

SUSTAINABLE STEEL INDUSTRY

AN INDIAN PERSPECTIVE
VOLUME : TEXT

N. VENKATA RAMANI



BlueRose ONE^{.com}
S t o r i e s M a t t e r

New Delhi • London

BLUEROSE PUBLISHERS

India | U.K.

Copyright © N. Venkata Ramani 2026

All rights reserved by author. No part of this publication may be reproduced, stored in a retrieval system or transmitted in any form or by any means, electronic, mechanical, photocopying, recording or otherwise, without the prior permission of the author. Although every precaution has been taken to verify the accuracy of the information contained herein, the publisher assumes no responsibility for any errors or omissions. No liability is assumed for damages that may result from the use of information contained within.

BlueRose Publishers takes no responsibility for any damages, losses, or liabilities that may arise from the use or misuse of the information, products, or services provided in this publication.



BlueRoseONE.com
Stories Matter
New Delhi • London

For permissions requests or inquiries regarding this publication,
please contact:

BLUEROSE PUBLISHERS
www.BlueRoseONE.com
info@blurosepublishers.com
+91 8882 898 898
+4407342408967

ISBN: 978-93-7825-667-7

Cover Design: Ajay Dhyani
Typesetting: Sagar

First Edition: May 2026

Special Note

The readers of the book may find some aspects (in text as well as in figures) getting repeated at more than one place. This has been resorted, to make possible a holistic appreciation of the specific approach/aspects without losing the contextual relevance.

Target Audience

Sustainability remains the much sought after aim even in case of steel industry. The concept of sustainability as now being demanded requires the industry chain to be equipped to positively address the Economic, Environment as well as Social angles. This in turn requires that the Steel plant designs factor these aspects in a holistic manner right at the design stage itself as far as the new capacities are concerned. The modifications/changes of the design of the existing installation to fall in line with the above would also have to follow suit.

The desired audience considering the above, would be the young engineers and technologists, who could benefit by developing holistic outlooks from the very beginning of their professional careers.

The target audience gets substantially enlarged further to the core steel plant designers to integrated teams which would address the diverse sustainability issues based on the understanding of the concepts and their impact as well as practicability angles.

The book can also serve as a good reference for the national planners and policy makers to evolve holistic perspectives. Based on the design solutions adopted by the different agencies/countries it is quite possible that even the competencies and their appropriate repositories may have to be reconfigured. Restructuring organizations at country level can facilitate DE bureaucratisation of many aspects which today are in this domain.

Limitations

Quite obviously, the subject of the book is very vast and nearly all enveloping. It becomes even more when a comprehensive narrative within a limited space is required as envisaged in the book. In view of this, recourse to brevity in many areas has been inevitable. Serious students of the steel industry can after getting an overall perspective and intricacies and linkages involved, can carry out further detailed studies and research in the areas of their interest. The students of steel plant design will appreciate that the aspects of design are now required to be covered by expertise spanning many and wide-ranging disciplines. This would be possible only through development of expert clusters to function together. Thus, closer working and in harmony is an attribute that would need to be developed right from the beginning.

The book has benefited from the vast array of references that are available in the public domain, thanks to the ready accessibility offered by technology. My gratitude and salute to all the authors who have presented various analysis, views and approaches providing a vast mosaic of references. The effort in the book has been to evolve relevant concepts and approaches factoring the core objective of Sustainable Steelplant Design with an Indian bias. The various data and results of experiences presented are typical and are intended only to indicate the magnitudes. Benchmarks and performance objectives are substantially dynamic

and location specific in many areas, and thus will continue to evolve with the various improvements and newer technologies and integrated outlook for steel as a sustaining material.

It may be noted that there may be apparent repetitions of some narratives at different locations. This has been resorted to ensure the completeness at the point of reference without having to resort cross referencing on a big scale. Many aspects are multi-dimensional and multi-faceted and are presented as per the needs of the relevant context. We seek the reader's consideration in this regard.

Acknowledgements

The steel industry in India has sustained my entire working life so far of over 60 years covering manufacturing to Design and implementation of large steel projects. Major gratitude to Hindustan Steel Limited (Now SAIL), the first public sector giant in India and the forerunner to the development of modern steel industry in India. Taking responsibility of shaping fresh minds into this high technology it provided comprehensive training and exposure to the entire gamut of steel manufacture.

M.N.Dastur and Co Ltd, India's pioneering and first Consulting Engineers to the steel industry would demand equal gratitude having provided requisite exposure, and global opportunities in the field of design and implementation of projects in Steel industry.

The long and productive journey would not have been possible without the mentoring and support from many doyens of the steel industry, I was fortunate to be associated with. Mr Hiten Bhaya, the General Manager of the Alloy Steels Plant Durgapur (Later Chairman of HSL and Member Planning Commission GOI) who was the first to recognize my potential and fearlessly expose me to the challenges. This has been the bedrock which led to many of the future attributes.

Dr. P.L.Agrawal (Ex.Chairman of SAIL) was a mentor right from 1969 when he was at ASP Durgapur for a short while and I had the privilege of working with him as his Technical Assistant. He continued to maintain interest in my development till his demise a few years ago and was always at hand for resolving knotty issues due to his experience, erudition and scholastics.

The major share of my achievements in professional life, however, are attributable to Dr.M.N.Dastur , the father of Indian Steel Consulting, who not only provided me a great career in his company, but was also a close mentor. It was his courage and conviction in my abilities that I was recipient of so many opportunities in my life related to steel plant design India and globally and acquire a holistic perspective. The crowning glory of my career was to have been entrusted the responsibility as the Project Head of M N Dastur and Co, Principal Consultant for the 3 MT coast-based Visakhapatnam Steelplant from Concept to Completion. That this project was Dr. Dastur's landmark contribution and placed India as a competent player in the steel road map would be an understatement. That the most challenging, near Rs 8000 Crs project (of the eighties) with mostly local resources could be executed to global standards is a major tribute to Dr. Dastur's vision, courage, belief in India's capabilities and commitment to the Industry.

The last 25 years of my career put me in a role of heading my own company. This provided great freedom and scope for application of many concepts without inhibition. The result was some of the most rewarding and extraordinary achievements in design and implementation of steelplant projects in India. Highly Optimised engineering and brown field implementation

concepts which have created landmarks include BF rebuild (F BF in Tata Steel by L&T), brownfield expansion of SMS and CSP to double its capacity in Ispat's Dolvi Site, Brownfield Expansion of tube-making facilities including hydroforming at Tata Steel and many more. All my colleagues who provided the major strategic, and intellectual inputs, expertise, global outlook and efforts would be the real heroes in these projects.

The greatest learning of the project planning and implementation in India has been the recognition that it is a massive effort which calls for millions of manhours from the lowest to the highest levels of knowledge, ability and intellect and commitment. That 70000 labour force was at the Vizag site during the construction would indicate the level of human involvement. There is a constant confluence of base human efforts and the highest technologies some of them just emerging. Respecting these without exception and evolving appropriate approaches has been a major learning and in many respects the secret of success.

In Indian context, the work related to design and engineering and implementation of VSP involved huge multi-disciplinary efforts (mostly manual) across skill and knowledge levels covering over 2500 technical personnel. I wish to express my gratitude to the hundreds of my colleagues in M N Dastur and Co as well as in Optimal Steelplant Design(OSD) who were involved in the various projects that I had the privilege of being associated in my life.

Last but not the least I owe to my parents what life I have been privileged with. The key principles handed down from them have stood me in great stead in all my life and enabled me to receive the respect and affection of many. My wife Chitra has been the silent backbone on which I have rested for ensuring the dedication of most of my time to the professional demands. Without her commitment, courage and support, many of life's achievements would not have been possible. Both my children (Mohan Ramani and Aarathi Ramani Sen) have patiently borne the impact of the poor attention that I could give to them in their formative years during my working life. They have also been a source of inspiration in many ways.

Contents

Chapter 1 INTRODUCTION.....	1
Chapter 2 STEEL AND ECONOMIC DEVELOPMENT.....	5
Chapter 3 STEEL INDUSTRY PERSPECTIVE	20
Chapter 4 SUSTAINABILITY REQUIREMENTS.....	41
Chapter 5 CIRCULAR ECONOMY	56
Chapter 6 LIFE CYCLE PERSPECTIVE	78
Chapter 7 STATUS OF STEEL TECHNOLOGIES & PROCESSES	86
Chapter 8 STEEL AND ENERGY USE.....	177
Chapter 9 STEEL AND ENVIRONMENT	196
Chapter 10 EMERGING TECHNOLOGIES	217
Chapter 11 DECARBONISATION AND INDIAN STEEL INDUSTRY	250
Chapter 12 SUSTAINABLE STEELPLANTS- INDIA CONTEXT.....	303
Chapter 13 EXTERNAL FACTORS GOVERNING SUSTAINABILITY	315
Chapter 14 - ROLE OF DESIGN IN SUSTAINABILITY	321
 BIBLIOGRAPHY AND LIST OF REFERENCES.....	 332
LIST OF ACRONYMS AND GLOSSARY	341
GLOSSARY.....	348

Chapter 1

INTRODUCTION

Background

Steel has engaged the attention of mankind for thousands of years having proved useful in day-to-day lives as well as strategic purposes. As far as India is concerned the steel industry has had an effective presence for over a century with the Bengal Iron and Steel Company establishing employed modern methods for the manufacturing for first in India in 1875. The narrative in the last 25 years has only strengthened steel's position as material of choice for numerous applications.

There are however misgivings which continue to raise concerns in many quarters in regard to its sustainability due to the adverse impacts that its production and processing have particularly on environment. This concern, however, cannot take away the pre-eminent role that steel has played and is destined to play in uplifting the large deprived population to reasonable living standards in India. The unparalleled achievements of PRC over the last 3 decades in this direction have proved this point.

Quandary

The overall CO₂ contribution from the industry hovers around 3.5 billion tons per year. This naturally is an aspect that would merit serious attention from the industry. Thus, decarbonisation of the steel industry is a vital element in the Global Climate Goals. While the concern on steel's role is readily understandable, the continued use of steel is an inevitable part of the modern society. Steel has presented itself as the most affordable, versatile and widely available metal spanning countless applications forming part of the industrial demands, human consumption as well as critical role in numerous areas.

Therefore, doing away with the use of steel being a pipedream, there is a need to evolve a compatible strategy for its decarbonisation, consistent with the Global Climate Control objectives.

Sustainability Vital

The sustainability of the Indian steel industry is thus a vital and inevitable requirement. This book has been inspired by this challenging objective demanding fast-track solutions to provide relief from the high level of emissions.

Inspiration

The narrative on decarbonisation of the steel industry has overridingly been championed on the basis of it being one of the chief polluters. This in spite of much higher contributions from other sources. The industry is identified by the epithet. Hard-To-Abate.

To put it in the perspective, the energy sector contributes nearly 75 % of the emissions. Of this Steel share of energy is around 7 to 8 %. In evaluating the Indian steel industry. Comparison with countries which have been in the developed category for decades and thus benefit from the higher availability (aided by the life style philosophies) of scrap and fairly plateaued steel demand thus makes the Indian industry look like an exception.

Similarly, in India itself the coal consumption of steel industry is near 10% the power industry. Thus, carbon emissions management remains an issue across all sectors including even agriculture.

These facts provided an impetus for putting the Indian steel scenario and its emissions in the right perspective from the point of view of sustainability of the industry. And hence the book.

Approach Adopted

The book primarily focusses on the Indian Steel industry, which is at the high point of its growth momentum driven by the need for economic growth. The steel industry is planned to more than triple its production level in the next 3 to 4 decades.

Uncontrolled BAU, could mean a massive rise in the overall increase in the emission levels which could be severely damaging to the environment and climate.

The approach required has to be in a form somewhat novel, as it envelops the multiple aspects that form the final edifice of Sustainability. The objective of the book is therefore to present a comprehensive approach, which could elucidate the various arms, if played together, could provide a reliable and sustainable approach for the Indian Steel Industry.

In this context, the design of the steel plants - the starting point for the realization of many dreams - needs a relook and a move away from the traditional. Therefore, an attempt has been made to prepare a holistic reference document, factoring the various realities, which can objectively present a road map towards sustainability based on appropriate designs and concepts.

An important point which needs to be referred at this juncture is the raging debate on overcapacity in steel industry globally and the futility of building further capacities at the cost of damage to the existing. The point may be valid in a large context. But when it comes to individual nations such as India, the priorities, affordability, trade status, need for introduction of technology are all issues which would beg attention. Further more than 30 to 35 % of the capacity installed in the world have outdated and inefficient units and technologies. They are also environmentally damaging. Therefore, it is the case that shutting down / replacement of substantial capacity will be a necessity. The most recent example would be PRC where nearly

150 million tons of obsolete and uneconomic capacities have been phased out. It is expected that nearly 100 million tons more may be phased out. Such steps cannot be restricted to PRC alone. All the steel producing countries of the world would have to consider such solutions, if required.

Therefore, installation of new plants and modernisation of plants through induction of breakthrough technologies will be inevitable and may continue for at least the foreseeable future.

As far as India is concerned, additional capacities (Nearly 150 to 250 million tons) in the next 15-30 years to meet the growing steel demand is a necessity. Replacement of obsolete units will also be required in India.

Book Coverage

The basic objective of the book is to present the Sustainability Angle of Steel Industry from an Indian Perspective. The evolution of the Indian industry and its present stage are briefly touched. The basis for planning the future of the industry is discussed, primarily considering the Government of India's policy for Steel Development and road map for the same.

The requirements of Sustainability as accepted globally and by the leading global organizations such as the United Nations, World Steel Association and others are reviewed and explained with relevance to the steel industry. The supporting attributes for ensuring Sustainability such as the Concept of Circular Economy, Life Cycle Analysis are outlined. Their role and relevance to the steel industry are presented. The environmental angle, particularly concerning the carbon foot print is reviewed in context. The scope for its reduction as well as the possibility of technologies that can considerably impact this aspect are also dealt with.

A shape of the steel industry of the future in India is presented. The concept of the future units along with the relevant principles are indicated. The steps that are required to place the existing industry segment on a sustainable platform are also presented.

Contents

The book contains 14 chapters including this Introduction. The role that steel plays in the economic well-being of any nation and its wide-ranging contributions are covered. The Global and Indian Steel scenes are presented covering the growth paths so far, as well as the future projections.

The Sustainability demands, and evolving concepts of Circular Economy, and Life Cycle perspectives are dealt with in detail to set the basis for directing the possible solutions.

The technology scene is reviewed in detail, and their relevance to the Indian scene are appropriately dealt with. The role of energy is outlined along with the special features of the integrated steel industry in energy management. Environment vis-à-vis steel industry is discussed in detail. The emerging technology options are dealt with along with their contextual relevance. Breakthrough technologies with the prospect of playing saviour are covered.

The decarbonisation paths for the Indian steel industry are presented in detail. Aspirational process shares and the projected CO₂ contribution levels based on the same are suggested. The ground realities of the Indian steel industry are detailed to provide a realistic relevance and practicability.

Future plans which would require Sustainable approach from the design stage, policy supports, and typical approaches are given.

Chapter 2

STEEL AND ECONOMIC DEVELOPMENT

Background

Steel has become the backbone of human civilization for industrialisation and is crucial to the development of any modern economy. Steel plays a critical role simply because no other material offers the same unique combination of strength, formability and versatility. Consequently, as nations around the world seek to improve their standards of living and lift populations out of poverty, it is inevitable that the demand for steel will increase.

In virtually every phase of our lives, steel plays an essential role. The rails, roads and vehicles that make up our modern transport systems use steel. Steel provides a strong framework and connections in the buildings where we work, learn and live, and shields people and property from the elements. Steel protects and delivers our water and food supply. Steel is a basic component in technologies that generate and transmit energy.

The level of per capita consumption of steel is treated as an important index of the level of socioeconomic development and living standards of the people in any country.

All major industrial economies are characterized by the existence of a strong steel industry and the growth of many of these economies has been largely shaped by the strength of their steel industries in their initial stages of development. It is a product of a large and technologically complex industry having strong forward and backward linkages in terms of material flows and income generation.

HISTORY OF STEEL

Steel was discovered by the Chinese under the reign of Han dynasty in 202 BC till 220 AD. Prior to steel, iron was a very popular metal and it was used all over the globe. Even the time period of around 2 to 3 thousand years before Christ is termed as Iron Age as iron was vastly used in that period in each and every part of life. But, with the change in time and technology, people were able to find an even stronger and harder material than iron that was steel. Using iron had some disadvantages but this alloy of iron and carbon fulfilled all that iron could not do.

The Chinese invented steel as it was harder than iron and it could serve better if it is used in making weapons. One legend says that the sword of the first Han emperor was made of steel only. From China, the process of making steel from iron spread to its south and reached India. High quality steel was being produced in southern India in as early as 300 BC. Most of the steel then was exported from Asia only. Around 9th century AD, the smiths in the Middle East developed techniques to produce sharp and flexible steel blades. In the 17th century, smiths in Europe came to know about a new process of cementation to produce steel. Also, other new

and improved technologies were gradually developed and steel soon became the key factor on which most of the economies of the world started depending.

STEEL AS A MATERIAL

Steel is both the most widely used and most recycled metal/material on earth. The world round us abounds in the presence of steel in virtually everything that we use for our existence, daily needs, economic development and vital services.

All steel is made of iron.

- Iron is the fourth most common element in the earth's crust.
- Iron ore is the third largest commodity in terms of production volume - after crude oil and coal and the second most traded commodity - after crude oil

Steel is central to our current infrastructure, housing, transport systems, manufacturing, agriculture, water and energy supply. It is also critical to the sectors and technologies that will enable and drive a green economy. Renewable energy, resource-efficient and energy efficient buildings and low carbon transport, infrastructure for fuel efficient and clean energy vehicles and recycling facilities – all of these things depend on steel.

Steel provides a key input into numerous activities which, in turn, help raise living standards across the world. In addition, many of the challenges posed by large scale urbanization, population growth, and poverty reduction in India can best be met by steel both from “A fit for purpose” and “Economical “perspectives Steel has come to be essential to the technologies and solutions that meet society’s everyday needs – now and in the future as well.

STEEL APPLICATIONS

Consistent growth of Steel applications has been possible due to the various developments and new products, supporting economics, ease of use and durability. Sector wise approaches are outlined below:

Construction

Most of the steel goes to the construction industry. Sustainable steel structures can be built quickly at a low price. Steel, in its various forms and alloys, can be designed to meet the requirements of unique projects, which allow it to be incorporated into infrastructure in all environments. Depending on the conditions that the structure is exposed to, steel can be alloyed or surface treated differently for protection. The development of efficient steel production techniques contributed to the advent of the high-rise buildings. Steel can also be found in low and high-rise buildings, sports stadiums, stations, reinforced concrete structures, bridge deck plates, piers and suspension cables, harbors, Large industrial buildings with cladding and roofing, tunnels etc.

Transport

Steel is found in transport materials such as trucks, transmissions, trains and wagons, rails, ships, aircraft undercarriages, and jet engines components. The growth of railways around the world was essentially possible due to the use of steel in large volumes. This effort was driven by the product, process and processing innovations that the steel industry consistently brought in to meet the increasing as well as critical demands. Various steels are used in transport vehicles.

Steel accounts for over 50% the weight of an average car. Advanced high-strength steels (AHSS) are used in all modern vehicles as it provides a lightweight material that requires less energy to produce and reduces CO₂ emissions.

The types and forms of steel in automotives vary and cover application of car body, doors, engine, gearbox, steering, suspension, wheel axles.

Energy

All segments of the energy sectors, including fossil, nuclear, wind power, electric and natural gas, solar demand steel for the equipment and infrastructure. Typical examples are the power turbine components, steam generators, wind turbines, transformer cores solar installations etc. Steel is also used for resource extraction, such as mining, earth-moving and quarrying and transporting equipment, in offshore platforms and energy transmission, cranes, special heavy lift tackles, mobile equipment and forklifts. Due to the demanding environments in all these areas, special steels have been necessary. These include carbon, micro-alloyed, special alloyed, high strength wear resisting steels, and stainless steels are all used in the production of different equipment and facilities used in the energy sectors.

Packaging

Steel packaging protects goods from water, air, and light exposure, and is fully recyclable. This method of storage has been around for over 200 years. Steel allows for high-speed filling and lightweight, easy to open packaging. Packaging steels are often made from low carbon cold-rolled steel strip and are surface finished. The steel is tin plated to prevent corrosion and then coated with a polymer, lacquered, and printed. The majority of steel packaging goes towards food and beverage container, followed by a general line, aerosols, and closures (e.g: bottle caps).

The development of containers for use in shipping, rail and road transport has added an extraordinary dimension to the entire concept of packaging. Since the containers are well made and protected fully from the environmental, safety and handling concerns, these have enabled many industrial products and components to be shipped in bulk without the conventional packaging. The main advantage of this has been the avoidance of elaborate packaging in the manufacturing plants (saving time and costs) easy classification and identification and ease of delivery at door step.

Appliances

About 75% of the weight of typical household appliances comes from steel. Steel is found in appliances like fridges, washing machines, ovens, microwaves, toasters, sinks, cutlery, durables etc.

QUANTITATIVE IMPACT OF STEEL USES

The global steel consumption is now nearly 1.8 billion tons. Globally about 50% of steel produced is used in buildings and infrastructure. Steel besides offering a long life, is highly economical having the highest strength to weight ratio of any building material.

Similarly, approximately 75% of all major household appliances are comprised of steel. Considerable amounts of special steels are used in these such stainless steels, painted sheet steels, heat resisting steels etc.

The container mode of shipping brought with it extraordinary benefits in terms of well protected products, ease of handling, cost savings due avoidance of extensive packing needs, and above all durability. About 17 million shipping containers are currently in use across the world and the majority are made from steel.

The length of the worldwide rail network spans over a million km. The rails (the principal component of the system) are a high quality specially manufactured product from the steel plants. Besides this, the wagons and coaches essential for the railway transportation, station infrastructure etc are predominantly made from steel including stainless steels and special steels. The type of Steels used in various the economic sectors are shown in Table 2-1.

TABLE 2-1 TYPE OF STEELS USED IN DIFFERENT SECTORS

SECTOR	TYPE OF STEELS USED
TRANSPORT	HR Sheets, CR Sheets, Galvanised sheets
	Colour coated sheets, HR Plates, Precision Tubes, Wires, Bars and Wire-rods, Bearings, Rails, Plates and Special sections
CONSTRUCTION And INFRA	Rebars, Steel beams, columns and other sections
	Doors and Windows, Roofing Sheets, Pipes and tubes
	Prefabricated houses, offices and installations
	Rebars (regular and special (large size, high strength))
INDUSTRIAL AND ENGINEERING	

Capital Goods, Industrial equipment and appliances	Bars and rods, Pipes and tubes, HR and CR sheets
	Galvanised and colour coated sheets, Tinplate, Plates, Structural Sections, Castings and forgings Pipes and Tubes,
AGRICULTURE	
Agri Equipment	Structural Sections, Castings and forgings HR and CR sheets Bearings
Fencing, Farming and Irrigation	Galvanised Wires and fencing, Sections Tools, Pipes and Tubes

STEEL AND ECONOMIC IMPACTS

A look at the wide-ranging steel uses would indicate that it has a very significant role in nations economic activity and its impact would be as wide ranging as well. Steel has far-reaching and unusually large global supply chain. As per the study by Oxford Economics for World Steel every \$1 of value that is added by work within the steel industry itself, supports a further \$2.50 of value-added activity across other sectors of the global economy, as a result of purchases of raw materials, goods, energy, and services. Also, for every two jobs in the steel sector, 13 more jobs are supported throughout its supply chain - meaning that, in total, some 40 million people work within the steel industry's global supply chain, generating over US \$1.2 trillion of added value.

The economic and social impact of the global steel industry can be appreciated from Figure 2-1.

Figure 2-1 ECONOMIC AND SOCIAL IMPACT OF GLOBAL STEEL INDUSTRY

Classification of Steel Impacts

This economic activity extends across multiple sectors and countries, far beyond the major steel-producing locations and enables high value activity across many sectors.

The contribution of the steel industry to the economy can be classified as Direct, Indirect and Induced impacts as shown in Figure 2-2:

Direct impacts

The manufacturing chain for steel encompasses the following major direct segments:

- Raw Materials: This requires mining and related activities, beneficiation in many cases.
- The second key activity is the manufacture of steel in the steel plants. The installation of a steel plant contributes to the economy right from the start of the planning stage. Huge investments are required in the purchase of equipment and facilities, construction and commissioning of the facilities. The investment for steel capacity creation can range from US \$ 350 to over 1500 per ton of crude steel depending upon the location, process route, scale of operations, product mix etc.

- The steel plant for conversion of raw materials to useful steel products consumes massive amounts of energy at different stages. The major energy in the integrated steelmaking route is derived from the carbon inputs from the raw materials. Electrical energy forms a very major part, particularly in the EAF route. Limited amounts of other energies such as natural gas, fuel oil etc. are also used. Thus, the steel industry has a direct impact on the energy producing and distributing sector being one of the largest consumers.
- The steel plant in its operation provides sustaining and large-scale opportunities for employment, maintenance and upgrades. The requirement of manpower considering the stage of development envelops demands across numerous skill levels. These include besides the lower end manual intensive areas, very high levels as well in terms of abilities for research in processes and product development, environmental compatibility challenges, process as well as model-based automation systems related etc.
- A very significant off shoot of the industry is in skill development on an ongoing basis. The very large and dispersed manufacturing and use chain of steel and its applications embrace diverse technologies and equipment and machinery, researches and analysis. As a result, a very large pool of multi-disciplinary skills gets established.
- Transport of raw materials, and distribution of the products provides great fillip to the transport sector. On a broad basis one ton of steel can demand transport support to the tune of 4 tons or more covering raw materials, waste disposal, product distribution and other uses. This indirectly impacts the energy sector, employment and infra development as well.

Indirect Impacts

The steel plant supports large number of industries and services linked to it both as forward as well as backward linkages. The key amongst them, are outlined below:

It can be appreciated that the value adds from iron ore to finished steel can be 10 to 15 times the iron ore value of this more than 50-60 percent is spent on purchase of raw materials, energy and services. The external supporting industries such as mining, raw materials beneficiation and upgradation, transport, bulk energy (Power, Coal, Natural gas, Fuel oil) keep progressing in line with the steel production.

The users of steel are spread all across the nation. An efficient distribution system is therefore a vital necessity for meeting the steel demand. The steel therefore gets destined to direct users as well as widely distributed small users. Close to 40 % of the total steel is sold by the distributors. There are downstream user industries which further process and add value to the steel supplied by the plants. All these activities in turn have direct and indirect contributions including employment, purchase of energy, transport, Operations and facility management, Multiple processing steps, packing and distribution.

The major indirect impact of the steel industry is also evident from a rightful share in the contributions that the various steel using sectors make to the economy at large as indicated above. The level of contribution would vary from sector to sector and the nature of its use.

Secondary Users

Steel forms a raw material for many secondary industries which convert these into higher value, special products or user specific forms. Typically, these sectors cover products pipes and tubes, special sections, structural tubing, galvanised and colour coated sheets, blanks, special products etc. using flat products. The applications using long products are Pre-fab structures, Cold drawing, Wire drawing, Galvanising Construction specific products etc. Generally, about 40 to 50% of the steel produced pass through these sectors both for distribution and retailing as well as value additions.

Induced Impact

The induced impacts occur when workers involved in direct and indirect (supplier) activities spend their wages as a part of their daily life and support relevant economic activity.

Overall impact of Steel

A detailed study was conducted by WSA along with Oxford Economics to capture the full impact of the global steel industry, to estimate what value-share of each sectors' work is attributable to steel, over and above the simple value of the steel embedded in their products.

The steel industry is active in all parts of the world, transforming iron ore into a range of products that are sold for a total annual value of US \$2.5 trillion. The industry employed more than six million people and supported an additional 49 million jobs around the world in 2017. The “added value” of its production processes totalled almost US \$500 billion. The steel industry's productivity per worker exceeds US \$80,000—three times the average across all sectors of the global economy.

The steel industry has an exceptionally large global supply chain. The WSA study calculates that, “for every \$1 of value that is added by work within the steel industry itself, a further \$2.50 of value-added activity is supported across other sectors of the global economy, as a result of purchases of raw materials, goods, energy, and services.

This economic activity extends across multiple sectors enables for every two jobs in the steel sector creation of 13 more jobs are supported throughout its supply chain and countries, far beyond the major steel-producing locations.”

The study has presented estimates considering a Narrow as well as Broad approach to steel's impact on economies.

Narrow (minimum) approach

The “narrow” approach assumes that the share of work facilitated by steel equates to the share of steel in each customer's total purchases of external inputs. By this metric, it is estimated that the steel industry facilitated a further US \$1.2 trillion of value-added output in

2017 and supported an additional 49 million jobs around the world. It is calculated that the total value-added contribution either supported or facilitated by steel in 2017 was US \$2.9 trillion (see Fig. 2-3) equivalent to 3.8 percent of global GDP that year, this activity is estimated to have supported a total of 96 million jobs.

By country of activity, China accounts for 36 percent of the steel industry's annual contribution to global GDP, the US for 11 percent, and Japan for nine percent. China also accounts for 36 percent of global jobs supported or facilitated by steel manufacturing, followed by India with 30 percent.

Broad (maximum) approach

The “broad” approach, assumes that the steel industry's share of customer sector outputs equates to steel's share of this smaller group of essential external inputs, rather than all external inputs (as for our narrow approach). On this basis, the value-added output facilitated by the use of steel in 2017 was estimated at US \$6.4 trillion, with an associated 213 million jobs in the customer sectors and their (non-steel) supply chains. The total value-added contribution of the steel industry was calculated as US \$8.2 trillion—equivalent to 10.7 percent of global GDP that year—and that it supported 259 million jobs (Fig. 2 - 4).

Under this broad approach, China accounts for some 31 percent of steel's value-added contribution, the US for 11 percent, and Japan for 10 percent. But the pattern of steel-related employment by country is quite different, with China accounting for 45 percent of the global total, followed by India with 16 percent.

Report on Impact in USA

As per a US Study the steel industry generated more than \$520 billion in total economic output and nearly two million American jobs in 2017. These jobs paid over \$131 billion in wages and benefits. The manufacturing process directly accounts for 76,000 jobs. products such as sheet, plate, pipes and bars, directly account for another 141,000 jobs. The iron and steel industry directly accounts for another 170,000 jobs related to ferrous metals foundries, steel product manufacturing from mill products, iron and steel product processing, and distribution through metals service centers and wholesalers. Thus, nearly 387,000 jobs paying \$34 billion dollars in wages and benefits are directly linked to the American iron and steel industry which in total produces more than \$200 billion in output. The study estimates that the American iron and steel industry supports 716,000 supplier jobs, paying \$53 billion in wages and compensation. These suppliers generate \$173 billion in economic output.

The study estimates that the induced impact of the industry is \$143 billion, and generates 878,000 jobs paying \$45 billion in wages and benefits. The American iron and steel industry also contributes to the public finances of the nation. This contribution consists of the direct taxes paid by firms and their employees, equalling a total of \$56 billion in revenues to the federal, state and local governments.

STEEL IN NATIONAL ECONOMY

Primary steel sector industries are fundamentally different from other industrial establishments in many respects. They are basically strategic industries that serve the long-term industrial needs of a nation through their unique role as feeder channels to myriads of other key establishments.

Steel as an Index of Power

Since the Second World War, the nations of the world have come to appreciate the unique role of steel as the base for rapid technological progress and Steel has become an index of National Power.

Steel as Economic Nerve Trigger and Strategic Material

The great importance of steelmaking to national economy is not restricted to its immediate or direct application. For its smelting alone, it triggers off a series of economic activities for its input raw materials and energy. The downstream is vitally dependent upon steel for its development and growth. Major sectors such as defence and armaments, Power generation and distribution are large steel users. All these make the steel a highly strategic industry of any modern economy. Today, over 80% of the world's industrial goods and infrastructure are steel based.

STEELS CONTRIBUTION INDIAN CONTEXT

The foregoing role of steel made India also to focus on steel industry. Indian Steel industry was in the vanguard in the liberalization of the industrial Sector and has made rapid strides since then. Currently steel industry contributes about 2 % of the GDP.

Post liberalization, adoption of the latest in technology, increased production, moving up in the value chain have been the hall marks. Indian steel is also an important element of the global exports, consequent to a greater integration with the global economy. The new plants have also brought about a greater regional dispersion easing the domestic supply position.

The current focus on infrastructure, housing and construction is driven principally by the assured availability of appropriate steels in adequate quantities.

Steel is likely to remain India's vital engineering materials for a long time to come. With strong backward and forward linkages, steel industry will continue to be an engine of economic growth. Steel is also vital to the nation's economic security as it is extensively used in strategic areas such as defence, power, atomic energy, and in creation of an equitable social and economic infrastructure of the country. Sector-wise steel consumption in India is shown in Figure 2-5.

The planned growth of domestic production of steel is appropriate also due to indigenous availability of major resources such as iron ore, coking and non-coking coals, skilled labour, technological competence and sustainable domestic demand. In Indian economy, steel has an

output multiplier effect of nearly 1.4 X on GDP and employment multiplier factor of 6.8X. and employs some 600000 people directly and 2 million people indirectly.

STEEL INDUSTRY REACH

The various sectors and activities linked with the steel industry and related economic sectors in India are shown below.

- **Steel Product Users**

Infrastructure & housing

Construction

Engineering & fabrication

Transport (Automotive, Railways, Shipbuilding etc.)

Energy incl oil and gas lines

Packaging

Consumer durables and white goods

- **Supply Chain Linked Sectors**

Raw Materials, Energy, Utilities

Mining (iron ore, coals, Fluxes, others)

Beneficiation and value addition (Classification, Concentration, Pelletising, Stand-alone DR units)

Raw materials Supplies (iron ore, coals, Fluxes, Pellets, DRI, Scrap)

Energy Supply (Power, Oil, Coal and Gas)

- **Downstream Processing**

Value added product manufacture

Fabrication

- **Services**

Specialised plant maintenance

Business and Financial services

Expert services (Environmental monitoring, Software support)

Sales and retail

Personnel related services (Health, Catering, Social)

- **Technology development**

Process Technology (Development, Localisation, Research)

Automation (Process Management, Supply chain management, Business Management)

Digitalisation and AI (Process improvements, Model based support systems, Asset Management and Operations Efficiency, Resource Optimisation)

- **Environmental Control**

Pollution Control Strategies

Process optimisation

Waste Management

Standards and Compliance management

- **Human Resource Related**

Employment (Direct and Indirect)

Skill building in multiple areas

High level big data and application Software skills

Enterprise management skills

- **Fillip to Machinery Manufacturing**

Heavy as well as High tech equipment manufacture

Component supply to steel industry

Allied products and components supplied across sectors

Repairs and refurbishment sources

- **Hinter area development**

Overall area development (Transport, Education, Medical and healthcare)

Downstream industries

Urban infrastructure expansion

- **By products including waste to wealth**

Recovery from wastes

New area development

Figure 2-6 shows the various sectors that are positively impacted by the steel industry in India. An area wise analysis of the larger impacts is discussed in the following paragraphs.

Direct Impacts

Raw materials exploitation and value addition

From the country's economic perspective, the value addition that the steel provides by converting iron ore may exceed 12 to 15 times. Steel could thus be one of the most appropriate options for the Raw materials exploitation and value addition through indigenous production.

