8.2 Energy efficient technology

Bottom stirring of liquid bath in EAF is a potential solution for better homogenization and to ensure uniform quality. The electro-magnetic stirrer (EMS) is a new generation stirrer arrangement for EAF. It has a stronger stirring ability and enables reduced tap-to-tap time in liquid steel production.

The EMS enhances melting of large scraps and reduces stratification as a result of forced convection. It leads to increased melt velocity, which is almost 10 times higher as compared to natural convection and results in less power ON time.



Source: ABB

Some of the special features of EMS system include the following:

- Low stirring cost, less than 2 kWh per tonne
- Low maintenance
- Fully integrated and automated control system.

8.3 Benefits of technology

The advantages of EMS system include the following:

- High yield
- Less 'power on' time
- Lower consumption of refractory and electrodes.

8.4 Investment required, Energy and GHG saving potential, and Cost-Benefit Analysis

The average energy saving with electro-magnetic based bottom stirring is estimated to be about 5%. Typically for a 50-tonne furnace, the investment requirement is about INR 400 lakh with a simple payback period of about 2 years. The GHG emission reduction potential is about 3690 tonne of CO_2 per year.

Tech 9: Foamy Slag Practice

9.1 Baseline scenario

The radiation loss from electric arc to the side walls of the EAF is negligible in the beginning, as the electrodes are surrounded by scrap at low temperatures. During melt-down, the temperature inside rises quite high and more heat is radiated to the side walls. The increased heat transfer to side walls leads to increased surface heat losses and refractory consumption.

9.2 Energy efficient technology

A layer of slag can be used to cover the arc, thereby shielding it. This would lead to retention of heat, less heat transfer to side walls and hence more effective heat transfer to molten bath. Often, adequate foaming occurs at the beginning of the refining process, but gradually decreases towards the end of the heat. The process of slag foaming involves reactions that generate and sustain gas bubbles along with proper slag.

The effectiveness of slag foaming depends on slag basicity, FeO content of slag, slag temperature, and the availability of carbon to react with either oxygen or FeO of slag. Slag foam results from the entrapment of gas bubbles in molten baths. The reactions that are involved in gas production inside the furnace include the following reactions. The reactions involving chromium oxide are mainly for stainless steel making.

Reaction between FeO of slag with carbon

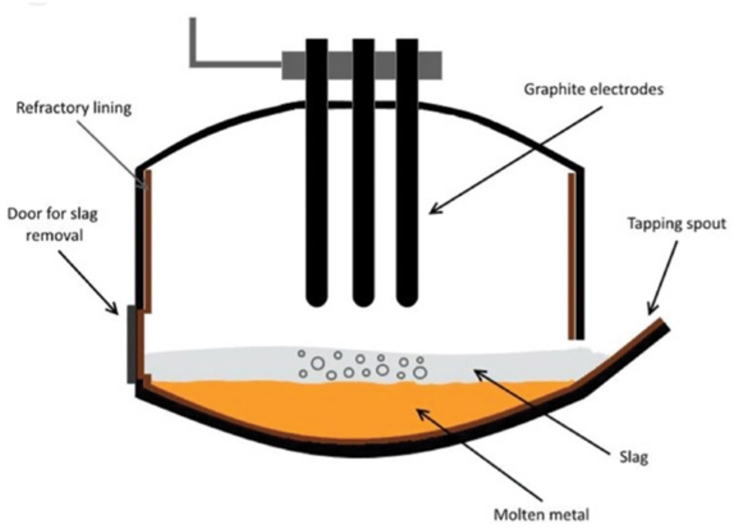
(FeO) + C = [Fe] + {CO}

Reaction between carbon and oxygen dissolved in metal

[C] + [CO] = {CO}

Reaction between chromium oxide and carbon

Cr2O3 + 3C = 2Cr + 3CO



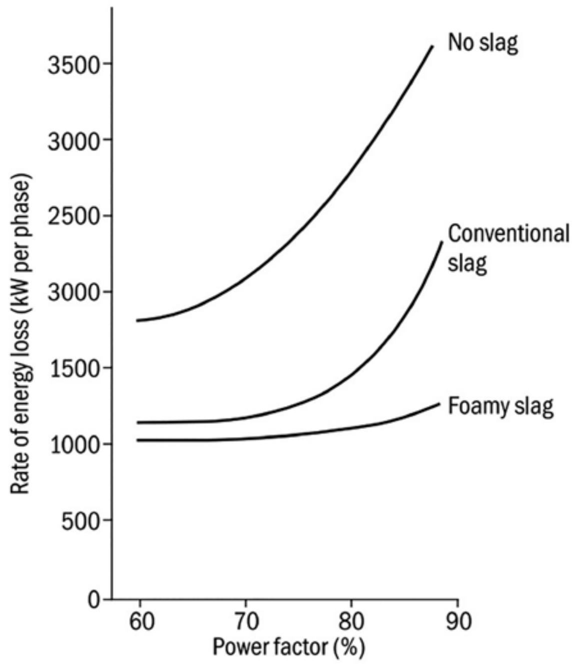
Foamy slag in EAF

Source: https://www.semanticscholar.org/paper/The-effect-of-carbonaceous-iron-on-slag-foaming-Svensson/b9ee56b1ac8e81449f1403529a913cd072e6dcc8

It is important that the foaming slag needs to be maintained throughout the refining period to minimize energy losses to sidewalls and the efficient use of electrical energy inputs. Injection of carbon and oxygen at multi-points in the bath would ensure and enhance the slag-foaming practice, especially, when the carbon content of the bath is insufficient. It would further help in the protection of the sidewalls and roof from intense heat generated from the EAF.

Slag foaming is done once a flat bath is achieved. In an EAF, oxygen is injected inside along with granular coal or carbon. The carbon reacts with FeO present in the slag and produces carbon monoxide (CO), which foams the slag. In an arc furnace, the slag thickness is typically about 4 inches (about 10 cm). With foaming practice, the slag cover can be increased up to about 12 inches (about 30 cm), which acts as an insulation cover for molten batch, retaining heat as well as increasing the temperature of molten metal bath. Further, with the formation of a deep, foamy slag, there is a potential to increase the arc voltage significantly, which would allow higher power inputs in the furnace.

Slag viscosity plays an important role in maintaining proper foamy slag, as it would determine the retention time of the CO bubbles in foam. Dololime addition using an automatic system would help in enhancing the formation as well as retaining the foamy slag. Suitable training of operators would be required in controlling the foaming practice.



Effect of foamy slag on heat losses

Source: http://etech.lwbref.com/Downloads/Theory/Fundamentals%20 of%20the%20EAF%20Process.pdf

9.3 Benefits of technology

The major benefits by maintaining foamy slag in the molten metal bath include the following:

- Enhance heat transfer to molten bath
- Reduce thermal load radiated to the furnace lining
- Decrease electrode and refractory consumption
- Better electric arc stability during long arc operations
- Minimize arc noise.

9.4 Investment required, energy and GHG saving potential, and cost-benefit analysis

The average energy saving with enhanced foamy slag practice is about 1.5%.Typically, retrofits required for enhanced foamy slag practice involve oxygen lancing and carbon injection. Most of the units are equipped with the required system for foamy slag; however, the level of foaming is limited to 4–6 inches, which can be further enhanced to up to 12 inches requiring marginal investment with immediate payback. The GHG emissions reduction potential is about 1100 tonne of CO_2 per year.

Tech 10: Use of Chemical Energy

10.1 Baseline scenario

The chemical reactions form part of EAF operation, which generate a significant quantity of heat during various phases. However, the heat generated is not utilized to its optimum potential by a majority of EAF units resulting in significant heat losses.

10.2 Energy efficient technology

The methods for utilizing the chemical energy available from the EAF include post combustion, oxidation reaction, and carbon injections.

(a) Post combustion

The off-gases from EAFs contain a substantial quantity of carbon monoxide (CO) along with hydrogen (H2). CO is produced in large quantities in EAF both from oxygen lancing as well as from the slag foaming process. As it is not possible for CO to burn CO_2 inside the furnace, CO will be the predominant gas generated from the process reactions. A large quantity of CO and H2 is generated at the start of the melting process that includes burning of oil, grease, and other combustible materials present in the scrap.

Incomplete reaction carbon and oxygen:

$C + ½O_2 = CO$

Cracking of hydrocarbons or reduction of water

H2O + C = H2 + CO

Adequate oxygen is required for the complete combustion of these compounds. As insufficient quantity of oxygen is generally available inside the furnace, it leads to the formation of CO. The heat of combustion further shows that C to CO_2 is about three times higher than the heat of combustion of C to CO. Thus, there exists a large potential energy source in the EAF in the form of CO. 'Post combustion' is a process of utilizing chemical energy present in CO and H2 evolving off the steel bath to heat the steel in the EAF ladle or pre-heat scrap to (300–800 °C), thereby reducing the electrical energy requirements for the melting process. During the EAF operation, post combustion (PC) must be carried out early at meltdown, while the scrap is capable of absorbing the heat.

PC can be carried out low in the furnace or in the slag itself. Oxygen is either injected into the furnace above the slag or into the slag before it enters the furnace freeboard. To maximize the CO retention time, the injectors are placed low in the scrap in order to transfer the heat. PC oxygen is generally provided at low velocities into the slag. The usefulness of the heat generated through PC is dependent mainly on the effective heat transfer to steel scrap or liquid metal. If PC oxygen level is more than 15 Nm^3 per tonne liquid metal, yield losses may become higher. If additional carbon is not supplied, a yield loss will occur. It may be noted that a yield loss of 1% is equivalent to a power input of 13.2 kWh per tonne.

(b) Oxidation reactions and carbon injection

The main oxidation reactions occurring inside an EAF are the oxidation of iron and carbon besides oxidation of silicon and manganese. Though the oxidation of iron generates more energy than the oxidation of carbon, it would lead to loss in productivity.

Oxidation reaction of iron

$Fe + \frac{1}{2} O_2 = FeO$; Heat content 6.0 kW/m^3 O_2

Oxidation reaction of carbon

$C + \frac{1}{2} O_2 = CO$; Heat content 3.5 kW/m^3 O_2

Therefore, there is a need to control and manage oxygen injection so that oxidation of iron is kept at a minimum. It may be noted that for bath carbon levels above 0.3%, all the oxygen present reacts with carbon to produce CO. If the level is below 0.3%, the efficiency of carbon oxidation to form CO drops and more and more FeO is generated in the slag. For scrap carbon levels below 0.1%, FeO levels in the slag can become quite high, which is an unavoidable yield loss. Carbon injection needs enhancement to control slag FeO levels and prevent excessive refractory losses. Carbon injection is beneficial where 100% scrap practice is being done or carbon content of the bath is insufficient to produce CO for slag foaming.

10.3 Benefits of technology

Advantages of adopting PC in EAFs are as follows:

- Savings in electricity consumption
- Reduction in tap-to-tap (TTT) time (3%–11%)
- Improves productivity
- Reduces bag-house emissions
- Reduces temperature of the off-gas system

10.4 Investment required, energy and GHG saving potential, and cost-benefit analysis

Studies have indicated a reduction in energy consumption of 4.5 kWh per Nm^3 of oxygen for PC occurring low in the furnace, or about 3 kWh per Nm^3 of oxygen for PC high in the furnace. PC at slag level typically covers about 20%–30% of CO generated in the furnace, whereas PC in freeboard would cover 80% of CO combustion.

The average energy savings with the proper utilization of chemical energy is estimated to be about 1%. The investment requirement is marginal and payback is immediate. The GHG emission reduction potential is about 740 tonnes of CO_2 per year.

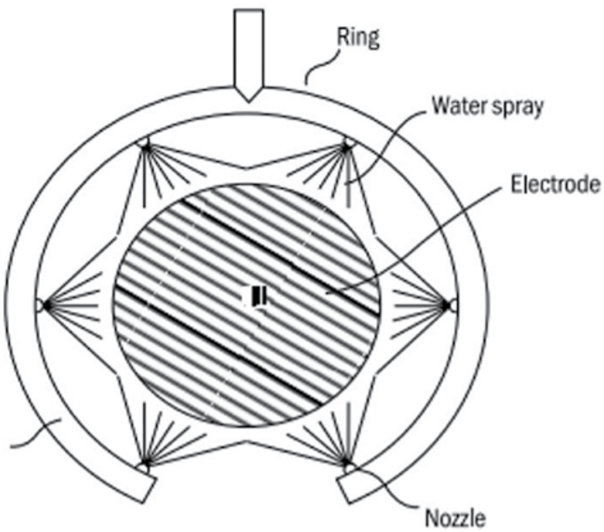
Tech 11: Mist Cooling for Electrodes

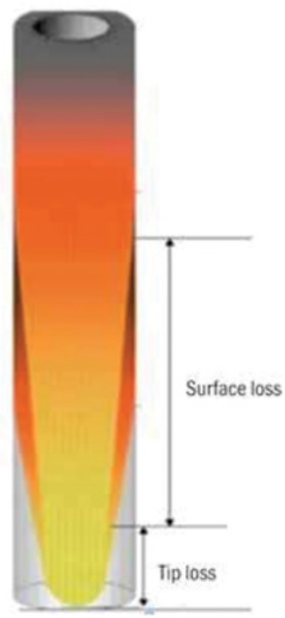
11.1 Baseline scenario

Typically, graphite electrodes are used in EAFs. The electrodes are clamped by an electrode holder and inserted in the furnace. The electric arc is generated between the tip of the electrodes, which produces heat to melt the material in the furnace. The side surface of the electrodes is oxidized and consumed due to the high temperature. During the operation of the furnace, the shape of electrodes changes and at the tip it decreases to as low as 70% of the original electrode diameter.

11.2 Energy efficient technology

The oxidation loss of the side surface of the electrodes in the EAF can be reduced by coating the outer surface or by reducing the outer surface temperature of the electrodes. For this purpose, a jacket of water mist is created over the outer surface of the electrodes thereby reducing the temperature of the side surface.





11.3 Benefits of technology

Mist cooling for electrodes will reduce oxidation loss of the side surface of the electrodes.

11.4 Investment required, energy and GHG saving potential, and cost-benefit analysis

When the flow rate of the cooling water is kept optimum depending on electrode diameters, the electrode consumption reduces by 10%–15%. The corresponding reduction in energy consumption is about 1%. The GHG emission reduction potential is about 740 tonnes of CO_2 per year.

Electrode consumption	Value (%)
Due to arcing	40
Side surface oxidation	50
Tip falls down due to thermal shock	10

Source: TERI energy audit study in EAF unit, 2016

Tech 12: Water-cooled Cables

12.1 Baseline scenario

The cables providing electrical power supply to the furnace from the transformer are water-cooled. The resistance of cables increases with usage and life, which almost doubles in about two years. The EAF units generally replace cables once in 3–5 years leading to energy losses.

12.2 Energy efficient technology

The EAF units should carry out periodic measurements of resistance of the water-cooled cables, at least twice in a year as a regular maintenance practice. As soon as the resistance of the cables increases to about 1.5 times of the design value, the older cables must be replaced with new cables which offer lower electrical resistance.

12.3 Benefits of technology

New water-cooled cable leads to lower energy consumption due to low resistance of the cables when comparing tools cables.

12.4 Investment required, energy and GHG saving potential, and cost-benefit analysis

The average energy saving by replacing old high-resistance water-cooled cables with new cables is estimated to be about 0.15%. Typically for a 50-tonne furnace, the investment requirement is about INR 20 lakh with a simple payback period of about 2 years. The GHG emission reduction potential is about 110 tonnes of CO_2 per year.

An EAF unit in India has adopted regular maintenance practices of its facilities. During regular maintenance, it was found that the resistance of the watercooled cables has increased to about 3.5 times than the design value. The unit replaced the old, high resistance cables with new cables having a resistance of about 90 mΩ. This had resulted in an estimated energy saving of 0.6 kWh per tonne of liquid metal.

Details of an EAF unit that uses a new cable

Particular	Old cable	New cable
Furnace capacity	40 t	40 t
Cable resistance	310 mΩ	90 mΩ
Energy saving	-	0.6 kWh/t
Investment	-	INR 20 lakh
Simple payback period	-	1.5 years

Source: TERI energy audit study in EAF unit, 2016

Tech 13: Copper-based Water-cooled Panel

13.1 Baseline scenario

The water-cooled panels typically used in the electric arc furnaces are made of mild steel. These mild steel-based water-cooled panels normally have low life. Over a period of use, the effectiveness of heat transfer reduces significantly, resulting in higher refractory consumption.

13.2 Energy efficient technology

The mild steel-based water-cooled panels can be replaced with copper-based water-cooled panels.

Copper-water cooled panel

13.3 Benefits of technology

The advantages of copper-based water-cooled panels are as follows:

- Increase in life of panels (up to 6 times)
- Decrease in number of panel failures
- Reduction in refractory consumption.

Tech 14: Improved Refractories

14.1 Baseline scenario

The quality of refractory materials used in the furnace is important for the overall performance. The consumption rate of refractories in smaller capacity EAFs is about 20–35 kg per tonne of liquid steel. For furnaces with water cooling systems, the refractory consumption is considerably low at about 5–10 kg per tonne of liquid metal. High refractory consumption in an EAF leads to high downtime resulting in lower productivity and higher production costs.

14.2 Energy efficient technology

The furnace bottom is generally made by ramming with magnesite ramming mass or dead burnt magnesite peas or ready mix and formed as a monolithic layer. The use of a type of magnesite is dependent on the grade of steel to be manufactured. For example, for the manufacturing of high-alloy steel or special steel, high-purity magnesia ramming mass is preferred. The furnace bottom is exposed to high temperature as well as high load conditions. Hence any dent or crevices formed during furnace operations need to be repaired immediately. The repairing of the furnace bottom is carried out if one or more of the following observations are made during the furnace operation: (i) small cracks at the furnace bottoms due to prolonged use (ii) penetration of liquid metal, or (iii) a damaged bottom.

Magnesite bricks were being used in construction of sidewalls up to the level of slag line in older furnaces. The modern practice includes the use of 'mag-carb' bricks, which is a composite material having high resistance to corrosion. Carbon addition in the bricks leads to high thermal shock resistance. At high temperatures, the porosity of refractories is reduced which brings down the potential for penetration by slag or molten metal. The slag line is fettled with dry dolomite or gunny mix after every heat.

14.3 Benefits of technology

The use of improved refractories, such as castable alumina and Mag-carb refractories, helps in improving the overall life of the furnace, for example the life of side walls with use of Mag-carb refractory is about 200 heats without any repair in case of continuously operated furnaces. This reduces the furnace downtime and enhances productivity.

14.4 Investment required, Energy and GHG saving potential, and Cost-Benefit Analysis

The use of improved refractories, such as castable alumina and Mag-carb refractories helps in improving the overall life of the furnace; for example, the life of sidewalls with use of Mag-carb refractory is about 200 heats without any repair in the case of continuously operated furnaces. This reduces the furnace downtime and enhances productivity. The average energy savings with the use of improved refractories is estimated to be about 0.2%. The GHG emission-reduction potential is about 150 tonnes of CO_2 per year.

Tech 15: Nitrogen as Carrier in Al-Mix Injector

15.1 Baseline scenario

In stainless steel production from EAFs, typically aluminium mix is injected in the furnace, which acts as a reducing agent. This reduces the yield of liquid metal from the furnace.

15.2 Energy efficient technology

In the aluminium mix injector, nitrogen (N2) can be used as carrier gas in the production of stainless steel.

15.3 Benefits of technology

The main advantages of the N2-based Al-mix system are as listed below.

- Reduction in chromium oxide (Cr2O3) in the slag
- Yield improvement
- Reduction in energy consumption.

15.4 Investment required, energy and GHG saving potential, and cost-benefit analysis

The average energy savings with nitrogen as carrier in Al-mix injector is estimated to be about 0.2%. The investment requirements are marginal with immediate payback. The GHG emission reduction potential is about 150 tonnes of CO_2 per year.

Tech 16: Waste Heat Recovery for Boiler Feedwater

16.1 Baseline scenario

The average temperature of melt inside the EAF is about 1650 °C. The off-gasses from the furnace leave at about 900–1200 °C, which is quite high. In most of the EAF plants in India, at present the off-gases are forced to cool down using industrial cooling water so that the gases can be passed through bag filters, which have temperature limitations. The waste heat available in off-gases, which is about 15%–20% of total heat input can be effectively recovered and reused. Although the best option for utilizing off-gas heat is pre-heating of scrap material, there may be constraints in the existing layout of the plant for installing a scrap preheating system.

16.2 Energy efficient technology

The EAF unit typically uses steam for applications, such as vacuum pump operation, in vacuum oxygen decarburization (VOD). The steam requirements are presently met through fossil fuel fired boilers. The feedwater required for steam generation is usually drawn at ambient temperatures. The industrial cooling water is used for reducing the temperature of off-gases in fumes extraction systems to meet the temperature requirements of bag filters. This water can be replaced by circulating boiler feedwater. The sensible heat in off-gases will help in pre-heating of feedwater, which would result in fuel saving in the boiler.

16.3 Benefits of technology

WHR for boiler feed water will increase the temperature of feed water that will reduce sensible heat requirements leading to lower fuel consumption and improvement in overall boiler efficiency.

16.4 Investment required, Energy and GHG saving potential, and Cost-Benefit Analysis

The energy savings for waste heat recovery (WHR) system for pre-heating boiler feedwater include reduction in fuel consumption. Additional electrical energy will be required for pumping of feedwater in WHR circuit. Typical investment required for WHR system is about INR 10 lakh with a simple payback period of about 3 months. The investment would depend on the physical distance between the EAF and the boiler. The GHG emission reduction potential is about 1510 tonnes of CO_2 per year.

Pre-heating boiler feedwater	
Parameter	**Value**
Steam generation	4.7 tph
Increase in feedwater temperature	45 °C
Furnace oil saving	22 kg/h
Net monetary benefits	INR 40 lakh
Investments	INR 10 lakh
Simple payback period	0.2 years

Source: Energy audits of EAF units supported by UNDP, 2017

Tech 17: Scrap Processing

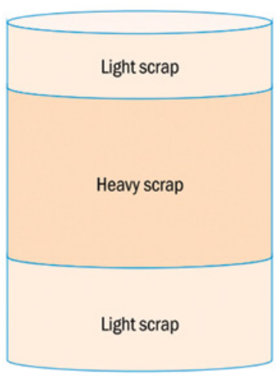
17.1 Baseline scenario

Scrap is an important charge material in EAF. The bulk density of scrap varies largely and affects the duration of melting. The EAF units use both heavy and light scraps. The scrap constitutes for almost 40%–50% of charge material, about 25%–30% being heavy scrap and about 15%–20% light scrap. A large number of EAF units do not follow proper procedure for scrap management. Scrap processing and management is one of the key parameters that influence the overall performance of the furnace.

17.2 Energy efficient technology

Pre-processing of scrap is required to accommodate for variations in bulk density of various types of scrap used by the plant. Scrap processing would comprise shredding, cutting, and bailing/bundling operations. Unwanted foreign material from the scrap is removed and the bulk density of scrap is enhanced by compacting and homogenization.

After pre-processing of scrap, attention must be paid towards preparation of a charge bucket that would help in ensuring proper melt-in chemistry and good melting conditions. The charging of heavy scrap at the bottom may lead to damages to the bottom refractory lining. Hence, it is preferable that a proper procedure shall be adopted, which would not only help in protecting the refractory lining of the furnace but also lead to an efficient melting process. The bottom of the charging bucket must be filled with light scrap or less dense material which will be followed by heavy scrap in the middle. Again, the light scrap will be charged at the top to enable faster melting.



Procedure for scrap charging in bucket

17.3 Benefits of technology

The key advantages of scrap processing are listed below.

- Ensures proper chemistry of metal
- Enhances melting rate
- Protects refractory lining at the bottom
- It further protects side walls and roof from electric arc

17.4 Investment required, energy and GHG saving potential, and cost-benefit analysis

The average energy savings with scrap processing and management is estimated to be about 5%–9%. Typically for a 50-tonne furnace, the investment requirement is about INR 350 lakh with a simple payback period of about 1 year. The GHG emission reduction potential is about 5170 tonnes of CO_2 per year.