Local raw materials include the iron ores, non-coking coals, limited coking coals, limestone, dolomite, manganese ores etc. The mining of these raw materials and the related activities such as beneficiation, pelletising etc are required on gigantic scale for meeting the steel industry demands.

Employment

The issue of labour productivity which very often is held against the Indian industries in general and iron and steel in particular has to be put in perspective. It is well understood that there are requisite steps and operations involved at the different stages of the manufacturing chain. The use of labour at each of the steps is determined by the amenability of the concerned step to use of machinery, level of automation, costs and management policies.

The use of labour at the different steps would cover direct as well as outsourced services. The current trend in the industry is to outsource as much as possible consistent with the needs being met properly. In such situations the labour cost component generally as reported by the steel producers would cover only the direct employed to appear efficient in a global context.

In the economic context, sustaining productive jobs would have a significant place and should be maintained to the maximum extent. This would also serve the larger national purpose.

With the advent of technology, automation, and increased productivity, the direct manpower demand of the steel industry has been reducing consistently. From a traditional requirement of 25000 to 30000 persons for a 1-2 MTPY steel plant, the present demand comes to less than 5000 for a 3 MTPY integrated plant. Thus, for a likely increase of about 100–150 million tons to meet the NSP objective, a direct employment of about 150000 to 200000 may be expected.

However, the indirect employment potential due to steel is huge and is placed at x 6.8 in NSP. Thus, employment potential of 1 to 1.5 million exists with the projected growth of the steel industry.

Technology development

The role of the steel industry in spreading the technological culture across the nation is not well appreciated. The Integrated steel plant encompasses scores of technologies at the different stages of its operations. These include the core process technologies related to iron and steel, maintenance of a very highly diverse ranges of equipment and machinery, power generation, water management, energy use and optimization, material handling and logistics, environmental control, automation and computerization, use of AI and big data analysis, plant safety, waste management techniques etc.

Substantial equipment and technologies used in auxiliary and support facilities for a steel plant are also used in many other industries and areas. The benefits of techniques adopted in the steel plants therefore spread across vendors, designers, maintenance, automation and improvements.

Skill building

The steel industry has traditionally been a huge reservoir inclined to play a significant role in the skill building of its employees. The Integrated steel plants in India generally have high quality infrastructure for this purpose. These are normally focused on enabling entry level freshers from colleges and technical institutes to be oriented for the steel industry requirements. Besides this, on the job upgradation is a normal today. This is also driven by the need for retrofitting in the older units, newer techniques and facilities for better maintenance, automation and overall upgrade.

The above strength of the steel industry in India plays a very important role in being a catalyst for skill building which can benefit the entire industrial infrastructure of the country.

It is a matter of great satisfaction that the country has managed the cross 100 mtpy growth in the last 20-25 years with nearly total domestic manpower both in terms of numbers and skills.

Hinter area development

The integrated steel plants by their very concept were manpower intensive. Their preferred locations were outback to optimize on transport, assembly and distribution costs. Thus, in the past all the major integrated steel plants in India namely Tata Steel Jamshedpur (Pioneer), IISCO Burnpur, SAIL plants at Bhilai, Rourkela, Durgapur, Bokaro JSW Tornagallu ended up having to build an all-new liveable township to sustain its work force.

This triggered large economic developments in the hinterlands of the steel plants. From the late seventies many of the newer installations were located close to some of the existing major cities such as Vizag steel plant near Visakhapatnam, JSW Ispat at Dolvi outside of the Mumbai limits, many smaller units around JAJPUR-KEONJHAR in Orissa, Bellary-Hospet in Karnataka, Raipur in Chattisgarh.

By products incl waste to wealth

The integrated steel plants have also been in the forefront of technology to ensure that the wastes generated in the process of iron and steelmaking are utilized appropriately leveraging their inherent properties and potential usages.

The most striking are the by products from the coke ovens which are large sources for Coal Tar, Ammonia, Napthalene, Benzol, Sulphur, Secondary and tertiary chemicals.

The biggest beneficiary of steel plant wastes has been the cement industry in the country. Presently over 12 to 15 million tons of slag from the BF iron making is granulated and fed to the cement industry. This material besides obviating need for natural mining to an equal extent also enable much better-quality cement to the nation.

The other construction materials offered by the steel industry are the aggregates from slag, building blocks made out of slag and other steel plant wastes.

Fillip to Machinery Manufacturing

Typically, a 3 MTPY integrated steel plant may require 250000 tons of fabricated steelwork, over and 200000 to 250000 tons of machinery. Of the ballpark investment of about Rs 40000 to 50000 Crs for a 5 MTPY ISP about 50 % to 60 % would be towards the equipment and machinery. The potential and fillip to the manufacture from the installation of a steel plant can be visualized from the required investment levels.

The steel plants in India built prior to the early seventies had to depend upon imports of machinery as the country's infrastructure had not been adequately developed. But the installations post that such as Bokaro Steel Plant, Visakapatnam Steel Plant, Tata Steel expansion, were heavily supported by the indigenous machinery industry. However post economic liberalization in 1991 the thrust on indigenous machinery has substantially reduced.

The secondary industry which accounts for nearly 30 % of the steel production has always preferred indigenous equipment adequate for the scale and technologies adopted by them.

The Government is moving towards incentivising the domestic manufacture through a slew of reforms and tax cuts. This is likely to be a critical need not just from the economic perspective, but also for ensuring cost optimization, export capability as well.

Indirect impacts

These are reflected in the activities supported throughout the Country by the supply chains of the country's steel sector.

Raw materials and Mining

The iron ore and other raw materials requirement by 2030-31 is estimated as shown in Table 2-2 below:

TABLE 2-2 RAW MATERIALS DEMAND BY 2030-31

Raw material	Demand (2030-31)
	MTPY (As Per NSP)
Iron ore	447
Coking coal	180
Non-coking coal for PCI	35
Non-coking coal for DRI	82
Limestone & dolomite	91
Others	31
Total raw materials	866

It will be observed that about 700 -750 million tpy mining activity will be required domestically to sustain the steel demand anticipated by 2030-31.

STEEL DEMAND DRIVERS

Growth in steel demand is a necessary corollary to economic growth as it presently contributes about 2% of the GDP in India. On this basis the steel demand in NSP has been formulated can be sensed from the Table 2-3 below (Fig 2-7)

TABLE 2-3 PROJECTED STEEL DEMAND IN INDIA

	STEEL DEMAND (NSP)
Growth Drivers	2030-31
	MTPY
Infrastructure & housing	90
Construction	45
Engineering & fabrication	43
Transport (Automotive, Railways, Ship building etc.)	18
Energy incl oil and gas lines	15
Others	19
Packaging	6
Total Finished steel	230

The intensity of steel use in the different key infrastructure sectors can be seen from the Table 2-4 below.

TABLE 2-4 STEEL USE INTENSITIES

Infrastructure	t	Per million ton of steel	Steel /unit of infrastructure
		Typical	Typical Ton
Roads	km	6000	150 /km
Railways	km	3300	300 /km
Power	MW	15000	70 /mw
Power transmission	km	28500	36 /km
Oil platforms	Nos	160	6250 /platform

Chapter 3

STEEL INDUSTRY PERSPECTIVE

An overall picture of the global steel industry is presented here. The Indian steel industry, both the historical perspective as well as the current status are reviewed.

GLOBAL STEEL PRODUCTION

Globally, the steel industry has witnessed astonishing growth in the last 50 years. The World Steel Association (WSA) recognises steel as the foundation for the last 100 years of global progress and as equally fundamental to meet the challenges of the next 100 years. Starting with less than 50 million tons post war (1945) the global steel production cracked the ceiling of 1 billion tons in 2004 (about 60 years). The global steel production during the period 2005 to 2024 has been shown in Table 3-1 and Figure 3-1.

TABLE 3-1 World Crude Steel Production 2005 – 2024

Sl.No.	Year	Million Ton	% Year of Year
1	2005	1148	
2	2006	1250	8.9
3	2007	1348	7.8
4	2008	1343	-0.4
5	2009	1239	-7.7
6	2010	1433	15.7
7	2011	1538	7.3
8	2012	1560	1.4
9	2013	1650	5.8
10	2014	1669	1.3
11	2015	1620	-3.1
12	2016	1627	0.4
13	2017	1729	4.9
14	2018	1814	5.2
15	2019	1869	3
16	2020	1880	0.1
17	2021	1950	3.8
16	2022	1888	-0.1
17	2023	1889	-0.19
18	2024	1839	-0.9

Current Status

Global crude steel production was 1962 million tones (MT) for the year 2021 and 1.885 MT in 2022, a 3.7 per cent decline and 1849(P) MT in 2023 a marginal decline over 2022. The production in 2024 was marginally less at 1839 MT Asia continued to be the main driver producing 1367 MT or nearly 74%. China's share of global crude steel production continued to exceed a billion tons with a mind boggling 55% share. Crude steel production in India the second largest steel producer in the world was a fraction with near 150 MT in 2024 (about 7.5%).

Top Steel Producing Countries

Out of 1849 MT in 2023, the top ten steel producing countries produced about 1.6 billion tons, the rest came in from other steel producing member nations. The top 10 steel producing countries produced nearly 86% as listed in Table 3-2 below and in Figure 3-2.

TABLE 3-2 TOP 10 GLOBAL STEEL PRODUCING COUNTRIES

Sl. No	Country	Crude Steel Production MT						
		2018	2019	2020	2021	2022(f)	2023(f)	2024
1	China	920.0	996.3	1064.73	1032.79	1035.1	1019.1	1005
2	India	109.3	111.2	100.25	118.13	112.3	140.2	149.6
3	Japan	104.3	99.3	83.84	96.33	58.8	87	84
4	USA	86.6	87.8	72.73	86.01	90.2	80.7	79.5
5	Russia	72.1	71.9	71.62	75.97	45.1	75.8	70.7
6	S. Korea	72.5	71.4	67.08	70.56	52.8	66.7	63.5
7	Germany	42.4	39.7	35.68	40.07	35.8	35.4	37.2
8	Turkey	38.37	38.33	35.81	40.36	37.0	33.7	36.9
9	Brazil	35.4	32.2	31.42	36.04		31.9	33.7
10	Iran	24.5	25.6	28.99	28.46		31.1	31
11	Vietnam			23.3	24.5	26.3		
12	Mexico			21.7	23.4	24.6		
	World	1814	1869	1880	1950	1889	1849	1839
	% Top 10	80	85	80	79	79	86	86.5

Industry Growth

The salient features of the growth of the global steel industry is summarized in Table 3-3.

TABLE 3-3 GLOBAL STEEL INDUSTRY GROWTH MILESTONES

Age Designation	Period covered	Crude steel production	Implied growth rate
		MTPY	% pa
Emerging age	Pre 1945	100	2.8
Golden Age	1945-1973	700	6.2
Efficiency Age	1974-1995	750	0.2
China Age	1995 -2020	1850	Over 6%
Stability Age	2020 onward	1950 & growing	

The highlights of the global steel industry development over the decades are shown in Figure 3-3.

The first large scale growth in steel was championed by USA and USSR and they reached leading positions in the sixties to usher in the golden age with a growth rate of 6.2% per annum. Japan went ahead at an extraordinary fast pace in the seventies and eighties to claim the high spot. Japan and S Korea kept the steel growth upward in this period. China made all these extraordinary achievements look rather small by adding nearly a billion tons of steel capacity in about 25 years' time (1980 to 2005) to emerge as the unbeatable leader for ever accounting for over 50-55% of the current world steel production and consumption.

The per capita steel consumption on a global basis has hovered around 214.3 kgs in 2013 to 227.5 in 2020. Against this, the same increased in India from 57.5 kgs in 2013 to 64.2kgs,75.5 kgs,81.1 kgs in 2020/21/22 respectively. The per capita consumption in China was 707.2 kgs in 2020,669 in 2021 and 645.5 kgs in 2022. i.e over 3 times the global average. There is of course a yawning inequality in country-wise consumptions ranging from a less than 10 kgs to nearer 1000 kgs per capita.

Industry Highlights

The steel production globally during 1950 to 2020, growth rates during this periods and decadal growth rates are presented Tables 3-4, 3-5 and 3-6 and Figures 3-4, 3-5 and 3-6 respectively.

TABLE 3-4 WORLD STEEL PRODUCTION GROWTH

1950 to 2024		
Sl. No.	Year-wise	Million Ton(MT)
1	1950	189
2	1955	270
3	1960	347
4	1965	456
5	1970	595
6	1975	644
7	1980	717
8	1985	719
9	1990	770
10	1995	753
11	2000	850
12	2005	1063
13	2010	1239
14	2015	1621
15	2020	1880
16	2023	1849

17	2024	1839

TABLE 3-5 WORLD STEEL ANNUAL GROWTH RATES

Period/Year	Average %
1950-55	7.4
1955-60	5.1
1960-65	5.6
1965-70	5.5
1970-75	1.6
1975-80	2.2
1980-85	0.1
1985-90	1.4
1990-95	-0.05
1995-2000	2.5
2000-2005	6.2
2005-2010	4.5
2010-2015	2.5
2015-2020	3.0

TABLE 3-6 WORLD STEEL DECADEL GROWTH RATES

Decade	MT	Decade Growth %
1950-60	268	
1960-70	465	174%
1970-80	652	140%
1980-90	735	113%
1990-2000	791	108%
2000-10	1097	139%
2010-20	1655	151%

India Share

India's share in global steel production stands at about 7.5% in 2024 as shown in Table 3-7. The progress in ASU (Per Capita Steel Consumption) is also shown there.(Fig 3-7).

TABLE 3-7 INDIA SHARE IN GLOBAL STEEL

Year	Global share	Production
	%	MT
2010	4.9	60.7
2020	5.3	100.3
2021	6	118.2
2022	5.9	112.3
2023	7.5	140.2
2024	8.15	150

As compared to the above China's share is whopping 54.6% in 2024. It was 56.7% in 2020. China is the largest steel producer in the world. Its steel production is more than the entire rest of the world combined. This results in per capita consumption of steel of over 995 kg, a feat which is unlikely to be surpassed by any country in the future. (Fig 3-8)

TABLE 3-8 CHINA SHARE IN GLOBAL STEEL

	Production	Global share
Year	MT	%
2010	551.3	44.5
2020	1064.8	56.7
2021	1032.79	52.9
2022	1035.1	54.79
2023	1019.1	55.1
2024	1005	54.6

WORLD STEEL CAPACITY

The world steel capacity by regions is given in Table 3-9 and Figure 3-9. It will be observed that Asia has the lion's share of nearly 70%. Of this over 70% is from China which has been the path breaker in capacity building in the last 4 decades.

TABLE 3-9 GLOBAL STEEL PRODUCTION REGIONWISE (2023)

	Region		
		MT	%
1	European Union	127.6	7.23
2	Other Europe	53.4	3.02
3	Russia and other CIS +Ukraine	56.1	3.18
4	North America	136.3	7.73
5	South America	41.1	2.33
6	Africa	35	1.99
7	Middle East	54.9	3.11

8	Asia	1251.6	71.0
9	Oceania	6.9	0.04
10	Total	1763	

The ratio of production of crude steel to steel capacity (capacity utilization) during the years 2000 to 2019 has hovered around 70 % during 2000 to 2016 and near 80 % in 2018 and 2019.

Steel Demand Drivers

A broad sector wise analysis of the global steel consumption is shown in Figure 3-10.

Building and infrastructure 52%

Transport 17%

Machinery including electrical equipment 19%

Metal products 10%

Appliances etc 2%

This would indicate the level of penetration of steel in the different key sectors of the global economy. The two key engines that have kept the steel growth story primed are the construction and transports sectors. Being fundamental to any economy including the poorer ones, these have been in the forefront of steel demand. The construction has primarily involved infrastructure, housing, roads and railways.

Steel Industry Initiatives

Steel industry has been globally a forerunner of many technologies, innovations and applications. The durability of steel along with these initiatives has ensured the sustained use of steel in the world. This focus is expected to continue for the foreseeable future as steel is likely to remain the key material of choice for many applications.

The global steel industry is one of the many significant contributors to the GHG emissions contributing approx 6-7% of the global emissions, over 70% of which derived from its energy use for production. The inevitability of the steel's contribution to emissions derives from the fact that there is still no real alternative to Carbon as far as reduction of iron ore to iron is concerned, on a scale commensurate with the demand. It needs to be recognized that almost every GHG mitigation technology relies on steel for its development be it

Thermal Energy

Electrification,

Renewable energy,

Mass transport, shipping

Smart cities,

CCS,

Hydrogen manufacture and use

INDIAN STEEL INDUSTRY

Historical Perspective

Steel usage in India dates to ancient times with strong evidences. But the production of steel using modern technology began during the late-nineteenth century. In 1875, the Bengal Iron and Steel Company employed modern methods in the manufacturing of pig iron which was a first in India. This is often considered as the initial push for what would later become the Indian steel industry. But the official establishment of the Indian steel industry can be traced back to the setting up of the Tata Iron & Steel Company (TISCO) in Bihar in 1907. The Indian steel industry was further strengthened post-independence, with the establishment of Hindustan Steel Limited in the Public Sector in 1954.

The important milestones in the Steel Industry development are shown in Figure 3-11. These are :

1875 Bengal Iron and Steel Company in Barakar

1907 Establishment of Tata Iron & Steel Company (TISCO)

1937 Establishment of Steel Corporation of Bengal

1954 Set-up of Hindustan Steel Pvt. Ltd.

1962 Completion of Durgapur, Bhilai and Rourkela steel plants

1973 Setting up of SAIL to replace the HSL (modified management structure)

1991 Government of India liberalises the steel sector

2005 India becomes one of the top 10 steel producers in the world

2018 India becomes world's second largest producer of crude steel

Post independence, Indian leaders' vision focused on power and steel sectors as the foundation for the nation's future development leveraging the availability of abundant deposits of iron ore and coal. True to this vision, steel played an extraordinary role in the development of the industrial and other infrastructure in the country in the decades to come.

Development Road Map

Besides the establishment of Bengal Iron and Steel Company in Barakar in 1875, Tata Iron & Steel Company (TISCO) 1907 and Steel Corporation of Bengal in 1937, the epoch-making step in the development road map of Indian steel industry was the setting -up of Hindustan Steel in 1954. At the time of independence in 1947, India had only three steel plants - the Tata Iron & Steel Company, the Indian Iron and Steel Company and Visveswaraya Iron & Steel Ltd and a few electric arc furnace- based plants.

The period till 1947 thus witnessed a small but viable steel industry in the country, which operated with a capacity of about 1 million tonne and was completely in the private sector. Completion of Durgapur, Bhilai and Rourkela steel plants all in public sector (Hindustan Steel) was the new restricted model for managing the steel industry. In 1991 Government of India liberalized the steel sector by removing iron and steel industries from the reserve list. In the 70 years span India has risen to be the 2nd largest crude steel producer in the world in 2018-19 and the largest producer of sponge iron.

Regulated and Controlled

Indian steel industry was under strict government regulation till 1991-92. The regulations were embedded in the following:

i. Capacity control measures:

licensing, reservation of large-scale capacity creation for the public sector units.

ii. A dual-pricing system:

Price and distribution control for the integrated, large-scale producers in both the private and public sectors, while the rest of the industry operated in a free market.

iii. Quantitative restrictions and high tariff barriers.

iv. Railway freight equalization policy to ensure balanced regional industrial growth.

v. Controls on imports of inputs, including technology, capital goods and restrictions on finances and exports.

Industry Liberalisation

The government initiated a comprehensive economic policy reforms programme in the early 1990s which included the following elements:

- Large-scale capacities were removed from the list of industries reserved for the public sector. The licensing requirement for additional capacities was also withdrawn subject to locational restrictions. This resulted in the private sector playing a more prominent role in the overall set-up.
- Pricing and distribution controls were discontinued.
- The iron and steel industry was included in the list of high priority industries for foreign investment, implying automatic approval for foreign equity participation up to 100%
- Freight equalization scheme was abolished in phases.
- Foreign trade in steel was made free.

Steel was the first core sector of the Indian economy to be freed from licensing and pricing and distribution controls in 1990-91, an epoch-making step in moving towards a liberalized economy. This opened up the steel sector from being earmarked for public sector to a completely freed sector allowing free flow of private investment. The system, thereafter, underwent marked changes.

Impact of Reforms

For the steel makers, economic reforms opened up new channels of procuring their inputs at competitive rates from overseas markets and also new markets for their products. It also led to greater access to information on global operational practices and steel technologies. This, along with the pressures of a competitive global market, increased the productivity and efficiency levels in the industry which made a significant section of the industry globally competitive.

The steel consumer, on the other hand, gained from expanded supplies in various products both from domestic and overseas suppliers. As a result of these economic reforms, country's steel capacity increased substantially. Large integrated steel plants were set up in the Private Sector, viz., Essar Steel, Ispat Industries and JSW, JSPL, BSL etc. Tata Steel also expanded their capacity.

Steels contribution to Indian Growth story

Steel has contributed immensely towards India's economic growth. The Per Capita steel consumption in India was around 75.5 in 2021 and 81.1 kg in 2022 substantial increase from the measly 12 to 14 kg per capita in the early eighties. This is evident from the similar growth patterns of India's GDP and steel production in the country, which also highlights the economy's dependence on steel. National consumption of finished steel rose from 6.5 MT in 1968 to near 120 MT in 2023, while GDP (at constant price, 2010) grew from USD 0.25 trillion in 1968 to near USD 4 trillion today.

Currently, the Indian steel sector contributes approximately 2 per cent to its GDP and forms the backbone of the manufacturing industry providing about 2.5 million jobs directly or indirectly.

INDIAN INDUSTRY FEATURES

The present structure of the Indian steel industry is hybrid in many respects.

From a **size perspective** it consists of large multi-million ton units as well as micro-units with capacities in the range of tens of thousands of tons per year.

From a **process perspective** it consists of fully-integrated steel plants covering the full spectrum of processes to mini-units based on much restricted process combinations.

From an **ownership perspective** it has both Private sector as well as Public Sector.

Producer Classification

The industry in India is now classified into Integrated Steel Producers (ISP) and Secondary Producers.

Integrated Steel Producers are companies that cover the complete steel value chain - starting from the conversion of Iron Ore to iron and steel, along with the supporting process units, processing and finishing and marketing of finished steel.

Secondary Producers include manufacturers of steel from sponge iron, pig iron and steel scrap. The secondary manufacturers units thus, have Mini Blast Furnaces, Electric Arc Furnaces and Induction Furnaces as primary facilities. These units are semi integrated in most cases and integrated in some. The classification of the Secondary Producers includes a wide variety of producers linked with the steel production. Besides the above two core types, other diverse units include:

- Re-rolling units for bars rods and structurals,
- Independent cold strip rolling units,
- Strip galvanizing units,
- Tin plate production units,
- Colour coated steel strip producers,
- Standalone sponge iron producers.
- Standalone and pig iron producers.

Substantial growth has occurred in this sector due to reduced initial capital outlays required to establish smaller capacities with less number of units, scope for value addition and smaller sizes at diverse locations, easier operations, and ability to meet near area demands effectively.

Production Level

Steel production in India during the last decade has grown from 87 million tons in 2014 to about 150 million tons in 2024, over 75 % as shown in Table 3-10 and Figure 3-12.

TABLE 3- 10 INDIAN STEEL PRODUCTION (1967-2024)

Sl.No.	Year	Indian Steel Production
		MT
1	2014	87.3
2	2015	89.6
3	2016	95.5
4	2017	101.5
5	2018	109.3
6	2019	111.4
7	2020	100.3
8	2021	118.2
9	2022	125.4
10	2023	140.2
11	2024	150

The Integrated Steel Producers account for about 45.0 percent of steel production in India. The largest integrated steel players in India include Tata Steel, JSW Steel, Steel Authority of India, Essar Steel (Now AMNSI), Rashtriya Ispat Nigam Limited (Vizag Steel), JSPL etc.

The size of the Indian ISP's varies from 1 MTPY to 5 to 15 MTPY. The JSW ISP at Tornagallu is the largest single location unit in India and is slated to have a present capacity of about 15 MTPY. The Tata Steel unit at Jamshedpur, the pioneering giant of the Indian steel industry has a capacity of about 12 MTPY. The largest unit in the public sector is the Bhilai Steel plant with a capacity of about 7 MTPY. The major producers (ISP's) and their slated capacities are indicated in Table 3-11.

TABLE 3-11 MAJOR INTEGRATED STEEL PRODUCERS IN INDIA

	Present (2021)	Planned (App)
SAIL	21.40	30
RINL (VSP)	6.30	12 +
JSW Steel Ltd	15.00	24
JSW Ispat Steel Ltd	5.00	10
JSW (BPSL)	2.50	5
Tata Steel Ltd, JPur	13.00	15
Tata Steel Ltd,KPO	8.00	15+
Tata Steel Ltd Bhushan	3.50	7.5
Tata Steel Ltd Neelachal	1.0	5
AMNS Ltd	10.00	15+
Jindal Steel and Power Ltd	8.60	15
New Units Planned		40 (est)
Approximate Total	90	200+

Steelmaking Capacity

The key steelmaking and conversion units and their capacities are shown in Table 3-12.

TABLE 3-12 STEELMAKING UNITS & CAPACITIES IN INDIA (2018-19)

Process unit	Nos	Capacity	Nos
		MTPY	
Process Units		Rounded	
Blast Furnace	58	80	60
EAF	48	38	50
IF	1126	40	999
BOF	17	50	18
Sponge Iron	320	46	312
Product Units			
Re-rolling	1166	62	1222
Hot Rolled Flat Products	28	56	
CR Flat Products	70	26	
GP/GC	24	7	
Colour Coated	16	3	

Process-wise Steel Production

The process-wise share of the steel production during the years 2013-14 to 2018-19 is shown in Table 3-13 and Figure 3-13

TABLE 3-13 PROCESS SHARES IN INDIAN STEEL PRODUCTION

	BOF %	EAF%	IF%	Total
2013-14	43	23	34	100
2014-15	42	26	32	100
2015-16	43	27	30	100
2016-17	43	30	27	100
2017-18	46	26	28	100
2018-19	47	26	27	100
2024	43	22	35	100

The steelmaking capacity in the Secondary sector as per FICCI is given in Table 3-14.

TABLE 3-14 SECONDARY SECTOR SHARE OF STEELMAKING

YEAR	EAF Units MTPY		IF Units MTPY	
	Capacity	Production	Capacity	Production
2010-11	19.63	17.67	30.24	22.94
2011-12	25.76	18.93	31.02	23.94
2012-13	26.19	19.25	33.95	25.66
2013-14	28.88	18.75	36.49	27.29
2014-15	29.90	19.44		28.283
2015-16		24.599		26.796
2016-17		28.962		26.972
2017-18		26.421		29.221
2018-19		27.71		28.77
2025-26 (P)	60.00			

Indian Steel industry has the unique distinction of being heavily dependent on internal strengths for decades grappling with issues arising out of raw material qualities, demands from technology from multiple sources in different sectors, infrastructure limitations, policy limitations etc. Post-economic liberalisation, the organised industry sector has raised its level to global standards and is thus well- positioned in global context.

It is important to note that in 2021, there were two Indian steel companies (Tata Steel Limited and JSW Steel Limited) in the nine steel companies recognised by WorldSteel as “Steel Sustainability Champions”. WorldSteel uses 8 indicators to measure key aspects of steel industry’s economic, environmental and social sustainability performance.

NATIONAL STEEL POLICY

Recognizing the strategic importance of the steel industry, the National Steel Policy (NSP) was announced in November 2005 by GOI as a basic blueprint for the growth of a self-reliant and globally competitive steel sector. The National Steel Policy 2017, which evolved factoring the changing global scene and the Indian economic environment, laid down the broad roadmap for encouraging long term growth for the Indian steel industry, both on demand and supply sides, by 2030- 31, with a vision to create a technologically advanced and globally competitive steel industry that promotes economic growth.

PROJECTED STEEL DEMAND

The National Steel Policy framed by the GOI has formulated a road map considering the likely demand of about 230 by 2030-31, as shown in Table 3-15 below. Figure 3-14

TABLE 3-15 PROJECTED STEEL DEMAND IN INDIA (NSP)

Growth Drivers	2015-16	2030-31	Increase
	MTPY	MTPY	%
Infrastructure	9.5	90	947
Construction	23.6	45	191
Engineering & fabn	36	43	123
Automotive	2.5	10	400
Railways	2	5	250
Packaging	2	6	300
Energy	3	11	367
Shipbuilding	-	3	-
Oil & gas	-	4	-
Defence	4	2	50
Other	-	11	-
Finished steel	81.5	230	282
ASU Per Capita. kgs	61	158	260

Industry Requirement by 2030-31

The following are expectations that form the basis to meet the projected demand for steel by 2030-31 as per the NSP

Steel-making capacity 300 million tonnes per annum

Crude steel production 255 million tonnes

Capacity utilization 85%

Production of finished steel 230 million tonnes,

Net exports of steel 24 million tonnes

Steel consumption 206 million tones

Per capita steel use 160 kg.

Raw materials Required

The projected requirements of raw materials is given in Table 3-16.

TABLE 3-16 PROJECTED RAW MATERIALS REQUIREMENT (As Per NSP)

Sl.No	Raw Material requirement	By 2030-31
		MTPA
1	Iron ore	447
2	Coking coal	180
3	Non-coking coal for PCI and DRI	117
4	Limestone & dolomite	91
5	Others	31

SECTOR WISE GROWTH OUTLOOK

A sector wise broad analysis can provide a better view of the context for projections of steel demand.

Construction (Incl Infrastructure) sector:

The sector including physical infrastructure and housing is expected to contribute roughly 60% of India's steel use or steel demand by 2030-31. The infrastructure sector, currently a huge focus area of the government, will expectedly drive growth in this sector as well as overall steel demand. Overall, the infrastructure segment is likely to grow by 9–10% per year, mainly driven by road projects and urban infrastructure.

Traditionally and even as per the experience so far , the demand for steel from this sector is limited to bridges, safety barriers, and smaller uses such as electric power transmission, pipework, toll structures etc.

The real estate sector continues to face the severe impact of the NPA resolution process. It is growing at a CAGR of over 4% and the affordable housing and smart cities initiatives will drive growth in this segment.

Automobiles

The Indian automotive industry is the fourth largest in the world. It contributes to around 4% of steel demand in India projected to grow to about 6 % by 2030-31. India is the largest manufacturer of two-wheelers, three wheelers and tractors, the fourth largest producer of passenger vehicles, and the seventh largest in commercial vehicles in the world. This sector will likely be under pressure due to increasing fuel costs, shift to mass rapid transportation dictated by environmental consideration and pricing.

Railways

This sector, which contributes nearly 2% of steel demand, is not highly significant from the volume perspective. This is also a cyclic requirement.

Capital goods

The sector is expected to contribute nearly 15% of total steel demand of the 20% Classified under engineering and fabrication. Machinery and equipment, a subset of the capital goods sector, accounts for less than 25% of total manufacturing and about 4% of India's total gross

value added (GVA). The Indian experience of this sector has been one of missed opportunities. The industry was not geared up for exploiting the opportunities presented by the high growth periods in the last 20 years where China went on to become the manufacturing hub of the world. The state-of-the-art facilities and the price advantage offered by the Chinese installations, has encouraged continuance with China as the focus. Further competition has also been looming with countries like South Korea Vietnam etc staking major claims on international supplies. Recourse to imports by domestic industries taking advantage of the liberalized regime as well as the cost advantages mainly from the Chinese sources has also propelled the move away from domestic manufacture. Significant gaps existing technology capabilities as well in this sector.

To ensure that the sector reaches high performance levels and becomes a driver for steel demand would require Herculean efforts and commensurate investments. Given India's thrust on the Make in India programme, the outlook for the sector is positive.

Consumer durables

The sector contributes about 5% of India's steel demand. India is a consumption-driven economy and traditionally this sector has witnessed robust growth. In 2018, for example, the sector grew by 21.7%. However, in line with declining GDP growth, there was a slowdown in this sector's growth performance in 2019.

INDIAN DEMAND PERSPECTIVE

The Policy projections had foreseen an implied annual growth rate of steel demand of about 7.5% during the 15-year period from 2015 to 2030.

The apparent steel consumption in the country was about 90 million tons 2017-18, 96 million tons in 2018-19 and about 100 million tons in 2019-20 and 120 million tons in 2023. Whereas the projected apparent consumption is about 230 million tons by 2030-31. Thus, the increase in consumption required to reach the projected demand in 2030-31 as per NSP in the remaining 7 years period is about 110 million tons, nearly double of the present level. The current reality would require a CAGR of over 10 % in the 7/8 year-period upto 2030-31. This looks unrealistic.

In this context, the Chinese experience in factors that drive demand in large population could be relevant. A sector wise steel demand during 2005 to 2020 is shown in Table 3-17. A critical analysis of the same would suggest that the better classification of user sectors vis-à-vis steel demand would make the projections more focused and realistic.

TABLE 3-17 SECTORWISE STEEL SHARE IN CHINA

Growth Drivers	2005	2010	2015 (e)	2020 (e)	200-05	2005-20	Sector share
	MT	MT	MT	MT	CAGR %	CAGR%	2020 %
Residential building	72	128	142	149	12.4	0.9	18.4

Commercial building	61	103	148	179	11	3.8	22
Machinery	60	113	147	171	13.4	3.1	21
Public Infrastructure	54	103	87	102	13.7	3.2	12.5
Transportation	25	65	77	86	21.2	2.1	10.6
Others	62	73	117	127	3.2	1.9	15.6
Total	334	585	717	814			

It is important to note that the unprecedented level of steel consumption in China is substantially (40% - 328 million tons in 2020) in the buildings both residential and commercial. China's stranglehold on manufacturing in the world is also reflected by the steel consumption in this sector of over 21 % (over 170 million tons in 2020).

Global Steel Demand

The global steel demand as per World Steel expectations is shown in Figure 3-15. As per this, the steel demand will grow in the future but not at a high rate. New and growing practices of reuse of materials and recycling will push the created steel demand into further future.

Desired Demand Imperative

The foregoing would suggest that the targets of steel demand set in the NSP be subject to a critical review considering the economic scenes, developmental priorities, and environmental imperatives. The demand projections may be well served by a fresh approach. Prospective approaches are outlined below.

The primary index which generally justifies the projected demand indicated is the level of Per Capita Steel consumption. This index compared to that of the developed countries (USA, Germany, Japan, South Korea etc) would appear much lower for India. The traditional per capita index is in many ways a distortion and particularly misleading in Indian context due to the high level of its population. While the projections are based on this index, the actual access to the steel still remains limited due to the low and average level of economic prosperity of the majority of the population. The life styles dictated by the local culture, climate and economic levels are also big factors to be reckoned with in arriving at the potential demand for steel. It may thus be unrealistic to expect that the projected 150 kg of steel consumption per capita (as compared to the present about 81 kg) year after year would actually materialize.

Another indicator aligning with the GDP growth is steel intensity which is expected to align with the same or even exceed it in some cases. A comparison of this index with that of the developed economies of the western world and APAC can be fraught with gaps, given the wide differences in population level, country's economic platforms and priorities, environmental issues, type of infrastructure, affordability, life style, cultural practices etc.

A better and more reliable approach would be to project the demands based on the individual user segments considering the sector specific physical achievable targets factoring the resource availabilities and priorities.