Scrap processing in EAF (capacity 90,000 tpy)	
Parameters	**Values**
SEC - without scrap processing	475 kWh/t
Reduction in power on-time	6.9 min
SEC with scrap processing	445 kWh/t
Annual monetary benefits	INR 195 lakh
Investment	INR 350 lakh
Simple payback period	1.8 years

Source: Energy audits of EAF units supported by UNDP, 2017

Tech 18: Scrap Pre-heating

18.1 Baseline scenario

Electric arc furnace involves a high temperature melting operation. The average temperature of melt inside the furnace is about 1650 °C. The off-gases from the furnace leave at about 900–1200 °C, carrying about 20% of input energy. This waste heat available in off-gases can be effectively recovered and reused, which would help in reducing the overall energy consumption of the furnace.

18.2 Energy efficient technology

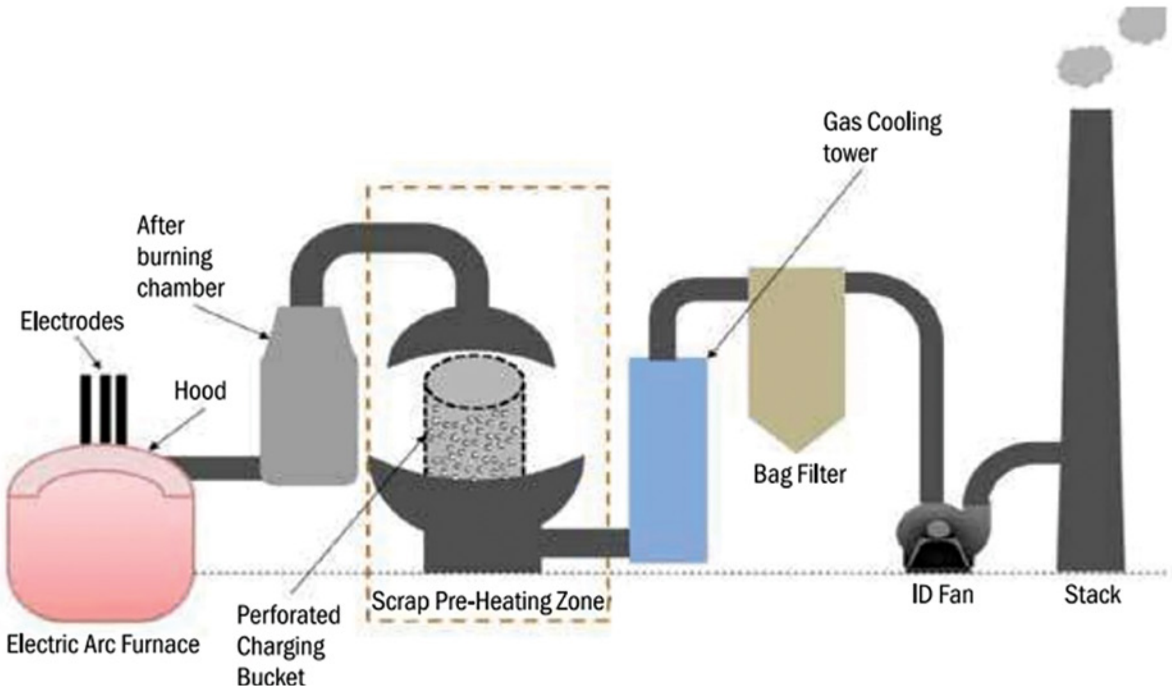
One of the major options for waste heat recovery from off-gases is pre-heating of input scrap material. In the bucket preheating system, hot off-gases from the furnace are directed into the scrap charging bucket with a piping and special hood arrangement. The off-gases enter the bucket at about 800 °C, and leave at around 200 °C, after imparting sensible heat to the scrap. The scrap can be preheated to about 400 °C.

The most established scrap preheating technologies applicable for EAFs are:

- Bucket pre-heating system
- Continuous scrap pre-heating system

(a) Bucket pre-heating system

The bucket pre-heating system was the oldest type of scrap pre-heating used in EAFs. In this, hot off-gases from the furnace are directed into the scrap charging bucket with a piping and special hood arrangement. The off-gases enter the bucket at about 800 °C, and leave around 200 °C, after imparting sensible heat to the scrap. The scrap can be pre-heated to about 400 °C. Some of the disadvantages of using bucket pre-heating system include the following: (a) inconvenient to operate, for example, scrap sticking to bucket, (b) short bucket life and (c) poor controllability of pre-heater system. Further, for tap-to-tap times less than 70 minutes, conventional scrap pre-heating would lead to minimal energy saving and hence the investment towards bucket-type pre-heating systems cannot be justified due to high payback period.



Bucket-type scrap pre-heater in EAF

(b) Continuous scrap pre-heating system

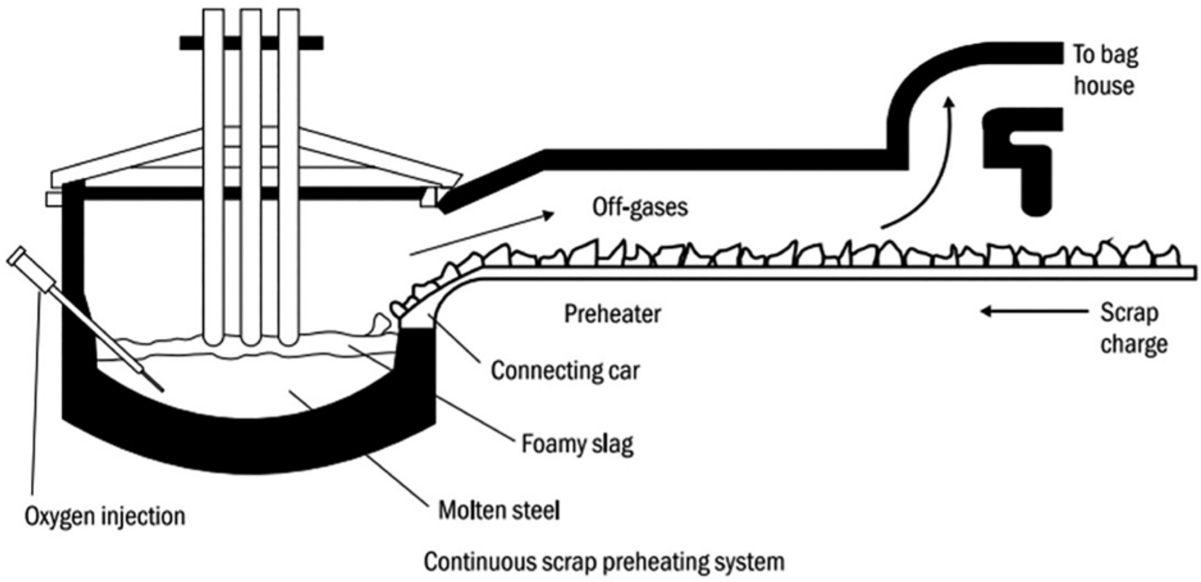
In a continuous scrap pre-heating system, the scrap is put on a conveyor and passed through the pre-heating section. The off-gasses from the EAF are routed through the pre-heater in a counter-flow direction. The pre-heated scrap fed to the furnace transferred through the conveyor car. Some of the important advantages of this system are:

- Increased productivity
- Low electrode consumption
- Reduced harmonic and flickers
- Reduction in dust generation

18.3 Benefits of technology

The key advantages of scrap pre-heating are as follows:

- Increase in productivity
- Removal of moisture from scrap
- Reduction in electrode and refractory consumption.



Continuous scrap pre-heating system
Source: http://infohouse.p2ric.org/ref/10/09048.pdf

18.4 Investment required, energy and GHG saving potential, and cost-benefit analysis

The average energy savings with scrap pre-heating using bucket arrangement is estimated to be about 8%, whereas in a continuous-type arrangement it can be as high as 12%. Typically for a 50-tonne furnace, the investment requirement for bucket arrangement is about INR 200 lakh with a simple payback period of about 0.5 year. The GHG emission reduction potential is about 5900 tonnes of CO_2 per year. The investment required for a continuous-type scrap pre-heating system is about INR 400 lakh with a simple payback period of about one year. The GHG emission reduction potential is about 8860 tonnes of CO_2 per year.

Scrap pre-heating	
Parameters	**Value**
Temperature of off-gases	800 °C
Temperature gain by scrap	300 °C
SEC reduction with preheating	41 kWt/t
Annual monetary benefits	INR 268 lakh
Investments	INR 200 lakh
Payback period	0.7 years

Source: http://ietd.iipnetwork.org/content/tunnel-furnace-preheating-%E2%80%93-consteel-process

Tech 19: Hot Metal Charging

19.1 Baseline scenario

Hot metal use is not a common practice among electric arc furnace units in India. A majority of the electric arc furnace units in India use charge materials at ambient temperatures. The units equipped with Direct Reduced Iron (DRI) process along with EAF can charge the hot DRI directly in EAF. The major reason for not using hot metal is improper layout to handle hot charge to feed in the furnace.

19.2 Energy efficient technology

Combining a charge of hot metal and scrap to an electric arc furnace would help in improving the operating performance of the system. Hot metal with dissolved carbon and silicon is one of the important sources of heat on oxidation. The heat on oxidation along with sensible heat available in hot metal helps in substantial reduction in power consumption of the furnace. Further, hot metal is free of foreign non-metallic materials which would have been removed as slag during the iron making process. There is a great potential to charge hot DRI/HBI directly into electric furnaces at a temperature of about 600 °C. However, the EAF units must take care of strong reactions in molten metal due to interactions between oxygen in steel and from lance and carbon in steel, hot metal, and lance. The hot metal can be charged in a controlled manner to take care of carbon content in liquid metal baths.

Different methods used for transfer of hot DRI into EAF include (i) pneumatic transfer, (ii) electromechanical conveyor system, (iii) gravity feed, and (iv) transport in insulated bottles. Pneumatic and electro-mechanical transfers would require minimum transportation and hence DRI reactors must be located adjacent to EAF. Gravity feed system would also require a closer distance between DRI and EAF, and will be elevated at about 20–30 m. The bottle transfer allows more distances compared to others as these are insulated systems. Charging of hot metal can be done in two locations namely, through roof or slag door.

It has been established that hot metal charge of 30%–40% is more suitable for electric arc furnaces. Hot metal charging up to 50% has been successfully used in some of the EAFs. However, hot metal charging of more than 50% would result in operational problems as excessive heat is generated through oxidation of elements, such as carbon, manganese and silicon, which can lead to overheating of the furnaces.

19.3 Benefits of technology

The major benefits associated with hot metal charging in EAF are as follows:

- Enhanced productivity
- Improved slag foaming
- Increased carbon content in the charge

19.4 Investment required, energy and GHG saving potential, and cost-benefit analysis

The energy savings for hot DRI charging depends largely on the share of DRI in input feed. Typically, furnaces with 50% DRI charging, the energy saving potential is about 150 kWh per tonne of liquid metal, considering a hot DRI temperature of 600 °C. The GHG emission reduction potential is about 22,140 tonnes of CO_2 per year.

Tech 20: Intelligent Control for Off-gas Cleaning

20.1 Baseline scenario

Off-gas cleaning is an integral part of EAF operation, which, however, remains as a neglected auxiliary system. It is often less efficient and offers significant potential for improvement. Gas cleaning is an important aspect in terms of complying with environmental performance standards as applicable.

20.2 Energy efficient technology

A gas cleaning system in an EAF comprises a number of extraction points from where the off gases are sucked. In a gas cleaning with intelligent control, the system is mapped in a mathematical model and loaded into the control unit. The model evaluates required flap settings and flow rates in individual network segments in real time and controls dynamically. The monitoring arrangement at an extraction point will ensure that the flow rate of off-gases does not fall below a certain minimum level, independent of flow rates required at other extraction points. The monitoring function of the control system ensures reliability in long-term planning for operation and servicing of the system.

20.3 Benefits of technology

Reduction in specific energy consumption, better control and reliability are the major benefits of intelligent control for off-gas cleaning.

20.4 Investment required, energy and GHG saving potential, and cost-benefit analysis

The typical energy savings with adoption of intelligent control for off-gas cooling is estimated to be about 20% of the fumes extraction system. Typically for a 50-tonne furnace, the saving is in tune of 1.0–1.5 kWh per tonne of liquid metal. The GHG emission reduction potential is about 210 tonnes of CO_2 per year.

Tech 21: Shaft Furnace

21.1 Baseline scenario

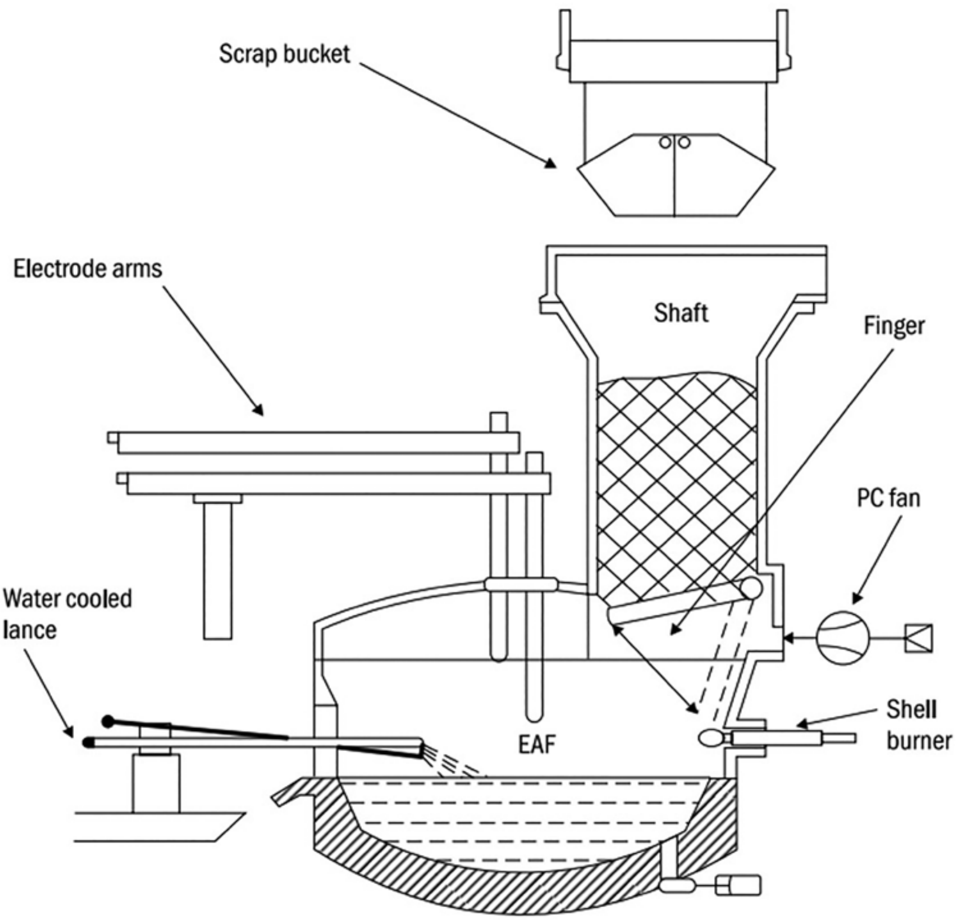
Scrap pre-heating is an important technology for improving the energy performance of an EAF. Typically, scrap pre-heating is either not in use or a bucket pre-heating arrangement is used. With this arrangement the improvement in energy efficiency is limited.

21.2 Energy efficient technology

Shaft furnace is an advanced scrap pre-heating system. In a shaft furnace, the pre-heating arrangement is mounted over the arc furnace itself. The different types of shaft furnaces used in EAFs are (i) single shaft, (ii) double shaft, and (iii) finger shaft.

In a single shaft furnace, about 50% of the scrap can be pre-heated. A double shaft furnace is an improvement to the single shaft furnace, which consists of two identical shaft furnaces, having twin shell arrangement and positioned next to one another.

The most efficient shaft- furnace design is the 'finger shaft furnace'. The scrap is charged into the furnace through the shaft. Off-gases pass through the shaft and heat the scrap. The finger shaft is water cooled to ensure smooth operation. With the availability of a scrap retaining system, pre-heating of the entire scrap can be accomplished effectively.



Finger shaft furnace

Source: http://global.kawasaki.com/en/corp/rd/magazine/140/ne140s01.html

21.3 Benefits of technology

The advantages of finger shaft furnace are as follows:

- High energy saving
- Increase in productivity by about 20%.

21.4 Investment required, energy and GHG saving potential, and cost-benefit analysis

The average energy savings with a finger shaft furnace is estimated to be about 15%–20%. Typically for a furnace of 50-tonne capacity, the investment requirement is about INR 2500 lakh with a simple payback period of about 3–4 years. The GHG emission reduction potential is about 11,070 tonnes of CO_2 per year.

Tech 22: Direct Current Arc Furnace

22.1 Baseline scenario

The EAF units in India use AC electric arc furnaces. In an AC EAF, the electric arc forms between the three electrodes and the melt. The major issues associated with AC EAFs include frequent electrode tip breakage and higher radiation loss to side walls. The electrode consumption of AC-arc furnaces in India varies between 3 and 6 kg per tonne of liquid melt, which is double the international standards.

22.2 Energy efficient technology

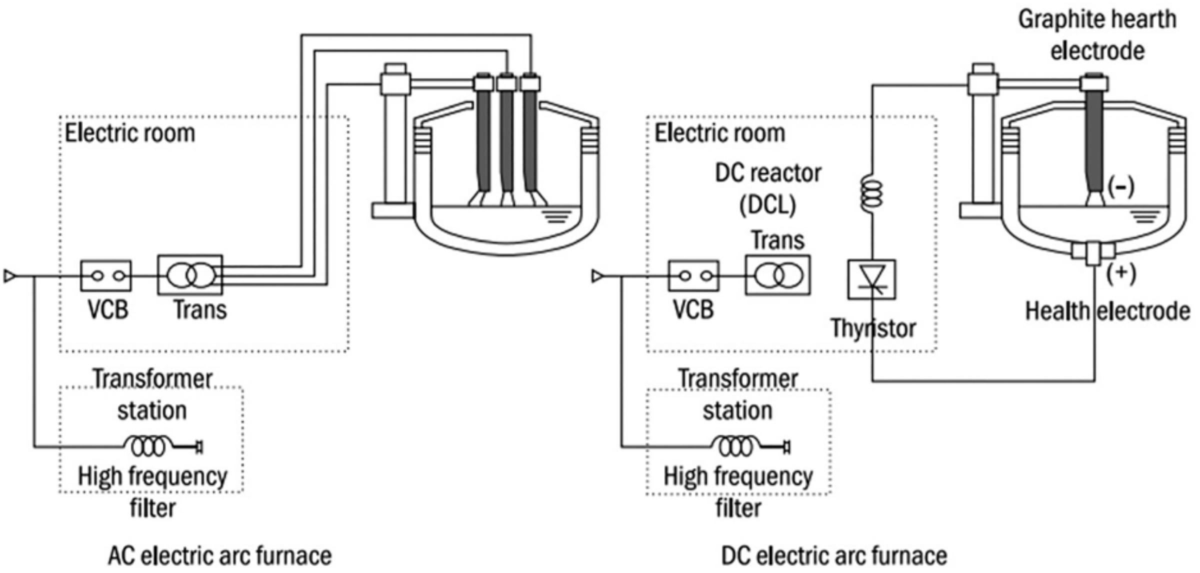
DC arc furnace is an alternative to the existing AC EAFs, which can reduce the electrode consumption and the refractory damages by arcing flashes. The output of the UHP transformer is converted to DC using a power rectifier, usually bridge-connected thyristors. A DC furnace has only one electrode, which acts as a cathode whereas a return electrode known as anode is at the bottom of the furnace for completing the electrical circuit.

The performance comparison of DC and AC arc furnaces are as follows:

(a) The electrical losses in AC arc furnaces are about 4%. The electrical losses in the DC arc furnace are 30%–50% higher than AC furnace due to additional reactors and rectifiers in place;

(b) The electrode consumption of the DC furnace is substantially lower. The side losses are one-third in DC furnaces as compared to AC furnaces, whereas the breakage loss is only 50%, though there is a slight increase in the tip losses which is primarily due to increase in current;

(c) The electrical energy consumption in DC furnace is about 5% less than that of AC furnace for similar capacity.



Source: Japanese technologies for energy saving/GHG emission reduction, NEDO, 2008

Shaft arc furnace with DC system: The furnace system consists of EBT lower shell, water-cooled upper shell, and the two identical shafts mounted over the upper shell. The unique design of shaft type DC arc furnace enables uniform pre-heating of the scrap. Water-cooled fingers retain the scrap in the vertical shafts.

22.3 Benefits of technology

The major advantages of DC arc furnace over AC arc furnace are as follows:

- High current density and power usage
- Reduction in electrode consumption
- Lower refractory consumption
- Reduction in flickers

22.4 Investment required, energy and GHG saving potential, and cost-benefit analysis

The average energy savings with a DC arc furnace is about 5%. Typically for a furnace of 50-tonne capacity, the investment requirement is about INR 2500 lakh. The monetary benefits from reduction in consumption of electrodes will be substantial. The simple payback period will be about 2 years. The GHG emission reduction potential is about 3690 tonnes of CO_2 per year.

Tech 23: Single Bucket Charging System - Telescopic Roof

23.1 Baseline scenario

In conventional EAFs, a minimum charge density must be maintained, which otherwise would lead to increase in the number of bucket charges. This would lead to interruptions in the melting process resulting in loss in productivity and poor energy performance. Typically, in Indian EAFs, roughly 10%–15% time is lost in every heat due to multiple bucket charging.

23.2 Energy efficient technology

In an EAF with a telescopic roof enclosure system, a single bucket system with low charge density can be used without increasing shell diameter and height. The telescopic furnace system allows flexible shell charging volume and the electrode length can be significantly shorter than other single charge type electric arc furnaces of similar capacities. The large distance between the top of the scrap pile and the horizontal portion of the roof allows for initial charge to be borne down with higher power and larger arcs, thereby increasing average power input.

With the start of scrap melting, the roof along with electrode columns is lowered to follow the reducing height of charge volume. The roof is gradually made to slide down to a completely closed position, which leads to overlapping between the roof and part of the upper shell. The lifting system for the roof and electrodes are independent, which allows electrodes to continuously track falling height of the charge pile. The cycle of telescopic movement between upper closing position after completion of charging and completely full close position is completed after 30%–40% of power-ON time.

23.3 Benefits of technology

The major advantages of single bucket charging system with telescopic arrangement include the following:

- Ability to handle low charge density, i.e., 0.55 tonne per m^3
- Less tap-to-tap time
- Low power-OFF time
- Low electrode consumption and breakage.

23.4 Investment required, energy and GHG saving potential, and cost-benefit analysis

The average energy savings with telescopic roof-based single bucket charging systems is estimated to be about 10%–15%. This type of furnace is presently available for capacity in excess of 100 tonnes. The investment requirement is about INR 3,000 lakh with a simple payback period of about 5 years. The GHG emission reduction potential is about 7380 tonnes of CO_2 per year.

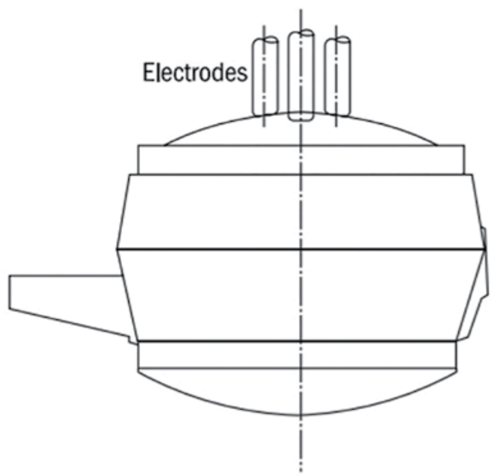
Tech 24: Tapered Shell Furnace

24.1 Baseline scenario

The EAFs have a uniform cross-section along the height of the furnace. This would result in hot spots close to side walls leading to reduced lining life of the furnace. It would further increase heat losses to side walls thereby reducing the efficiency of the furnace system.