Realistic Perspective

There is a distinct prospect of de-intensification of steel (Demand Intensity vs GDP) due to a number of factors that have emerged which could significantly disrupt the demand scenario. These are

- Material substitutions,
- Quality improvement of materials and
- Changing design
- Usage optimization
- Circular Economy and Life cycle perspective

The factors that are impelling the de-intensification process are:

- Increasing adoption of Circular economy driven by economics, environmental and Sustainability concerns
- Increase in useful life of assets and facilities, and focus on life cycle perspectives
- Digital technologies enabling reduced intensity of products through optimized designs
- Materials research (new products and processes as well as improved properties)
- Automotive light weighting driving innovative steel products and substitution for steel

Perspective on Demand Moderation

As per a scenario projected by Accenture, the impact of the disrupting factors is likely to be substantial. As per this demand forecast, it is projected that global steel demand grows by 1.4% per annum to reach around 2.0 billion tons by 2035. However, after applying the estimates of the impact of disruptors, the projection is that global steel demand growth may get tempered to 1.1% per annum to reach 1.87 billion tons by 2035

In a Radical scenario, global steel demand is projected to grow by 0.4% per annum to reach 1.75 billion tons by 2035, which is 12.5% below the baseline forecast of 2.0 billion tons

The factors that are likely to impact the global consumption level of steel are:

Shifting Peak Consumption of Steel per Capita

Reduction in demand for sector's product

Increase in useful life

Change in steel intensity

Region-wise, it is expected that Demand in mature economies will show zero to slightly negative growth rates. Demand growth in emerging economies will be in the range 2.5% to 4% and demand in India is forecast to grow at around 5.6% per annum to reach around 240

million tons (as per NSP target) which now seems very unlikely. Demand in China is expected to decline at 1.1% per annum.

The projected ASU and steel use per capita as per the above projection are shown in Table 3-18.

TABLE 3-18 APPARENT STEEL USE (MTcs/KG/Capita)

		EME	DEV	China	India	Total
ASU(MT)						
Base line	2015	369	389	672	80	1500
	2035					2000
2015-35	CAGR					1.4%
Incremental	2035	715	285	537	237	1873
2015-35	CAGR	2.9-3.6%	0.1/-0.1%	-1.1%	5.6%	1.1%
Radical	2035	664	352	504	228	1749
2015-35	CAGR	2.4-3.2%	-0.4/-0.5%	-1.4%	5.4%	0.8%
ASU(kg/capita)						
Base line	2015	173/204	703/321	497	61	235
	2035					263
2015-35	CAGR					0.6%
Incremental	2035	260/226	704/289	388	150	246
2015-35	CAGR	2.1/0.5%	0.0/-0.5%	-1.2%	4.6%	0.2%
Radical	2035	239/208	636/267	365	145	229
2015-35	CAGR	1.7-0.1	-0.5/-0.9	-1.5	4.4%	-0.1%

A brief overview of the potential factors favouring moderation of steel demand is given below:

CIRCULAR ECONOMY VIS-A-VIS STEEL DEMAND

It is now well recognized that adoption of Circular Economy may well be part BAU of all sectors of the economy. Successful adoption of this has the potential to effectively lead to much reduced virgin production. This would have a very direct bearing on the Sustainability of the steel industry as well. While such opportunities could exist in all steel-using sectors, the greatest opportunities lie in the automotive and construction sectors which together account for around two thirds of all steel use.

Automotive Sector

Currently, over 75% of the passenger car emissions arise from the use of the vehicle and 23% from its production. Specifically, for steel and considering the combined opportunities for improved recycling, better material efficiency and shared business models, Material Economics has estimated that the primary steel required per million passenger kilometers could fall by 70% in terms of tonnage (Table 3-19).

TABLE 3-19 CE IMPACT ON AUTO SECTOR STEEL DEMAND

	TS/MPKm*
Base line	1.85
Potential Savings	
Material Circulation	0.29
Product Material Efficiency	0.35
Circular Business models	0.65
Total Potential	1.29
Net Circular Scenario	0.56
Savings Potential %	30%

*TS/MPKm Ton Steel /Million Passenger Km

Construction

The optimization and reduced material usage is also at the core of emission reduction. Construction accounts for about 50% of all steel demand globally, and here too there may be significant opportunities to reduce required steel use through CE models. In the Indian context this sector including infrastructure is expected to form over 60 % of the projected demand by 2030. Material Economics estimate potential emission reductions from all materials input to the buildings sector (steel, plastics, aluminum and cement) of 34% by 2050 (in EU) if all opportunities for improved construction efficiency could be achieved (Table 3-20).

TABLE 3-20 CO₂ EMISSIONS FROM MATERIALS USED IN BUILDINGS

Million Tons Per Year CO ₂				
	Steel	Plastics	Aluminium	Cement
Current	78	26	29	74
Reference Scenario 2050	90	31	33	77
Scope for Reduction				
Circular Models				
Cement Recycling				13
Waste Reduction	3	2	2	3
Reuse of building components	7	3	3	7
Material Efficiency	12	3	4	8
Sharing	4	1		4
Subtotal	26	9	9	35
CE Scenario by 2050	64	22	24	42
Reduction {Potential%}	34%	29%	27%	46%

Such approaches will inevitably affect the level of conventional demand projections substantially. The above approach also coincides with the “De growth” approach with focus on reduced consumptions as a major tool for sustained decarbonisation.

INDIA APPROACH

Therefore, the factors which have to be given due attention are:

- Economic model suited to Indian context considering population, local culture, and life style.
- Optimised demand estimates and leveraging benefits of CE
- Effective resource use
- Impacts due to Life cycle perspectives in the industry.
- Likely shifts in mass transportation, and likely stunting of ICE automotive due to environmental concerns.
- Sustainability initiative impacts

A more realistic and achievable demand target would therefore be inevitable to provide a basis for planning the capacities. A 4-6 % (optimistic considering the current realities) rate itself will mean that a demand level of near 200 million tons would be realistic by 2035-36.

Critical Analysis of the Product mix

A very strong bias gets built in towards flat products while projecting steel demand for the future and planning future capacities. With a hybrid economy like India, it would be reasonable to assume that construction and infra, and manufacturing will have to be key drivers of steel demand. This is also borne out by the steel policy where these sectors are the key contributors. This would push the non-flat steel (bars and rods and sections) on a priority list.

Need for Energy and Emissions Control

In this context, it is important to pay focused attention to the energy scenes as well as the emissions impacts. IEA has done a critical analysis of the factors that need to be incorporated in the future road maps of all industries and more particularly manufacturing. The key takeaway for the steel industry from this would be the need for improvement in efficiencies in consumptions as well in material efficiencies. A potential of nearly 40 % in demand moderation has been projected.

Key Actions Required

- Realistic and achievable steel demand targets
- Effective leveraging of steel’s durability
- Technology focus on environmental mitigation and carbon reduction.
- Focused recycling strategy covering process transitions and realignments.
- Well-debated and nuanced raw material policy with focus on lower grade resource use.

- Additional Capacity creation strategy with focus on dispersal and effective distribution.
- Policy level support for domestic growth and sustainability

In the above context and in the light of the uncertainties that are now introduced in the global economy and energy scene, it will be prudent to tailor the development plans on a realistic basis with the focus on:

- Serving demand in most efficient manner
- Ensuring environmental compliance particularly with respect to resource efficiencies and energy transition and management.
- Exploiting AI and digitalization to enable innovation and optimisation in all facets.

Key Industry Challenges

- High level of fragmentation with non-optimal plant sizes and technology- needs to be addressed for rectification on priority.
- Capex optimization with increased local participation in equipment manufacture and efficient project execution.
- Well-researched, effective and productive use of digital technologies consistent with the need to avoid large scale disruption, avoidable additional investments, technology mismatches and unaffordable skill demands.

Cautionary approach to Capacity Creation

From the various analysis of steel capacities and likely demand it becomes clear that over capacity could be a major problem in the future. Considering the impact of disruptive developments, various inward-looking initiatives in most of the countries and trade limitations etc, export opportunities may also get limited. Also, the potential available in steel for enabling “doing more with less” needs to be fully developed and exploited to support sustainability as well. Therefore, a well-founded detailed evaluation of the aspect is essential in going forward with creation of additional capacities particularly in the Indian context.

Chapter 4

SUSTAINABILITY REQUIREMENTS

Sustainability has taken center stage today in most of the key fora and policy making bodies globally. The most striking challenge that is faced today is the adverse impact on the environment and ecology and its human impacts. This has been so striking that the world has had to sit up, take note and fight for finding viable and sustainable solutions while mitigating the already created adverse effects to the maximum extent practicable. Steel industry contributes about 7% of the global emissions and thus is a priority sector for reducing emissions. This chapter outlines the requirements for Sustainability and its contextual positioning with the steel industry.

Concerns on Sustainability

The economic prosperity which many parts of the world experienced in the last 7 decades has definitely helped in fighting poverty on a considerable scale globally, but it has also thrown up numerous unexpected and unwelcome consequences. The explosive developments over the last three decades particularly the quantitative dimensions arising out the developing countries particularly China have also brought into greater focus the impacts of unbridled development. There is a sudden urgency in the world therefore to evaluate in greater depths these adverse impacts and the steps that are required for a possible mitigation and a sustainable solution.

The steel industry has been no exception in facing pressure for improving environmental performance being a contributor of nearly 7 percent of the global emissions. It is against this background and concern that there is an urgent need to evaluate the developments and redefine sustainability in the current steel industry context. The Sustainability Goals that can ensure long term mitigation are also need to adequately dealt with.

WHAT IS SUSTAINABILITY

The key aspects that enable growth are resources (raw materials, energy, water), transport, technology (processes for conversion to value added and useful products), and human efforts. Developmental solutions in each of these areas would largely positively impact the economic, and social spheres. However, there are collateral impacts and damages on environmental, ecological, human and social spheres.

The efforts, therefore, are to strike an appropriate balance between development and its adverse consequences. The major concerns arise on account of depleting finite resources and deteriorating environmental conditions which can have serious impacts on future generations and life styles.

In the above context, the now commonly accepted definition of Sustainability is – **“Development and growth in the present without compromising the future ”**

ROOT CAUSES IMPACTING SUSTAINABILITY

It is necessary to understand the root causes of the adverse experiences over the last decades to evolve sustaining solutions for the future. Prima facie four major causes seem at the root of major impacts:

- Economic Model for development
- Materialism fuelled and supported by globalization.
- One size fits all concept
- Exploding Population

Relevance of economic model

The world has largely believed that economic prosperity defined mainly in terms of GDP growth would be an appropriate indicator of its level. The underlying belief being higher growth would translate to better lives for the population, through industrialization, food security, education opportunities, sustainable jobs and increased comforts in living. Thus, the nations' prosperity and well-being were getting evaluated on the basis of living standards and national per Capita income etc.

This approach provided a good benchmark to enable organized planning with other additional benefits. However, in actual experience the sharing of the positives of growth has been extremely skewed with a major section not being a significant beneficiary at all. This has created major and yawning inequalities within societies. A clear divide is evident today between the affluent and the not so well-off categories in population (country-wise as well as within the nations) in most parts of the world, more so in the poorer and developing nations.

In most countries of the world, the selective affluence achieved has been substantially driven by the theory of market economics and its related priorities. In this approach, the status of the lower economic strata gets defined only in aggregate terms without adequately factoring in the specifics in the economic models that are likely to impact them adversely. The neglect of this segment keeps getting even more compounded with time. The effects of these are clearly to be seen all over the world. Even in so called developed countries such as USA, the gap between the haves and have-nots continues to grow to unforeseen levels.

Materialism

The population is seen by businesses and the investors only as a potential market. The key efforts are obviously to encourage consumption leading to increasing materialism considerably detracting from the core issues related to greater human wellbeing, upliftment of the poorer sections of the society and generally providing an egalitarian approach and equality in sharing resources and benefits of developments.

Viability of business being at the core, the major thrust is towards higher value and greater margins. Short use product lives are also essential for ensuring sustained production of consumption items over time. Most of these items may not be relevant to the larger sections (read poorer) of the local population but the niche section itself in most populations in the

developing world is a very large market with overflowing resources and disposable money to sustain this onslaught. India and China are clear examples, a small fraction of their population being massive compared to most nations of the world. This is one of the key aspects which aids in embedding a considerable measure of inequality in society.

The section that keeps this cycle moving blissfully turns a blind eye to the consequences including those inflicted on the other sections of the population.

Globalisation

One of the key roots of strong focus on rank materialism is the current concept of globalization. This seeks to break all barriers national and international and make the world a single marketplace. Obviously, it is only those with enormous money power, resources, reach and ability can practice such a model. This model has shown its potential to play havoc with the developing nations by taking away their local powers by holding finance and marketing as the basic elements for their success, and the core activities carried out in the smaller nations/locations getting relegated to the background. The key negatives of this approach are:

- Economic models largely dictated by the financial focus than by national demands of the population.
- Creation of burgeoning demand in areas/products not so relevant and not essential for the major population of the country in question.
- Ignoring distortions due to the unequal wage structures, life styles and comfort interpretations in the different societies, local realities and their level of development.
- Reducing scope for local enterprise and innovation
- Leveraging massive low-cost resources in developing locations to benefit the haves leaving the low-end work, and limited opportunities to local entities, with hardly any scope for innovation, research and development to the poorer partners.
- Depriving nations of the rightful shares normally due, by diluting the locational and their competitive strengths through global based pricing policies. Iron ore, Coal, Energy are clear examples.
- Gradual decay of many of the traditional local practices which are both sustainable and economic and culturally relevant.
- Pushing towards high-cost economy as the profitability aspect can only be supported by such models.

Consumption is the Key

The economic models presently adopted generally embrace the principles driven by the originating forces (read Private sector enterprises, public sector enterprises, Governments). The dominant global position of driving the model today is occupied by the Private sector, the major part of the world having generally embraced Capitalist philosophy as an efficient solution. China and Russia are the notable exceptions though they have also created space for

the private sector and selective capitalist principles within their limitations of their basic principles.

The adoption of Capitalist economic models is largely driven by concepts of prosperity through consumption and commercially measured terms of success of enterprises. Scale without reference to the locations has formed a key requirement to achieve the so-called lower costs, introduction of technology as well as increasing the reach in society. This has necessarily led to concentration of the major levers for development in selected locations, large players with deep pockets and the investors.

Ignoring Local Cultures

The local culture, lifestyle, sensibilities, affordability, priorities for well-being etc, therefore do not find an appropriate place in evolving the economic models considered necessary for overall development. Exploiting the locational attributes to further the commercial objectives has become the key principle, euphemistically defined as competitiveness. As a result, the need for factoring the local requirements and conditions, cultures and priorities have not received the attention that they deserve. The indisputable fallout of this approach has been that the major proportion of the fruits of this model are found to be beyond the affording capacity of large sections of population in most countries. The growth markets thus get developed in islands in line with the investor perceptions and the global interests with the business angle receiving near total attention.

The Consequence

The consequence of such development is for us to see, wherein the majority of the population in most of the countries particularly the developing world is deprived of even minimum requirements for decent life at the cost of windfall benefits and unsustainable practices accruing to the smaller wealthy sections.

Strikingly, a recent international survey places India embarrassingly low in the list of the Happiness Index and near bottom on environmental compliances as well.

This experience would, therefore, dictate the need for a review of the economic models so that a more balanced and sustainable approach suited to the local realities and interests of larger sections of the population can be adopted.

WORLDVIEW OF CURRENT ECONOMIC MODELS

Some of the expert views have succinctly presented an evaluation of the present state of affairs after taking a global view which runs as follows.

“Neo-liberalism driven by globalized finance capital would be a reasonably appropriate definition of the way the world including India at large has moved ahead in the last 2/3 decades. The essence of neo-liberalism was the relatively free flow of goods and capital, including finance, across country borders. Sadly, the main champion of the above, the USA itself has been putting up barriers against the free flow of goods. At the core of such approach may be the acute distress and unemployment among American workers.”

An expert view from a world-renowned economist, aptly summarises the present state of Capitalism the world.

Quote

“I think capitalism is under serious threat because it’s stopped providing for the many, and when that happens, the many revolt against capitalism,”

“It’s not providing equal opportunity and in fact the people who are falling off are in a much worse situation,”

Unquote

Even the USA, which was the champion and chief protagonist of the present popular global approach has started to renege on many of its basic principles, having recognized that with the current approach, the larger population remains deprived in spite of the so-called economic developments. It also recognizes that the private sector alone may not be the best course for ensuring economic prosperity.

The events triggered by the Russia-Ukraine war has also brought to focus the risks associated with unfettered global trade as well as with over centralization for scale (from Agriculture to Manufacture to Services).

The COVID Shocker

That the current economic priorities are skewed has been amply demonstrated by the experiences of all the nations of the world in the fight against the COVID pandemic inflicted on the world in 2020, affecting all - affluent as well as the ones not so. That the focus for vital needs of the larger population, namely healthcare, sustainable living etc have been given the go by in most of the systems is quite apparent and well understood now. The financial and human resources demanded to counter the pandemic have fallen woefully short.

Another key learning out of this pandemic is the impact of inequalities in the society, which has transcended to even the access to lifesaving efforts. A glaring impact of the Covid reality is the need for social security reflected in terms of the doles that have had to be provided in countries such as USA and Europe to provide succor and survival support for a very large section of the population. In case of India this task is of massive proportions considering the population size and the diversity.

One Size Fits All

The adverse impact of “One size Fits all” and so-called economy of scale have also come into great focus in India more so during the pandemic, given the state of the MSME’s in India. Varying statistics emerge regarding the numbers employed in these sectors, but these are over 5 Crores (50 Million) as per one estimate or nearly 3.6% of the population. That this sector is vital and a key to national economic well-being has sunk in but the models are yet to recognize the changes needs dictated by the reality of this sector. The contribution of this sector particularly in the export front has also become evident and thus begging for attention.

But with the economic model focusing only on scale as the panacea, does not have appropriate solutions suited to the smaller players. The same impact is also seen in the

agricultural sector in India (Largest employer) which is very small scale and highly fragmented.

Also using the MSME sector as the economical sub-contract producer deprives them of their rightful role, in terms of fair value as well as growth trajectory.

Exploding Population

The global population has grown from 1 billion in 1800 to 7.9 billion in 2020. The current world population is around 8 billion. As per UN projection – the world population is likely to be 8.6 billion by mid-2030, 9.8 billion by mid-2050 and 11.2 billion by 2100. Population of 10 largest nations and their population densities is shown in Table 4- 1. (Figures 4-1 and 4-2).

TABLE 4-1 POPULATION TOP 10 COUNTRIES

Sl.No,	Country	Population 2022	Land Area	Population density
		No	Km2	Nos/km2
1	China	1,448,471,400	9,706,961	149
2	India	1,406,631,776	3,287,590	428
3	USA	334,805,269	9,372,610	36
4	Indonesia	279,134,505	1,904,569	147
5	Pakistan	229,488,994	881,912	260
6	Nigeria	216,746,934	923,768	235
7	Brazil	215,353,593	8,515,767	25
8	Bangladesh	167,885,689	147,570	1,138
9	Russia	145,805,947	17,098,242	9
10	Mexico	131,562,772	1,964,375	67
	World	7,994,475,787		

The increase in population has resulted in highly increased demand on resources namely food, water, housing, infrastructure, mineral resources etc. The availability of these support facilities per capita has become woefully low in many parts of the world due to the development process not being able to keep pace with the population growth. The poverty levels have thus increased considerably alongside the industrial and agricultural prosperity.

Resource depletion

There is a fixed supply of non-renewable resources, such as coal, ores as raw materials for metal production, oil and gas as chief energy sources, and these resources will inevitably be depleted in time. A view that is gaining currency among many economists is that decreasing demand is the only way of permanently closing the non-renewable resources demand gap. A focused approach in this direction could well be the biggest contributor to decarbonisation in the steel industry.

SUSTAINABILITY REDEFINED

The foregoing narrative would therefore demand a more sensitive and all-encompassing definition of Sustainability for the world to follow. The following may reasonably represent the need of the hour.

“Sustainability can therefore be redefined as - “Development and growth in the present recognizing the adverse impacts of the past, ensuring their mitigation and adopting solutions focused on majority population, human and environmental well-being without compromising the future”

SUSTAINABILITY AND STEEL INDUSTRY

Unique Role of Steel

Steel provides a key input for innumerable activities which, in turn, help raise living standards across the world. Steel is the material of choice for the diverse uses due to its extraordinary attributes, namely exceptionally long life, on scale availability, recycling potential and above all affordability. As a result, steel has come to be accepted as essential for the well-being and prosperity of the global population.

The world around us abounds in the presence of steel in virtually everything that we use for our existence, daily needs, economic development and vital services. Steel is central to our current infrastructure, housing, transport systems, manufacturing, agriculture, water and energy supply. It is also critical to the sectors and technologies that will enable and drive a green economy. Renewable energy, resource-efficient and energy efficient buildings and low carbon transport, infrastructure for fuel efficient and clean energy vehicles and recycling facilities – all of these depend on steel.

Sustainability of the steel industry, therefore, can be rightfully considered a global priority and essential for the global long-term well-being. The components of Sustainability in Steel Industry are shown in Figure 4-3.

Inevitable Impacts of Steel Manufacture

That there are certain fundamental and non-compromise able imperatives in steel manufacture which revolve around reduction of virgin iron ore to iron and then to steel is a reality. Being a highly energy-intensive operation, a level of environmental impact due to the emissions in the process of its manufacture is foregone. The steel industry has invested massive resources in research and development in processes, energy efficiency, collaborative product development, improving performance parameters etc over the last many decades. These have resulted in much greater efficiencies, reduced material usages, highly reduced energy inputs, higher rates of recycling etc. The steel industry historically has focused on HSE aspects being a highly labour-intensive industry in its initial form.

Considerable volumes of process arisings (co-products) and wastes are another area demanding industry attention. There have also been large scale and serious attempts to manage and to develop technologies for their beneficial reuse.

Historically, the bigger steel plants in India have been preferably located near ore sources and access to good logistics. Accommodating the very large work force and their families and ensuring their normal urban life with all the associated requirements (housing, schools, healthcare, other infrastructure) has required huge efforts as well as resources from Steel industry, particularly in India and the developing world.

Steel is Unique

Steel is an abundant, sustainable material that can be recycled endlessly. Iron is believed to constitute 1/3rd of the earth's weight. Steel is highly affordable and is cheaper than a bottle of drinking water in many developed nations.

Steel represents 90% or more of the metal products. Steel has diverse properties unmatched by any other metal or substitutes on scale. (Fig 4-4).

Steel has infinite potential due to its extra-ordinary strength supported by the other attributes. (Fig 4-5)

Steel More Sustainable

In spite of the concerns of steel manufacturing impact on environment, it is appropriate to put its position in perspective against the materials that are intended and/or are being used in a limited way as a replacement for steel. Reference to Table 4-2 will indicate that the carbon impact of Aluminium is 4x and fiber-reinforced plastic 4.5x as compared to high tensile steel for the same automotive component despite some of their attractive attributes.(Figure 4-6)

TABLE 4-2 STEEL vs OTHER MATERIALS - CO₂ IMPACT
(Comparison for manufacture of Same Automobile Component)

	Constructional Steel	High Tensile Steel	Aluminium	Carbon fibre reinforced Plastic
Functional Equivalent Weight, kg	100	75	67	45
Total CO ₂ Emission, kg	223	169	851	990
CO ₂ Emission per unit kg, CO ₂ /kg	2.2	2.3	12.7	22

WSA (Worldsteel), the key global coordinating body for the majority steel industry of the world (over 180 countries accounting for over 90% of the world steel production), has been playing a key role in furthering the industry approach to Sustainability. WSA has provided an effective forum for action plans factoring and sharing global experiences encouraging sustainable actions across the industry. Research, reports, debates and approaches have been provided to act as a reliable guide to its members.

Recognising that Steel will have a near-eternal value for the world, WSA has focused on making its manufacture environmentally compatible, Sustainable and affordable. For over 5

decades now, WSA has been demanding focus on issues that enable or affect this overall objective. Intercountry cooperation in research as well as pilot studies and projects have also been possible due to its wide reach. The various actions evolved and undertaken by WSA to ensure steel sustainability will be evident from Figure 4-7 which effectively traces the journey of the steel body and the industry from 1967 to 2021.

WSA has advocated the following Key Sustainability goals for the industry covering its essential parameters:

- Environmental Sustainability
- Social Sustainability
- Economic Sustainability

The factors covered under each are identified and the industry performance monitored annually. Benchmarks have also been proposed against various items. The industry performance during 2018 to 2022 is shown in Table 4-3 and Figures 4-8, and 4-9.

TABLE 4-3 STEEL INDUSTRY SUSTAINABILITY PERFORMANCE

Sl.No.	Indicator	Unit	2018	2019	2020	2021	2022	2023
Environmental Sustainability								
1	CO ₂ intensity	tCO ₂ /tcs	1.81	1.85	1.89	1.91	1.92	1.92
2	Energy intensity	GJ/tcs	19.51	20.06	20.62	21.02	20.99	21.27
3	Material Efficiency	Materials converted to products & coproducts %	96.33	97.49	97.86	97.56	97.654	98.15
4	Environmental management systems (EMS)	Employees & contractors working in registered production facilities %	97.07	97.16	96.13	95.66	96.15	94.81
Social Performance								
5	Lost-time injury frequency rate	injuries / million hours worked	0.84	0.83	0.85	0.85	0.656	0.76
6	Employee training	training days / employee	6.48	6.90	7.18	6.72	7.78	8.9
Economic Performance								

7	Investment in new processes & products	% of revenue	6.12	7.09	8.03	6.29	6.298	7.25
8	Economic value distributed	% of revenue	94.18	98.27	97.75	93.78	96.57	98.82

It will be clear that the industry is pursuing relentlessly the objectives of sustainability in all its dimensions. Further efforts are ongoing keeping in view the climate change concerns.

WSA Sustainability Principles

As a major step, WSA has formulated comprehensive Sustainability Principles, as can be seen from Figure 4-10. It would be noted that the same is also coordinated with the UN Sustainability Goals which are accepted and are being implemented for Sustainability on a global scale across all sectors. Appropriate programmes against each of the principles are also outlined and indicated in the figure.

STEEL VIS-A-VIS UN SUSTAINABILITY GOALS

The spirit of the above redefinition has been largely captured in the policy pronouncements from many global institutions and national bodies. There is now an increasing push towards finding solutions in this direction. The global focus has given rise to evolving specific Sustainability goals which could be of considerable value in setting and achieving the avowed objectives. In this context, the United Nations has taken a number of initiatives and the lead in defining these in a comprehensive way under its Sustainability Goals. These are discussed in the following paragraphs.

UN Sustainability Goals

As a step towards urgent global action towards Sustainability, United Nations has laid down 17 Sustainability Goals. These are shown in Figure 4-11.

While all the goals listed in UN goals would be of general relevance to the steel industry and its various dimensions, the following goals would demand direct and/or indirect actions from Steel as a material and Steel plants as the source of this material. These are:

UN Goal 3: Good health and well-being

UN Goal 6: Clean water and sanitation

UN Goal 7: Affordable and Clean Energy

UN Goal 8: Decent work and economic growth

UN Goal 9: Industry, innovation and infrastructure

UN Goal 10: Reduced inequalities

UN Goal 11: Sustainable Cities and Communities

UN Goal 12: Responsible consumption and production

UN Goal 13:Climate action

UN Goal 15:Life on land

UN Goal 17:Partnership for Goals

The impacts and mitigative roles that the different areas of the steel industry can and must play towards contributing to sustainability goals as outlined by UNSG are discussed in the following paragraphs. The goals have been sequenced in order of their criticality to the steel industry.

UN Goal 12: Responsible consumption and production

Prima-facie this goal may seem opposed to the philosophy of Growth, but there is no denying that this is a vital key to Sustainability. This is an area which the steel industry has to take serious note of, as the principle outlined has direct as well as indirect (uses and application areas) consequences and impact on the overall planning of the industry itself. An informed analysis would indicate that this approach driven by Life Cycle Concepts can throw up extraordinary opportunities towards sustainability and more than mitigate the likely adverse consequences.

It has deep significance in numerous ways as far as the steel industry is concerned. At a direct level within the steel industry itself, adoption of this goal as ‘sacrosant’ will enable greater fillip to optimization in material usage, reduction in waste generation, moving towards zero waste manufacture, reduction in energy demand, better and more equitable use of available infrastructure. Recycling ability of steel is an extraordinary attribute which is in complete sync with the climate and human well-being. This can also reflect in better use of existing facilities obviating the need for large scale environment-friendly expansion and its consequent benefits in many cases.

UN Goal 13: Climate action

Steel industry is a very large energy consumer particularly in the form of carbon (coal and coke) and consequently a major contributor to the GHG emissions globally. There is considerable concern and willingness to tackle this problem head on and provide relief.

It should be noted that the climate impact steel production and consumption is relatively much lower than many other key inputs for the economy. The overall magnitude seems daunting at times due to the large volume of steel produced and consumed globally.

The key efforts towards climate action in the steel industry are therefore focused on research and innovations aimed at reducing/replacing carbon as the reductant for iron ore, overall energy optimization and zero waste manufacture, reaching Circular Economy (Closed Loop manufacture) within the industry units, and exploiting its life cycle potential.

A highly significant and potentially important area, which would facilitate all round improvement including carbon footprint reduction is the increase in the level of recycling. Although steel is the most recycled metal at present in the world, concerted efforts at improving the recycling further, particularly in the developing world would reduce the demand for virgin production with consequent reduction in the carbon foot print and in overall virgin resource

optimisation. The process of manufacture in this case is also much less energy intensive. It is expected that the level of recycling has the potential to reach 70 % by 2050 which would in effect reduce the virgin support to only 30% of the gross steel requirements. Achieving this would also have enormous environmental benefits due to the reduced demand for raw materials, energy, water etc.

Development and popularization of alternatives to Carbon as a reductant also deserve well focused efforts. Use of hydrogen as a substitute which is looming large could be the possible long-term solution.

UN Goal 9: Industry innovation and infrastructure

The UNSDG requires the following dictum to be followed.

“Build resilient infrastructure, promote inclusive and sustainable industrialization and foster innovation.”

The steel industry has been one of the key drivers of innovation in the twentieth century industrial world. The impetus towards this has been due to the need for Energy optimization, environmental demands, cost optimization through productivity, Scale, and efficiency.

Industrial automation has received a strong push from the steel industry in areas such as material handling, process improvements, controls and monitoring, Artificial intelligence, data analytics and efficient large scale plant management. This focus enabled the industry to adopt digital solutions including communications effectively. Industry 4.0 and 5.0 are now becoming key areas of focus in many areas of manufacture

The innovations, so far, have helped steel industry achieve productivity levels which are extraordinary. The manpower used has dropped from tens of thousands for an integrated steel plant to less than a few thousands at present. The productivity has reached over 2000 tons per man-year in many cases, enabling economic cost of production.

The innovations in equipment, technology and processes have led to an energy reduction of over 60% over the last 50 years.

Similarly, the innovations have led to a reduction in water consumption of over 50 to 75% over the last 50 years.

The infrastructure uses such as railroads, housing, buildings, bridges etc have benefited from the innovations in designs and material uses driven by the wide range of products that are made available by the steel industry.

UN Goal 15: Life on land

This is an area which is important to the steel industry as it has been a large land user. But by the same token the industry unit also have had major positive impacts on the ancillary industries and hinter area development. Integrated Steel industry in general requires large tracts of land due to its size, complexities, multiple processes, huge levels of raw materials, finished products, intermediates and wastes. Besides the production facilities, considerable land area has been required traditionally for waste handling particularly steelmaking slag. Aligning with

this goal will demand optimum use of land, improving use intensity and consequent reduction in requirements, and improvements through innovation.

Breakthrough technologies such as Near Net shape Casting and direct rolling, and increased recycling have shown that the land area requirements could be reduced to a fraction of what has been traditionally planned.

UN Goal 8: Decent work and economic growth

The steel industry is one of the largest industrial employment-generator direct as well as indirect. The indirect employment triggered by the steel industry in India is estimated as 12x globally. In India it provides direct employment for over 2.5 million (direct and indirect).

Improved technologies introduction of automation and scale have reduced the direct employment potential considerably over time. However, better utilization of the human resources and higher skills provide scope for larger employment in newer areas such as big data analysis, AI, Process improvements, Product development, R&D, Implementation of circular economy solutions, new applications developments, Extending asset lives, Green energy solutions etc.

UN Goal 7: Affordable and Clean Energy

The steel industry does not play the role of an energy developer or a provider. But it has an indirect role being one of the very large energy consuming industries in the world both in the Integrated production route as well as in the Semi integrated route based on electric furnaces.

Energy recovery from processes as well as by products has been one of the important focus areas of industry all along. The increasing cost of energy as well as the adverse environmental impacts have further energized the industry in this direction. The process emissions have considerable heat value as a fuel. This has prompted the recovery of the gases to be used as fuel from the key iron and steelmaking processes. The industry now recovers practically the entire by product fuel (Coke oven gas, BF gas, BOF gas), key effect of carbon usage, which forms part of the industry's circular economy loop. Besides this the sensible heat available at different stages of manufacture is also considerable. These have also been well addressed and large-scale heat recovery has now become a reality.

A major leap in reducing the level of energy demands of the industry is possible with the increasing emphasis on recycling of steel. Recycling reduces the energy demand per ton of steel to nearly one third as compared to virgin production. The recycling goal of nearly 60 to 70% by 2050 will place the steel industry in an extremely favourable position in terms of energy demands. This will also reduce proportionately the carbon demand and consequently the GHG emissions.

UN Goal 6: Clean water and sanitation

The steel industry does not have a direct role to play in this area. But being a very large consumer of water in the manufacturing cycle, it can further this objective by being a responsible user of water.

The present steel industry consumes on an average about 3 to 12 cum of fresh water per ton of steel produced. This level is a fraction of what the facilities demanded a few decades ago. The industry has now well-established practices such as cascading, effluent treatment and recirculation, nearing zero discharge levels of effluents etc. The increasing concerns on water availability have also impelled industry to continue efforts towards reduction in the process water demands through better designs and innovation in equipment and technologies, reduction in make-up water through more efficient closed loop systems, rain water harvesting etc.

A major leap in further reducing the level of the make-up water demands of the industry is possible with the increasing emphasis on recycling of steel.

UN Goal 3: Good health and well-being

Having evolved from being highly labour intensive, the steel industry maintains extraordinary attention to good health and well-being of its employees. Major initiatives in the areas of innovations and improvements (Safety, Environmental compliance, Automation and Reduced manual interventions) and robust monitoring practices have also been impelled by this concern. The steel industry can continue to ensure that its operations are focused on this aspect and adopt supportive Health, Safety and Environment (HSE) practices. Compliance with the various regulations and standards both national as well as global would be a necessary step.

Being a very large source of key building materials, the steel industry can further the production and use of sustainable and human friendly materials and towards green building initiatives.

UN Goal 10: Reduced inequalities

This area can only be addressed by the industry in an indirect manner. The areas of attention towards this would be fair wages and compensation, unrestricted skilling and upgrade opportunities, gender sensitivities, social concerns etc. Greater attention to community concerns and social impacts over the last decades has enabled the industry to participate in efforts towards the above objective.

LOOK AHEAD

From the foregoing, it will be obvious that the steel industry has been committed to actions towards sustainability in a consistent manner. These have covered Manufacturing processes and efficiency with focus on global cooperation in research and development, Sustainable products, Environment and climate change compatible initiatives, technologies for effective transition towards decarbonization on scale and appropriate well-coordinated policy initiatives.

Replacement of inefficient and outdated technologies with technologies which can reduce carbon contribution including Carbon Capture Mechanisms by the industry would merit serious and immediate attention in Indian context.