24.2 Energy efficient technology

One of the solutions for reducing the hot spots and heat losses to side walls is use of tapered shell design for the furnace. In this design, the furnace volume is increased without increasing the shell height. This is achieved by increasing the shell diameter only midway between sill-line and the top bezel ring. The bezel ring helps in maintaining the shape of the top of the furnace shell. This arrangement is more useful for large capacity furnaces.



Tapered shell furnace

24.3 Benefits of technology

The associated benefits of tapered shell furnace include the following:

- Longer life of side wall lining due to larger diameter of the shell at the hot spots
- Reduced heat losses and enhanced heating of the charge material

Tech 25: Neural Network for Process Control

25.1 Baseline scenario

The present control systems for EAF operation through modeling of the dynamic parameters have not yielded optimum results. The existing process control for electrode regulation systems provide energy saving of about 3%. However, there is a further scope for more efficient operation based on state-of-the-art process control.

25.2 Energy efficient technology

Recent advancements have led to the use of artificial intelligence-based electrode controllers. Intelligent data processing with neural networks offers a better solution for electrode regulation systems. These intelligent systems integrate real-time monitoring of process variables, such as liquid metal temperature, carbon percentages, and oxygen lancing practices.

25.3 Benefits of technology

The advantages of using neural network for process control are listed below.

- Control and reliability
- operation control optimization
- Reduction in electrode consumption
- Improvement in productivity

25.4 Investment required, energy and GHG saving potential, and cost-benefit analysis

The average energy savings with neural networks based electric arc furnace electrode regulation system is estimated to be about 3%–5%. Typically for a furnace of 50-tonne capacity, the investment requirement is about INR 150 lakh with a simple payback period of about 6 months. The GHG emission reduction potential is about 2950 tonnes of CO_2 per year.

Neural network for process control	
Parameter	**Value**
Energy saving	20 kWh/t
Electrode saving	0.5 kg/t
Productivity improvement	10%
Monetary benefit	INR 140/t
Investment	INR 150 lakh
Simple payback period	0.5 years

Source: "The State–of-the-Art Clean Technologies (SOACT) for Steelmaking Handbook", December 2010

SECTION 5:
Common Technologies

Tech 1: Energy Efficient Motors

1.1 Baseline scenario

Three-phase induction motors are most commonly used to run various applications in all sectors of steel industries. A 3-phase induction motor has two main parts: the stator or the stationary part and the rotor or the rotating part. Stator is made by staking thin slotted highly permeable steel lamination inside a steel cast or cast-iron frame. Windings pass through slots of stator. When a 3-phase AC current is passed through it, it produces a rotating magnetic field. The speed of rotation of the magnetic field is called synchronous speed.

A rotor is similar to a squirrel cage, which is placed inside the magnetic field; current is induced in bars of the squirrel cage, which are shortened by the end ring. In effect, the rotor starts rotating. To aid such electromagnetic induction, insulated iron core laminas are packed inside the rotor; such small slices of iron ensure that the eddy current losses are minimal. The rotor always rotates at a speed slightly lesser than the synchronous speed; the difference is referred to as slip. Rotational mechanical power is transferred through a power shaft. Energy loss during motor operation is dissipated as heat; so, a fan at the other end helps to cool down the motor.

Motor efficiency is defined as the ratio of mechanical power output to electrical power input. Generally, conventional motors are used with an efficiency range from 75% to 88% depending on the size. At times, motors fail and work of a unit may come to complete stand still. Motor failures can be attributed to mechanical and electrical reasons. Causes such as improper voltage, voltage fluctuations, improper lubrication, and damaged bearings lead to rise in motor winding temperature ultimately leading to failure. These electrical failures lead to the next obvious step, which is motor rewinding. The motor efficiency further decreases with each rewinding as it is mostly carried out by unskilled workers. Normally, a typical unit follows 7–8 times rewinding of a motor with its lifespan of 10 years. Considering 1% efficiency drop in each rewinding exercise, it may lead to significant financial and energy losses.

1.2 Energy efficient technology

Compared to conventional systems, the efficiency of energy efficient motors available in the market ranges from 80% to 95% depending on the size. Energy efficient motors operate at higher efficiencies compared to conventional motors due to the following design improvements:

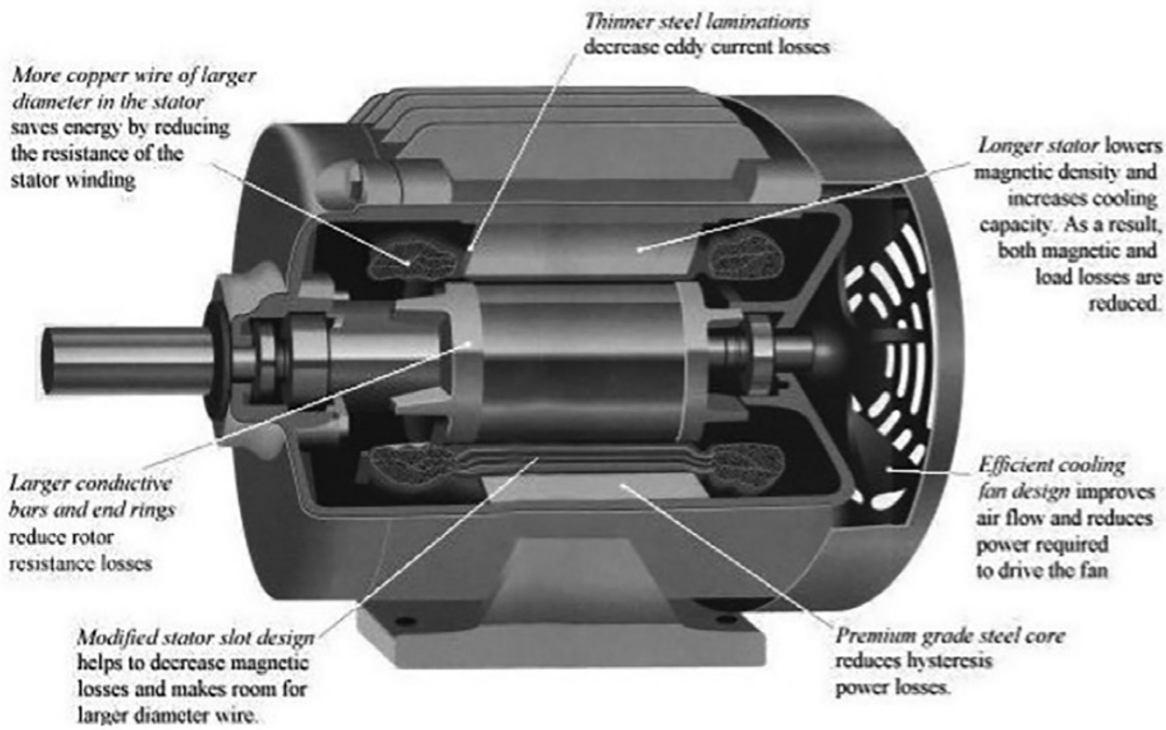
Stator and rotor copper losses constitute for 55%–60% of the total losses. Copper losses are reduced by using more copper conductors in stator and by using large rotor conductor bars.

Iron loss accounts for 20%–25% of the total losses. Using a thinner gauge, low loss core steel, and materials with minimum flux density reduces iron losses. Longer rotor and stator core length, precise air gap between stator and rotor also reduce iron losses.

Friction and windage losses constitute about 8%–10% of the total losses. Friction loss is reduced by using an improved lubricating system and high-quality bearings. Windage loss is reduced by using energy efficient fans.

Stray load loss accounts for 4%–5% of the total losses. Use of optimum slot geometry and minimum overhang of stator conductors reduces stray load loss.

Conventional motors operate in a lower efficiency zone when they are loaded less than 60%. The efficiency of energy efficient motors drop when they are loaded less than 50%. However, the efficiency of energy efficient motors is always higher than conventional motors, irrespective of the loading.



Energy efficient motor parts

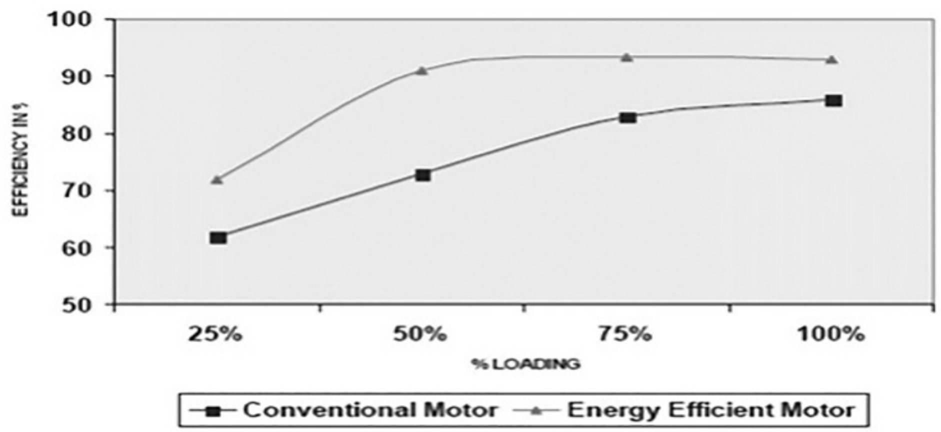
Source: https://www.rcet.org.in/uploads/academics/rohini_41694730614.pdf

When old motors are rewound more than 5 times, energy efficient motors can be considered as an ideal replacement. The technical specifications of a 40-hp energy efficient motor are presented below.

Specifications of an energy efficient motor

Sl no.	Parameter	Value
1	Capacity of motor	40 hp
2	Type of motor	AC induction
3	Motor power	40 kW
4	Rated current	60 A
5	Rated voltage	415 V
6	Power factor	0.8
7	Frequency	50 Hz
8	Efficiency at full load	93.9%

The loading vs efficiency curve for energy efficient motors vis-à-vis conventional motors is shown in the figure below.



Loading vs efficiency for motors

Source: https://www.energymeasuretosave.com/ECPoints/ECPHtml/motor-efficieny-vs-loading.html

1.3 Benefits of technology

The advantages of using energy efficient motors over conventional motors are listed below.

- Operate more satisfactorily under abnormal voltage
- Savings in electrical power consumption is by 20%
- Operating temperature is less
- Noise level is lower

1.4 Limitations of technology

Adoption of energy efficient motors has no limitations, whatsoever.

1.5 Investment required, Energy and GHG saving potential, and Cost- Benefit Analysis

To understand the cost-benefit analysis, let us consider a 40-hp crusher motor. The cost-benefit analysis of an energy efficient motor is tabulated below.

Cost-benefit analysis of an energy efficient motor

S/ no.	Parameter	Existing motor	Energy efficient motor
1	Connected load	40 hp	40 hp
2	Connected load	29.84 kW	29.84 kW
3	Motor efficiency	82%	93.9%
4	Measured power	30.96 kW	27.0 kW
5	Loading	80%	80%
6	Working hours per day	16	16
7	Working days in a year	300	300
8	Annual power consumption	1,48,608 kWh	1,29,775 kWh
9	Power tariff	INR 7/kWh	INR 7/kWh
10	Total energy cost	INR 10.4 lakh	INR 9.1 lakh
11	Energy savings due to energy efficiency	18,833 kWh/y	
12	Cost of energy savings	INR 1.32 lakh/y	
13	Investment required	INR 2.50 lakh	
14	Simple payback period	22.76 months	
15	Annual energy savings potential	1.62 toe/y	
16	Annual GHG emissions reduction potential	13.37 tCO_2/y	

1.6 Technology summary

The technology impacts for energy efficient motors are summarized below.

- Annual energy saving : 1–4 toe
- Annual GHG emission reductions : 10–18 tCO_2
- Annual monetary saving : INR 0.8–1.9 lakh
- Investment : INR 1.4–3.8 lakh
- Payback period : 18–34 months

Tech 2: Energy Efficient Lightings and Fixtures

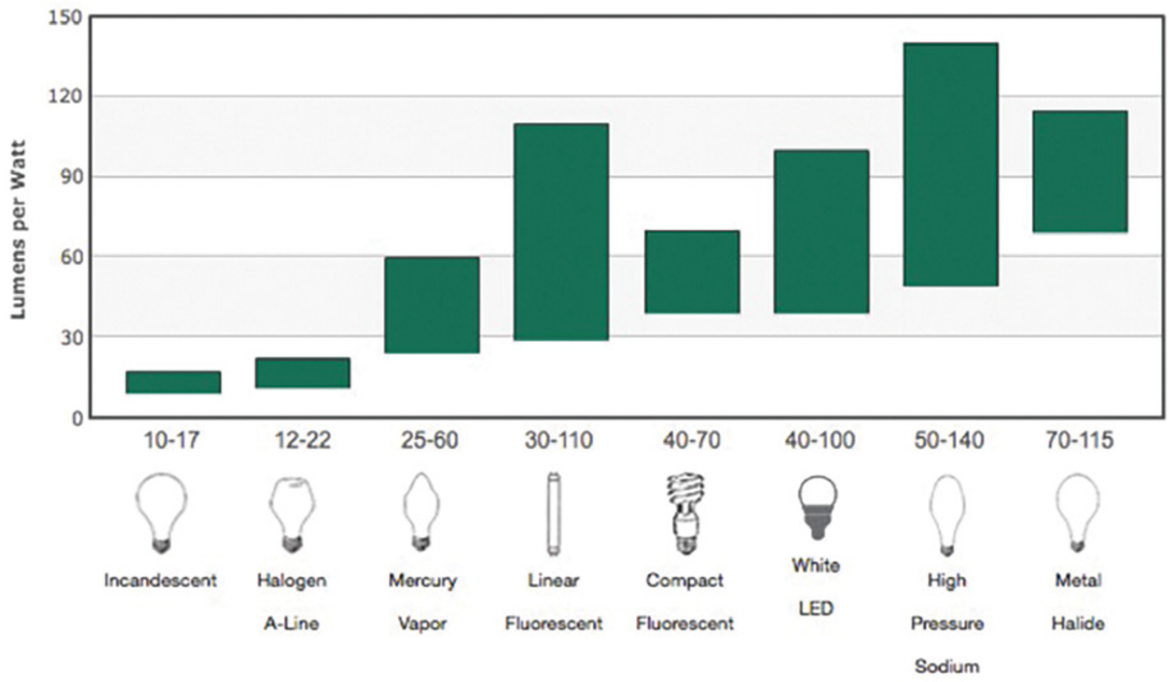
2.1 Baseline scenario

Lighting accounts on average for about 10% of total electricity used in industry. Most conventional units use a variety of lighting fixtures such as fluorescent tubes, incandescent and mercury vapour lamps, and metal halide (MH). in their offices and factory sheds. These conventional lighting fixtures consume a lot of energy. Also, lives of such fixtures are limited. Most steel units are operational for the whole day long and consume a significant portion of energy on account of lighting and fixtures. Also, due care is not given towards the lux level of different areas. Most of the units have sheds covered with asbestos sheets with negligible or no provisions for natural lighting.

2.2 Energy efficient technology

Recent developments in lighting technology combined with planned lighting control strategies can result in significant cost savings, typically in the range of a third to a half of the electricity traditionally used for lighting. Some of the important areas of energy conservation in steel industries are listed below.

- Replacement of conventional lighting with energy efficient LED lighting.
- Maximize the use of daylight to reduce the need for electric lighting.
- Roof lights are particularly efficient as they disperse light evenly over the whole floor area. Provision of natural lighting in the bay area of unit using translucent sheets in the shed is suggested.
- Painting of surfaces (including the ceiling) with matt colours of high reflectance to maximize the effectiveness of the light output. Light/bright colours can reflect up to 80% of incident light; dark/deep colors can reflect less than 10% of incident light.
- Astronomical-based timer controls have adequate control and automatically operate light based on weather information and latitude–longitude data. Astronomical-based timer control on high wattage fixtures, i.e., HMT lights, boundary lights, etc.
- Occupancy sensors in washrooms and individual personnel office cabins.



Lumens per watt for different type of lights

Source: https://www.bijlibachao.com/lights/why-led-lights-are-better-than-fluorescent-lights-even-when-lumens-per-watts-are-the-same.html

2.3 Benefits of technology

The advantages of using energy efficient lighting and fixtures over conventional lights are listed below.

- Reduced energy consumption
- Longer lifespan
- Improved lighting quality

2.4 Limitations of technology

Adoption of energy efficient lighting and fixtures has no limitations.

2.5 Investment required, energy and GHG saving potential, and cost-benefit analysis

To understand the cost-benefit analysis, let us consider a 15-tph SRRM unit. The cost-benefit analysis of energy efficient lighting and fixtures are tabulated below.

Cost-benefit analysis of energy efficient lighting and fixtures

Sl no.	Parameter	With conventional lighting	With energy efficient lighting
1	Productivity	15 t/h	15 t/h
2	Operating hours per day	16	16
3	Operating days per year	300	300
4	Specific power consumption	120 kWh/t	
5	Annual power consumption	86,40,000 kWh	
6	Considering lighting load as 8% of overall load, total power consumed in lighting	8,64,000 kWh	
7	Energy saving (considering 20% energy savings due to adoption of energy efficient lighting innovations)	1,72,800 kWh	
8	Monetary savings in terms of power saved	INR 12.10 lakh	
9	Investment required	INR 32 lakh	
10	Simple payback period	31 months	
11	Annual energy savings	15 toe/y	
12	Annual GHG emissions savings	122 tCO_2/y	

2.6 Technology summary

The technology impacts for energy efficient lighting and fixtures are summarized below.

- Annual energy saving : 10–20 toe/y
- Annual GHG emission reductions : 80–150 tCO_2/y
- Annual monetary saving : INR 8–15 lakh/y
- Investment : INR 25–40 lakh
- Payback period : 30–40 months

Tech 3: Replacement of Reciprocating Compressor with Screw Compressor with Variable Frequency Drive and Permanent Magnet Motor

3.1 Baseline scenario

Compressed air requirement of the plant is met by either a screw-type or reciprocating-type compressor. In many of the units, these compressors are operating without a VFD although they have variable loading; also, these compressors have induction motors.

Induction motors use two parts: a stationary stator and a rotating rotor. The electric current passes through the stator to produce a rotating magnetic field. This, in turn, induces a current in the rotor, which creates a second magnetic field. The interaction between these two magnetic fields produces turning torque, causing the rotor shaft to turn.

But the induction motor shaft and the magnetic field do not turn at the same pace. Due to losses in bearings and other elements, the rotor cannot keep up with the field and is usually below the magnetic field synchronous speed by approximately 1%–5%. This is called slip. Over time, slip can cause damage to your motor and compressor.

3.2 Energy efficient technology

Screw compressor with VFD and permanent magnet motors are best suited for continuous variable load applications. A VFD provides efficient operation over a wide range by closely matching the output with the demand.

High-speed permanent magnet motors offer increased energy efficiency compared to conventional asynchronous induction motors. A permanent magnet motor has air-cooled winding heads and water-cooled housing for reliable operation, and extremely low-loss lamination grade material in the motor core results in low iron losses. Non-contact magnetic bearings are used to hold the motor shaft in place, so there is less vibration and no friction between the components, resulting in less wear.

Permanent magnet motors offer excellent performance without inadvertently damaging compressors, leading to less wear and longer system lifespan.

Screw compressor

Source: https://www.atlascopco.com.cn/en/compressors/products/Air-compressor/oil-free-air-compressors/oil-free-air-compressors-ZR-ZT

3.3 Benefits of technology

The advantages of using screw compressor with VFD and permanent magnet (PM) motor are listed below.

- Energy efficient
- Precise control with wide operating range
- Improved part-load efficiency
- Compact design and reduced maintenance costs
- Lower noise levels

3.4 Limitations of technology

Adoption of screw compressors with VFD and PM motors has no limitations. However, if it is run at maximum capacity with constant load, the benefits of speed control and reduced energy consumption will be not significant.

3.5 Investment required, energy and GHG saving potential, and cost-benefit analysis

To understand the cost-benefit analysis, let us consider a 35-kW screw compressor without VFD. The cost-benefit analysis of a screw compressor with VFD and PM motor are tabulated below.

Cost-benefit analysis of a screw compressor with VFD and PM motor

Sl no.	Parameters	Value
1	Loading time	60%
2	Unloading time	40%
3	Maximum loading power	35.6 kW
4	Minimum unloading power	9 kW
5	Electricity consumption	24.96 kWh
6	Energy savings due to VFD	18%
7	Electricity saved by installing VFD	4.49 kWh
8	Electricity saved due to higher efficiency of PM motor	1.00 kWh
9	Total operating hours of compressor in a year	4800
10	Annual electricity savings	26358 kWh
11	Electricity charges	INR 7/kWh
12	Annual monetary saving	INR 1.85 lakh
13	Investment required	INR 7 lakh
14	Simple payback period	46 months
15	Annual energy saving potential	2.27 toe
16	Annual GHG emissions reduction potential	18.71 tCO_2

Energy saving and GHG emission reduction will be much higher (almost by another 20%–25%) if the plant replaces the reciprocating compressor with screw compressor with VFD and PM motor.

3.6 Technology summary

The technology impacts for a screw compressor with VFD and PM motor are summarized below.

- Annual energy saving : 1.8–4 toe/y
- Annual GHG emission reductions : 15–25 tCO_2/y
- Annual monetary saving : INR 1.5–2.5 lakh/y
- Investment : INR 5–12 lakh
- Payback period : 40–60 months

Tech 4: Energy Efficient Compressed Air Network

4.1 Baseline scenario

In a compressed air system, pressure drops naturally happen as compressed air moves through the distribution system around the plant or facility. A well-made compressed air piping system should incur a pressure loss of less than 10% of the air compressor's discharge pressure, when measured from the air compressor discharge outlet to the point of use.

In an ideal case, the pressure drop in the pipes does not exceed 0.3 bar between the air compressor discharge point and the furthest point of consumption. However, generally, plant personnel increase the discharge pressure at the air compressor end to compensate for the pressure drop, but they are using more energy than they should. And, if demand along the pipes is reduced, the pressure drop reduces, and pressure at the point of consumption unexpectedly rises above the allowed level. This is not economical, and leads to more inefficiency and raises energy costs.

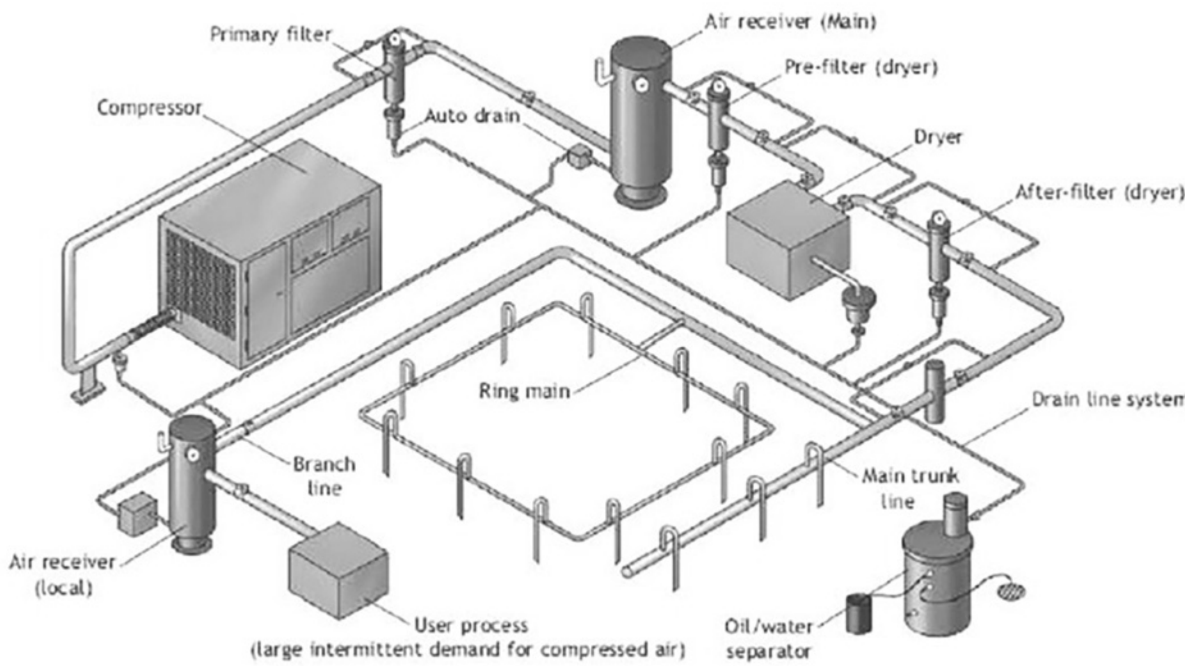
4.2 Energy efficient technology

The best solution involves designing a closed-loop ring-pipe system with proper piping material and design. From this starting point, branch pipes can run to various consumption points. This approach provides uniform compressed air supply, as air is led to the consumption point from two directions.