Degrowth and sustainable development

One of the important aspects which can assist in a big way the sustainability efforts of the steel industry is the need for ensuring minimal production from virgin sources of depleting raw materials. Effective and optimal use of steel products and their uses can enable a reduction in the demand for new production.

In this context the "degrowth" movement currently in evolution may be of great relevance to the steel industry as many steps that are contemplated by the industry may be in sync with the overall objective of this concept.

While the concern for sustainability does not contradict de-growth, sustainable development is rooted in mainstream development ideas that aim to increase capitalist growth and consumption, leading to inherently unsustainable environmentally stressed world. Relocalizing to allow people of the poorer nations to become more self-sufficient and efforts to end the overconsumption and exploitation of resources in the Third World by the richer nations would be a major step to aid this process.

The IEA 2020 report has emphatically focused on the reduction in global demand through material efficiencies and other steps as a measure of sustainability of the industry.

In the Sustainable Development Scenario in 2070 as per IEA 2020 report, the projected global demand of over 2.8 billion tons of steel by 2070 is shown to be potentially reduced to 2 billion tons, that is nearly 0.8 billion tons or nearly 30%. Improvements in Product design and fabrication (about 40% of the reduction), Use-decrease (extended life) and Use-increase End of life (about 40% of the reduction) are the key contributors. (Fig 4-12,4-13).

Chapter 5

CIRCULAR ECONOMY

As indicated in Chapter 4, Sustainability is a key aspect deserving immediate and well-focused attention. It is particularly important in the context of the steel industry whose sustainability is vital for human well-being. The concept of Circular economy which basically subscribes to zero waste aspect is, therefore, a key element in furthering this objective. Circular Economy and its attendant features are discussed in this chapter.

CE CONCEPT

“It’s not the biggest or strongest that will survive, it’s the most fit to face and evolve successfully to meet the challenges that lie ahead. “Charles Darwin

The above quote may be highly appropriate when discussing the current buzzword in Strategy and Business “**Circular Economy**”. The Circular Economy Concept is not new, and has been in the formation for quite some years now. It has now become a point of focus and is receiving increased impetus as the industry looks for survival strategies in the 21st century to cover Sustainability, Profitability, Competitiveness and Environmental concerns. Thus, more efficient use of resources will be necessary in the context of increasing demand, declining resource availability, and rising costs.

The Principle

The contemporary understanding of the Circular Economy (CE) and its practical applications to economic systems have evolved incorporating different features and contributions from a variety of concepts sharing the idea of closed loops.

Linear " Take, Make, Dispose" industrial processes, and the lifestyles dependent on them, use up finite reserves to create products with a finite lifespan. These end up in landfills or in incinerators at the end of it. The circular approach, by contrast, takes insights from living systems. It considers that systems should work like organisms, processing nutrients that can be fed back into the cycle — whether biological or technical — hence the " *Closed Loop*" or " *Regenerative*" terms usually associated with it. Refer Figure 5-1.

WEF Definition Of Circular Economy

Quote:

“A circular economy is an industrial system that is restorative or regenerative by intention and design. It replaces the end-of-life concept with restoration, shifts towards the use of renewable energy, eliminates the use of toxic chemicals, which impair reuse and return to the biosphere, and aims for the elimination of waste through the superior design of materials, products, systems, and business models.”

Unquote

Ellen McArthur Foundation's Definition

Quote:

“Looking beyond the current take-make-dispose extractive industrial model, a circular economy aims to redefine growth, focusing on positive society-wide benefits. It entails gradually decoupling economic activity from the consumption of finite resources and designing waste out of the system. Underpinned by a transition to renewable energy sources, the circular model builds economic, natural, and social capital. It is based on three principles: design out waste and pollution; keep products and materials in use; regenerate natural systems.”

Unquote

UNIDO Definition

“An industrial economy that routes materials, parts and products back into use several times and creates more value and less waste. It is an alternative in which value is maintained for as long as possible, products are designed to last, and the generation of waste is minimized”.

EVOLUTION OF CIRCULAR ECONOMY

Efficient use of resources, waste reduction, and supply chain system optimization have received considerable attention in the last decades. These have formed the backbone of the development of the CE Concept. The attention received by this approach would be well reflected in the chronology of key approaches of the concept of Circular Economy. Refer Table 5-1. (Figure 5-2)

TABLE 5-1 CIRCULAR ECONOMY EVOLUTION

Sl.No.	Author	Year	Aim/Context
I	Kenneth Boulding (Expression Circular Economy was not used)	1966	Raised awareness of an "open economy" with unlimited input resources and output sinks, in contrast with a "closed economy", where resources and sinks are tied and remain as long as possible a part of the economy.
	Walter Stahel and Genevieve Reday	1982	Vision of an economy in loops (or circular economy) Jobs for Tomorrow: (Book The Potential for Substituting Manpower for Energy)
II	David W. Pearce and R. Kerry Turner And Walter R Stahel, Bill Rees, and Robert Constanza	1989	They pointed out that a traditional open-ended economy was developed with no built-in tendency to recycle, which was reflected by treating the environment as a waste reservoir

	Tim Jackson	1990s	Synthesised these findings into a manifesto for change, moving industrial production away from an extractive linear system towards a more circular economy. (Books: Clean Production Strategies Material Concerns: Pollution, Profit and Quality of Life)
III	China	2006	11th five-yearplan included Circular Economy as policy
IV	Commissioned by the Ellen MacArthur Foundation and developed by McKinsey & Co	2013	Towards the Circular Economy: Economic & Business Rationale for an Accelerated Transition. <i>“First of its kind to consider the economic and business opportunity for the transition to a restorative, circular model.”</i>

Core Of The Circular Economy

At its core, a circular economy model aims at designing out waste and reach a Zero Waste manufacture. To achieve this, products are designed to last (durability a key) and optimized for a cycle of remanufacture, reuse and recycle. The goal is to preserve and enhance natural capital (materials and resources) by controlling finite stocks and balancing resource flows.

Circularity and Sustainability

These terms are very often used together and somewhat interchangeably, but are they really the same? Is Circular Economy always sustainable? However, there are significant differences between the two.

“ In fact, sustainability aims at benefiting the environment, the economy, and society at large ... while the main beneficiaries of the Circular Economy appear to be the economic actors that implement the system.”

“There is also a difference in agency, influencing the understanding of the agents that should influence system changes. While agency is diffused in the case of Sustainability, as the priorities should be defined by all stakeholders, the Circular Economy has a clearer emphasis on companies and governments ...”

“The perception of responsibilities is also clearly distinct between both concepts. In the sustainability debate, responsibilities are shared, but not clearly defined, while the literature considers that the responsibility for the transition to a circular system lies primarily with businesses, regulators, and policymakers. Moreover, the commitments, goals, and interests behind the use of the terms differ greatly. The focus seems to be on interest alignment between stakeholders for sustainability, whereas the Circular Economy prioritises financial advantages for companies, and less resource consumption and pollution for the environment.”

“Circular Economy focuses on environmental performance improvements rather than taking a holistic view on all three dimensions of sustainability.”

“The Circular Economy ... refers mostly to individual economic benefits through input reduction, efficiency gains, and waste avoidance with relatively immediate results compared to sustainability.”

To sum it up, the current Circular Economy model is an intentionally designed human construct, grounded in the techno sphere with a clear emphasis on companies/manufacturers and governments. Sustainability, on the other hand, aims at benefiting the environment, the economy, and society at large.

Thus, at the policymaking and legislative formulation stages, the need for leveraging the priorities of both in a constructive and mutually beneficial manner would have to receive considerable attention.

CE PRINCIPLES

At the current stage of its development the basic (fundamental) principles based on which the CE functions can be summarized as follows : **Refer fig 5-3.**

REDUCE ENVIRONMENTAL FOOTPRINT

OPTIMISED RESOURCE USE

GENERATE INCREASED INCOME

CE ELEMENTS

Now popularly known as 4 R's these are:

- Reduce
- Reuse
- Remanufacture
- Recycle

Refer Figures 5-4 ,5-5 & 5-6

Circular business models can also be defined as business models that are closing, narrowing, slowing, intensifying, and dematerializing loops, to minimize the resource inputs into and the waste and emission leakage out of the various systems. This comprises

- Recycling measures (Closing),
- Efficiency improvements (Narrowing),
- Use phase extensions (Slowing),
- More intense use phase (Intensifying),
- Substitution of products by service and software solutions (dematerializing).

These strategies can be achieved through the purposeful design of material recovery processes and related circular supply chains. As illustrated in the Figure 5-4, these five approaches to resource loops can also be seen as generic strategies or archetypes of circular business model innovation.

The actual solutions and the manner of adopting CE will significantly vary from material to material, sector to sector and country to country. The solutions will become more and more involved spanning large segments of the entire gamut of design, manufacture and use as well as demanding in terms of support infrastructure to support the closing of the many loops within each system and application. This, in turn, will establish needs for reorienting, restructuring, realigning some of the existing processes, designs, approach to applications, user perceptions and economics, appropriate skilling and may be a complete overhaul in extreme cases.

WHY CIRCULAR ECONOMY

The positive impact areas, and specifically on optimizing steel demand in future are shown in Figure 5-7, 5-8 and 5-9 respectively.

A circular economy is the one single effective step that can lead the charge and propel the world towards greater sustainability and would greatly enhance the economic balance away from primary extraction with the key benefit of reduced fresh natural resources and energies. It creates a new sector dedicated to reverse cycle activities for reuse, refurbishing, remanufacturing, and recycling. The impact of the introduction of Circular Economy could be mind boggling. In the EU context, one estimate puts the benefits of this step to savings of nearly 20% of the current level by 2025.

Reduced GHG Emissions

One of the goals of the circular economy is to have a positive effect on the planet's ecosystems and to fight the excessive exploitation of natural resources. When it comes to reducing greenhouse gases, a circular economy can be helpful:

Thanks to reusing and recycling, the role of virgin raw materials and the environmentally damaging processes are reduced considerably without impacting the quality and range of application of products.

Because co-products and waste are treated as valuables, they are absorbed as much as possible in order to be made useful to other applications or reused in the process.

Other Benefits

There are very high potential benefits to the economies in general and to the industries in particular that the concept of Circular Economy holds. The Economies will benefit from substantial net material savings, mitigation of volatility and supply risks, potential employment benefits, and greater sustainability towards long-term resilience of the economy. It can also enable nations to plan for greater level of self- sufficiency in many areas. This step has the potential to reduce the wasteful and infructuous transportation requirements globally.

CE will thus enable preservation and enhancement of natural capital by controlling finite stocks and balancing renewable resource flows

The resource yields will also get optimised by circulating products, components and materials in use at the highest utility at all times. It will enable greater system effectiveness by avoiding impacts from externalities

Another major aspect but not so much into focus is the extraordinary benefits that the Circular Economy can provide due to revolutionising the way the resources are used. In the Linear model so far adopted, a substantial amount of resources (space, energy, transportation, actions for environmental acceptability, disposal, infructuous efforts, etc) are required for the management of the wastes. A well- developed Circular Economy model has the potential to (avoid ??) save bulk of these efforts, energies and resources as the core problem itself would reduce in magnitude considerably. As a consequence, these resources would be available for effective use in other sectors of the economy.

Idealized CE Future

It is now well accepted that a fully closed, circular material cycle could be a cornerstone of a sustaining economy and human well-being. This is primarily due to the wide and multi directional reach that CE demands for its success. Thus, the coordinated sensitivity that is the need of the hour may well be centering around CE adoption. The areas that CE can cover in a comprehensive manner are being defined as 7 pillars as follows:

- Materials are cycled at continuous high value.
- All energy is based on renewable sources.
- Biodiversity is supported and enhanced through human activity as one of the core principles.
- Human society and culture are preserved.
- The health and wellbeing of humans and other species are structurally supported by minimizing toxic and hazardous substances
- Human activities maximize generation of societal value.
- Water resources are extracted and cycled sustainably.

Potential Savings from CE

Increased Potential For Economic Growth

It is important to decouple economic growth from resource consumption. The increase in revenues from new circular activities, together with a cheaper production by getting products and materials more functional and easily disassembled and reused, has the power to increase GDP and therefore economic growth.

More Resources Saved

When compared with the raw material extraction that's common on the linear approach, the circular economy model has the potential to lead to a bigger (up to 10 to 70%) depending upon the area and the resource involved) amount of material savings. Considering that the total demand for materials will increase due the growth of the world population, a circular economy leads to lower material needs, as it skips landfills and avoids recycling, focusing on making materials' cycles last longer. On the environmental side, it also avoids bigger pollution that extracting new materials would represent.

Volatility and Risk Reduction in Supplies

Moving towards a circular economy model means reducing risks of the price volatility of raw materials. This would also act as a safeguard for many of the supply chains. Supply chains which have the potential risk of being destroyed or damaged because of climate change events triggered by the relentless exploitation of natural resources. CE would mitigate this aspect to a considerable extent.

EU Projections

A report on the impact of CE concept adoption in the EU has projected the following:

Quote : “

Substantial net material savings.

The report estimates that the circular economy represents a net material cost saving opportunity of USD 340 to 380 billion p.a. at EU level for a 'transition scenario' and USD 520 to 630 billion p.a. for an 'advanced scenario', in both cases net of the materials used in reverse-cycle activities. The latter would equate to 19 to 23% of current total input costs or a recurrent 3 to 3.9 % of 2010 EU GDP. Benefits in the advanced scenario are highest in the automotive sector (USD 170 to 200 billion p.a.), followed by machinery and equipment (USD 110 to 130 billion p.a.), and by electrical machinery (USD 75 to 90 billion p.a.). These numbers are indicative as they only cover 'sweet spot' sectors that represent a little less than half of GDP contribution of EU manufacturing sectors. They also assume the addition of only one product cycle with today's technologies. Yet many cycles would be possible and technological innovation could likely lead to rapid improvements and additional cost .”

Unquote

Sectoral shift and possible employment benefits.

The report also expects that creating a 'user-centric economy' especially in the tertiary (services) sector will lead to increased rates of innovation, employment, and capital productivity, all of which are important multipliers.

According to a Ellen McArthur's Foundation report, a circular economy model has the potential to create demand for new services and new job opportunities such as:

- “Collection and reverse logistics companies that support end of life products being reintroduced into the system

- Product marketers and sales platforms that facilitate longer lives or higher utilization of products
- Parts and component remanufacturing and product refurbishment offering specialized knowledge”

Reduced externalities

A reduction in volumes will also lead to a reduction in associated externalities (embedded) - higher than any incremental efficiency improvement in the existing material chain. Thus, moving manufacturing away from wasteful linear material consumption patterns could prove to be a major innovation engine.

UNIDO REPORT ON CE

Quote:

“UNIDO report has classified the potential benefits of CE into the following segments. Refer Table 5-2.

ECONOMIC OUTCOME:

ENVIRONMENTAL OUTCOME and

SOCIAL OUTCOME:

TABLE 5-2 POTENTIAL CE OUTCOMES

ECONOMIC OUTCOME	ENVIRONMENTAL OUTCOME	SOCIAL OUTCOME
Increased resource productivity	Reduced environmental impact	Improved well-being
Reduced production costs	Reduced emissions of greenhouse gases	New jobs and incomes
Improved competitiveness		
New business activities and models	Reduced emissions of pollutants and end-of-life waste	Improved health and working conditions
New markets and investment opportunities	Quality of ecosystem services	New partnerships and collaborations
Enhanced consumer loyalty	Natural resources (water, & materials) preserved and ensured	Innovations and technologies that make life easier
Increased long-term availability of supply	Biodiversity safeguarded	

The Global Context

From 1970 to 2017, global gross domestic product (GDP) has grown fourfold, and the global extraction of materials grew from 27 billion tons to 92 billion tons, with the projection that materials use will have risen to 167 billion tons by 2060. Natural resource extraction and processing is responsible for about 50% of greenhouse gas emissions and for about 90% of resource-related impacts on water stress and biodiversity loss due to land use. It is critically important therefore to improve resource efficiency by closing the loops with circular economy practices to achieve climate change, biodiversity and water related targets, the Paris Climate Agreement and the Sustainable Development Goals (SDGs).” Unquote

A more recent analysis shows that the global resource extraction between 1980 and 2020 (E) grew 200% from 40 billion tons to 82 billion tons. Whereas the metal ores growth is expected to be nearly 300% from 4 billion tons to 11 billion tons by 2020.

It is significant that nearly 60% of waste arising from the tonnages of total material streams is not recycled, composted or reused.

CE and Emerging Economies

As far as the emerging economies are concerned, which includes India, Circular economy provides the opportunity to leapfrog to efficient and sustainable solutions right at the start without having to replicate the steps that the developed world has gone through to reach the current levels. Such an approach would have immense impact on the manufacturing sector in particular where capacity demands for newer production will substantially reduce with corresponding impact on all the forward and backward linkages of the manufacturing chain.

In case of existing industrial sectors, CE will provide the opportunity for a holistic modernization and upgrade towards sustainability at lower costs factoring the benefits of the existing infrastructure, support facilities, and practices.

Circularity and Steel Industry

Steel industry, as is well known, is probably the largest manufacturing chain the world has lived with for decades. Besides the size, it is also inclusive of multiple technologies, wide range of diverse industrial machinery both in the manufacturing process directly and indirectly, multitude of applications revolving around hundreds of technologies and manufacturing methods.

Steel, being the most widely used affordable and durable material of choice, Sustainability of the steel industry is a global necessity. Hence there is great pressure to ensure its economic viability as well. The application of Circular Economy can have a very important role in the steel industry in cementing its position still further.

Demystifying Concept

In some respects, the term CE has currently acquired a somewhat mystic aura, primarily due to the fact that a full understanding of the import of this concept now encompasses the complete supply chain and is not limited to specific sections or players in the chain as traditionally has been. Also, presently the number of discontinuous processes and steps (for

special processing, value additions and applications) which besides the main steel manufacturer are carried out by agencies external to the steel plant have also increased.

The fundamental aspects which form the pillars of the newly defined Circular Economy have been in parts an integral part of the steel plant processes for many years. Resource optimization and usage reduction, recycling, recovery of wealth from waste are regular practices in the steel industry established over decades though in varying degrees and are the cornerstone of its CE adoption.

The wide reach of steel applications and the areas of impact of CE in steel production and use chain are shown in Figure 5-10. The benefits arising out of steel's recyclability are shown in Figure 5-11.

Industry Approach

World Steel Association (WSA/Worldsteel) the global body of steelmakers has been in the forefront propagating, encouraging and evolving an industry level approach to Circularity. The concept of Circular Economy in Steel where 4 key R's around which the adoption of Circular Economy is rested pursued by the WSA is shown in Figure 5-4 earlier. The experiences that have prompted this development are briefly indicated below:

Reduce

The decreasing amounts of material energy and other resources used in creating steel and reducing the weight of steel used in products are significant achievements.

Reduction of inputs of raw materials and energies engages huge attention due to their impact on the economics of production of steel. Nearly 3 tons of virgin raw materials are required for the production of one ton of steel through the integrated production route. Reducing the weight of products, and therefore the amount of material used, is thus key to the circular economy in the steel industry. Through investments in research, technology and good planning, steelmakers have over the past 50 years drastically reduced the amount of raw materials and energy required to make steel. In addition, the steel industry is actively promoting and developing the use of high-strength and advanced high-strength steel grades in many applications. These grades contribute to the light weighting of applications, in various sectors such as automotives, buildings and construction, infrastructure, transport as less steel is needed to provide the same functionality, strength and safety.

The global resources are being consumed at an alarmingly high rate, signalling the need for moderation and saving. The steel industry approach is comprehensive and tries to address all the areas of concern. Refer Figures 5-12, 5-13. 5-14

Use and Reuse

Because of its durability, steel can be reused or repurposed in many ways. This already occurs with automotive components, buildings, railway track rails and many other applications. Reuse of steel is not limited to its original application; repurposing dates back to ancient times (turning swords into ploughshares). Reuse occurs in sectors where it is

technically possible without compromising on safety, mechanical properties and/ or warranties. (Figure 5-15)

Remanufacture

Many steel products, such as machineries (Pumps, Gears, Fans and blowers and even electric motors in many cases) automotive engines and power and wind turbines, can be remanufactured for reuse to take advantage of the durability of steel components. Remanufacturing restores durable used products to like-new condition. It differs from repair, which is a process limited to making the product operational, as opposed to thorough disassembly and restoration with the possible inclusion of new parts. This approach has been popular for ages particularly the developing economies where ready availability as well as finances are real issues. This concept has also received fillip from the global focus on life cycle thinking where such as approach has a lot to contribute.(Figure 5-16)

Recycling

Recycling has been carried out in the steel industry ever since steel was first made. Steel is 100% recyclable and can be recycled over and over again to create new steel products in a closed material loop. Recycled steel maintains the inherent properties of the original steel. The magnetic property of steel ensures easy and affordable recovery for recycling from almost any waste stream while the high value of steel scrap guarantees the economic viability of recycling. Today, steel is the most recycled material in the world. Over 650 Mt of steel are recycled annually, including pre- and post-consumer scrap.

With critical hopes rested on recycled steel for environmental mitigation and carbon reduction in the future (over 60% of steel production projected from recycled steel by 2050), recycling has donned a new dimension globally. (Figure 5-17)

CE AND THE STEEL INDUSTRY VALUE CHAIN

Adoption of CE will require a holistic approach as it has impacts across the entire value chain. The key specifics can be seen from Table 5-3.

TABLE 5-3 CE AND THE STEEL INDUSTRY VALUE CHAIN

IMPACTED AREAS AND APPROACHES				
R&D	Raw materials	Process / Production	Products	Logistics and services
Improvements towards zero waste	Effective use of resources and upgrades	Minimize losses Reduce emissions	Superior products for high performance and reduced usage.	Reverse logistics for a wide range of product categories
Decarbonisation	Eco-friendly raw materials	Efficient management of resources and waste streams	Longer service life, recyclable steel	Multi agency coordination and logistics

Net Zero		Coordinated technology development	All co-products as a revenue stream	Multi agency coordination

The sustaining impact of CE enveloping the foregoing concepts would be the possible overall reduction in demand for steel without compromising on the developmental requirements. This would also indirectly mean release of scarce national resources to pressing human needs.

Aligning the Steel Industry to CE

The implementation of the Circular Economy concept in the steel industry on a global basis, its monitoring and tailoring to changing requirements can be achieved only through a very high level of coordination among the different sections of the manufacturing and application chain. This is quite involved and complicated as it embraces diverse technologies and processes, multiple sectors, locations and mega in scale. The industry has enormous backward and forward economic and social linkages which arise during its manufacture and use which also need to be factored in.

CE cycle of steels's manufacturing chain indicate the large span and arms that form part of this process. Besides this, the introduction of CE would add a sizable number of participants to complete the loop. Further the policy frameworks have yet to take the shape that would enable efficient adoption of CE without serious hindrances.

Within the manufacturing chain itself the steel industry process chain is fairly well placed to understand, appreciate and implement the CE demands. The backward links of mining of raw materials has to be considerably restructured as the focus here would be on maximizing the use of quality products through better yields, beneficiation as required, conversion to usable forms (pelletisation). Maximising yield, improved productivity and reduced energy demands would be high on the priority.

Performance so Far

Efficiency and usages

Major achievements have been made in the steel industry for improving resource efficiency. Efficient use of energy, recovery of waste heat and exploring new forms of energy has also received and continues to receive huge attention. In very many areas the results achieved are near the theoretical minima leaving very little room for further improvements. However, there are major divergences in these aspects across the production units due to legacy from location to location which impacts the overall industry picture. The industry has grown over years and decades and continues to cradle diverse technologies (some not as efficient or even inefficient). Therefore, it would not be appropriate to conclude on the industry performance on a common yardstick.

Reduction and Recovery of Waste

In management of wastes arising during manufacture, large improvements have been made and efforts continue to achieve 100% productive use of the waste arisings.

Steel scrap would be a clearly visible item, being generated at the different process steps of the direct manufacturing chain. Collection and reuse of this is part of the standard operating practice of the industry. Nearly the entire arising of the scrap in processes is recycled, normally within the works itself.

Steel plant slags form the major chunk of waste in steelmaking, and has positioned itself as an important raw material for cement manufacture globally. Thus, it also contributes to better circularity of the cement industry as well through reduction of virgin material needs. The progress made in the effective use of the coproducts can be gauged from the Table 5-4 below which indicates the typical figures covering the large part of the steel industry of the world. (Figures 5-18 and 5-19.)

TABLE 5-4 SLAG RECOVERY RATES AND USAGES

Slag type	Total %age recovered	Percentage use of material recovered		
		Cement	Roadstone	Fertiliser
BF slag	>97% (upto 99%)	78%	21%	< 1%
BOF slag	> 86% (upto 90%)	8%	91%	< 1%
EAF slag	86%	18%	82%	0%

Other process waste consists mainly of dust and emissions which are addressed individually with a view to recoveries, treatments and possible reuse in the manufacturing process. Thus, Process developments are focused on the achieving near zero waste manufacture.

The arisings also include co-products such as the process gases during the coking process, Blast furnace gas, and BOF gas. In all the modern installations these are almost entirely recovered for use as a fuel or as an input for power generation.

In terms of energy use, the industry has reached a level now of lower than 40 % of the level of fifty years ago. Further efforts have ensured that the sensible heat which was being discharged to the environment is also being recovered from most of the processes. The recovered waste heat is used for making hot water and or steam for power generation.

Focus Areas of CE

The areas of the application of the 4 R's per-se in steel industry that can have potential benefits are well known and addressed in some way or the other by sections of the industry over the decades. Further improvements and innovations can take this forward. Specifically, adoption of the CE components can have sustaining benefits in the following areas for the steel industry

Raw material inputs

Process improvements and innovations

Energy inputs

Emissions

Employment

Digitalisation

Raw material inputs

The raw material inputs for iron and steelmaking vary considerably depending upon the quality of raw materials. For example, the Silica and Alumina content in iron ore, ash content in coals, Silica content in lime stone and lime, all have major impacts on the quantity of input requirements.

The real solution to this, therefore, would appear to be selectiveness in the raw materials used. But with depleting high-quality resources and the restricted availability of better quality, there is a pressing need for focus on the increased use of inferior grade raw materials as well. Better classification techniques, beneficiation of low-grade materials, blending etc are key areas that can have potential for furthering CE.

Use of better raw materials and their consistency can also enable process improvements which can in turn reduce the raw material inputs considerably. For example, in case of the Blast furnace, the carbon input can be substantially reduced using high quality burden, higher oxygen injection, and PCI. The requirement of coke, one of the major inputs having restricted sources and supply concerns, can be reduced to around 300 kg per ton of iron, supplemented by injection of non-coking coal to the extent of 200 kg. With appropriate burden the slag make can be reduced to less than 200 kg per ton of iron.

Process improvements and innovations

Adoption of technologies such as Dry cooling of coke provide multiple benefits in terms of environmental friendliness (reduced emissions and water pollution), water savings, energy recovery, and improved yield (improved material use),

Extraordinary improvements have taken place in steel processing technologies most prominent among them being the casting and direct rolling of products. This has the potential to catapult the effective use of sensible heat and nearly eliminate the energy requirements for reheating an intermediate for final product rolling.

Near net-shape casting has enabled huge reduction in material inputs and energy optimization. Increasing adoption of in-line processing also enables reduction of the manufacturing cycle time with attendant benefits. Efforts towards strip casting have the potential to further improve this aspect quite drastically with all round benefits.

Dust Arisings

All the raw materials used in steelmaking are prone to generate dust due to varying decrepitating characteristics. The emissions largely consist of dust, which arise from two sources. The first is from the handling, transport and storage of the raw materials. The second is the dust generated as part of the process right from the mining. Process improvements,

material preparation and dust abatement and collection are now practiced on a very large scale. However, there is a need for reviewing this aspect in a holistic manner particularly in the older installations and upgrade measures taken as required.

The dust arising out of material handling can be addressed by suitable handling techniques, improved storage systems and dust abatement measures. Secondary dust inside the shops and premises can be collected through improved building designs and powerful dedusting systems.

Well classified collection of the dust arisings and appropriate treatments can enable bulk of these to be used as part of the feed system for steel production, thus contributing to the Circular economy effectiveness.

Emissions

These have been one of the main concerns globally, given the fact that steel is manufactured on a very large scale, is energy intensive and is a large carbon user. On an average nearly 2 to 2.5 tons of CO₂ is produced for every ton of steel produced. With the efforts and developments made so far, the industry is now well placed to effectively control arisings as well as handle nearly all the arising waste gases. The technologies developed for cleaning of gas and its collection, extensive waste energy recovery, and specialized equipment have enabled removal and collection of almost the entire suspended particulate matters. Ambient conditions have also improved due to these efforts.

Energy use in steelmaking

The steel production process is a very high temperature process, which requires large energy input. However, the processes adopted now are such that process energy is used to their maximum extent with support from external energy as required.

In integrated steel plants which have the coking facilities, the in-plant energy requirements besides the carbon inputs are substantially met from the by-product gases that are recovered in the Coke ovens, Blast furnaces and BOF converters operations. In large plants with modern energy optimized configurations and technology, this may be adequate to meet nearly 60 to 70% of the plant's energy requirements.

The production of steel using the Electric arc furnaces using steel scrap has electricity as the main energy source. The emissions and carbon footprint in this case is substantially less, nearly 40 to 60% than the integrated route.

Employment impact

The industry alignment for Circular Economy adoption may be quite disruptive particularly the raw materials and manufacturing ends as these have so far rested on traditional approaches. This need has been driven by the long life of the steel plant assets (Over 25 years, and many ranging upto 60 years and beyond). The highly capital-intensive nature of the industry is also a major barrier towards changes.

Employment Angle

The first reaction to adoption of Circular Economy could smack of considerable employment reduction due to the reduced requirements and greater use of simplified processes,

and increased recycling. However, this would be considerably neutralized by the new opportunities that realignment with the Circular Economy would throw up. The major potential areas for introducing innovations and improvements which can provide huge employment opportunities are:

- Considerable research and trials in Raw materials including collaborative approaches for usages can lead to better utilization and optimisation of resources, reduced environmental damage, and help in establishing closed loops in the mining and beneficiation sectors,
- Reduction in waste arisings and their effective use and recovery/conversion to useful products would require appropriate designs, technology and facilities.
- Process improvements with focus on reduction of carbon usage, use of alternative renewable energies, Improved modelling and decision - making tools would demand huge well qualified efforts at R&D and scaling.
- Adoption of automatic diagnosis and controls, supported by AI based models is another area which holds great potential for employment.
- Collaborative research with the user segments for development appropriate and effective product alternatives would throw up new opportunities as well.

Thus, properly structured, the Circular Economy can open up huge new opportunities for employment in the steel sector, but with the emphasis on significantly different from the traditional. Managing this transition will require a well thought out plan for reskilling, induction of qualified personnel in the new areas and technologies, and their orientation to the steel industry, high level of skills to ensure interface management, etc.

Digitalisation

Digitalisation and big data analysis provides for efficient models which can be readily replicated for the steel industry in the context of the above elements. This also has the potential to easily link many of the components of the Circular Economy including the manufacturing chain, downstream and the user sections, providing the opportunity for comprehensive development of new products and properties in coordination with the potential applications. The newer and modernized steelplant installations have introduced numerous measures in this direction over the last 3 decades and are well placed to take the same further. Consolidation of the industry and replacements of the inefficient and obsolete technologies can provide big opportunities for these.

KEY LEVERS TO CIRCULARITY

The CE components and required approach would indicate that participation of all elements (including external) of the total Manufacturing and supply chain is inevitable for achieving total success in this direction. Thus, a collaborative and cooperative model will be an essential driver.

The likely Innovations, arising out of this approach, would thus not be limited to silos defined by the core manufacturing facilities alone but by the requirements and strengths of the forward and backward linkages of the entire chain as well. This will enable coordinated harnessing of full range of expertise particularly in evolving processes for better use of raw materials, recoveries from various coproducts and wastes, and also product innovations. The automotive industry and steel industry have been in a way a forerunner in some these aspects over the last decades, though the efforts are mainly limited to product innovations for weight reduction and fuel efficiency.

The key levers to Circularity and the new opportunities particularly focused on manufacturing are that they can potentially inspire are:

- **Process Optimisation:** Fundamental to the efficient adoption of Circular Economy leading to reduction in the use of raw material and energy inputs along with reduction in the generation of process wastes.
- **Product optimization:** A holistic approach would enable coordinated design and development of products which can address key requirements of CE with sensitivity to the stakeholders of entire supply chain and the total potential impacts.
- **Recycling effectiveness:** This would be substantially governed by the ability to identify and locate the various material uses and their juxtaposes. Tracing the various material components and ensuring their recovery and return to the system would play a vital role in the success of CE. With the technological advances in products, this can be daunting and successful only if backed by expert tracing and return systems addressing the diversity in each product.
- **Elemental Separation:** One of the key elements in achieving the above would obviously be the ability to separate the elements. Separation of the components, material-wise, would be the challenge in applications where multiple materials have been used such as steel, aluminium, carbons, plastics, and others. This would thus create huge opportunities for development of Advanced recycling technologies for effective separation and recycling.
- **Modular design;** This approach could have a significant role for ensuring easy upgrade and repairs, quick and cost-effective remanufacture and or reuse of components. Thus, the machinery reuse (recycle in useful sense) can reduce potentially new Capex demands for modernization and upgrades as well the benefits arising out of the increased life cycles.

CE and AI

Technological innovation plays a major role in bringing the circular economy vision to life. It may not be an overstatement to say that the successful adoption of CE would have to heavily depend on technology in order to provide communications and data reach, address innovations and enable high level of analysis and well researched solutions. Model based systems have been at the core of the process optimization and improvements in iron and steel-making

processes. In the current context, with greater accessibility, AI will have a very important role and can be crucial to make the evolving scene more productive and sustainable. For instance,

- Intelligent and connected assets can enable better asset management, productive use, reduced idle time as well as adoption of predictive maintenance to prolong the asset availability and life
- Block chain can create traceability and transparency in supply chains to reduce waste as well as for coordinated development efforts.
- Repair is made easier by 3D printing of spare parts.

Thus AI, as an emergent ‘Fourth Industrial Revolution’ technology, can support the steel industry to accelerate innovation to design products, enable successful circular business models with numerous stakeholders, and optimise the infrastructure needed to loop products and materials back into the manufacturing system.

Challenges to Circularity

The major challenges to Circularity considering the above are likely due to

- Mixed streams of products from different industries
- Disjointed supply chains
- A genuine circular economy will require a life cycle approach focusing on the specific requirements of the various components in the manufacturing and use chain, adjustments required to resolve conflicting situations with focus on the overall environmental, social and economic factors.
- Lack of data and infrastructure to support closed-loop system, global material flows, lifecycle environmental impacts.
- Need for greater digitalization of the recycling chain

Existing Barriers

The existing barriers to recycling industry expanding its reach can be summarized as follows:

Economic Barriers

In our current economic system, there are some barriers to the implementation of a circular economy model, such as:

- Social and environmental externalities are not considered in prices, thus favouring financial market signals instead of people and nature when economic decisions are made;
- Prices of raw materials are volatile and impose unforeseen strains on supply as well as costs.