To maintain ideal pressure, all air compressor installations should use this system. The only exception is if there is a great distance between the machine and point of consumption, where a separate main pipe is added.

Distribution of compressed air generates pressure losses caused by friction in the pipes. With this in mind, the pressure generated directly by the compressor is usually not fully ready for utilization. In addition, throttling effects and changes in the direction of flow occur in valves and pipe bends. Losses, which are converted to heat, result in pressure drops.

Material selection (i.e., Aluminum or stainless steel pipe) and compressed air network should be designed by keeping all these in mind. This can lead to energy saving and lower specific energy consumption for overall compressed air network.



Typical compressed air system

Source: https://www.researchgate.net/figure/Typical-compressed-air-system_fig4_265395773

4.3 Benefits of technology

The advantages of using energy efficient compressed air network are listed below.

- Low pressure drop between the compressor and the point of consumption
- Minimal leakage from the distribution piping

4.4 Limitations of technology

Adoption of energy efficient compressed air networks has no limitations.

4.5 Investment required, energy and GHG saving potential, and cost-benefit analysis

To understand the cost-benefit analysis, let us consider a screw compressor of 215-cfm (cubic feet per minute) capacity. The cost-benefit analysis of energy efficient compressed air network is tabulated below.

Cost-benefit analysis of energy efficient compressed air network

Sl no.	Parameters	Value
1	Compressed air capacity	215 cfm
2	Operational specific energy consumption (SEC)	0.18 kW/cfm
3	Electricity consumption	38.7 kWh
4	Loading %	80
5	Annual energy consumption	1,85,760 kWh
6	Compressed air saving	15%
7	Annual electricity savings	27,864 kWh
11	Electricity charges	INR 7/kWh
12	Annual monetary saving in INR	INR 1.95 lakh
13	Investment required	INR 5 lakh
14	Simple payback period	31 months
15	Annual energy savings	2.40 toe
16	Annual GHG emissions reduction	19 tCO_2

4.6 Technology summary

The technology impacts for energy efficient compressed air network are summarized below.

- Annual energy saving : 2–4 toe
- Annual GHG emission reductions : 15–25 tCO_2
- Annual monetary saving : INR 1.6–3.0 lakh
- Investment : INR 4–8 lakh
- Payback period : 25–40 months

Tech 5: Energy Efficient Pumps

5.1 Baseline scenario

A pumping system is an integral part of auxiliaries in the induction furnace operation. Pumps are installed for coil cooling, heat exchanger, and panel cooling. Mainly, mono-block-type pumps are used in the cooling water circuit of the induction furnaces. The pumping system contributes to about 5%–6% of the total energy consumption per tonne of production. Existing pumps were found to be old and inefficient in the majority of the units. The performance evaluation of some of the existing coil cooling pumps indicates operating efficiency to be about 40%, which is quite low.

5.2 Energy efficient technology

To reduce the power consumption of the auxiliary system, it is recommended to replace the existing pump with an energy-efficient pump matching the designed head and flow. A comparison of performance of existing pumps with the more energy efficient pumps available in the market revealed that there is significant energy saving potential, if these pumps are replaced.

Energy efficient pumps

Source: https://empoweringpumps.com/mean-energy-efficient-motor/

5.3 Benefits of technology

The advantages of using energy efficient pumps are as follows:

- Reduced energy consumption
- Operational flexibility due to VFD

5.4 Limitations of technology

Adoption of energy efficient pumps has no limitations.

5.5 Investment required, energy and GHG saving potential, and cost-benefit analysis

To understand the cost-benefit analysis, let us consider a pump with 37-kW motor capacity. The cost-benefit analysis of energy efficient pumps is tabulated below.

Cost-benefit analysis of an energy efficient pump

Sl no.	Parameters	Value
1	Water flow	93.84 m^3/h
2	Total head	43 m
3	Fluid density	1000 kg/m^3
4	Hydraulic power	11 kW
5	Power consumption of motor	34 kW
6	Motor efficiency	80%
7	Power input to pump shaft	27.2 kW
8	Pump efficiency	40%
9	Number of pump	1
10	Existing power rating of pump	37.3 kW
11	Existing total energy consumption in a year	2,04,000 kWh
12	Proposed power rating of pump	22 kW
13	Proposed total energy consumption in a year	1,19,953 kWh
14	Annual electricity savings in a year	84,047 kWh
15	Electricity charges	INR 7/kWh
16	Operating hours per day	20
17	Number of operating days in a year	300
18	Annual monetary saving	INR 5.88
19	Investment required	INR 6 lakh

Sl no.	Parameters	Value
20	Simple payback period	12.2 months
21	Annual energy saving potential	7.2 toe
22	Annual GHG emissions reduction potential	60 tCO_2

5.6 Technology summary

The technology impacts for energy efficient pump are summarized below.

- Annual energy saving : 5–12 toe
- Annual GHG emission reductions : 45–70 tCO_2
- Annual monetary saving : INR 4–10 lakh
- Investment : INR 5–12 lakh
- Payback period : 11–18 months

Tech 6: FRP Blades in Cooling Tower

6.1 Baseline scenario

Cooling towers are used to serve the cooling water needs for various uses in the industries. The cooling water from the cooling tower comes to the pump suction by gravity and the pump supplies it to the required section. The cooling water from the section then goes back to the cooling tower. Existing cooling towers had induced axial flow fans with metallic/aluminum blades. It is well known that metallic/aluminum blades are heavier and need relatively greater starting torque.

6.2 Energy efficient technology

The use of FRP blades instead of metallic/aluminum blades will save energy and improve the performance of the cooling towers owing to the better aerodynamic shape of its blades. The power measurements show that the fan with FRP blades consumes less power compared to the metallic blade fan. The difference in power consumption is about 25%–30%. It is recommended to replace existing metallic/aluminum fan blades in the cooling tower with fibre-reinforced plastic blades.

FRP blade in cooling tower

Source: https://encongroup.co.in/product/FAN

6.3 Benefits of technology

The advantages of using FRP blades in cooling tower are listed below.

- Energy efficient due to their lightweight and aerodynamic design
- Corrosion resistance
- Reduced noise
- Low maintenance

6.4 Limitations of technology

Adoption of FRP blades in cooling towers has no limitations.

6.5 Investment required, energy and GHG saving potential, and cost-benefit analysis

To understand the cost-benefit analysis, let us consider a cooling tower fan of 7.5-kW motor capacity. The cost-benefit analysis of FRP blades in cooling tower is tabulated below.

Cost-benefit analysis of FRP blades in a cooling tower

Sl no.	Parameters	Value
1	Rated power consumption of cooling tower (CT) fan	7.5 kW
2	Existing power consumption of CT fan	4.5 kW
3	Operating hours per day	24
4	Number of operating days in a year	300
5	Existing power consumption of CT fan	32,400 kWh/y
6	Anticipated savings with installation of FRP blades	25%
7	Expected power consumption of CT fan after installing FRP blades	24,300 kWh/y
8	Annual energy saving	8100 kWh
9	Electricity charges	INR 7/kWh
10	Annual monetary saving	INR 0.57 lakh
11	Investment required	INR 0.5 lakh
12	Simple payback period	10.6 months
13	Annual energy savings potential	0.7 toe
14	Annual GHG emissions reduction potential	5.8 tCO_2

6.6 Technology summary

The technology impacts for FRP blades in a cooling tower are summarized below.

- Annual energy saving : 0.5–1 toe
- Annual GHG emission reductions : 4–8 tCO_2
- Annual monetary saving : INR 0.4–0.8 lakh
- Investment : INR 0.35–0.7 lakh
- Payback period : 10–18 months

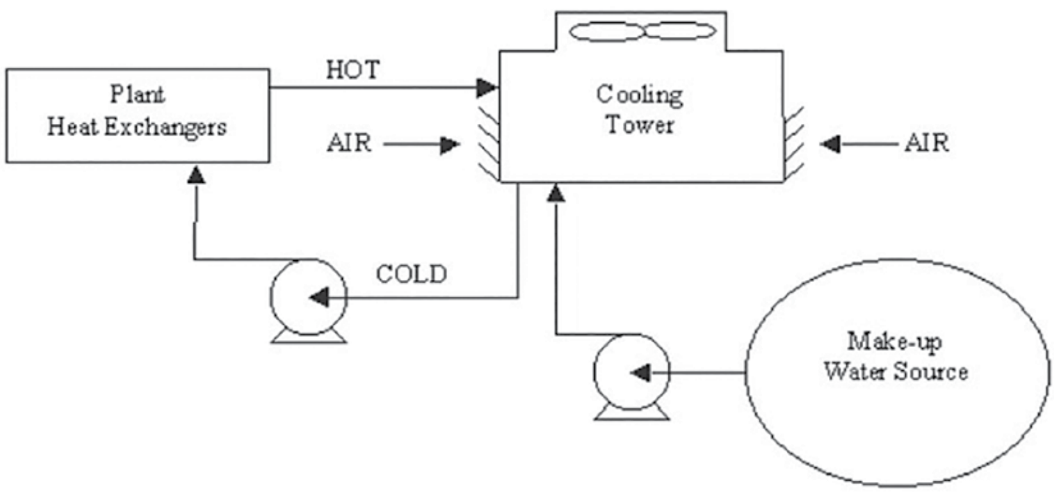
Tech 7: Energy Efficient Cooling Towers

7.1 Baseline scenario

Cooling towers are extensively used in all rolling mills and electric induction furnace units. Cooled water is required for process applications such as quenching of re-bars, cooling of coil in induction furnace, and mill cooling. Cooling happens through heat exchange between water and ambient air. The performance of a cooling tower depends on heat load, ambient air conditions, and fan design. The fan in the cooling tower moves a specific quantity of air into the cooling tower system. While moving air into the cooling system, the fan has to overcome resistance. It is called Pressure Loss. The fan's efficiency is the ratio of the work done to the power consumed by the fan. The fan efficiency depends on the profile of the fan blades and the material of the fan.

Conventional cooling towers use metallic fan blades. The metallic blades are heavy. Also, as they are manufactured by casting process, it is difficult to achieve an aerodynamic profile. Due to the heavy weight of these fans, their installation and maintenance require more effort and labour. Also, the power consumption is considerably high.

Other components – i.e., efficiency of motors, advanced control system with temp monitoring and fill material – also impact the effectiveness and performance of the cooling tower.



Cooling tower system

Source: https://beeindia.gov.in/sites/default/files/3Ch7.pdf

7.2 Energy efficient technology

An energy-efficient cooling tower is designed and operated to minimize energy consumption while effectively removing heat from industrial processes. These cooling towers are optimized for performance, reduce operating costs, and have a lower environmental impact. Several features and design considerations that contribute to their energy efficiency; a few are listed below.