- Circular economy business models are harder to develop, as most investors are still working under a linear economy logic and sometimes upfront investments are required;

Institutional Barriers

When it comes to implementing and developing the circular economy, many different barriers might need to be overcome, such as:

- The current economic system is geared towards the demand of the linear economy and is yet unprepared to deal with circular economy requirements;
- Plenty of businesses rely on old and/or strong alliances, making it harder to create new alliances and therefore to close loops.
- The fact that the circular economy model is a long-term value creation model goes against many of the existing enterprises which still have goals and evaluation models that focus on short-term value creation.
- The GDP indices do not consider social and environmental externalities, disregarding the creation of value in both these areas. In Centralised economies the concept of Social cost-benefit analysis was quite popular and more easily carried out due to the Planning and executing framework. This does not become readily feasible at the entrepreneurial level not connected to a holistic evaluation (at the economy or the national level)

Overall Perspective

A Swedish study conducted in 2017 suggests that the main barriers to moving towards the circular economy model can be divided into financial, structural, operational, attitudinal and technological. These are:

- The challenge of measuring the financial benefits of CE and its profitability.
- The ‘structural’ barrier that follows has to do with being unclear of who gets responsible for CE within companies. The problem is even greater when a holistic supply chain aspect is taken into account.
- Consequently ‘operational’ challenges arise which represent the difficulty of dealing and staying in control of processes within the value chain.
- The ‘attitudinal’, barrier has much to do with the lack of knowledge about sustainability issues, status-quoist attitudes and also a big risk aversion to disruptive changes that could accompany the change to circular strategies.
- Finally, the technological demands needed for changing and re-designing products and production/ take-back systems. These needs create concerns about the ability to do achieve this and still be competitive and sustain quality products.

Enablers to Circularity

The adoption of CE can be successful if only an appropriate enabling environment of practices, standards and legislative framework becomes available. While at a global level the need for CE is recognised as a policy, its implications are not fully evolved and analysed.

Obviously, the approach to this aspect will be country specific within an overall framework so that the local aspects are adequately factored in the policy. However, some of the common essentials are listed below:

- **Overall acceptable policy framework:**

The Circular Economy measures have to be consistent with other economic and policy objectives without compromising on the needs of the CE per se.

ii. Raw materials policy:

This would form the backbone to support the introduction of CE as this is one area which is likely to be impacted most in terms of reduced requirements in the future due to adoption of CE. Many of the key raw materials are today globally governed. Their pricing is also dictated by the global realities. In some selected cases, countries vitally depend upon raw materials as the principal source of their income for supporting the economy. Ensuring national interests along with the equitable address to global concerns will be the key.

iii. Life-cycle thinking

In LCA, a comprehensive impact assessment that takes into account not only the raw materials mass, but also the efficient production and use of resources as well as their impact on the environment, the economy and society throughout their whole life in order to reflect the correct picture. A well accepted approach could pave the way for avoiding many conflicting situations and also fair pricing policies. Thus, the resource-efficiency indicators should reflect product life-cycles.

iv, Optimised Material Use

Alongside CE, there would be considerable scope for optimisation of material use which in effect can lead to reduced demands for various applications, leading to reduced demands on virgin raw materials energy and other needs for manufacture. Maturity of demand levels will also be achieved faster particularly in the developing economies facilitating long term sustainability in the process.

v. A full supply chain approach

The policy framework needs to be designed from a full supply chain perspective whereby the economics of CE and recycling needs are weighed against all the potential benefits including the environmental, economic and societal benefits. Here again, the transition from the existing approach to the new, could lead to a number of conflicts in many areas. These would have to be identified item-wise and appropriate mitigation arrived at.

vi. Standards and Definitions

This may be the first step if properly conceived which could prove to be a good foundation for adoption of CE in a coordinated manner. Being at an evolutionary stage, there are already many definitions and acronyms floating around. Aligning them would be a necessity which could provide an effective starting point for evolving widely applicable standards and legislations.

vii. Legislative Frameworks

Considering the possible reach of CE, this aspect would demand serious attention. That hundreds of legislations, standards and requirements would be involved would be an understatement. The diversity challenge would not only be in terms of CE specific demands alone, but national and global alignment would be even more critical. The experience on evolving Climate change approach has shown that there would be numerous conflicting responses and reaching a common plane can be arduous, complicated and time consuming. Laws and regulations appropriately suited to large scale innovations that can be triggered by CE will be a necessity.

viii. Local factors

That CE is fundamentally required to align with respective economies has to be clearly recognised. Accordingly, most of the factors to be addressed would be country specific and local. Geology, consumption habits and scrapping policies, energy mix, waste management systems, affordability levels, and many of the other factors governing the benefits of a circular economy concept may be local. Whereas aspects related to global aspects such as multi-country manufacture, trade, legislative conflicts would also beg for attention.

ix. Prioritisation

Circular Economy aims will have to be comprehensive and apply to as wide a range of economic sectors as possible. As a consequence, the impacts could be far reaching and very wide-ranging. The use of different resources including raw materials, energies, and even environmental sinks, such as the atmosphere, ambient air, freshwater resources, soils & sediments and land presents different environmental challenges and raises different sustainability concerns – some more acute than others.

Circular Economy Categories

The various concepts now covering CE, their scope and characteristics are shown in Table 5-5.

TABLE 5-5 SCOPE AND CHARACTERISTICS OF CE CONCEPTS							
Scope	Characteristics	CE Concepts					
		Circular Economy	Cradle to cradle	Closed Supply chain	Industrial ecology	Performance economy	Natural Capitalism
Overall Approach	Focus on Environment	*	*	*	*	*	*
	Focus on Profitability		*	*			
	Social Responsibility	*	*			*	*
Waste Management	Waste reduction	*	*	*	*	*	*
	Efficiency	*	*	*	*	*	*
	Move to Zero waste	*	*	*	*	*	*

	Co-product enlargement	*	*				
Life cycle adaptations	Raw material Optimisation	*	*	*			
	End of life strategies	*	*	*	*		
	Product development	*	*	*		*	*
Economic sectors covered	Primary sector	*	*		*		*
	Secondary sector	*	*	*	*	*	*
	Tertiary sector	*	*			*	*
Operational system	Organisational reach	*	*				*
	Focus on operations		*	*	*		
	Measurability	*	*	*	*	*	*

As far as the steel industry is concerned, Cradle to Cradle would be the model appropriate to it. This would mean that the number of players and the coordination level required would be challenging. Scrap recycling could prove to be a substantial answer to Carbon reduction and Sustainability. Thus, CE along with life-cycle approach could be a game changer.

Chapter 6

LIFE CYCLE PERSPECTIVE

The word “Life cycle” conjures up a flood of ideas in the mind, as the term encompasses a very wide spectrum of the human and economic scene. Man’s first introduction to the life cycle was with the concept of age which defines the duration of the human beings’ journey on the planet. In most cases one looks at Life cycle as an indication of the duration of the species, material or the activity. Thus, there is a note of finiteness in this understanding.

However, the term Life Cycle (LC) in the context of the current efforts at achieving Sustainability (Industrial, Environmental and Economic) makes this aspect transcend the present dimension. The objective is to focus on the attributes of materials, equipment and facilities, buildings and infrastructure from the perspective of its useful service life and its ability to be a part of the so-called rebirth.

Life Cycle Thinking

Life Cycle Analysis has, so far, largely been popular in assessing costs and financial aspects of materials and products. However, it has potential for a more wide-ranging role enveloping the other impacts such as Climate change, environmental degradation, and sustainability.

The need for Circular Economy has now come to be recognized as part of any manufacturing chain or exploitation of natural resources, energy use etc. A life-cycle approach may be a vital element to make this even more efficient by focusing on a “Cradle to Grave/Cradle” approach. Life Cycle Thinking can have a sustaining role in ensuring precedence of Circular Economy concept at every stage of the material and its use.

Life Cycle and Sustainability

It is clear from the previous chapters (4 and 5) that optimization of raw materials and energy uses are fundamental to Sustainability. While the manufacturing including recycling and reuse, and their related positioning to suit sustainability are important, durability has a very significant role in reducing exploitation of natural resources. Thus logically, more durable a material and its applications, the easier it would be to move towards greater sustainability. It is in this context that Life cycle perspective has to be positioned and as an essential aid to Sustainability.

Another major impact that life cycle thinking (LCT) can have, is the assistance in reducing the demand for virgin resources. Durability and appropriately designed uses with focus on increasing the life cycle has the direct impact of reducing demand for products and materials and in the process on virgin raw materials demand as well.

LCA - An Evaluation Tool

Climate change and the sustainable use of natural resources are among the main challenges on the top of global concerns. Focusing solely on one aspect of a product's life, such as the material production, distorts the real picture because it might ignore potential increased impacts during another life cycle phase, such as the use phase. A full-life cycle approach can provide possibly an effective way to assess the product's total impact on the environment and other aspects of sustainability. An objective evaluation based on this could help in informed decisions being made on the use of materials and their economic importance. This is particularly relevant to steel, the material with unlimited recyclability.

Life cycle assessment (LCA) provides an opportunity for a holistic approach that considers and consolidates the potential impacts from all stages of manufacture, product use and end-of-life (reuse, recycling or disposal). Cumulative contributions/savings over life cycle can indicate realistically the sustainability level of the materials/products. By calculating the resources and energy used, and the waste and emissions produced at every stage along the journey of the materials/products its true environmental impact can be quantified.

The benefits provided by the effective use of co products and their indirect impacts (or mitigation) also play a role in arriving at the net impacts. Thus, there could be an objective evaluation and comparisons between competing materials.

The different phases covered in LCA are shown in Figure 6-1.

LCT (LIFE CYCLE THINKING) AND STEEL

Steel is recognised as one of the most durable materials the world has ever seen and got used to in day-to-day life in numerous aspects. This obviously showcases steel's prima-facie sustainability as a material. The steel industry has been involved with user industries such as Automotive for product development where LCA also plays a role. The construction and buildings industry has also been a part of the steel industry partnerships. The adoption of LCT can help the industry in bringing into focus the realistic nature of the impacts of steel on a long-term basis. Steel's life Cycle is shown in Figure 6-2. Life cycle thinking for steel in which the evolving Circular Economy Concepts have a major role is shown in Figure 6-3.

Potential of LCT

The concept of the circular economy seeks to create a more resource-efficient world, focusing on waste minimization. The steel industry in general has been doing this indirectly and in parts for decades. The moment life cycle as a factor is placed alongside the steel, the durability of steel comes to the fore.

Steel has a very long service life - a potential step to carbon reduction through extended life (several decades) - which results in reduced new demand for virgin raw materials and processing. The energy efficiency of buildings, plants, machinery and transportation is also highly improved with the new steels developed for the specific uses. Avoided CO₂ emissions from the use of high-grade applications are on average 6 times higher than the CO₂ emissions from the production of these advanced steels.

Attributes favouring Steel LCT

The major attributes of steel which can enable LC thinking and have huge impacts due to its adoption include

- Durability
- Environment friendliness as a material
- Developing newer varieties of steel specifically suited to the diverse applications.
- Affordable costs

Worldsteel Initiative

Worldsteel has taken the initiative to focus on the LCA aspects and has evolved a practical road map which covers the better part of the steel industry of the world. Worldsteel provides a detailed methodology to consider the benefits obtained by recycling steel from products that have reached the end of their useful life. Taking a holistic view, a triple bottom approach is being popularized by WSA covering between them the entire priorities globally demanded. These are:

- Environmental Sustainability
- Social Sustainability
- Economic Sustainability

Social sustainability

Social sustainability is achieved if the manufacture, use and end-of-life processes for a given product are respectful of the human being and ensure that future generations can enjoy the same lifestyle we do today. Steel as construction and building material has proved itself to be of almost endless use without any critical impacts to society subject of course to normal maintenance and upkeeps. This is clearly evidenced by the continuing existence and use of buildings (industrial, office and other) and infrastructure (bridges, transport facilities etc) over decades or even century without causing any adverse impact on the life and safety of the humans using them. As per one estimate around 75% of steel products ever made are still in use today.

Economic sustainability

Steel as a material has held its position as probably the most affordable material for many uses encompassing daily human needs. The industry through its constant efforts at improvements and optimisation in all facets of its manufacture and use has ensured its competitiveness and affordability in the face of many alternative materials which have emerged in the last many decades. It is now well established that it would be very difficult to dislodge steel from the preeminent position in the industrial as well as social existence due to wide uses that it has.

Recyclability has ensured that the demand on virgin resources can be contained and also economic production of steel through recycling and its greater affordability make it a technically preferred and desirable solution.

Technological sustainability

Steel industry has been the **most tenacious industry of the world** having survived for centuries. In the course of its existence, it has been highly dynamic and sensitive, and introduced consistently new processes and technologies towards sustainability. It has also embraced and nurtured co-technological developments in many cutting-edge areas, such as, large and critical manufacturing technologies particularly the heavier machineries, safe machine designs, automation, large scale use of computers and microprocessors in process applications, Big-data collection and analysis, use of AI etc. Its major negative of carbon impact, is also being vigorously attacked on multi-fronts by the industry to reach sustainable levels in the future.

STEEL LCA IMPACT

This end-of-life recycling rates for steel which denote the steel within the final product that will be recycled when the product reaches the end of its useful life are above 95% for the automotive sector, around 85% for construction and around 70% for packaging. As per the latest World steel data, the positive environmental impact in terms of reduction in PED (Primary Energy Demand), and CO₂ are indicated for three categories of steel products namely Sections, Hot-rolled coils and hot-dipped galvanized steel after factoring the life cycle aspects in Table 6-1.

TABLE 6-1 - LIFE CYCLE IMPACT OF STEEL PRODUCTS

Steel Product	Cycle	Energy	CO ₂
		MJ/t	t/t (ISP)
Sections	Cradle-to-gate	18.9	1.6
	Net recycling benefit	-2.8	-0.33
	Cradle-to-gate including recycling	16.2	1.27
Hot rolled coil	Cradle-to-gate	23.8	2.33
	Net recycling benefit	-9.6	-1.17
	Cradle-to-gate including recycling	14.2	1.16
HD Galvanised steel	Cradle-to-gate	30	2.81
	Net recycling benefit	-10.6	-1.28
	Cradle-to-gate including recycling	19.4	1.53

It would be noted that the net positive impact due to the recycling ranges from 15% to 40%, and the reduction in Carbon contribution 20% to nearly 50%. This would put in perspective the impact of durability of steel on sustainability.

Steel vs Other Materials

As shown in earlier chapters, the various developments in steel's properties and processing coupled with its recycling ability puts steel in a much lower CO₂ bracket as compared to the competing materials (Aluminum, Composites etc). Improved strengths and better properties of the newer steels (AHSS) have enabled steel to nearly match even the weight for weight comparison with Aluminum. Table 6-2 shows the Carbon emission during the manufacture of the competing materials.

TABLE 6-2 GHG Emissions STEEL vs OTHER MATERIALS

Material	GHG during production
	Avg Kg CO ₂ /kg material
Conventional steel	2.0 – 2.5
Aluminum	16.5 – 16.6
Magnesium	36 - 56
Carbon fibre reinforced plastic	21 - 23

A typical comparison of the overall CO₂ contribution during production for an automotive part made from different materials factoring in their weight advantages is shown in Table 6-3

**TABLE 6-3 STEEL vs OTHER MATERIALS
(For a Typical Automotive Part Manufacture)**

	Estimated part weight	Mid-range CO ₂	Total CO ₂
	Kg	Kg/Kg	Kg
Conventional steel	100	2.3	230
AHSS(Advanced High Strength Steels)	76	2.3	173
Aluminium	67	16.5	1106
Magnesium	50	46	2300
Carbon fibre-reinforced plastic	45	22	990

At first glance, materials that weigh less than steel, such as aluminium, magnesium and plastics, may appear to be interesting alternatives. But with improved steels the picture is quite reversed. However, when the total life cycle of a material is taken into account, steel has no competition. (Figure 6-5)

Steel and Automotive (LCA Impact)

The carbon impact during life cycle of uses such as automobile are far greater as can be seen from the results of an LCA type of analysis carried out on a passenger car. The analysis considers that the car has covered 150 000 km in 10 years, with a gasoline consumption of 8 l/100 km gives the total energy necessary for producing the car and its fuel and use for 10 years, amounts to 540 GJ, whereas the materials part of this energy consumption of all materials put together, is 32 GJ, i.e. 6 % of the total.

Besides the above, the ULSAB10 project has shown that a weight reduction of 20% as compared to current industry standards could be brought about by making a more sophisticated use of the variety of available steels. A 25% reduction on the 271 kg body-in-white of a 900 kg car would thus mean a reduction of 5 to 11 g of CO₂ emission per kilometer.

Steel and Wind Energy Turbine (LCA Impact)

The above equipment is very highly steel intensive in its composition. A cradle-to-grave LCA study has enabled Vestas to calculate the energy payback of its V112, 3.3-megawatt (V112-3.3 MW) wind power plant. The calculation shows that the energy required to produce a V112-3.3 MW wind turbine will be paid back 37 times over the turbine's life in medium wind conditions. When 1 kWh is invested in a wind energy turbine, 37 kWh of energy is generated in return. Vestas' use of LCA has enabled them to demonstrate that the environmental impact associated with production of a wind turbine is minimal over its average 20-year life cycle.

Steel and Buildings/Infra (LCA Impact)

A comparison of concrete construction versus the composite of steel and concrete shows that the Carbon footprint over life cycle in the latter case is nearly 45% lower than concrete.

In case of a road bridge, where the steel can be predominant component, the impact is even greater. The Dutch authorities and experts use an index MKI which is a comprehensive environment indicator. The MKI score in Euros for steel is nearly 75 % lower (About 8000 to over 20000 Euros)

Similarly, a tool made of steel necessitates 4 times as much carbon as one made of wood, but it will still be more carbon-efficient than wood as its life cycle generally far exceeds 4 times that of wood.

Similar impacts can become evident in other applications as well through LCA.

KEY LEVERS TO LCT

The Life Cycle Thinking is in a stage of evolution. LCA can become a tool to measure the impacts on the environment of decisions taken in an enterprise. To this effect, LCA is presently the only tool by which an enterprise can truly measure the extent to which its actions are resource neutral.

Acceptance of LCA as a sustaining tool for decision making would lead to development of large number of technologies and support systems. These would open up new opportunities for employment counterbalancing the job losses that could accompany the reduction in uses due to CE and consequent LCT.

The key lever to LCT and the new opportunities that it can potentially inspire is the Integration of the Circular Economy as a standard practice covering the entire manufacturing and use chain. This would be essential for a realistic assessment of the Life cycle impacts and their application to evolving appropriate practices and policies. The use phase of the materials

and their applications have a very large role to play as the durability and sustainability of applications over a period are an essential feed to the LCA.

Challenges to LCA

The major challenges to LCA are likely due to the following:

- As explained under Circular Economy, in most cases the complete manufacturing and use chain has numerous steps and participants besides the core manufacturing. These are multi-locational, highly diverse depending on the number and type of process steps, user and application bases. Thus, a coordinated and reliable feedback and data transfer in a credible manner required (which is the key to resource use) would be daunting.
- Lack of infrastructure to support closed-loop systems to address the diverse needs for reuse and recycling of materials and components would come in the way of arriving at a reliable indication of the real-life phase of each item.
- The current enterprises and financial investors are entrenched with Linear models for their evaluations and decision-making. LCT, which requires a longer-term perspective, calls for a significant change in the mindset, approaches and planning.

Enablers to LCA

The adoption of LCA can be successful, only if an appropriate enabling environment of practices, standards and legislative framework becomes available. While at a policy level the need for LCA is recognised, its implications are not fully evolved and analysed.

It is a daunting task given the disjointed actions that have been taken so far in selected industries and areas primarily to address the major adverse impacts that have come to fore. A holistic approach has still not taken much root. Obviously, any approach to be effective will have to be country and sector specific within an overall framework so that the local aspects are adequately factored in the policy. However, some of the common essentials are listed below:

Acceptable policy framework

The LCA basis and approach will have to be consistent with other economic and policy objectives.

Life-cycle thinking

A well-structured LCA approach could provide a reliable indicator. This could also provide a basis for fair pricing policies of raw materials and intermediates which have now come to be considered largely global.

Standards and Definitions

This may be an important first step if properly conceived which could prove to be a good foundation for adoption of LCA in an acceptable manner. Being at an evolutionary stage, there are already many definitions and acronyms floating around. Aligning them would be a necessity which could provide an effective starting point for evolving widely applicable standards and legislations

Legislative Frameworks

Considering the possible reach of LCA linked to Circular Economy, this aspect would demand serious attention. That hundreds of legislations, standards and requirements would be involved would be an understatement. The overlapping requirements of CE as well as LCA will also have to be reckoned with.

Local factors

Fundamentally LCA is required to align with respective economies. Accordingly, most of the factors to be addressed would be country specific and local such as Level of the economy, Pricing, Consumption habits, attitude to durability and long lives, energy mix, waste collection systems and many of the other factors

Global Factors

Similarly, aspects related to globalization such as multi-country manufacture, interdependence on raw materials and intermediates, international trade, legislative conflicts etc would also need to be addressed.

Affordability

It would be obvious from the foregoing narrative that the adoption of LCA on an industry-wide and countrywide basis would require drastic changes in existing systems, and creation of appropriate infrastructure involving substantial costs. The ability of the nations to afford such investment would be fundamental to its universal adoption.

Prioritisation

For countries to reap rich benefits, LCA will have to be comprehensive and apply to as wide a range of economic sectors as possible. As a consequence, the impacts could also be far reaching. Considering the magnitude of efforts involved in evolving practices and legislations for meeting this requirement, creation of enabling infrastructure and costs involved, it would be essential to prioritise. Initially a broad framework could be evolved to generally accept and use as a starting point in some of the well-established sectors with visible and more easily achievable benefits.

Chapter 7

STATUS OF STEEL TECHNOLOGIES & PROCESSES

Steel production has been the mother of numerous technologies and related equipment and machinery over the decades. Numerous technologies and processes that are used for the manufacture of steel from raw materials are well established. The basics of these have evolved and matured over decades addressing the various diversities, energy priorities, raw material dictates, increasing product application demands, profitability, environmental compliances etc for sustaining the industry.

The status of the various technologies adopted in each of the steps of Steel Manufacturing Chain are outlined and discussed in this Chapter. The emphasis is on the developments that have taken place over the years in the various process equipment and technologies, energy recoveries, material optimization and environmental control.

PROCESS ROUTES

Two distinct process routes have evolved and sustained over the decades. The first one involves a fully integrated process from raw materials to products and includes coke-making, agglomeration, iron-making in Blast furnace, BOF steelmaking, Casting and rolling, and finishing. The second is the simplest process route in the steelmaking using EAF with steel scrap (as the principal metallic), casting and rolling. An extension of this with limited process steps is the semi-integrated process with the Direct reduction of iron ore and its conversion to steel. This option envelops the DR process, EAF steelmaking, Casting and rolling.

The processes that form the above Manufacturing chains of steel are shown in Fig 7-1 for the different routes.

STEELMAKING STAGE PROCESSES

The various stage processes, features and current status are discussed in the following paragraphs.

COKE MAKING

Role of Coke in Steel Production

Coke has been a vital raw material sustaining iron production in blast furnace over decades. Coke is also used in electric smelting furnaces for ferro-alloys production. Nearly 60 percent of the current global steel production which is based on the BF-BOF route needs coke as a reductant. The coke demand for Blast furnaces globally accounts for 85% of coke production.

Coking Processes

Coke is basically the solid residue of destructive distillation of coal obtained by carbonisation accomplished by heating a suitable blend of coals in an oven in absence of air. There are two proven processes for manufacturing metallurgical coke on the scale commensurate with the ISP demands. These are Recovery Process (including recovery of by-products) (BPO) and Heat Recovery (Non-recovery) Process (HRO).

By product coke ovens (BPO)

By-product coke making is so-called, because the volatile matter evolved during the coking process is collected and refined into byproduct chemicals. The BP ovens are narrow and long chambers in which the coal is charged from the top. They operate under a non-oxidizing atmosphere. A positive pressure within the oven cavity prevents air ingress and subsequent combustion of the volatile matter. Volatiles driven off during the coking process pass through a collector main to the byproduct chemical plant. Tars are condensed by cooling the crude gas with flushing liquor and then in a primary cooler. An electrostatic precipitator removes the remaining tars. The gas is further treated, producing additional byproducts, including light oil, naphthalene, ammonium sulfate and sulfur, depending on market demand. The cleaned gas, known as coke oven gas (COG), is normally stored in a gas holder and boosted in pressure for use around the steel plant as a heating fuel or reducing gas.

Size and Capacity

BP ovens are classified based on their size and capacity. Small Ovens have oven of height less than 4 m and inner volume less than 15 m³. Medium Size Coke Oven Ovens are from 4 m to 6m tall, and inner volume of 15 to 35 m³. Tall and High Capacity are more than 6 m tall and have inner volume of more than 35 m³.

Technological Developments BP ovens

Major technological developments/improvements in BP oven technology that have taken place over the years to address issues on use of variety of coals, quality, productivity, pollution, etc are the following:

Partial Briquetting of coal charge (PBCC)

Briquetting of coal improves the coking characteristics of the charge and results in the production of good quality coke from blends containing inferior coking coals. In this technique a part of the coal charge is briquetted in a roll press and charged into the oven. Due to the compaction the density of the charge increases and contributes to increase in the productivity.

Coal Moisture Control

A decrease in the moisture content in the coal blend being charged into the ovens improves its bulk density. NSSC has adopted two processes in this direction designated as CMC and DAPS. The CMC uses a rotary dryer with steam as the medium. The DAPS is a fluidized bed dryer. In DAPS the fine coals are collected and agglomerated. A 2 % reduction in moisture is reported. It is reported that the blend ratio of semisoft coking coals has increased from 10% to 20% in CMC and 40% in DAPS.

Stamp Charging

The stamp charging technique is an important milestone in the quest for reducing the requirement of hard metallurgical coking coal. This technology enables production of good quality coke using cheaper coal blend with a larger proportion of inferior coking coals. The stamping incidentally increases the density of the charge which in turn improves the oven productivity.

The conventional BP oven design remains unaltered with the introduction of stamp charging. However, the charging system is different and oriented to the making and charging of the large cake into the oven. The coal charge is stamped outside the oven in the chamber mounted on the stamping cum charging machine.

While stamp charging was not highly favoured earlier due to its larger Capex requirements, the surge in coking coal prices in the last two decades has spurred considerable interest in its increasing popularity. Many of the newer installations have incorporated this technology from the beginning.

The increase in capital cost of the stamp charged ovens is substantially neutralised by the recurring savings in the reduced cost of coal blend. The level of benefits keep compounding with the increasing gap in the prices of coking coals and the lower grade blends. The limited and shrinking and reliable sources of supply of coking coal and the volatility in its availability and price and also the increasing cost of logistics favour stamp charging with potential for use of locally available coals in many cases.

Coke Dry Quenching (CDQ)

A major area of concern in the operation of the coking plants has been the use of water for quenching the hot coke, and its environmental impacts. In recent years, Water quenching has been viewed as a major contributor to the environmental problems associated with coke making. The development of the dry quenching technology has provided an effective solution even as it provides significant additional benefits of energy recovery and the ability to reduce the environment pollution.

CDQ is a system to cool the hot coke at about 1,000°C with inert gas. The sensible heat in the cooling gas is recovered by the heat exchange in the cooling chamber and utilized effectively for the steam generation. The electric power generated from the CDQ is a clean environment-friendly energy.

CDQ process has many advantages both ecological as well as economic as follows:

- The use of water is obviated which reduces water usage as well issues of related polluted effluent and its treatment.
- The power generation potential from the waste heat in a typical 200 t/h CDQ installation is approx. 36MW (over 250 million kwh, equivalent 12 t/h heavy oil use with 36 t/h CO₂ emission to the atmosphere).

- Prevention of dust emission during coke wet quenching (approx. 300-400 g/t-coke) due to the fully closed operations. The dust emission volume from CDQ is less than 3 g/t-coke.
- The overall experience in CDQ has confirmed that the coke quality from CDQ is better than that from the wet quenching in terms of higher mechanical strength (about 1.5%), 2.5% increase in strength after the reaction (CSR) and reduced moisture in the coke (nearly zero) are reported.
- The fuel consumption in BF is reduced by a small percentage due to the elimination of extra heat energy for the evaporation of moisture contained in the coke. This reduction also contributes to the CO₂ reduction at BF, and an improvement of power generation on TRT due to the higher temperature at the top of BF.

Pollution Control

In BPO, atmospheric emissions (dust as well as toxicity) during charging as well as pushing of coke have been the most major concerns. These have been addressed substantially through the adoption of pollution control equipment in the installation. The charging machines and the pushing machines are equipped with built-in emission collection devices. The oven designs have also been improved to ensure more effective gas collection.

The High-Pressure Ammonia Liquor Aspiration System (HPALA) is effective for controlling charging emissions in coke oven batteries. The benefits include

- Emissions control
- Appreciable saving in quantity of process steam required
- Increased raw gas yield/byproducts generation, due to elimination of gases vented into the atmosphere

Land based pushing emission control systems mitigate pollution substantially. Facility includes effective collection and smoke purification. The air is dissipated into the atmosphere after purification by the pulse dust collector and cooling

Heat Recovery Ovens (HRO)

Heat recovery or Non-recovery cokemaking, is a process in which all of the volatiles in the coal are burned within the oven to provide the heat required for the coke making process. Because the ovens operate on negative pressure, door leaks are non-existent. New generation non-recovery ovens are claimed to be environmentally friendly and incorporate incineration systems which are claimed to destroy 99.99% of toxic hydrocarbon emissions.

The oven is a horizontal design and operates under negative pressure. Due to the temperatures generated, all of the toxic hydrocarbons and byproducts are incinerated within the oven. Hot gases pass in a waste gas tunnel to heat-recovery steam generators (HRSGs), where high pressure steam is produced for either heating purposes or power generation. The cool waste gas is cleaned in a flue gas desulfurization plant prior to being discharged to the atmosphere.

HR oven technologies

Considerable developments in NR ovens took place in the 1960's -1970's with the construction of the next generation ovens.

The notable newer type NR ovens are, the Jewel Thompson (USA), Illwara (Australia), and Pacti(USA and Mexico) designs. China has been a major entrant with its own version of the facility. One of the earliest large installation is the FDS plant in Toledo Ohio, USA based on NR oven technology. This plant with a capacity to produce 1.4 million tons of coke with a co-generation of 135 mw of power. Tata Steel in India has a 2 MTPY coke plant with Power generation of 120 MW at a standalone location.

POWER GENERATION

One of the benefits of having a captive coke plant in an ISP is the possibility of power generation using the by-product gas/waste energy. Coke oven gas, which has a calorific value of about 4,300 kcal per Ncum is an acceptable gaseous fuel for combined-cycle with the improvements in the cleanliness of gas input to the turbines. The thermal efficiency of a 'combined cycle' plant will be higher and will be in the range of 45 to 50 percent as compared to 30 to 35 percent efficiency for the 'Conventional cycle' plant. Thus, from the view point of better economics of power generation it is preferable to adopt 'combined cycle'. The crude tar from BPO is also a fuel available for power generation.

The power generation potential of HRO, where the off gas is at about 1100°C, is expected to be 0.75MW for every 10,000 tons of coke production. One waste heat boiler can serve a group/bank of 20 ovens to even out the fluctuations in the waste gas generation, as most of the combustible gas is generated in the early stages of carbonisation. The steam generated from the various waste heat boilers of a coke oven plant is led to the power plant turbo-alternator for power generation.

This step also enables overall carbon reduction due to the replacement of purchased power to that extent. The by-product energy is also technically a green energy as it is entirely based on by products/wastes.

BPO VS HR OVENS

Both the BPO and HRO are capable of providing good quality coke for the modern blast furnace operation. However, there are many distinguishing features of each as shown in Table 7-1.

TABLE 7-1 BPO vs NRO COKEMAKING

Sl. No.	BPO	HRO
1	Taller ovens are more productive, minimize number of charges and pushes and related emissions to make the needed tonnage.	Number of ovens and the size of the installation required is much larger than the BPO due to small ovens and long coking time.
2	Coke quality is superior.	Overall coke yield is lower by nearly 2 % due to the full combustion inside the ovens.
3	Compact layout with much less land requirement	Large area due to large number of ovens. Infrastructure support also larger (Raw material charging, Coke handling, Steam, Utility and Power leads).
4	Chemicals of commercial value separated from off-gases and sold. Contributing to environment friendliness and improved economics.	No coproducts for recovery.
5	By product Gas energy used inside the steel plant reducing the needs of external energy.	Heat energy in the waste gas recovered for power generation with improved economics, reducing the needs of external energy.
6	Pollution prone due to gas emissions, by product handling, and water quenching.	Pollution avoided due to complete combustion and operation under suction. Water quenching of coke a contributor to pollution.
7	The emissions during the oven charging and pushing addressed by providing appropriate fume extraction facilities	The emissions during the oven charging and pushing addressed by providing appropriate fume extraction facilities
8	Adoption of stamp charging allowing use of lower grade coals readily feasible.	Limited improvements in bulk density achieved with well-designed stamping facility. Cake handling is more involved. Operations impacted by the larger number of units to be served.
9	Dry cooling of coke readily adoptable due to larger volume of ovens. easier coke collection, and lower leads due to compact layout	Adoption of dry cooling is not preferred due to the smaller batches and collection issues.
10	Superior refractories essential.	Smaller sizes, and the technological dictates enable use lower quality refractories.

Newer Developments

Jumbo Coke Reactor

This is new coke making technology based on 'Jumbo coke reactors' (850 mm wide, 10 m to 12.5 m height, 19 m to 25 m long, 150 m³ to 250 m³ volume and 100t to 165t coal charge) and has been tested on pilot scale in Germany with an aim to increase productivity and reduce environment pollution.

Much larger ovens with Oven heights of 7.6m and a useful volume of nearly 80m³, are getting popular due reduced number of ovens and the number of pushing & charging operations per day. This also reduces the number of possible fugitive emission sources

Super Coke-Ovens

One of the revolutionary approaches to improvement in Coking technology was the Scope 21, an initiative by NSC and Sumitomo in Japan. The process comprises a fluidized bed coal dryer where it is preheated, dried, and classified into coarse and fine coal, a pneumatic preheater for rapid heating of coal to 330–380°C, and a hot briquetting machine for coal fine. The efforts confirmed that it is possible to produce coke of sufficient strength even at markedly high blending ratios of non- or slightly-caking coal (from 20% of the conventional wet coal charging process to 50%). Charging of hot and dry coal dramatically shortens the carbonizing time in coking chambers enhancing the plant productivity, requires smaller number of coking chambers, and greatly decreases the energy consumption.

Commercial scale plants have been installed and in operation for nearly a decade at NSC Oita and Nagoya. The installations have an annual coke production capacity of one million tons per year. They consist of 64 ovens, each 0.45 m in width, 6.7 m in height, and 16.6 m in length (effective volume 43.7m³). The coking time has been reduced to 13h. The ratio of non- or slightly-caking coal has exceeded 55% at Oita, and 60% at Nagoya without sacrificing coke strength.

AGGLOMERATION OF IRON ORES

This section of the integrated steel plant came in as an aid to using fine ores as well as process fines. Sintering of ores has now come to be an essential part of the ISP. Development of sintering as an agglomeration process for ore was also driven by the need to tackle permeability problems in the blast furnace due to finer sizes charge. Also, the generation of fines during mining (both due to the ore characteristics as well as mining practices) continued to rise. The depletion of the high-quality iron sources also caused the utilization of lower grades upgraded through the process of beneficiation. The lower iron content ores such as magnetites also warranted beneficiation for upgradation of the iron content. Beneficiation/concentration operations cause a fine granulometry that makes necessary the utilization of agglomeration processes, such as nodulizing, briquetting, pelletizing, and sintering for its productive use.

Iron ore agglomeration technologies

The major agglomeration technologies include briquetting, nodulization, pelletization and sintering. Sintering and pelletization are the most important and widely used agglomeration technologies.

Briquetting

Briquetting is the simplest agglomeration process. Fine grained iron ore is pressed into two pockets with the addition of water or some other binder agent (molasses, starch, or tar pitch) to form briquettes. A traditional application is the agglomeration of coal, other example is the agglomeration of ultrafine oxidized dust produced in the steel and the ferroalloys industry.

Nodulization

Nodulization is a process like sintering as it does not need a binder. The iron ore concentrate is mixed with carbon, and fed into a rotary kiln, where, Iron Ores and Iron Oxide Materials form nodules at high temperature. The temperature is enough to soften the ore but not to fuse it. Problems of the nodules are the considerable differences in composition and density (they are too dense), and the lack of a well-developed porosity (permeability). This process remains at a small scale, as briquetting, and is mainly used for the recycling of iron ore wastes in steel plants.

Pelletization

Pelletization is an agglomeration process of iron ore concentrates with a granulometry lower than 150 micron and low concentration of impurities. The iron ore is mixed with water, bentonite (or other organic binders less expensive and contaminant and lime and treated in a furnace at temperatures of around 1200 C, with the purpose of obtaining a product of 10–20 mm in diameter with suitable physical, chemical, and mechanical properties to be fed into the blast furnace or as feed for the production of DRI (Direct Reduction Iron).

Sintering

Sinter is a clinker-type iron bearing material that is produced when a mixture of iron ore fines known as sinter feed, finely ground fluxes, carbon (coke breeze or anthracite) and various recycled iron bearing materials are uniformly fired along a continuous traveling grate reactor. Fuel in the sinter mix is ignited and generates temperatures high enough for the fine particles to fuse together into a porous clinker material which is subsequently crushed and sized after cooling to room temperature. The resulting sinter is suitable for use as a blast furnace burden material. This technology was also developed for the acceptance of the various iron bearing wastes fines within the steel plant.

The various benefits experienced with use of well calibrated sinter and its very positive impact on hot metal production in the blast furnace led to its becoming the most widely accepted and preferred Blast Furnace burden material.

Need for Beneficiation

A major offshoot of the raw material cost escalation and the depleting high quality resources globally is the focus on increasing use of low-quality and economical raw materials. This has

resulted in a wide range of iron ores to be part of the feed chain of the Blast furnaces over the decades through beneficiation of the ores.

High grade hematite iron ores particularly in India are estimated to be less than 10% of the total reserves. Traditionally ROM iron ore with Fe less than 58 – 60% discarded as waste. Adoption of beneficiation of iron ore can substantially improve the overall yield of quality iron ore.

The magnetites which have substantially lower Fe have to be upgraded for use. They are amenable to the magnetic separation which is widely adopted. But the process requires high level of milling of iron ore less than 200 micron in size in order to ensure the effective separation. This micro fine product requires to be effectively agglomerated to enable its use.

The beneficiation techniques will vary from iron ore to iron ore to suit the specific characteristics and the focus areas. For example, considering the adverse impacts of alumina in ore, washing has become popular for removal of the same to a large extent. This leads to a yield improvement of nearly 3 to 5%. Utilising low grade ores demand technologies that would ensure

- Economic beneficiation.
- Reduction in slime loss by recovery of iron values from slimes in case of wet processes.
- Development of appropriate technology to agglomerate recovered micro fines (sintering or pelletising)

SINTERING A KEY SOLUTION

Sintering has gained acceptance as an economic solution for iron ore fines for ISP's and occupies a dominant position at present. Presently more than 70% of hot metal in the world is produced through the sinter. In India, nearly 60% of hot metal is produced using sinter feed in Blast Furnaces.

Benefits of Sinter use

It is important to note that Sinter plays a vital (exceptional) role in ironmaking in the blast furnace and is the bedrock on which the BF productivity and economics have heavily rested. It has also, in a very large measure, enabled recycling of ferrous, coking and flux system fines generated in the steel plant processes assuming a central role in the extension of Circular Economy in steel industry. This ability has improved the operations and economics of units such as the raw material handling units, coke ovens, gas cleaning plants in iron and steelmaking, casters and rolling mills. and recycled sinter particles from sinter screening are treated in the sintering machine.

The major advantages of using sinter in BFs are

- Productive Use of iron ore fines. This is one of the key benefits that has sustained the use of sinter in integrated steelplants. With increasing exploitation of iron ores, the level of fines production during mining rose very much (as high as 50 %). There were

also many ores which easily decrepitate during mining and handling. There were naturally occurring fine portions in ores such as blue dust as well. With the global iron ore prices on the upward and availability of lump ores getting restricted and at high cost, sintering became the obvious choice.

- Better reducibility of sinter and other high temperature properties increased BF productivity.
- The use of sinter led to the Reduction in coke rate in blast furnaces. The improvements in productivity and the savings in coke were adequate to justify the investment in sinter as a necessary and optimizing investment.
- The initial role of sinter as a scavenger in the steelplant continued with new techniques being used for the effective use of these arisings in the sinter mix. The current day sinter mix includes coke breeze, iron bearing wastes such as fines arising during handling, bag filter and ESP dusts, lime and dolomite fines, other metallurgical wastes,
- The increasing use of system dusts (material handling as well as process) has encouraged the use of dry systems (Bag filters and ESP's) for recovery and collection. This has opened up opportunities for avoiding the large-scale use of water in handling dusts obviating the generation of sludge which has been a very difficult as well as expensive waste to handle.
- Improved quality of hot metal

Developments in Sintering Technologies

The principal improvements and technologies which have enabled the sinter to retain its dominant position are:

- Flexibility in raw materials specifications and increased use of sinter and pellets
- Enlargement of machine size
- High levels of productivity through improved raw materials preparation, powerful support equipment automation, and process standardisation
- Use of alternative fuels (non-coking coal, natural gas, coal tar etc) to replace part of the coke breeze requirements.
- Waste heat recovery for energy optimization
- Long campaign lives Improved pallet designs, materials of construction

Machine size

One of the key developments in keeping with the leapfrog of Blast furnace size has been the machine area in a sinter plant. From a level of near 200 sq m per strand in the seventies, the machine area has consistently gone up and today machines of 450 to 500 sqm are standard. Machines with a strand area of 700 sqm and more have also been installed.

The above has been primarily achieved by increase in the pallet width, which has ranged from 2.5m to the present day 5.5 to 6m. This approach helped the machine length to be retained almost near the popular levels of about 150 to 200 m.

Productivity

Although the principal measures for increasing sinter production are higher sintering speeds and improvements in yield, an increase in the sintering area by improving the permeability of the ore bed was an early step. Sinter productivity has improved from near 25 tpd per sqm of sinter area to over 30 to 40 tons tpd per sqm in case of selected raw materials. This has come about due to the following other major developments as well:

- The use of powerful sinter exhaust fans has enabled the bed depth of sinter strand to reach nearly 600mm and more at present.
- Improved combustion system designs, efficient automation and control have helped in improved sintering rates as well as efficiency.
- Intensive feed preparation and control provides uniform and well calibrated feed.

Service life Extension

Sustainability demands and cost pressures globally have brought into focus the need for service life extension of sinter plants as well. This approach focuses on the modernization and upgrade of the existing older installations which had the following advantages.

- One of the world's largest machines, at its time was the NSC Kimitsu No. 3 DL commissioned in 1971 with a sintering area of 500m² made as 5m×100m. Similarly the NSC Oita No. 2 DL (commissioned in 1975 had a sintering area of 600 m² through 5 m × 120 m machine area. The space available in the older sinter plant area including the strand buildings are generally adequate for the installation of large capacity compact systems of the present-day machines. The space requirements therefore can be readily optimized even with high capacities.
- The modern intensive material preparation systems have both high capacities, are compact, efficient as well as deliver quality levels. The demands of these systems in terms of power supply and utilities of larger unit capacities is not significantly higher than the older heavier and multiple unit installations.
- Improved pallet designs, and materials provide much longer lives.
- The main consumer of water in the older sinter plants were the wet gas cooling and sludge handling requirements. The adoption of dry gas cleaning and pollution control facilities does not make additional water demands.
- The introduction of pollution control through installation of ESP's and Bag filters can be achieved to suit layout demands of each installation.
- Meticulous operation and quality control can be ensured using modern day automation including model-based systems.

Automation

State-of-the-art process control and automation solutions have helped to ensure stable and continuous production, high level of plant availability and reliability, and excellent end-product quality with minimum intervention from operators.

All the modern-day automation tools and systems have been adopted in the sinter plants with enormous benefits to cover quality, energy efficiency, productivity and environmental control. In addition to basic functions such as data acquisition and set-point execution, the technological controls (main control loops) are implemented in the basic automation system. These include process model-based tools for raw-mix-ratio control, raw-mix-feed control, Sinter composition Control bed distribution supervision models Productivity analysis etc

Environmental issues

A key concern with the sinter plants is the issues related to environment as sintering is an energy and pollution intensive process. A very large part (75– 80%) of the energy used for sintering is produced by using solid fossil fuels, such as coke breeze, anthracite, etc.

Fugitive Dust is a major source of pollution in the sinter plant operations including the raw materials area. Dust generation is inevitable in the ores and additives used for sintering as well as in the handling and preparation processes of the raw materials. The sources include conveyors, screening systems, crushing and screening installations, storage yards, blending yards etc. Conveyor transports may account for nearly 15 to 25 kms within the raw materials and the iron making areas. The numerous transfer points and junction houses, level adjustments due to drop demands etc have extensive impacts.

The sintering process is the main contributor to Particulate matter (PM_{10/2.5}) emissions in an integrated steel plant accounting for nearly 50 % of the total emissions. Due to the temperatures reached during the sintering process, components with noticeable vapor pressure like alkalis and heavy metal chlorides are volatilized and then re-condensed in the off-gas system resulting in a high fraction of PM_{10/2.5}. End of pipe measures include electrostatic precipitators high-quality filter bags, increasing moisture content extending granulation time etc

Use of coke for combustion generates NO_x emissions. NO_x emissions can be reduced by using low nitrogen content combustibles as 90% (vol %) of NO_x comes from the fuel. Combustion control and use of low NO_x burners are possible measures for reduction.

Sintering has been recognized as an important source of organic micro-pollutants such as PCDDs and PCDFs. The best option in the problem of dioxins is minimizing their formation. Use of ammonium sulphate is seen as inhibitor of dioxin formation

PAH (Polycyclic Aromatic Hydrocarbons) are generated by the inhomogeneous and incomplete combustion processes.

Environmental Control measures

With increasingly stringent regulations, pollution control in the sinter plants has received humungous attention with highly beneficial results. Measures to enhance air quality in sinter plants can be divided into three categories

- Primary measures, based on preventing or minimizing the release of pollutants
- Secondary measures, consist in basically end-of pipe treatments
- Tertiary measures, consist in treating polluting wastes and raw materials in a single facility, concentrating there the source of pollutants.

Material handling

Extensive pollution control measures are now part of the raw materials system planning in ISP's. Covered storages can avoid fugitive emissions. Sprinklers are used for local dust abatement wherever required. Wherever bins are used for storage such as the proportioning bins, feed stations, sinter cooler storages etc are equipped with integrated dust extraction.

Processing systems such as Wagon tipplers, Crushers, Screening facilities etc are all equipped with inbuilt dust extraction and collection facilities.

Closed conveyor systems are now used increasingly. All the junction houses and drop points are equipped with local dust extraction systems which are made into a composite system for the purpose of dust collection and aggregation.

Process Improvements

Improvement in the granulating properties of the feed material can help the fine coke to burn at higher temperatures with consequent decrease in NO_x generation. An environmental measure of special importance is the use of burnt lime. With the addition of burnt lime, the granulating properties of the feed material were also significantly improved. Use of low NO_x burners is also now a standard feature.

Emission Optimized Sintering

Conventional sintering uses ambient air to transport heat within the sinter bed, requiring a high air flow rate. Iron ore sintering thus creates substantial off-gas volumes. Treating these in order to meet increasingly stringent environmental standards calls for large pieces of equipment and systems

One of the new technologies has been the introduction of a selective waste-gas recirculation system in which the off gas from selected zones of the sinter machine is mixed with hot cooler off-air and is then recirculated to the sinter strand. Since only a part of the oxygen in the air is consumed for coke combustion, part use of the flue gas provides a source of oxygen. This component is recycled after being enriched with ambient air to raise the oxygen content to 13–14 % and used as intake process air. The main benefits of WGR are:

- Waste gas volume reduction up to 50% of the normal
- Decrease in specific in solid fuel consumption of upto 10%

- Lower emissions along the following lines

Dust emissions 35–45%

NO_x level in flue gas discharge 20–45%

Dioxins, in flue gas discharge 60–70%

SO_x 25–30%

CO₂ up to 10%

CO 40–50%

The use recycling technology can also result in lower capital investment in new installations.

Injection of additives

The increasing demands of pollution control have also impelled injection technologies for off gas treatments for efficiently binding and removing to a large extent heavy metals, harmful and hazardous organic components, as well as sulphur- dioxide and other acidic gases. The injection of additives has two different objectives. Objective one is the desulfurization of the off-gas (DeSO_x) by injection of specific desulfurization powders. Objective two is the reduction of heavy metals, PCDD/F (dioxins/furanes) and other toxic organic compounds VOC (volatile organic compounds). This is achieved by finely distributing adsorption and desulfurizing agents, such as activated carbon and either hydrated lime or sodium bicarbonate, into the off-gas flow.

Selection of Desulphurisation agent

The Lime or sodium bi-carbonate are options for desulphurization of off gas cleaning in the Sinter plant. An overall comparison of the two is presented in Table 7-2.

TABLE 7-2 DESULPHURISATION OF SINTER EXHAUST

DeSO _x Agent	Soda bi-carb	Hydrated Lime
DeSO _x level	> 95%	< 85–90%*
Stoichiometric factor	1.1	1.7–2.0*
Residue amount	70%	100%
Additive costs	180–200%	100%
Temperature after DeSO _x	(no cooling) due to higher reaction temp.	90–100°C
Investment	Lower	Higher
Residue disposal	Lower	Higher

The use of sodium bicarbonate appears preferable, if DeSO_x degree is high. It also is more environment friendly and does not demand water use.

Energy conservation measures

The energy optimization efforts in Sinter plant have covered both the reduction in the consumption as well as recovery of waste heat from the system.

Lower COG unit consumption has been achieved through improvement in the efficiency of the ignition furnaces. Direct ignition at the ore bed surface using burner flames improved efficiencies and led to reduced ignition furnaces sizes.

The main exhaust blower is a key electric power consumer accounting for nearly 50% of the power consumption of a sintering plant. Improved designs, Variable voltage variable frequency (VVVF) and other control methods help in greatly decreasing power consumption.

WASTE HEAT RECOVERY

The sintering process consumes heat at rate of approximately 1500 to 1800 MJ/t-sinter of this nearly 50% is lost to the air through the sinter exhaust and sinter coolers, which are the major potential sources for Heat recovery. The waste heat recovered can be reused in a variety of different applications, including:

- To provide preheated combustion air for the burners
- To generate hot water and steam for process and heating purposes
- For power generation up to 4 to 7 MW (at 600 tph production rate)

Heat recovery has been limited to high gas temperature zone of the sintering section and primary sinter cooling section, where gas temperatures of 300 deg C or higher are encountered. The large gas volume of sintering process helps in sustaining economical heat recovery.

Adoption of a pressure-type circular cooler has complemented the demands of higher cooling capacity and efficiency. The introduction of pressure-type circular coolers provided for stable exhaust gas temperature at around 400 deg C.

The gas heat recovery systems can be categorized to circulation type and non-circulation type. In circulation type, gas after heat recovery is circulated to the respective process-section as cooling-gas replacement, whereas in non-circulation type, the gas after heat recovery is led to gas treatment facility directly.

Circulation type

After heat recovery from hot gas zone, cooling gas is lead to cooler and reused for sintered ore cooling. Cooler gas temperature rises through recirculation and consequently results in higher heat recovery. On the other hand, cooling gas temperature rises up to the level of 180 deg-C, due to which the cooling capability may decrease.

Non-Circulation type

After heat recovery from hot gas zone, cooling gas are emitted to atmosphere. As cooling gas temperature does not change with heat recovery system, cooling capability also remains unaffected before and after augmenting heat recovery system

A comparison of the two types of recovery systems is given in Table 7-3.

TABLE 7-3 CIRCULATION TYPE VS NON-CIRCULATION TYPE COOLERS

Items	Sinter Cooler Type	Circulation		Non-circulation	
Sinter	Temperature Zone	High	Low	High	Low
	Input t/h	800		800	
	Temp. at inlet oC	600		600	
	Sinter Temp. outlet °C	108		72	
Cooler	Flow rate m3N/h	650,000	800,000	480,000	970,000
	Temp. before oC	180	25	25	25
	Cooling Gas Temp. after °C	444	225	425	190
	Cooler Fan Power kW	2,690		2,000	
	Flow rate m3N/h	568750		420,000	
	Recovered Steam t/h	40		26	
	TG Recovered Power kWh	7,100		4,600	

It will be noted that recovered energy increases by about 50% in circulation type compared to non-circulation type. Fan power consumption is larger in case of circulation type, however, far larger recovered power can readily justify this.

Present Day Installations

A well acceptable sinter plant installation leveraging technology as well as much greater environmental compliance at the present day will include:

- Large sinter strands 6 m wide and with a sintering area of upto 700m², capable of producing 30–40 t/m²/day.
- Integrated pollution control facilities with individual equipment, effective dust collection and recycling facility.
- High intensity mixing and nodulizing
- Minimized off-gas volumes with effective sealing.
- Reduction in off-gas cleaning capacity through Selective Waste Gas Recirculation
- Efficient sinter cooling and installation of heat recovery system providing energy savings together with reduced emissions
- Effective and productive automation and control systems.
- Efficient Pollution control systems.

PELLETISATION

The other major and popular process of agglomeration of iron ore is Pelletising. Pelletising became essential due to the need for a process to handle the micro-fine sizes (150 micron and below) of beneficiated ore (Taconites and magnetites). Iron ore pellets are being used for long in blast furnaces in many countries. While the global production of pellets is currently in excess of 500 million tons, its principal use as BF burden is practiced in USA. In other countries it has formed part of the burden consisting of sinter as well as lump iron ores.

Pelletizing turns very fine-grained iron ore into balls of a certain diameter, also known as pellets, which are suitable for blast furnace and direct reduction. Pellet plants can be located at mines, near harbors or be attached to steel mills.

Heat hardened pellets are produced to a specific size range by forming iron concentrate into green pellets and then hardened in a dedicated induration furnace. Magnetite ores do not require carbon additions as the magnetite oxidation in the induration furnace provides enough heat to sustain the process.

The mixed materials are formed into 8-16 mm diameter balls through rotating drums or discs at a controlled moisture, with a binder such as bentonite. The green balls are then fired at controlled temperatures in an induration furnace which can be one of two types: a single straight grate induration furnace or a train of three reactors consisting of a travelling grate, rotary kiln and cooler, known as the grate-kiln process.

The use of pellets is greatly supported by the increasing gas-based DRI production where raw materials are generally purchased and high quality is demanded. Annually, over 150 million tons of the Pellet production is expected to be directed to the DRI production currently.

Advantages of pellets

Pellets have a number of advantages as indicated below:

- Being preceded by the concentration and preparation, pellets have high iron content (63–68% iron, mainly Fe_2O_3). The lower gangue is a great asset to the blast furnace burden as well as in producing quality iron.
- Easy handling and transportation as pellets have high strength and can be transported to long distances without generation of high levels of fines. Pellets also have good resistance to disintegration.
- A very high level of uniform size range can be achieved in Pellets, generally within a range of 9–16 mm.
- Strength – high and uniform mechanical strength even under thermal stress in reducing atmospheres
- Good Reducibility - Because of their high porosity that is (25-30%), pellets are usually reduced considerably faster than hard burden sinter or hard natural ores/lump ores.
- Due to the processes adopted in the pellet making, the products have uniform chemical composition & very low LOI.
- Equipped with advanced environmental technology, pellet plants can be designed to be near pollution-free, generating no solid or liquid residues.

Pelletising Options

Straight Travelling-Grate Process, and the Grate Kiln Process are the two pelletising processes appropriate for the scale and quality demanded by the steel industry.

Straight Grate System

In the straight grate system, a continuous parade of grate cars moves at the same speed through the drying, induration and cooling zones. The facility used in this system is similar to the sinter plant Grate system. The Traveling Grate process, accounts for two-thirds of the world's installed pelletizing processes. It comprises three steps:

- Raw material preparation
- Forming green pellets
- Pellet hardening

Process

Iron ore fines ground to microfine sizes (150 micron and below) are the principal raw material for pelletising. Water is added to the fine iron ore, to adjust the moisture content, and the ore is mixed with small amounts of binding agents such as bentonite (approximately 0.5%) and fluxes such as limestone, olivine and dolomite (1–5%). These agents give the pellets the prerequisite physical and metallurgical properties required for further processing. Mixing takes place in continuously operating drum or pan-type mixers with capacities going up to 1,200 t/h. The process of pellet making consists of the following steps:

- Making of green pellets
- Induration of Pellets
- Cooling and screening

Green pellets are formed either in pelletizing discs or drums. The travelling grate carries the green pellets on a bed 30–55 cm thick through a furnace with drying, preheating, firing, after firing and cooling zones.

Traveling grates are now available for sizes over 750 m² reaction area 2.5–4.0 m machine width with capacity going upto 7.25 mtpa in single unit or even more. Specific production rates (grate factor) between 15 t per day m² for weathered ores and >35 t per day m² for high-quality magnetites are achievable.

A major advantage of the traveling grate is that the green pellets remain undisturbed throughout the process. Multiple handling of the pellet is avoided with minimized dust and fines generation. Numerous burners in the preheating and firing zones in the strand system allow precise control.

A range of recuperation techniques are applied to the gas flow for the traveling grate, in order to optimize fuel consumption and gas emissions. These include

- “Direct recuperation” of heated process gases (850–1,000°C) from the first cooling zone, transferring the gases to the preheating and firing zones
- “Wind box-recuperation” of exhaust gases (approximately 330°C) from the wind boxes to the drying and preheating zones

- The use of exhaust gases from the second cooling zone (approx. 350°C) for updraft drying
- The use of exhaust gases from the final cooling zone (approx. 250°C) for the first cooling zone

Environmental impact

Pelletisation process generates less than 1 % fines (less than 1 mm). Travelling grates installations are supported by highly efficient and effective gas cleaning systems, such as electrostatic precipitators and desulphurization units. It is energy-intensive as natural magnetites require about 240,000 kJ heat/t pellets and limonites 1,500,000 kJ. Electric power (25–35 kWh/t) is required for mixing, balling and induration, depending on raw material and plant capacity. If the energy requirement for the beneficiation (fine grinding) are added this would increase substantially.

Grate-Kiln System

In this process, pelletisation is carried out in two main stages:

- Agglomeration and
- Induration.

The Grate-Kiln® induration machine consists of three separate process equipment.

- A traveling grate is used primarily to dry and preheat green balls for feeding into the rotary kiln, where they are indurated. It utilizes the heat coming from the subsequent kiln and cooler to perform this heat recovery.
- The induration is carried out in a refractory lined rotary kiln which ensures mixing of the material bed. In the rotary kiln, the preheated balls are heated and maintained at a set temperature to develop pellet quality. The process flexibility is provided due to the use of one burner, which can use liquid gas, or solid (coal or biomass) fuels separately or in combination.
- Hot pellets discharging from the rotary kiln are discharged directly to the annular cooler. The forced air cooler is used to cool the fully indurated pellets. This recoups the heat and allows for handling of the pellets to storage and shipping.

Grate kiln Plants today are operating at close to 6.0 million tpy, with claims to 7 million tpy. Due to the separation of the process steps, it is possible regulate heat transfer with high, medium and low temperature gases. The heat coming from the kiln and cooler enable heat recovery. The mixing action in the rotary kiln is important for the production of a homogeneous pellet product. Use of a single burner reduces maintenance costs and improves fuel efficiency.

Sinter Versus Pellet

The principal difference between sinter and pellets arises from the type of raw materials used in their preparation and the nature of the sinter and pelletizing agglomeration processes. Depending on their final user, pellets are often categorized between blast furnace (BF) pellets

and direct reduction (DR) pellets, the latter having a higher Fe and lower gangue content consistent with the requirements of the direct reduction process. Both have their relevance, specific areas as well as advantages. These are briefly indicated in the Table 7-4.

TABLE 7-4 SINTER vs PELLET

	Sinter	Pellet
Ore processing	Simpler processing	More involved with the need for fine grinding.
Raw materials flexibility	Much wider including use of iron bearing process wastes	Specific to the ore exploitation.
	Micro fine utilization increasing	Separate mini pelletisation possible
Scope for beneficiation		Easier to integrate fine grinding being part of the process.
Transport	Not desirable due to decrepitation	Well suited for long distance transport
Iron (Fe) content %	55.0 - 58.0	62.0 - 66.0
Energy Demand		
Electrical Energy kWh/t	40	70
Thermal Energy MJ/t	90	800
Total Energy , MJ/t	1534	1400
Environmental impact	Higher	Lower in steelplant if purchased
		Aggregate impact will include beneficiation impact
Carbon Carrier	(50 – 55 kg/t)	(15 kg/t)
Cost	Lower	Higher. Subject to volatility
Slag make in BF	Higher due to higher burden.	Lower due to reduced burden
Impact on coke rate	Effective	Greater scope for reduction

Process Atmospheric Emissions

A comparison of typical emissions for the two agglomeration processes is indicated in Table 7-5.

TABLE 7-5 Typical Emissions of Sintering and Pelletising

Air Emissions	Sintering (Typical)	Pelletizing (Typical)
Waste gas flow Nm ³ /t	1,500 - 2,500	1,940 - 2,400
Dust g/t	41 - 559	14 - 150
SO _x g/t	220 - 973	11 - 213
NO _x g/t	302 - 1031	150 - 550
CO g/t	8,783 - 37,000	<10 - 410
CO ₂ kg/t	162 - 368	17 - 193
VOC g/t	37 - 673	5 - 40
PAH mg/t	0.2 - 592	0.7 - 1.1

The major differences in dust arise due to the type of feed used in each of the processes. It will be noted that the environmental performance of the pelletizing process is significantly better than the sintering process, as the typical emissions of all the pollutants are lower. The use of solid fuel in sintering is the cause for the higher Carbon footprint. However, if the beneficiation operation is linked to pelletising this advantage may get diluted. Newly constructed sintering plants include modern pollution control equipment designed to achieve lower emissions.

Blast Furnace Carbon Emissions

The blast furnace carbon emissions are somewhat higher in the cases of sinter use due to the higher coke rate as compared to the full pellet operation. Lower slag rates resulting from pellet use also contribute to the overall reduction in materials handling activities and consequently, particulate and carbon emissions.

IRONMAKING TECHNOLOGIES

The alternative processes available for producing the iron are as follows:

i.Hot Metal Blast Furnace

Smelt reduction technologies

ii.Direct reduction

Gas Based Processes

Coal based Processes

The hot metal plays an overwhelming role in meeting the requirements of integrated steel production. DRI which is in solid form is relatively minor contributor. Steel scrap is an alternative metallic, which forms nearly 30 % of the global metallics supply along with the DRI accounts for about 30% of the global steel production.

BF DOMINANCE

The world crude steel production is shown in Table 7-6 and Fig 7-2.

TABLE 7-6 WORLD CRUDE STEEL PRODUCTION BY PROCESS, 2022

Process/ Geography	Production	Oxygen	Electric	Other	Total
	Million ton	%	%	%	%
European Union	136.3	56.3	43.7	-	100.0
Other Europe	45.8	37.1	62.9	-	100.0
CIS (incl Russia)	85.8	63.7	33.0	3.3	100.0
Russia	71.5	65.0	33.1	1.0	100.0
North America (incl USA)	111.3	30.7	69.3	-	100.0
United States	80.5	31.0	69.0	-	100.0
South America	43.4	66.4	32.7	0.9	100.0
Africa	21.1	13.3	86.7	-	100.0
Middle East	50.4	5.0	95.0	-	100.0

Asia (incl)	1 383.8	81.3	18.4	0.3	100.0
China(e)	1 018.0	90.5	9.5		100.0
India	125.3	45.8	54.2	-	100.0
Japan	89.2	73.3	26.7	-	100.0
South Korea	65.8	68.5	31.5	-	100.0
Taiwan, China	20.8	59.7	40.3	-	100.0
Total of above	1 884.2	71.5	28.2	0.4	100.0

The dominance of the Blast furnace and hot metal routes can be gauged from the share of the BF BOF route in global steel. It is a whopping 71.5% in 2022. In 2023 also the BF-BOF share has been of the same order. (71.1%). In India it was near 44%.

The Blast Furnace has been the work horse for the production of liquid iron from the ores for nearly centuries. Iron making being the primary process by which the iron ore is reduced to metallic iron is the key element of integrated steel plants. It encompasses raw materials, and their preparation for use in iron making as well. Thus Coke plants, Sinter/Pellets plants which provide the primary raw materials for the Blast furnace are an essential adjunct to it in the integrated steel plants. The iron making complex forms nearly half of the ISP (in the present-day compact plants even more). Substantial facilities and investments in the integrated plants are driven by the Blast furnace.

The consistent improvements in all aspects of the technology of iron making in blast furnaces have enabled the Blast furnace to remain a very critical part of the integrated steel plants. Relentless efforts for the development of a replacement for the blast furnace over decades have still not made much headway to challenge its role both in terms of viability, and scale in integrated steel plants. The mind-boggling capacity development in PRC which has added nearly a billion tons of steel capacity in the last 40 years has given further fillip to the blast furnace.

BF Installation

The blast furnace is a non-stop operation in a steel plant. The large blast furnaces in the world today, with diameters up to 16 metres or more, produce over 10,000 to over 12000 tonnes or more of hot metal per day.

By-Products

Slag

Slag is an essential by product which carries the impurities from the raw materials. The amount of slag produced is essentially determined by the quality of materials and their gangue contents. Slag make can range from 170 kg per tlm to even beyond 350 kgs per ton of hot metal. Obviously, this is a large quantity requiring to be evacuated as frequently as possible from the furnace.

Granulation of the BF slag by rapid cooling with a high velocity water stream has gained ground and it is now almost universally adopted. This ensures that the BF slag is converted to a useful form in real time manner and the problems associated with the collection transport,

cooling and disposal of the slag are avoided. The blast furnace slag has proven itself to be an extraordinary input for cement making replacing a large part of the limestone.

BF Gas

Another coproduct of the blast furnace operation is the gas which is extracted from the top of the furnace. It generally contains: CO₂ 22% H₂ 5% CO 22% N₂ 51% Its heating value is approximately 2.7 – 4.0 MJ/Nm³. The volume of BF gas produced can vary from 1200 – 2000 Nm³ /t hot metal. This gas is, therefore, recovered for reuse as a fuel in the plants. The BF installation itself needs considerable fuel for heating in the Hot blast stoves. About 50% of the gas produced gets consumed in the HBS and the balance is surplus fuel.

As the gas passes through the furnace, it carries with it small particles of solid raw materials, which then have to be removed. The gas is cleaned sequentially in dust catchers, scrubbers and electrostatic precipitators, ensuring its quality to be commensurate with the use as fuel as well as environmental control. The flue dust, because of its high iron content, is collected and recycled as a feed for the making of sinter.

Top Pressure Recovery Turbine (TRT)

This is a facility for power generation, which converts the physical energy of high-pressure blast furnace top gas into electricity by using an expansion turbine. The benefits from this installation include:

Generates electric power of approximately 40-60 kWh/t pig iron

- Flaring of BF gas avoided

Blast Furnace Heat Recuperation

These are used to heat the combustion air of the blast furnace using the sensible heat of the flue gases, (approximately 2500 C). The Fuel savings in Hot Blast Stove vary between 80-85 MJ/t hot metal.

Technological Improvements in Blast Furnaces

Consistent efforts have been made in the industry for improving the blast furnace operations energy efficiency and cost effectiveness. Many technological improvements have been made in the last 50 years, initially by USA, USSR and some of the European countries but led by Japan from the seventies and South Korea from the eighties. These have played a highly significant role in the sustenance of the BF. The emergence of PRC as the largest steelmaker in the world of nearly a billion tons annually, of which nearly 90 % is BF-based, has provided major support in the nineties and till now. The principal focus on technologies which have enabled the blast furnace to retain its dominant position ones are:

- Enlargement of unit size
- Flexibility in raw materials specifications and increased use of sinter and pellets
- Use of alternative fuels (non-coking coal, natural gas, coal tar etc to replace part of the coke requirements. The coke requirements are reduced to less than 400 kg per ton hot metal.

- High levels of productivity through improved raw materials, automation incl AI, process-standardisation and equipment upgrades.
- Long campaign lives (upto 20 to 25 years)

Furnace size and Productivity

The average furnace inner volumes which was about 2000 cum in the sixties gradually increased to 5000cum in the mid-seventies. This development is substantially attributable to the Japanese steel industry which developed this as an economic solution. Adoption of very large size blast furnaces and ensuring their efficient and stable operations were the hallmark of the Japanese industry. This was dictated by the demands of the very large unit sizes of blast furnaces that Japan introduced in the quest for providing optimized Mega steel plant (12 to 15 million tons in capacity) configurations with minimum number of units.

Thus, the 10000 ton per day blast furnaces on scale became a reality. China has installed scores of large sized furnaces as part of its expansions. In India also, the newer installations have all preferred to install large Blast furnaces (3500 to over 5000 cum). The following typical data (Table 7-7) indicate how high productivity is being achieved in a variety of furnace sizes in different parts of the world.

TABLE 7-7 BLAST FURNACE KEY PARAMETERS (TYPICAL)

Country	Hearth Dia., M	Productivity T/M3/day	Burden	Injectant
Finland Rukki BF1, BF2	7.2	3.4	sinter	Oil
Canada AMDofasco 4 BF	8.5	2.9	pellets	PCI
USA Severstal NA BF C	8.8	3.1	pellets	PCI
AK Middletown BF3	8.9	4.2	pellets, HBI,	N.Gas
China Wuhan BF5	12.2	2.0	sinter	Coal
Netherlands Tata Ijmuiden BF7	13.8	2.7	sinter	PCI
BF6	11.0	2.9	pellets	Coal
Korea Gwangyang BF's 1 - 4	13.2	2.7	sinter	Coal
Japan Nippon Steel,Oita BF2	14.8	2.4	sinter	Coal
Japan JFE Keihin BF 1	13.0	2.8	sinter	Coal

The increased productivity accomplishments outlined above have been primarily the result of the evolution of reduction of total fuel rate. This along with introduction of labor-saving facilities, automation and rationalization of furnace equipment and improvement in furnace operation has automatically led to the increase in labor productivity with Japan's ironmaking productivity exceeding 1,500 t/manyear.

Facility Modernisation

The successful operation of blast furnaces with hearth diameters exceeding 15 meters and producing over 12000 MT/day has been noteworthy. In most countries medium to large sized

furnaces are producing over 6000 to 10000 MT/day. What needs to be appreciated is the new construction or rebuilding of smaller and medium sized furnaces with modern equipment to achieve high productivity, low reductant rates, and extended campaign lives. This has been accomplished by either building medium sized furnaces where plant configurations do not favor large blast furnaces or by selectively upgrading older, smaller furnace.