- **Variable speed drives (VSDs):** Energy-efficient cooling towers often use VSDs to control the speed of the cooling tower fans and pumps. VSDs allow the cooling tower to adjust its output to match the cooling load, reducing energy consumption during periods of lower demand.
- **Efficient fan design:** Energy-efficient cooling towers utilize FRP fans with aerodynamic designs that reduce air resistance, resulting in less power required to move air through the tower. Modern blade profiles and optimized fan configurations improve energy efficiency.
- **High-efficiency motors:** Cooling towers may employ high-efficiency motors, such as IE3, IE4 motors or permanent magnet (PM) motors, to reduce energy losses associated with motor operation. These motors have better energy conversion characteristics and lower heat losses compared to traditional induction motors.
- **Advanced control systems:** Energy-efficient cooling towers may incorporate sophisticated control systems that have temperature control system with real-time data and algorithms to optimize fan speed, water flow, and other operating parameters. These controls ensure that the cooling tower operates at peak efficiency under varying conditions.
- **Use of low-fouling fill material:** Cooling tower fill material is responsible for facilitating heat transfer between the air and the cooling water. Energy-efficient cooling towers often use low-fouling fill materials that minimize scaling and fouling, reducing the need for frequent cleaning and improving heat transfer efficiency.

7.3 Benefits of technology

The advantages of energy efficient cooling towers are listed below.

- Lower operating costs
- Improved cooling efficiency
- High effectiveness
- Less water requirement

7.4 Limitations of technology

There is no limitation for adoption of this technology.

7.5 Investment required, energy and GHG saving potential, and cost-benefit analysis

To understand the cost-benefit analysis, let us consider a re-heating furnace of 15-tonne capacity. The cost-benefit analysis of energy-efficient cooling towers is tabulated below.

Cost-benefit analysis of an energy efficient cooling tower

Sl no.	Parameter	Conventional cooling tower	Energy efficient cooling tower
1	Connected load	45 kW	30 kW
2	Annual operating hours	6000	6000
3	Annual power consumption	1,89,000	1,26,000 kWh
4	Unit cost of power	INR 7/kWh	
5	Annual cost on cooling tower	INR 13.23 lakh	INR 8.82 lakh
6	Annual monetary saving	INR 4.41 lakh	
7	Investment required	INR 5 lakh	
8	Simple pay-back period	14 months	
9	Annual energy saving potential	5.42 toe	
10	Annual GHG emission reduction potential	45 tCO_2	

7.6 Technology summary

The technology impacts for an energy efficient cooling tower are summarized below.

- Annual energy saving : 4.5–8.0 toe
- Annual GHG emission reductions : 35–60 tCO_2
- Annual monetary saving : INR 4–6 lakh
- Investment : INR 4–7 lakh
- Payback period : 12–20 months

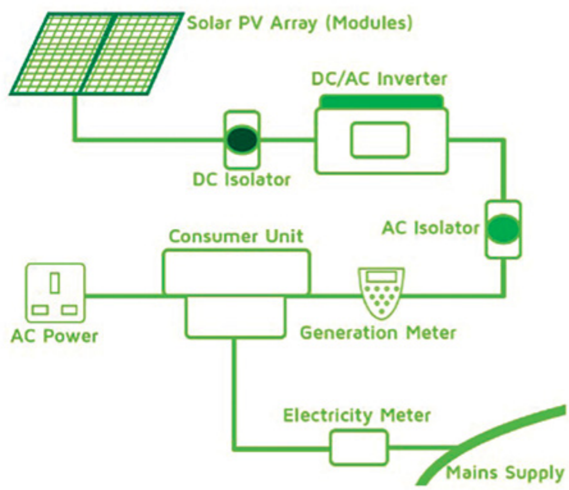
Tech 8: Installation of Solar PV System

8.1 Baseline scenario

Electricity and coal are the key energy input components in the steel industries. In industries where the melting and other processes are done by induction furnace, arc furnace, and kilns, electricity is a major component of energy input. Fossil-fuel-based power plants are a threat to the country's natural resources and have negative environmental impacts as well. Switching over to renewable energy for power generation is an important contribution towards the country's sustainable development.

8.2 Energy efficient technology

Power generation using solar energy using a photovoltaic (PV) system is a sustainable alternative to survive in the growing competitive market environment. A PV system, also called a solar power system, is a power system designed to supply usable solar power by means of PV. It consists of an arrangement of several components, including solar panels to absorb and convert sunlight into electricity, a solar inverter to convert the output from direct to alternating current, as well as mounting, cabling, and other electrical accessories to set up a working system. It may also use a solar tracking system to improve the system's overall performance and include an integrated battery solution.



Solar PV system

Source: http://www.ews-solarpower.co.uk/24-how-does-the-system-work

PV systems range from small, rooftop-mounted or building-integrated systems with capacities from a few to several tens of kilowatts, to large utility-scale power stations of hundreds of megawatts. Nowadays, most PV systems are grid-connected, while off-grid or stand-alone systems account for a small portion of the market.

The steel industries have a significant potential to generate power using solar PV systems by either going for roof-top installation or ground-mounted installation. Using a net metering system, the total electrical energy generation using PV system can be accounted for and deducted from the total grid-supplied electricity.

Rooftop solar PV system

Source: https://www.geogreenpower.com/solar-panels/commercial/sectors/factory/

8.3 Benefits of technology

Adoption of solar PV system has the following benefits:

- Captive generation of electrical energy
- Clean and greener source of electricity
- Can be integrated with grid with net metering system
- Minimal operating and maintenance cost
- Long service life
- Only one-time investment

8.4 Limitations of technology

Adoption of solar PV system needs high capital investment. Generation of dust in the industrial area causes hindrance on the efficiency of the PV system. Installation of solar PV system on rooftop requires structural strength, which needs to be analyzed as per site conditions.

8.5 Investment required, energy and GHG saving potential, and cost-benefit analysis

To understand the cost-benefit analysis, let us consider a solar PV system of 100-kWp capacity. The cost-benefit analysis for adoption of the technology is tabulated below.

Cost-benefit analysis of a solar PV system

Sl no.	Parameters	Value
1	Approx. rooftop area available	1000 m^2
2	Capacity of solar PV system	100 kWp
3	Solar power generation capacity	4 kWh/kWp
4	Electricity generation potential from SPV (equivalent grid electricity will be displaced)	400 kWh/d
5	Annual solar radiation days	330
6	Electricity generation potential per year	132,000 kWh
7	Electricity charges	INR 6/kWh
8	Depreciation benefits in the first year	INR 5.04 lakh
9	Annual monetary saving	INR 12.96 lakh
10	Investment	INR 42 lakh
11	Simple payback period	38.9 months
12	Annual energy saving potential	11 toe
13	Annual GHG emission reduction potential	94 tCO_2

8.6 Technology summary

The technology impacts for solar PV system are summarized below.

- Annual energy saving : 8–15 toe
- Annual GHG emission reductions : 80–140 tCO_2
- Annual monetary saving : INR 8–15 lakh
- Investment : INR 38–50 lakh
- Payback period : 35–55 months

Tech 9: Replacement of Old Ceiling Fans with BLDC (Brushless Direct Current) Fans

9.1 Baseline scenario

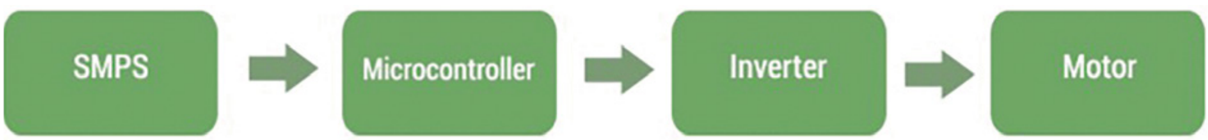
A ceiling fan is a mechanical fan mounted on the ceiling of a room or space that converts electrical energy into mechanical energy. It uses hub-mounted rotating blades to circulate air. First, the capacitor of the ceiling fan torques up the electric motor, thereby causing it to start and run. As the electrical current reaches the motor, it enters coils of wire that are wrapped around a metal base. When this current passes through the wire, it creates a magnetic field, which further exerts force in a clockwise motion. In this way, the electric energy is converted into mechanical energy and causes the motor coils to spin. The blades attached to the motor also start gaining motion with the spinning of the coils.

In industry units that use AC ceiling fans, the AC motors use the supplied power from the electrical wiring directly. Speed can be regulated by controlling the frequency of the current. The electricity consumption in such fans range from 52 watts to 80 watts and sometimes for older or rewinded fans, it even goes beyond 100 watts.

9.2 Energy efficient technology

A BLDC fan takes in AC voltage and internally converts it into DC using SMPS (Switched Mode Power Supply).

The main difference between BLDC and ordinary DC fans is the commutation method. A commutation is basically the technique of changing the direction of current in the motor for rotational movement. In a BLDC motor, there are no brushes so the commutation is done by the driving algorithm in the electronics. The main advantage is that over a period of time, due to mechanical contact in a brushed motor, the commutators can undergo wear and tear, this thing is eliminated in a BLDC motor making the motor more rugged for long-term use.



Major components of BLDC fan

BLDC fan

Source: https://atomberg.com/shop-ceiling-fans-atomberg-ikano-bldc-motor-with-remote-3-blade-ceiling-fan-1

BLDC uses a combination of permanent magnets and electronics to achieve the kind of efficiency and performance it delivers. A BLDC fan comprises three main components:

1. Stator
2. Rotor
3. Electronics.

The electronics contain a driving algorithm, which drives the BLDC motor. The position of magnets in the fan is sensed by electronics that either use a hall-effect sensor or back EMF. Modern BLDC motors use back EMF for commutation due to proven disadvantages of hall-effect sensor over a period of time.

To increase the torque of the motor, modern motors excite the other 2 phases too to create repulsion hence increasing the torque of the motor.

Technical specifications of ceiling fans

Parameter description	Value
Product	Ceiling fan
Sweep	1200 mm
Service value	> 4
Motor technology	AC induction and / or electronic brushless direct current
Rated voltage	230 V (+/–10%)

Parameter description	Value
Input watts at maximum speed	50–80 watt for fans powered by AC induction motor
32–35 watt or less for fans powered by BLDC motor	
Air delivery at rated voltage	> 210 CMM
BIS standard	IS 374:1979

9.3 Benefits of technology

Adoption of BLDC fan has the following benefits:

- Energy efficiency
- Remote and smart control
- Low maintenance

9.4 Limitations of technology

There is no limitation for adoption of this technology.

9.5 Investment required, energy and GHG saving potential, and cost-benefit analysis

To understand the cost-benefit analysis, let us consider a unit having 100 conventional fans. The cost-benefit analysis for adoption of BLDC fans is tabulated below.

Cost-benefit analysis of having BLDC fans

Sl no.	Parameter	Value
1	Electricity consumption at present	70 W/fan
2	Total number of fans	100
3	Electricity consumption of BLDC fan	32 W/fan
4	Number of working days in a year	300
5	Total electrical saving in a year	18,240 kWh/y
6	Electricity charges	INR 7/kWh
7	Annual monetary saving	INR 1.28 lakh
8	Investment	INR 2.4 lakh
9	Simple payback period	22.6 months
10	Annual energy savings potential	1.6 toe
11	Annual GHG emission reduction potential	13 tCO_2

9.6 Technology summary

The technology impacts for BLDC fan are summarized below.

- Annual energy saving : 1–3 toe
- Annual GHG emission reductions : 9–16 tCO_2
- Annual monetary saving : INR 1–2 lakh
- Investment : INR 1.8–3.0 lakh
- Payback period : 18–26 months

The secondary steel sector or the mini steel plant sector forms an important link to the overall iron and steel sector in India. The sector comprises (a) Steel Re-rolling Mill, (b) Electric Induction Furnace, (c) Direct Reduced Iron, and (d) Electric Arc Furnace. There are over 3000 mini steel plants in the country.

Energy efficiency is considered as one of the important pillars for advancing towards sectoral decarbonization and net-zero pathways.

This publication provides a compilation of key low-carbon technology packages for mini steel plants. Each technology has been explained in detail with information on the technology, benefits, limitations, cost-benefit analysis, and impacts. The publication can be used as a ready-reckoner by industries and can be helpful in advancing energy efficiency in the sector.

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