The scarcity of capital and the constraints of existing plant layouts have also forced upgradation of many furnaces originally built in the 1950's and 1960's. These upgrades have been directed at intensified blast conditions (stove upgrades, installation of coal injection, enhanced oxygen enrichment), improved cooling and refractory configurations, and retrofitted burden distribution equipment, instrumentation & automation, pollution control, energy recovery and cast floor improvements.

Typical BF size increases in Japan in select NSC installations during the relining and rebuilding at the end of the campaign lives are:

NSC Nagoya No. 3 BF from 3,424 to 4,300 m³,

Kimitsu No. 3 BF from 4,063 to 4,822 m³,

Muroran No. 2 BF from 2,296 to 2,902 m³,

Kimitsu No. 4 BF from 5,151 to 5,555 m³ and

Oita No. 2 BF from 5,245 to 5,775 m³ (one of the largest blast furnaces in the world)

This approach has enabled capacity expansions of BF ironmaking with significantly lower investments and without disturbing the overall logistics of the original installation. Similar achievements also exist in Indian steel such as Tata Steel, JSW etc.

Technology for use of economical raw materials

Sinter is still the material of choice in most circumstances for tonnage BF plants worldwide. From a process perspective it has been demonstrated that equally good blast furnace performance can be obtained with fluxed sinter or fluxed pellets

The ability of the sinter plants to recycle the majority of steel plant waste oxides, including steelmaking slags, mill scale, dusts and some sludges makes it even more relevant in the current context of environmental concerns and efforts at Circular economy in production. For some of the materials not suitable for sintering such as oily mill scale, BOF dusts, some sludges, potentially promising approach is the installation of rotary hearth furnace (RHF) direct reduction plants in North America and Japan. The DRI (or HBI) could be utilized mainly in steelmaking furnaces but also in BF.

Raw Materials

The Raw materials inputs (mainly Iron ore/Sinter/Pellet and Coal and coke) for blast furnaces form the major production cost component (currently 70 % or even more) of the blast furnace iron. Since the early 1990s, the prices of the raw materials and fuels have also been going northward consistently. The global factors have been a major factor in this increase. The

situation has reached a level where the paradigm “Companies with control on raw material prices will be the Winners” now rules the steel world.

A major offshoot of the raw material cost escalation and the depleting high quality resources is the focus on increasing the use of low-quality and economical raw materials. This has resulted in a wide range of iron ores to be part of the feed chain of the Blast furnaces. Beneficiation of the ores has become an essential part of the iron ore production and use chain. The sintering processes have been upgraded to suit the characteristics of the different ores.

Use of semi-soft caking coals for cokemaking

Stamp charging provided an opportunity to increase the proportion of non- coking coals to form part of the coal blend. It is reported from the Japanese steel industry that a mixing ratio of the semi-soft caking coal surpassed 50% in the coal blend. India has also been pursuing this option effectively.

Pulverized Coal Injection (PCI)

The most significant and sustainable action towards the use of lower grade and cheaper raw material is manifested by the increased use of non-coking coal as a replacement for part of the coke in the blast furnace.

Prior to the 1980's the preferred injection fuel was oil, but the two major oil crises and sharply increasing oil prices led to other fuels being used, such as natural gas in USA and Australia and coal in most other countries. Oil and gas availability is far restricted when compared to the availability of non-coking coal. Thus, non-coking coal has drawn much greater attention as a substitute for coke in the blast furnace.

Pulverized Coal Injection (PCI) has now been implemented in most steelworks around the world. During the 1960s and 70s, the steelmakers of Japan introduced the concept of the reducing-agent-rate (RAR), which has now become a standard parameter for evaluating BF performance. The maximum PCI record of 250 kg/t-pig iron was achieved at Kakogawa No.1 BF 254 kg/t-pig iron, and Fukuyama No.3 BF 266 kg/t-pig iron. The coke demand in present day newer as well as modernized Blast furnaces has reduced to a level of 300 to 350 kg per ton hot metal which is a significant reduction over the earlier levels. Typically, 25 to 40% of the coke requirement is replaced by the coal in modern installation.

Similar experiences ca also been seen in India particularly in Tata Steel, JSW etc.

Though increased injection of coal was initially driven by high oil prices, the present increased use of PCI is driven essentially by the need to reduce raw material costs through reduced coke demand. It is by now well established that the injection of coal into the blast furnace leads to:

- Increased the productivity of the blast furnace,
- Reduced consumption of the more expensive coking coals by replacing coke with cheaper and wide range of soft coking or thermal coals;
- Assistance in maintaining furnace stability;

- Improved consistency of the quality of the hot metal and reduced silicon content of the pig iron.
- Reduced greenhouse gas emissions,
- Increased coke oven life

One of the Life Cycle Analysis by Tata Steel showed a 6.7% reduction in CO₂ emissions when the PCI rate increased from 16 kg/tHM to 116 kg/tHM. The wide spread development of PCI systems has resulted in the maturing of milling, storage and distribution and safe operational technologies.

Raw materials preparation

The most significant aspect of this development was driven by the large size furnace preferences and the demand of the increased productivity levels. This mandated a very high level of attention to be paid to raw material characteristics for feeding the Blast furnace both in terms of strength as well uniformity (analysis and size) and quality. Large scale blending and ensuring uniform feed to the furnace on a sustaining basis were also driven by Japan as it imported raw materials from many different sources globally in great quantities. Providing a uniform and stable raw material input required that blending be practiced.

Interaction with Downstream Processes

One of the major issues facing the blast furnaces in the large integrated installations is the need for flexibility to adjust to the near continuous production chain from the hot metal to the cast product in the steelmelt shops. The reduction in the number of operating blast furnaces, the enlargement of steelmaking shops, and the nearly universal adoption of continuous casting has simplified in-plant material flow, but has removed flexibility from the system. Any interruptions or delays in casting or steelmaking quickly cause a build-up in hot metal inventory. Thus, many blast furnace operations are faced with start-stop modes dictated by downstream processes. Some plants have installed pig-casting/granulation facilities to produce pig/granulated iron during such interruptions. But the humongous sizes and hourly outputs of the large BF's make the task quite challenging. The cold metal produced can be either used later in the same plant or sold externally as the need for virgin iron units in EAF operations provides a new market.

Technologies for extending service lives

Sustainability demands and cost pressures globally have brought into focus the need for blast furnace campaign life extension. Various technologies have been developed to extend the campaign life of a blast furnace, reduce the huge cost of relining and minimize the production decrease during a relining period. The factors essential for extending a furnace campaign life are

- Adequate furnace design at the construction.
- Innovative designs and construction techniques to enable older plants to upgrade and introduce modern technologies.

- Adoption of modularized concepts and construction technologies to reduce the outages required for the changeovers.
- Extensive use of Highly efficient cooling staves including copper staves in all the high heat loads areas.
- Improvement in the refractories particularly the hearth.
- Meticulous operation control during the campaign duration
- Well-conceived repairing measures for equipment as well refractories and cooling systems.

With this approach, the campaign life expectations are now in the range of 20 years or more.

Automation & Simulation models

Introduction of automated control systems and the automation of their operations may well be considered the foundation of the large-scale steel plant automation that we see today in the industry. This again was introduced on a large and sustaining scale with extraordinary cooperation between the Steel plant and the System designers and manufacturers. Integrated production control systems covering from order receipt to product despatch was a path breaking approach and its successful adaptation has laid the foundation for many of the attributes that are in demand today including big data analysis and use of AI.

Process models capable of simulating a blast furnace as an integrated system have been developed as a tool to clarify the phenomena in the furnace inside and analyze the process. In contrast to the two-dimensional total models of blast furnaces developed by the Japanese steelmakers in the 1980s three-dimensional steady-state and non-steady-state models and advanced, four-phase models (that dealt with gas, solid, liquid and power), and five-phase models (that dealt with slag and hot metal as two different liquid phases in addition to the other three), are now available. Visualization systems exhibiting the phenomena inside a blast furnace based on information from sensors has now come to be an essential element of the operation of the Blast furnaces.

Technologies for resource recycling

Circular economy and Carbon reduction demands, have enabled the BF to play an important role in enhancing recycling of process wastes and arisings e.g

- Recycling the dust and sludge containing iron and carbon are formed into pellets or briquettes to convert to DRI.
- Recycling outside waste plastics utilizing ironmaking facilities. JFE and Kobe Steel in Japan inject waste plastics into Coke-Oven and blast furnaces, The total treatment capacity in Japan has increased to more than 200,000 metric tons per year
- Recycling of used steel-chord tyres is also receiving attention in Japan.

GLOBAL BF STATUS

Status of BF contribution globally is shown in Table 7-8. (Figs 7-3 and 7-4)

TABLE 7-8 – STATUS OF GLOBAL BF CAPACITY

	Plants/ Units	Capacity	Operating	Announced	Construction	Pre- retirement
	Numbers	MTPY	MTPY	MTPY	MTPY	MTPY
China	306	1018	788	73	55	96
India	64	229	103	97	25	0
Japan	15	93	73	50	0	8.5
Russia	9	65	56	3.7	0	3.7
S Korea	3	52	50	0	0	0
Brazil	15	40	34	1.2	0	0
USA	10	35	24	0	0	2
Ukraine	9	34	12.6	0	0	0
	6	32	16	10	6	0
World	518	1842	1262	208	100	192

It will be noted that as per the Global BF tracker, nearly 85% of the BF capacity is accounted for by the top 5-6 producers. Of this, 60% is due to China alone with the rest 25%. India is estimated to have a capacity of nearly 229 MTPY.

DIRECT REDUCTION

Direct reduction processes, though technically well-known and established for quite some time, have only seen moderate growth through the last decades. The world DRI production has been increasing steadily from 76.2 million tons in 2012 to around 106 million tons in 2020 and 136.5 million tons in 2023. It is observed that about 70 percent of the DRI is produced using natural gas-based processes, and the balance of world DRI production was from coal-based DR processes. The main fillip to the coal based DRI has come from India where the adoption of micro complexes has given rise to large number of such units.

Direct reduction plants have been location specific mainly due to the following dictates:

- Availability of cheap natural gas is a prerequisite for the economic production of gas based DRI
- Non-metallurgical coal for use as reductant in the coal based DRI plants should be of good quality and economical in price.
- Good quality lump iron ore or pellets are required as the iron bearing raw material

Direct reduction Processes

A large number of Direct reduction (DR) processes have been conceived and tried out on a laboratory scale, pilot plant scale and commercial scale. Only a few of them have reached industrial scale with commercial operation.

The well-established gas-based processes are Midrex and HyL processes. Coal- based DRI is made in Rotary kiln processes, mostly inspired by the original SL-RN development of the sixties.

DRI Production

The world DRI production by country for the years 2016-2023 is given in Table 7-9 and Fig 7-5.

TABLE 7-9 WORLD DRI PRODUCTION (MT)

Year	2016	2017	2018	2019	2020	2021	2022	2023
World	77.9	92.2	104	111.3	106	119.3	125.1	136.5
India	24.6	29.5	34.2	36.8	33.6	39.0	42.3	49.6
Iran	16	19.4	25.7	28.5	30.2	31.6	32.9	33.4
Middle East	30.6	34.1	41.2	43.6	42.4	45.4	47.8	49.0

Process-wise distribution of DRI production is shown in Table 7-10.(Figure 7-6)

TABLE 7-10 WORLD DRI PRODUCTION (PROCESSWISE)

Process	2019		2020		2021		2022	
	MTPY	%	MTPY	%	MTPY	%	MTPY	%
Gas Based								
Midrex		60.5		60.2		59.5		57.8
HYL / Energiron		13.2		12.4		12.7		12.1
Pered				2.9		2.2		2.2
Coal Based								
Rotary kilns		24		24.4		25.4		27.9
Other		2.3		0.2		0.1		0.1
Total	111.8		106.3		119.2		126.2	

It will be observed that 74% of the DRI production accounted for by Middle east and Iran is all gas-based. In case of India 70 % of the DRI production is through coal based Rotary kilns and the balance with gas-based processes

The accelerated development of these direct reduction process has been conditioned by the following facts:

- Rapid development of steelmaking in EAF and in part from Induction furnaces (india and China) where apart from scrap DRI can be used as major input.
- DRI has lower impurities due to possible use of high-quality virgin inputs as compared to scrap.

- A considerable number of countries had access to inexpensive natural gas.
- Non-coking coals and lignite can also be used (as solid reducing agents).

GAS BASED DR (GDRI) PLANTS

MIDREX and HYL are the two gas-based DR processes which account for over 70% of the global DRI production. The gas based DRI production is dominated by Midrex with near 84% share, and balance from HYL process. Advantages of the GDRI are

- It is a viable alternative to hot metal in specific cases.
- The process can produce cold or hot GDRI as well as HBI for use as a scrap substitute for steelmaking.
- An important energy saving development has been the use of hot GDRI for steelmaking in integrated installations. The temperature of hot GDRI delivered to the EAF generally averages 700°C, providing an electrical energy savings of 120-140 kWh/t of liquid steel.

The GDRI plant capacities can go up to 2.5 to 3 million tpy or more at the present level of technology.

Alternatives to Natural Gas

The non-availability of natural gas in many parts of the world and the abundant availability of non-coking coal has prompted the evolution of alternatives to Natural gas for direct reduction.

COG

Coke ovens generate an off-gas containing hydrogen and carbon monoxide which can be adopted for DRI production.

Corex Export Gas

Corex process of hot metal production, generates huge volumes of off- gas due to large use of coal in the charge. This off gas has been used for the production of high quality DRI.

Syngas

Syngas, or synthesis gas, is a gas mixture consisting of hydrogen, carbon monoxide and carbon dioxide resulting from the gasification of a carbon-containing fuel. Coal gasification technologies have been in use for decades, but have now acquired greater focus due to the overall energy situation, costs as well as the environmental issues with direct use of coal in many processes. A very high-quality syngas can be produced by gasification technology regardless of the quality of the fuel. This allows for use of various bituminous and sub-bituminous coals, lignite, pet coke and petroleum refinery bottoms. Syngas from gasified coal has already been paired with large DR unit (about 2 MTPY) with encouraging results.

COAL BASED DR PROCESSES

These processes differ from the gas-based ones in that the reductant in this case is coal. Although the initial enthusiasm of these processes led to installation of units with capacities of about 600,000 tons per year, their operations did not sustain at this level. Smaller plants (30,000 to 150,000 to 200,000 tpy) have gained acceptance and form bulk of the units installed in the last few years. The process remains relevant mainly in India where a capacity of over 30 million tons has been installed using micro and mini plant sizes.

The SL/RN process is the well-established Rotary kiln process using coal. It can use iron ore lumps or pellets as feed. Almost the entire world production of coal based DRI is produced in rotary kilns. Typically, the metallization is about 92-93% and carbon content about 0.1 to 0.2%. The combustion off-gases from the kiln are burned off in an afterburner and the off-gas sensible heat can be recovered in an HRSG. A power potential of about 5 MW from a 500 tpd kiln has been experienced.

This process has been attracting attention in India as non-coking coal is available in plenty in India and so is good lump iron ore.

DRI in Perspective

Use of DRI is, essentially, as a source of metallics in the EAF. It has been used in a limited way in the Blast furnace as well as BOF as an additional feed. While its use in the blast furnace is an option for quick increase in production of hot metal, it is more expensive as compared to the conventional BF feed. In BOF, it is used as replacement for steel scrap as a coolant. This use is limited to about 30 to 40 kg/tls.

Gas-based DRI is an attraction in comparison to the hot metal from Blast furnaces due to the lower carbon foot print and non-use of coking coal. Globally, there is considerable push towards increasing scrap recycling. It is expected to reach a level of more than 30 % by 2030 and even more than 60 % by 2050. The most environment and energy friendly steelmaking process is EAF melting of 100% scrap. Larger availability of scrap for recycling will open up the opportunities for DRI use as well, though from environmental considerations, the steel scrap is the best choice as a metallic for steel production.

However, exclusive use of obsolete steel scrap has potential adverse impacts on high quality steelmaking. Therefore, better alternative metallics must be used for quality steelmaking. GDRI offers the minimum CO₂ route with high quality DRI. Availability and cost of NG make this option unattractive in many regions. In this context ore reduction through off gases in ISP, and gasified coal provide an effective solution.

With increasing use of EAF in the future, the use of DRI can also add additional fillip for providing a competitive alternative to integrated steel plants. The use of DRI and scrap in combination can help besides enabling scale, quality steel production due to the lower impurities in DRI. The energy efficiency also stands to improve due to the hot DRI charging saving nearly 15 to 20 % of electricity as compared to the cold practice.

In the event of share of EAF steelmaking reaching 50 % of global steel production by 2050, it would contribute nearly a billion tons. With 50 % steel scrap in the charge, the balancing DRI demand can reach 500 million to 600 million tons. This objective can be sustained with possible cost-effective gasification of coal and ready availability of NG at competitive prices and electricity at reasonable prices

Such a vision has the potential advantage of reducing the dependence on Coking coal and injection coal substantially for iron ore reduction as well as consequent reduction in Carbon foot print from the ISP's. Increase of preference to market driven locations can lead to decentralized capacities and overall transport system optimization with consequent energy and environmental benefits.

Global energy transition for carbon reduction has focused on use of Hydrogen as the first choice. Hydrogen forms an important part of the reducing gas in the GDRI processes. The feasibility of using upto 90 % hydrogen in reducing gas has also been demonstrated in existing gas-based DR installations. This success places the processes in a viable position for hydrogen transition in the future.

A number of alternatives to Natural gas (Off gas from Coke ovens in ISP's, Corex off gas and Syngas from Coal gasification) have also emerged in the last decade as indicated above enlarging the scope for the adoption of this process.

STEELMAKING TECHNOLOGIES

The commercially proven steelmaking processes globally may be classified broadly in two groups, namely, processes based on hot metal (liquid iron) and the processes using scrap or Direct Reduced Iron-DRI(solid) as the melt stock. The steelmaking processes adapted to use of hot metal are

- i. Basic Oxygen Furnace (BOF)
- ii. EAF (Electric Arc Furnace)

The steel scrap or a combination of scrap & DRI can be converted to steel in Electric Arc Furnace (EAF). These processes for steelmaking are reviewed in this chapter.

BASIC OXYGEN PROCESS

With the dominant share of ironmaking taken by the Blast furnace (Liquid hot metal), BOF has come to be the natural choice and workhorse for steelmaking in ISP's. The dominance of BOF in world steel production can be seen from Figure 7-7.

TABLE 7-11 BOF SHARE IN GLOBAL STEEL PRODUCTION

	BOF	EAF	Others	Total
	%	%	%	
2021	73.2	26.3	0.5	100
2022	71.5	28.2	0.4	100
2023	71.1	28.6	0.3	100

Status of Technology

Basic Oxygen Process (BOP) conventionally known as LD process is a well-proven process for converting hot metal to liquid steel. It revolutionised the steelmaking process through the use of pure oxygen as the blowing medium. It provided an extraordinarily efficient, fast and energy optimized solution for steelmaking using hot metal. Completion of a heat in 60 minutes and less became a reality, changing forever the time-scale applicable to the steel making plant planning. The steelmelt shop capacities as a result increased many-fold from the open-hearth furnaces (which took more than 4 hours per heat per unit). This reduced time scale led to high volume production using far less number of operating units, rationalised and streamlined operations and paved the way for the efficient planning of the large-scale integrated units. The steelmaking plant capacities in a single shop now range to over 10-12 million tons per annum. There are shops operating at nearly 15 MTPY as well.

The technological improvements and process control capabilities supported by efficient pre- and post-treatment facilities have enabled BOF to provide good and sustaining solutions for the production of a wide range of steels (both flat and non-flat), special steels, and low alloy steels.

Backbone of Global Industry

The BOF has thus been the backbone of the integrated steel production for the last five decades. Presently over 70 % of the world steel production is through the BOF process.

Top Blown Converter

BOF is a top blown reaction vessel which treats liquid iron in a fast and highly efficient unit for the conversion of hot metal to steel. Oxygen and the chemical energy of the oxidation reaction inside the converter are the source of energy.

Bottom Blown converter

OBM/Q-BOP (Oxygen Bottom Blowing) was developed by Maxhutte of West Germany during seventies. The idea was to address the issues related to the tall building requirements dictated in the BOF, and the problems of slopping. It was also expected to be an option for the then existing open hearth furnace shops to install the Q BOP inside existing shops. The extraordinary benefits to be derived through the use of existing open hearth shop infrastructure caught the attention of steel plant management and there was promise of very fast growth. However, the major benefits of better operations as compared to the top blown converter

claimed by the process did not materialise in actual operation. Thus, the process went into oblivion pretty soon.

Combined Blowing

Combined blowing adopted in the current day BOF, takes advantage of the bottom blowing concept and builds in some of these advantages in the modern day top blown converters.

BOF Key Attributes

The supremacy of the BOF process over the other processes is that irrespective of heat size (converter capacity) say, 10 ton to 350 ton, the oxygen blowing time as well as tap-to-tap cycle times are of the same order. Under favourable conditions, each operating converter can produce consistently in the range of 30-40 heats per day. In addition to hot metal, the process can melt steel scrap in the range of 15-30% of the charge. The scrap is used as a coolant for control of tapping temperature. The BOF process is flexible and can be used for the production of all grades of carbon steels required for the long as well as flat products. In conjunction with the ladle refining facility, higher carbon grades are also consistently produced.

The quality of steel produced in the BOF is excellent, low in nitrogen (as compared to the EAF), low in residuals and very uniform. It makes it the ideal process for meeting the stringent requirements of the flat product applications.

BOF Choice Triggers

The key developments which can be considered as vital contributors to the positioning of the BOF as the automatic choice for large scale hot metal-based steelmaking are:

- The development and scaling of the tonnage cryogenic oxygen plants in capacities (2000 tons per day and even more) paved the way for the availability of this key input of required quality for BOF at economical price.
- Extraordinary developments in Blast furnace practices (particularly raw materials preparation and their quality), has enabled the hot metal feed to be tailored to match the BOF leading to efficiency quality and productivity.
- The fast process of the BOF was quite harsh on the refractory linings used in the vessels used for production. Coordinated developments in the refractory qualities, intermediate repair practices, and tailoring the operating practices to become more refractory friendly led to the consistent lining lives per campaign of over 5000-6000 heats on an average (15000 heats is regularly achieved and Upto 40000 heats per lining campaign have been reported in selected installations in USA).
- BOF as an environment-compatible solution, became a sustaining reality due to the developments in the efficient off-gas collection and cleaning systems and its use as an effective fuel in the steel plant.
- The increasing vessel size (upto 400 tons per heat), appropriate process technologies and downstream support (continuous casting) have made possible a single BOF shop

with 3 vessels to produce over 10 to 12 million tons (even 15 MTPY) per year of liquid steel.

- The economics of the BOF shops have received extraordinary fillip due to the vessel availability being 2 out of 2 in modern units. Single vessel BOF shops have also now become a reality taking advantage of the consistently high refractory lining lives.

BOF Development Road Map

As the experience of faster refining in the BOF process gained ground in the sixties, efforts were directed at increasing the heat sizes. This was successfully achieved due to the scores of the supporting attributes which ensured that the BOF heat time could may well be independent and irrespective of the vessel size. As a result, remarkable advances were made in the efficiency of high-speed oxygen blowing of converters, on line pre-treatment of hot metal in ladles (conventional as well as torpedoes), dephosphorization and desulfurization and high-speed secondary refining and degassing, etc.

The development of steelmaking during the decades is represented in Figures 7-8 and 7-9. These have been possible due to the extraordinary developments in secondary steelmaking aided by the process optimisation efforts moving towards zero slag steelmaking. While the main focus is from Japanese steel, the general developments are globally seen in similar vein.

Over the last two decades, the BOF process has been optimized nearly to its limits. In efforts to improve its productivity, the stepwise process functions traditionally of BOF have now been split, leaving BOF to perform its most required and efficient function.

Multi-Step Refining (Steelmaking)

Nippon Steel, Japan has developed the MURC process, whereby dephosphorization and decarburization are done continuously in one converter vessel with intermediate deslagging between them. This process enables efficient dephosphorization using low-basicity slag and under high oxygen potential, making good use of the strong stirring and high-speed oxygen blowing functions of converters. Using this process, the slag formed during decarburization is left in the vessel and reused for the dephosphorization of the following charge, which enables counter-flow refining with minimum heat loss and reduced slag generation. However, since hot metal pretreatment and decarburization are done continuously using the same converter the processing time tends to be longer. This process has proved effective in the production of ordinary steels (except for ultra-low-P steels) in terms of decreased CaO consumption and slag generation and effective use of the thermal potential.

BOF Lining Life and Converter Availability

The extremely fast process accompanied by very high refractory wear limited the campaign-life of an operating vessel between relines. Therefore, in order to ensure uninterrupted operations of the integrated production chain, the BOF shops were designed with multi vessel configurations. One operating out of 2 installed or 2 operating out of 3 vessels became the conventional practice. This obviously meant that the Capex and the supporting infrastructure costs were higher and asset utilization was also impacted.

This aspect of the shop received considerable attention from the refractory makers in close coordination with the steel producers which resulted in improved refractories, highly effective gunning practices for intermediate repairs and practices such as slag splashing. However, one of the most significant factors that helped in leapfrogging the lining lives is the improvement in the hot metal quality from the Blast furnace. Production of low silicon hot metal with consistent quality (Popularised by the Japanese steel industry) became a standard practice. Pre-treatment of hot metal to remove the impurities such as silicon, sulphur and in some cases even phosphorus reduced the process load and consequently the slag make in the BOF. The secondary treatment facilities also helped in transferring a part of the load of the process converter vessel

As a result of these developments, today internationally, lining lives of 4000 to 6000 heats are considered normal. Most plants have achieved lining lives in the range of 10000 to 15000 heats, where this level gets considered as SOP. Much higher lining lives are, however, achieved in many installations with specific practices and inputs such as intermediate repairs, slag splashing, zoning, hot metal control etc. The impact of improved lining life reflects in lower operating costs and better converter availability. However, the major impact that it has is on the design of the Steelmaking facility and the Capex. Against the conventional 1 out of 2 or 2 out of 3 combinations adopted in the past, the present operations center around 1.6 out of 2 to 2.6 out of 3 converters. Even single converter shops are now a reality.

Support Technologies

Alongside the great leaps by the BOF in establishing itself as the automatic choice for the hot metal conversion to steel, numerous support technologies and support systems made good strides addressing specific concerns on different aspects of the process and facilities as the key to successful integrated steel plant operations and sustainability. The important ones are discussed below:

Energy Recovery from BOF Gas

LD (BOF) gas recovery is an economic and environment-friendly solution for primary waste-gas treatment that is completely integrated with the process. Converter waste-gas cooling is highly challenging due to the tough operating conditions with high loads of abrasive dust particles as well as high temperatures and the general cyclic nature of this batch process. The main focus of the solutions for LD (BOF) gas recovery is on high-calorific-value CO-gas-enrichment efficiency, plant reliability and safety. The major benefits of this process adjunct are:

- Recovered energy up to 100 Nm³/t of steel converter gas which can be use as clean fuel inside the steelplant.
- This helps in reduction of purchased energy and thus the carbon foot print gets reduced.
- No large-scale flaring of the off gas takes place generally, thus limiting the emissions to the environment.

Major benefits of the evaporative-cooled cooling stack system include value creation from waste, energy savings and reduced CO₂ emissions. The system is typically designed for suppressed combustion in combination with CO gas recovery. Heat is transferred from the waste gas through the heating surface to the cooling water, thereby generating steam. The steam is stored in a steam accumulator for constant feed into the overall plant steam network. Potential exists for energy recovery of 80 kg steam per ton of liquid steel.

Secondary refining

Fast and Efficient secondary refining support including Ladle furnaces, and Vacuum treatment units have added to the flexibility and productivity of the BOF operations. Steels with very low residuals, very low carbon and hydrogen could be produced on a consistent basis on a large scale. The automotive sector with large demand for high quality sheets has been a major beneficiary of this. The simplified secondary refining processes have now replaced conventional methods of deoxidation and composition adjustment using ladle bubbling after tapping from converters.

Post Combustion

The post combustion of CO produced during refining in BOF and transferring the heat of combustion to the slag and metal offers an additional amount of energy. The advantages of exploiting post combustion potential area:

- Higher melting rates can be achieved
- Reduced green-house gas emission/ton of steel because of increased scope for scrap use
- Reduction in slopping. Due to increase in slag temperature which helps lime dissolution and decreases slag viscosity.

Installation of post combustion burners/injectors are now being accepted as a standard feature of the newer installations.

Slag splashing

Splashing of slag to coat the refractory lining, has become a standard practice to increase the lining life. The process was simple to adopt and yielded rich returns. The benefits of slag splashing are:

- Extension of lining life
- Increased recycling of BOF slags, thereby reducing the slag disposal quantity and related issues.
- The lime (CaO) consumption in BOF process may be reduced to some extent due to possible dissolution of basic slag coating.
- Decrease in slopping with increase in yield.
- Rapid formation of slag occurs due to melting of low temperature phase of the coating.

Slag-free tapping

This technology was driven by the demand for cleaner steels and better casting practices. Carry-over of slag during tapping results in the following adverse impacts:

- Steel cleanliness can be affected.
- During ladle treatment impurities can revert back from slag to metal.
- Secondary steel-refining operations such as desulphurization/deoxidation etc can be affected due to composition of synthetic slag getting altered. This can lead to increased consumption of deoxidizers
- Carried-over slag can increase the refractory wear.
- FeO and MnO of slag react with Al and forms Al_2O_3 which is a solid inclusion at the steelmaking temperature, this will affect the quality of steel.

Several methods are developed and in use to minimize slag carry-over. Tap-hole plug, slag cut ball pneumatic slag stopper and slag detection methods are commonly in use. These have now become an essential part of the BOF shop design.

Sub-lance and Dynamic control

One of the major break-throughs in process control of the BOF process, was the development of the dynamic control. Model-based systems supported by high level of automation and computerization have helped to perfect the system which now has become an essential part of the BOF installation.

The introduction of sub-lance has integrated many facets namely Process Control through modeling, achievement of consistent and predictable results, process optimization and automation. Benefits of sub-lance with dynamic control are:

- Improved tap-to-tap time and productivity

The elimination of the manual sampling and temperature measurement saves time and reduces personnel requirement. This can potentially improve tap-to-tap time by nearly 15% and consequently converter productivity improves.

- Improved process efficiency

The adoption of the sub lance with dynamic modeling has enabled fine control of the entire process cycle. Sub-lance measurement results are available approximately four seconds after the measuring probe enters the steel bath. which enables the real-time responses and controls. The process efficiency is improved due to:

- Improved hit rates of end point temperature
- Improved hit rates of end point carbon
- Consequent Reduction in the number of re-blows
- Decrease of Fe content in slag

- Increased converter lining life
- Optimised scrap melting
- Effective production planning
- Improved environmental compliance due to better process control and reduced usages of materials.
- Improved working conditions

Hitting Rates

Hitting rates, that is the index of achieving the planned heat analysis and temperatures, are reported to be over 90% from well operated plants. This enables the shops to be operated on a well-planned and efficient basis.

- Process cost reduction

The application of the sub-lance and Dynamic control has become an important tool in cost optimization. The effective control and predictability offered by the system in terms of the bath analysis, temperature, state of the bath enables optimisation in the consumption of hot metal, fluxes, oxygen and energy accurate information regarding etc. These result in cost savings.

It is reported that the use of SL & DM has shown the following savings in metallics and oxygen use. (Table 7-12)

TABLE 7-12 Raw material savings with SL&DM

Item	Impact
Hot metal	10kg/t reduction
Scrap	10kg/t Increased use
Oxygen	1.0 standard m3/t reduction

Online Phosphorous Measurement

With the increased use of high P iron ores, the measurement of P at end point in BOF steelmaking continues to be a subject of interest because of its impact on steel quality. Efforts are directed towards finding an effective online measurement system.

Dry Gas-Cleaning

An important forward step in making the BOF more environment-friendly in the last decade has been the increasing adoption of Dry Gas cleaning for the BOF off-gas. Adoption of this system enables, wet sludge treatment, handling and disposal to be avoided and consequently reduces the water consumption on this account. The focus is on efficient gas cleaning, high energy-efficiency and maximum availability with minimum energy-consumption.

In the dry-type dedusting process, converter off-gas is ducted from the cooling stack into an evaporation cooler, where water and steam are sprayed into the gas stream by means of dual-flow nozzles. Coarse dust is removed from the off-gas in the evaporation cooler, while

fine dust is removed in an electrostatic precipitator by means of high-voltage fields. The cleaned converter off-gas is exhausted through the system by the induced-draft fan.

It will be noted that in Dry GCP, an electrostatic precipitator (ESP) is used, in place of the venturi scrubber used in the Conventional wet system. The principal elements in this system are

- Hood and skirt system along with appropriate duct work for leading the gas from the converter vessel to the treatment plant.
- Conditioning tower/ Other facility for primary cooling of gas,
- ESP system for cleaning the gas.
- ID fan and related system.
- Gas holder for recovered gas.

The pressure drop inside the dedusting plant is lower than the conventional wet gas cleaning systems hitherto largely adopted in the industry. This results in the reduction the required ID fan capacity leading to substantial power savings in operations. A comparison of the key features of the dry GCP against the Wet system is given in Table 7-13.

TABLE 7-13 DRY vs WET GAS CLEANING SYSTEM

Item	Dry Gas Cleaning	Wet Gas Cleaning
Dust separation	Dry	Wet / Sludge
Dust content at outlet	Less than 10mg/Nm ³	30 mg/Nm ³
Collection efficiency	99 %	Lower
Ease of use of dust for further treatment/use	Efficient and effective	Long storage and cumbersome disposal
Water requirement	Minimal	Higher
Water treatment	No	Required
Sludge treatment	Not required	Required
Energy consumption	55%	100%
Investment costs	100	75
With WTP	100	100

Granulation of BOF Slag

Another important development, which has considerable potential in addressing the slag management in BOF and the conversion of waste to wealth is the Granulation of the BOF slag. When successfully adopted it provides the following advantages:

- Real-time treatment of the liquid slag helps in avoiding elaborate slag dumping, cooling and removal.
- The granulation renders the entire slag management process more environment-friendly and safer in operation.

- Granulation provides the opportunity to convert the BOF slag into a useful construction material, without having to wait for long periods for aging as is conventionally experienced.

The experience so far indicates that about 35 to 60 % of the slag can be granulated, as solidification of part of the slag is inevitable. This will need to be dumped and treated in the conventional manner.

Presently, two types of slag granulation systems are offered. One is the Wet System where a high-pressure water spray is the medium for granulation as is practiced in the BF slag. The other is a dry atomizing system. The potential advantages of this system are:

- Granulation converts the slag into a useful product/s. Ageing for slag is avoided.
- It has been observed that the granulated material exhibits good physical properties such as spherical shape, high strength, high abrasion resistance.
- Because of these properties, the products have found uses such as reinforcing material, aggregates, abrasive blasting material and a substitute for river sand as construction material.
- The plant operations are carried out in a safe and an environment-friendly manner.
- Ageing is avoided and consequently the demand on space for holding is considerably reduced.

The atomizing units are small and therefore the installation for large shops will have to consist of multiple units.

Quality improvement

The BOF steel is placed very favourably for producing superior steel for flat products as compared to the EAF due to lower Nitrogen, lower residuals and quality. However, the demand for higher functionality (lighter weight, better workability, greater strength, improved product surface quality etc.) of steel products that are devoid of surface and internal defects continues to rise.

Remarkable progress has been made in tailoring the steels to specific industry and application needs through extremely regimented composition ranges and highly controlled processing for achieving controlled microstructures. This in itself has increased the demand for consistency and nuanced process controls at the steelmaking stage to which the BOF has responded very well.

Environmental Control

The major concern in the BOF initially was the adverse impact on the environment due to the off gases discharged from the converter during the blowing process. However, the gas collection cleaning and recovery systems have kept pace with the demands of the process developments as well as the increasingly stringent environmental regulations. The waste gas

from the converter is rich in carbon monoxide and as such can be used as fuel in the steel plant. The BOF gas is now effectively collected as a rule in ISPs for use as a fuel in the plant.

The BOF process itself as a steelmaking step is extremely environment friendly with minimum carbon foot print as compared to the EAF and the Twin shell processes. The consumption of energy is the lowest in this case (turning net negative with the gas recovery as fuel). This is due to the ability of the process to use the process chemical energy as the main source. However, due to its dependence on Hot Metal as a principal charge, the overall CO₂ load on a composite basis considering the raw material input gets very high.

The BOF gas cleaning systems in the initial years were wet systems for ensuring effective dust removal and gas cleanliness. The sludge arising out of this operation became a major environmental concern. Its disposal required large additional facilities (treatment, storage and drying). However, in the last two decades the use of Dry gas cleaning has been developed into an effective and safe solution. This, besides effective gas cleaning also ensures reduced water demand. The iron oxide fines recovered in the gas cleaning plant can be efficiently collected and consumed in the sinter plant.

With the increased need to save energy and reduce CO₂ emissions, the recovery ratio of LD converter gas (LDG) has been increasing consistently through better equipment and controls, improved collection and treatment and use of the gas as an integral part of the plant fuel system.

Besides the use of off gas as fuel, the sensible heat in the off gas as it emerges from the converters is also being increasingly recovered. A steam generation potential as high as 90 kg/t crude steel have been reported. On an average 50 to 60 kg of steam can be generated. The steam from converter exhaust gas can be used in the steam network of steelworks or can supplement the power generation units. This step can serve to improve energy efficiency as well environmental friendliness.

FUTURE DIRECTIONS

HOT METAL PRETREATMENT

Pre-treatment of hot metal for feeding the BOF converters is gradually taking center stage as it provides the following advantages:

- More efficient use of converters for dephosphorization and desulfurization.
- Significant improvements in BOF operations, and productivity.
- Scope for cost optimization by improvements in productivity, yield and hit rate.
- Increase in BF productivity
- Scope for increased use of lower grade raw materials in the Blast furnace feed.
- Scope for reducing the slag quality in the BOF
- Improvements in product quality

Accordingly, multi-stage refining as a practice is gaining greater acceptance. In this approach, Silicon, Sulphur and Phosphorus contents in hot metal are reduced and tailored through pretreatment. Different reaction vessels are used for hot metal pretreatment which can include Hot metal ladles - Open top, torpedo ladles as well as transfer ladle in BOF shop. The BOF converter vessel also offers a very convenient option in the existing shops due to the ready availability of the hot metal handling facilities and established logistics, availability of support facilities such as slag management, process control systems, handling facilities etc.

While the introduction of the increased process steps increases the logistic issues and points of attention, the overall benefits outweigh these concerns.

Desulfurization

The need for sulphur reduction is essential from product quality and processing view-points. Any increase in Si content in hot metal leads to increased CaO consumption in steelmaking, causing increased cost and slag generation. Control of silicon is also essential for improvement of the steel yield in converters. External desulphurization in open top or Torpedo ladles provided the opportunity to transfer part of this load from the blast furnace with consequent benefits of higher productivity and raw materials flexibility in the blast furnace. Desulphurisation can be carried out using CaO-Mg system or a Calcium-carbide based compound. Equipment (Injection, slag raking) suited to the processes are well developed.

However, as the technology for stable operation of large blast furnaces and use of high-quality burden have enabled substantial silicon control in the BF itself. Thus, bulk of the furnaces produce hot metal with optimized silicon content suitable for efficient BOF operation. However, in selected cases, a moderate Si content level through optimum hot metal pretreatment.

Dephosphorization

The hot metal dephosphorization was conventionally carried out in torpedo ladle cars (TPC). While this pre-treatment enabled stable production of low-P, low S steels, it decreased the thermal allowance for decarburization in converters, and as a result, limited the scrap proportion. This problem gets resolved with the adoption of the converter-type dephosphorization processes, which use the converter vessels in existing shops or have separate converters installed in new shops for this purpose. The large freeboard, effective oxygen system and infrastructure provide scope for high-speed dephosphorization with strong stirring and high scrap melting capacity,

Zero-Slag Steelmaking

A number of approaches towards reducing slag make in BOF and to improve productivity through reduced processing times in BOF have been made in different plants. They are similar in approach to the ZSP. The improvement of the BOF efficiency along with cost effectiveness coupled with improved environmental friendliness have been the motive force. Desiliconization and dephosphorization and use of pre-treated metal as the feed in BOF are at the core of a possible 100% slag less steelmaking operation. The elimination of this need for

dephosphorization using bulk of the oxygen blowing and refining time in the BOF automatically ensures shortened tap-to-tap time in BOF by 15 to 20%.

The actual implementation of this process concept will vary from location to location driven by the specific conditions, existing shop capabilities etc. For example, the pre-treatment of hot metal can extend to desiliconisation (to produce ultra-low silicon), desulphurization prior to BOF, dephosphorisation in the BOF or in a separate vessel and finally decarburization in BOF. This approach has enabled in NKK Fukuyama, to attain a 100% slag-less steelmaking operation, while minimizing the formation of by-product slag in the BOF. The slag generated earlier at a rate of more than 100 kg per ton of steel, was decreased by half. The slag generated in the converter dropped to less than 10 kg/t.

The net impact of these developments can lead to increased shop productivity, better quality steel and drastic reduction in the quantity of slag generated. The reduction in the slag besides making the installation highly eco-friendly, also reduces energy consumption, consumption of utilities and additives. Better converter lives and thus better overall operations are also achievable.

A number of existing BOF installations have installed dephosphorisation vessels in the existing shops to enable multistep processing. POSCO is a good example where such facilities have been incorporated both the Pohang as well as Gwangyang plants. Among the newer installations, Shougang Jintang at Caofodian, PRC is a leading example. The BOF shop at 10 MTPY ISP in Viet Nam is also planned with such facility.

Converter refining

With the increase in the hot metal pretreatment ratio, the role of converters came to focus on decarburization. In order to enhance productivity leveraging pretreated metal, rapid refining techniques are now developed. This includes higher oxygen blowing rates supported by slopping sensors and exhaust gas analyzers to achieve reduced decarburizing time in converters. Decarburisation times, as little as nine minutes, have been reported. With high-speed oxygen blowing, the lance design and blowing patterns have become increasingly important. As the molten steel yield decreases with increased oxygen blowing speed, suppressing dust generation remains an important countermeasure to sustain the yield.

Operation scale

Efficient steelmaking practices, highly integrated process control, extraordinary lining lives, have all catapulted BOF operations to very high productivity levels. Thus, the production of more than 10 million tons of Steel from a single shop with 3 operating vessels has now become a sustainable reality. This ability can have far reaching implications on future steel plant designs and the modernization and expansion strategies of the existing steel plants globally.

The large BOF shop at NSC Oita (3 x 400T) produces over 10 MTPY. Posco Gwangyang, which has now become the world's largest steelplant installation with a capacity of near 24-25 million tons gets most of the production from two BOF shops. The larger shop is understood

to produce over 12 MTPY. The Shougang Jintang, Caefodian plant in PRC has a modern BOF shop planned to produce more than 10 MTPY with 300-ton BOF converters.

BOF vs BF

It may not be an exaggeration to say that the BOF provided a long lease of life to the blast furnace by providing an extremely energy efficient, highly productive, fast and economic steelmaking from the hot metal. The scale of operations of steelplants also thus became what they are today (Over 12 to 15 million tons in one site) primarily due to the BOF initiatives.

BOF Challenges

With increasing pressure for decarbonisation, the scope for the coke-based BF and other coal-based smelting processes are highly challenged to provide an environment friendly (reduced carbon) solution. Beyond this the other challenges for BOF are outlined below:

- Environmental standards are getting tougher, requiring better air-cleaning technologies for fugitive emission control and in-shop work environments. The adoption of Dry gas cleaning and use of ESP's can provide welcome relief. However further improvement in efficiencies of dust collection and reduced emissions will continue to be demanded.
- The very long campaigns of converters (10000 heats and more) warrant appropriate Vessel shell design and materials.
- The increasingly lower phosphorus specifications for steels reduces the recycle of BOF slag to Sinter plants and blast furnace due to the faster build-up.
- Upgrading computer and expert systems and model-based tools will also be demanded to achieve consistent process control. The development and use of in-blow sensors with possible feedback control, on line Phosphorus control, etc, will be new areas which would need to get integrated with existing instrumentation and automation systems.
- One key area that requires technological development is role of scrap and its systems. Ability to increase scrap proportion in the charge would reduce the hot metal load and thus enable the carbon footprint to be reduced considerably. Already high scrap practices use more than 25 to 30 % of metallics. Currently, scrap delivery analysis and classification systems are also quite complicated and, somewhat unreliable. Better systems would, therefore, be essential for improving the scrap use in the BOF, the amount of scrap used and effect on quality is limited

ELECTRIC ARC FURNACE

Technology Status

EAF technology has been the work horse for steel production in the last several decades in locations where the steel scrap formed the principal metallics source. USA which has large scrap generation has been the prime mover. The increasing emergence of DRI as an alternative to or as a principal metallics also provided great fillip to EAF. This was particularly driven by the Gas based DRI production in the Middle East.

The flexibility to configure market-oriented units and adjustable scale has also enabled EAF to be preferred in a number of cases in many countries.

The early adoption of EAF as the main process for steelmaking for alloy and special steels has enabled it to cement its place as the first option for these steels as well. EAF technology has gained increasing importance in the steel industry in the last few years because global focus on carbon foot print reduction, sustainability etc. Electric Arc furnace steel currently accounts for about 28 % of global steel. In some of the countries the ratio is as high as 90% or more.

EAF Key Attributes

The EAF process has sustained itself as an essential option for steelmaking due to its following key attributes:

- Steel scrap is generated on a substantial scale in most of the economies. The recyclability of steel and its remanufacture to good steel has been made possible by the EAF. This is due to the ability of the EAF to accept a full solid charge. Thus, as long as steel scrap continues to be available the use of EAF would be irreplaceable as of now.
- The EAF process has been flexible and used for the production of numerous grades of steels particularly alloy and special steels, stainless steels etc. In conjunction with the secondary refining facility (ladle treatment as well as converter vessels refining), the process has become even more flexible.
- The concept of tailored steel capacity to meet local market sizes was made possible by the scale and flexibility of the EAF process.
- .Technology and operating practices have enabled the steel quality from EAF to meet nearly all quality requirements, except in very special applications.
- .Electric power the key energy source is abundantly available, making the process easier for adoption.

EAF Choice Triggers

The developments which can be considered as vital contributors to the positioning of the EAF as a viable choice for steel plants are:

- Large scale scrap generation in developed economies encouraged the development and use of EAF, as it is the only choice for conversion of scrap into steel on a scale.
- The plant sizes using EAF can be tailored over a very large range from 100000 tpy to over 3 million tons per year.
- The facilities required are substantially less than the demands of integrated steelmaking, thus making the plant configuration, operations and management simpler.

- The development and scaling of the tonnage cryogenic oxygen plants and process developments and adoption of oxy-fuel and combination injection systems have enabled product quality in carbon steels in most cases on an economic scale.
- Raw materials flexibility in the modern furnaces which can range from steel scrap and DRI/HDRI to liquid hot metal in varying proportions has added a new dimension to the EAF.
- The process speed and the productivity of the EAF has reached levels comparable to the BOF.
- EAF is a more environment friendly option with much reduced carbon footprint as compared to the hot metal-based steelmaking. It has become more so also due to the developments in the efficient off gas collection and cleaning systems and heat recovery

EAF Development Road Map

The EAF technology has matured over the decades, and the technology upgrades have kept pace with the increasing demands for energy efficiency, productivity and quality. The figure 7-10 would show the improvements in parameters that have taken place in the last decades.

The typical energy input and output in EAF steel production is shown in Figure 7-11. It will be seen that there is a significant increase in the share of chemical energy (Carbon and oxygen injection) which enables optimized and quality steel production while substantially aiding increase in furnace productivity.

Technology Impacts

The major developments over the last four decades and their impacts on energy efficiency and productivity can be seen from Figure 7-12. It will be observed that there has been near 50% reduction in the energy consumption. The tap-to-tap times have dropped from 180 minutes to less than 40 minutes. The trend continues towards further improvements. These remarkable quantum leaps have enabled EAF to present itself as a viable alternative to the superfast BOF steelmaking.

It would be evident that the developments have covered all aspects from processes, equipment, technology to raw materials and more. Further improvements have consistently taken place beyond these levels in the last two decades, driven by the need for flexibility in terms of raw materials, environmental concerns, lower costs and productivity. Extended campaign lives have been made possible through better and efficient cooling elements and refractory practices. High level of automation and model-based solutions have provided extraordinary improvements in quality steel manufacturing in EAF.

MODERN EAF FEATURES

The major technologies that form an inseparable part of the 21st Century EAF are:

- Larger furnaces to provide scale
- Flexibility to accept variety of raw material inputs

- Enlarged furnace configuration to enable retention of large metal pool and enable single bucket charging in scrap-based EAF's.
- Ultra-high power input
- High oxygen injection rates
- Use of auxiliary injection of fuel, and flux
- Hot DRI charging
- Multistep steelmaking

The important features of the modern EAF design are outlined below in somewhat more details as its relevance to future steelmaking is slated to be quite considerable due to the emphasis on recyclability, sustainability and green energy increases:

Scale of operations

The scale of EAF-based steel units has been consistently increasing. Integrated units with 3 MTPY and more are now in operation in different countries. The EAF unit sizes of 300 T and above are feasible. 150/ 200 T EAF's are now common and typical of most newer installations.

There are many leading companies using EAF with very large aggregate steel production such as Nucor Steel (Over 30 MTPY) Steel Dynamics (about 12 MTPY) etc in USA, the same are distributed over a number of locations, taking advantage of the markets as well as locations specific benefits.

Larger Furnace Volumes

The furnace volumes per ton of capacity have become a key attribute in the modern plants. This has been triggered by the larger liquid pool (EBT demand) to ensure faster melting of solids, maintaining process continuity, and optimization of power consumption and better lining performance.

The shell design has kept pace with the changing requirements dictated by the use of increasing hot metal in the charge. This has resulted in split shell design. The shell diameter and size have become bigger to enable adequate scope for the chemical processes induced by the high level of oxygen use. The shell design has also incorporated efficient cooling and reduced the refractory dependence as a lining material.

The larger upper shell also endows the capability of single bucket charging in scrap-based EAF's. This is a very vital requirement for ensuring productivity, and energy efficiency in scrap-based EAF's. The vessels can now be exchanged by overhead crane in total or separated as bottom and upper shell, to minimise maintenance time. The current day shops have EOT crane capacities planned accordingly.

Super high-power EAF

Power input being the heart of the EAF process has received considerable attention both in terms of higher inputs and stability. Ultra-high power (UHP) EAFs typically had a specific

electrical power capacity greater than 0.8MVA/t. Today furnaces are being planned with a specific power input of 1.5 MVA per ton of capacity. The equipment (Superior Current conducting electrode arms (CCEA), facilities and system designs (SVC) supported by the improved scrap processing and preparation to enable this in a safe and efficient manner. This feature has resulted in quantum leaps in terms of productivity, particularly in the scrap-based EAF where the higher power during melting forms the most significant energy demand.

Efficient Water-cooled Panels

The water-cooled panels which have substantially replaced the refractory lined walls and roof have seen an increasing use of copper and innovative designs resulting in more efficient cooling system, and better panel life. Double layer water-cooled panels have also been developed with the potential to reduce the heat losses from the furnace.

Power System Compensation

One of the chief issues dogging the EAF has been its adverse impact on the grid power supply system. EAF is also a strong source of harmonics. This is particularly significant in areas where the grid strength is limited.

The issue has been very well recognized and considerable efforts have been made to successfully overcome the impacts. SVC mitigates these adverse impacts to power quality in the plant system as well as the supply network. The Static Var Compensation (SVC) addresses fluctuating reactive power, which, if not remedied, will lead to voltage fluctuations and flicker. SVC has become an inseparable part of the system design for EAF power supply. This ensures considerable reduction of network disturbances emanating from the operation of a very large electric arc furnace (EAF) as well as power factor correction.

Refining combined injection technology

The need for faster and better refining along with the use of chemical energy to replace part of the electrical demand has led to extraordinary developments in the injection of oxygen, fuels and fluxes in the EAF. The use of hot metal in EAF charge and the development of the Twin-shell furnace concept provided the real opportunity for popularising this approach. The increased hot metal in charge demanded a high level of oxygen use.

A combination of auxiliary burners and new injection technologies better known as refining combined burner (RCB) has become an essential part of the EAF installation. The injectors operate as burners in the initial stages of the meltdown, after which they switch to lance mode, promoting the total combustion of the injected carbon.

The facility has enabled carbon injection on the scale demanded by the need for utilizing increased chemical energy. Similarly, it is possible to inject any other fine-grained materials such as lime, Fe-Si and dusts as well. Burner capacities in the range of about 6 MW each are now possible. The number of burners also extend upto 6 to 9 (total 30 to 50 MW power equivalent)

Post combustion and Emission Control

The development in the injection technologies has also provided the opportunity to install post-combustion injectors. These improve the furnace efficiency and also improve the emission control.

The introduction of post-combustion chambers in the circuit enables the retention of the off-gases in a high temperature zone for a sufficient time to destroy the toxic organic compounds;

Raw Material Flexibility

The modern EAF supported by the various developments has positioned itself as an extremely flexible alternative in terms of raw materials acceptability. Thus, steel scrap, iron scrap, DRI (coal based as well as Gas based), HDRI/HBI, and hot metal are all usable in EAF charge. The processes adopted for the use of the different raw materials are discussed in the following paragraphs.

Scrap Preheating

Scrap preheating can reduce the power consumption of EAFs through use of waste heat to preheat the scrap charge. Various systems have been developed such as Consteel tunnel-type preheater, Fuchs Finger Shaft, and Twin Shaft.

Consteel process benefits claimed are

- Productivity increase of 33%
- Reduced electrode consumption of 40%
- Reduced dust emissions⁵²
- Electricity savings estimated to be 60 kWh/t for retrofits

The FUCHS shaft furnace consists of a vertical shaft that channels the off-gases to preheat the scrap. Benefits claimed include:

- Almost 100% scrap preheating possible
- Potential Electricity savings of 120 kWh/t and fuel increases of 0.7 GJ/t •
- Reduced electrode consumption
- Yield improvement of 0.25-2%
- Up to 20% productivity increase
- 25% reduced flue gas dust emissions (reducing hazardous waste handling costs)

SCRAP CHARGING

The options of scrap for EAF include the following:

- Bucket charging
- Continuous charging

Bucket Charging

Well-processed scrap with high bulk density is now a governing paradigm for high productivity shops predominantly using steel scrap. The most important support required in this connection is the capability to ensure single bucket charging of the entire charge for a heat. Single bucket charging ensures that the roof opening is avoided during the steelmaking, preventing heat loss and saving process time. This places the following demand on the plant design:

- Adequate scrap bucket volume
- Matching handling facilities (Bucket filling, EOT cranes, transfer cars)
- Suitable building (Height and clearances)

Continuous Charging

Systems have been developed for continuous charging of scrap to the EAF. The sensible heat of the furnace off-gas is used for preheating the scrap leading to energy saving. The system demands an appropriate layout and integration with the scrap feed facilities. The benefits provided are the avoidance of large capacity EOT cranes and handling facilities for bucket charging, lighter building and energy savings. The adoption of this facility introduces a level of inflexibility in the area layout and demands high level of scrap preparation.

DRI Charging

DRI can be charged in any of the following manner:

- About 20-25% DRI can be charged in the basket along with steel scrap in the EAF as part of the charging through bucket.
- With Continuous charging coupled with large hot-heel practice, the use of DRI for the steelmaking may go up to 100 %.
- Direct hot charging

The charging method to be adopted is dictated by the process location, plant facilities and the raw material approach of the units. The Gas-based DRI units can adopt any of the methods. The scale and the operations in the Gas-based DRI units are well-suited to continuous and direct hot charging.

Hot Charging of DRI

Need to improve energy efficiency has led to the feeding of the DRI in hot condition to the EAF through a direct link between the DR plant and the EAF. This has led to the savings of more than 100 kwh per ton equivalent energy input.

USE OF 100% DRI

Many steel makers having integrated Gas-based DR and steelmaking facilities prefer 100% DRI in the melt. Continuous charging of DRI is required for efficient production. The DRI feeding rate depends upon the furnace transformer capacity, and may be 30-33Kg/MW/minute. Use of DRI results in slightly higher power consumption, increased slag volumes and longer

heat times. The problems of uncertainty in availability of scrap, fluctuations in its quality, residual elements, and the increasing quality demands of the various steel products (both bar and flat products), have made DRI an ideal alternative metallic for steelmaking. The use of DRI in large quantities calls for foamy slag operation which helps in faster process and better quality. Coal reduced DRI generates larger slag volume, increases the power consumption compared to gas based DRI/ HBI. Increase in the size of the DR units, development of HBI (ease of handling), productivity improvements and lower carbon footprint in the DR units has placed the DRI in a very competitive position. The EAF is the only process which can effectively convert the DRI into steel.

Environmental implications

It is well accepted that the all-scrap EAF steelmaking provides for the lowest energy consumption and carbon impact per ton of LS. The level of carbon foot print however begins to increase with the increasing proportion of metallics other than steel scrap. DRI and hot metal use substantial energy for their manufacture, bulk of which is coal and coal based, thus adding to the carbon foot print. The carbon foot print with Gas-based DRI and EAF using DRI and Hot metal can go upto 1.5 to 2 tons as compared to 2.2 to 2.7 tons by the ISP's.

Support Infrastructure implications

The major demand from an EAF installation is in terms of quantum power supply and the stability of the grid system to support its unique demands. Therefore, the systems have to be designed considering the adverse impacts that the furnace operation can have on the power system.

The inability of the power system to support large EAF's is one of the considerations and major deterrent which has prevented the installation of EAF's in many locations, particularly in the developing nations. EAF operation becomes considerably smoother from the power perspective when the charge includes substantial amount of DRI or hot metal and maintenance of a liquid pool obviates the frequently varying peak demands, arcing loads, flicker etc.

Waste arisings and management

The waste arising in EAF is generally much lower in scrap-based units. The slag is handled in the same manner as the conventional except in cases where the possibility of heavy metals being part of the feed scrap. Zinc from the galvanized scrap is also a major issue. The zinc bearing dust from EAF cannot be readily disposed-off without appropriate treatment, which can be involving substantial costs.

The current-day designs of EAF have addressed the issue of dust arising in the process through process as well as collection solutions. The dust collected from the bag filters can be pelletised for reuse in the charge. Part of it may be usable in the sinter charge where appropriate subject to the analysis.

Use of hot metal in EAF

The need for reduction in power demand improved energy efficiency, flexibility in metallics, and steel quality led to use of hot metal as an alternative/supplementary metallic

feed to the EAF. A number of attendant advantages accompanied the introduction of hot metal. These are:

- Lower electrical power requirements (MVA)
- Controlled/reduced grid power system impacts
- Leveraging chemical energy leading to reduced power consumption (approx. 3 kWh/ton per % hot metal)
- Reduced nitrogen levels in finished products
- Reduced residual contents in finished product
- Higher productivity

Level of Hot Metal Usage

The level of hot metal usage in EAF, initially was around 20 % of the charge. However, with experience and process improvements and safety of operations the proportion has seen consistent increase in many locations even beyond 80%. The EAF designs have also been considerably upgraded to suit the high hot metal usage in the charge. Today tailor-made solutions focused on large hot metal in EAF charge are readily available from multiple sources.

Development of Twin Shell

This combination leads to an Electric Arc Furnace where the tap-to-tap times can be extremely short and the corresponding productivity reaches the level of larger furnace sizes or converter plants.

The two main reasons for this are:

- The possibility of a higher electrical power input and
- A far higher efficiency of chemical energy, decarburization and scrap preheating compared to the same size (tap weight) standard furnace.

Technology Impacts

The twin shell installations have the benefit of all the developments which have impacted the conventional EAF and EAF's using hot metal as a major part of the charge. The additional benefit, which is sought in Twin shell EAF, is the increased productivity with optimized electrical installation. The investment in two independent systems is avoided. The approach leads to improvement in productivity as compared to one shell.

Status of Twin Shell Technology

The Twin-shell EAF technology has matured over the last two decades, and the technology upgrades have kept pace with the demands of increasing proportion of hot metal in charge, energy efficiency, productivity and quality. The technology has now evolved as a combination of the conventional Converter process with Electric steel making in a furnace having two identical vessels. The furnace is equipped with one set of electrodes which is connected to a

transformer and can be slewed alternatively over each of the two shells. The oxygen is injected through a top lance.

The process is split into two stages

- The converter process during which the liquid iron is decarburised by injection of oxygen through the top lance.
- The electric arc process where electrical energy is used for the melting of cold charge (DRI or scrap) and for the super-heating of the bath to tapping temperature.

Scale of operations

The scale of Twin-Shell units is essentially in line with the EAF based steel units. Units in the range of 100 to 250T are in operation.

Metallics demand

Scrap was initially the principal metallics source in the early Twin-Shell EAFs driven by the ability of EAF to provide an efficient process to convert it to steel and the optimisation attendant with it. But with time and in keeping with the changing scenarios alternative metallics have come to be considered.

Hot metal as metallics source

The Twin-Shell EAF as a process alternative to BOF has emerged in the last decade or so mainly made possible by the introduction of hot metal as feed material. It has also positioned itself as a viable option in ISP's where hot metal is available and limited increases in steel production through this route are planned. The advantages that have accrued are:

- Reduced energy consumption
- Lower electrode consumption
- Higher productivity
- Lower electrical power requirements (MVA)
- Reduced residual contents in finished product
- Operating fluctuations from obsolete scrap eliminated and operations made consistent
- Reduced nitrogen levels in finished products
- .Reduced conversion costs compared to 100% scrap

The EAF designs have also been considerably upgraded to suit the high hot metal usage in the charge. Today, tailor-made solutions focused on large hot metal in EAF charge are readily available.

Environmental implications

Scrap based EAF steelmaking provides for the lowest carbon footprint. The level of carbon footprint however begins to increase with the increasing proportion of metallics other than

steel scrap namely, DRI and hot metal. The adoption of Twin-Shell EAF with a large hot metal ratio in the charge, thus contributes to increased carbon foot prints.

Support Infrastructure implications

The Twin-shell operation becomes considerably smoother when the charge includes substantial amount of DRI or hot metal obviating the frequently varying peak demands, arcing loads, flicker etc.

Flexibility to meet changing requirements

Twin-Shell EAF also offers the highest flexibility in terms of the charge composition. This can range from 100 % solid charge to 100 % hot metal. This feature can be leveraged provided the initial design and the installation has considered the possibility of such variations.

The shop will need to have provisions for the DRI charging (including hot where relevant), use of hot metal including its treatment where necessary. In case of large quantity of hot metal usage, the slag handling will also demand specific attention. Slag granulation is now being increasingly adopted in new shops. Granulation besides addressing the aspects related to waste management also reduces the logistics issue attendant with slag handling.

Waste arisings and management

The waste arising in Twin-Shell EAF with large hot metal charge will be nearer BOF's depending upon the level of hot metal usage. The slag is handled in the same manner as the conventional. However, with large capacity planned (3.5 to 4 MTPY) the waste handling, collection, reuse/disposal will need to be tailor made to the situation.

Features such as slag granulation, waste heat recovery can be incorporated considering the location specific issues.

FUTURE EAF FEATURES

Furnace Design

EAF technology will be required to play an even greater role in the global steel production in the coming decades where the share of steel from recycled scrap is projected to reach 50% or more by 2050. Also, with greater share of DRI the need for EAF becomes even more critical. The challenges of scrap quality, process amenability to produce high grade steels, increasing environmental legislations and cost optimisation will demand increasing performance levels.

Demands for consistent heat cycle times of less than 40 minutes will dictate use of well processed clean scrap. The height of the furnace as well as the building and supporting facilities will have to be tailored to single bucket charging. Injection technologies as a major support will take center stage to enable chemical energy input, and higher oxygen input.

Campaign lives will need to extend further as the EAF's would have to support the near continuous production chain driven by the developments in extended continuous casting cycles, hot charging, direct rolling. Furnace panel designs, slag zone and bottom refractory lives, quick change of furnace sections will have to match the above demands.

Typical features of the future EAF are indicated in Table 7-14.(Figure 7-13)

TABLE 7-14 - TYPICAL FEATURES IN FUTURE EAF

	Conventional EAF	Future EAF
Furnace size	150 t	150 t
Furnace volume	180 m ³	280 m ³
Volume per ton capacity, cum/t	1.2	Near 2
Scrap charge, nos	2 buckets	1 bucket Mandatory
Bucket size	150 m ³	Suit single charge
Transformer	1,000kVA/t, 150MVA	1,500kVA/t, 225MVA
Utilization of chemical energy		
Oxygen gas burners	3	3
Refined combined burners (RCB)	3	6
Carbon injectors	2	5
Post combustion injectors		5

Energy recovery from waste gases

Presently, majority of the EAF installations do not have facilities for heat recovery from the waste gases. Recognising that almost 25 to 35 % of the energy input of the EAF gets carried away in the waste gas, this aspect is now receiving considerable attention. Considering the large amount of energy in EAF off-gas, energy recovery solutions have by far the biggest potential for improving overall energy balance of the EAF. The indirect benefit due to the reduced carbon footprint makes these solutions even more attractive.

Energy output in EAF

Typical energy output in EAF per ton of liquid steel is shown in Table 7-15.

TABLE 7-15 Energy output of EAF (TYPICAL)

Distribution of energy (equivalent kwh)	Low chemical energy	High chemical energy	100% DRI
	%	%	%
Liquid steel	55-58	50-52	48 to 52
Slag	8	7	8
Off-gas content	25	30-35	30-35
Cooling water Radiation losses etc	12	12	12
Total	100	100	100

Utilization of recovered energy

The principal means of recovery of waste heat has been through heat exchange with production of hot water and or steam. The most important applications for waste heat utilization are.

Hot water production for heating purpose

The most efficient way to use the recovered energy is to use the heat directly for heating purposes. The heating system is operated in a separate cycle, where the heat is provided via a plate heat exchanger. This can also be integrated with the power generation system if necessary.

Steam production

The recovered heat can also be used for the generation of steam. In order to compensate the fluctuating off-gas conditions a storage system (steam accumulator/HW tank) has to be foreseen. The produced steam can be used directly for certain consumers, such as

- Steam ejectors for creating vacuum
- Steam for process heating (e.g. steel pickling)

Typical steam consumption in the areas outlined above are:

Vacuum pumps in VD Units 14 tph of steam

Power generation 7 tons of steam per MWh

Air separation plant (1 ton steam for 300 m³ of oxygen)

Chilled water (6 tph of steam for 2.4 MW of chilled water)

Chilled water production

Chilled water plants would be an area of considerable potential which can create the opportunity for utilization of a low temperature waste-heat recovery, a source for producing chilled water. A widely used and proven technology for thermal chillers are absorption-type heat pumps.

Electrical power generation

The WHRB is used for power generation using a Steam turbine. The outlet temperature of WHRB is estimated at approximately 210 degrees C, combining with the gas from secondary de-dusting system, the gas temperature can be equalized from 120 to 130 degrees C. And also, as gas volume is reduced by heat exchange at WHRB, it is possible to downsize the bag filter.

Granulation of EAF Slag

Normally, the EAF shops have practiced dumping of slag in close proximity to the furnace from where the same is transported after getting solid. This was practical due to the small volume of slag particularly in the scrap-based shops. This practice required close attention to slag handling from the point of view of ensuring good house-keeping and safety. Explosions are prone due to the sprays generally adopted to quicken the solidification process.

Granulation of slag is now an option in EAF shops due to the following benefits:

- The granulation renders the entire slag management process more environment friendly and safer in operation.
- Granulation provides the opportunity to convert the EAF slag into a useful material, without having to wait for long periods for aging as is conventionally experienced.
- However, only a part of the slag can be amenable to granulation as the drop in liquid temperature during the ladle transport and granulation operation will result in solidification of a part (expected to be about 30 to 50%).

SECONDARY STEELMAKING

The introduction of vacuum treatment of liquid steel in ladles was the first step in what has developed into a large steelmaking support by now grouped under the Secondary Steelmaking.

The primary objective of this additional step was to remove hydrogen in steel to avoid flaking. Similarly, the need for temperature adjustments in the ladle after the tapping from the primary furnace prompted the development of the ladle heating better known as Ladle furnace.

Over time and with greater experience of highly controlled steelmaking, a whole gamut of ladle-treatments has been developed covered by what is known as Secondary Steelmaking

Vacuum Treatment in Ladle

The initial method for vacuum treatment in ladle was Tank Degassing where a full ladle was placed in an enclosed tank like installation. The whole unit was sealed and a vacuum was induced. This enabled the dissolved gases also to evolve from the liquid steel. Thus, significant hydrogen reduction was achieved. The development of vacuum tank degassing is based on Mare's proposal in 1938 for ingot casting under vacuum, In the 1950s, 150t vacuum ingot casting, also well known as "vacuum stream degassing (VSD)" was successfully installed and operated at Gußstahlwerk Bochumer Verein in Germany to produce turbine blade for power generation.

A major breakthrough in vacuum treatment was the development of the so- called vacuum lift processes in which only part of the liquid steel gets treated in the treatment units for degassing. The DH and RH processes were the first such processes introduced in the sixties. In these processes an enclosed reaction vessel is used which sucks a portion of the liquid steel into the vessel. The vessel is under vacuum. The suction process is through snorkels dipped in the liquid bath in the ladle. The DH process used one snorkel which was the only connected to the ladle, whereas the Rh process used two snorkels.

The development of the vacuum-lift processes made way for short treatment cycles and thus faster production. While the initial installations were restricted largely to alloy and special steels production, the increasing quality demands in carbon steels from the integrated steel plants led to the popularization of the vacuum units as an essential part of the integrated steel plant steelmaking process.

Besides the reduced cycle times and efficient degassing there were other benefits which accrued. These included:

- Scope for increased decarburization enabling ultra-low carbon steel production on a scale.
- Utilisation of the units to act as aids for final adjustment of the steel chemistry with suitable additives, for which requisite systems were integrated into the installation.
- Use of additives and injection to provide desulphurization capabilities.
- Much cleaner steel for casting.

Current Status

Ladle treatments and Vacuum degassing have assumed a significantly vital position in the steelmaking chain in the last 2-3 decades with the steel applications increasingly demanding very high-quality levels. This led to the improvements in secondary steelmaking with better equipment, facilities, greater controls and improved logistics to match the primary units and automated integrated production control systems. Considerable efforts were directed towards reducing the treatment cycle times to ensure coordinated operations among the different process steps. Consequent advantages are:

- Increases in productivity of the steel-melt shops,
- Production of ultra clean steels
- Development of new steel qualities suited to specific applications
- Consistent steel quality from heat-to-heat.
- Shortening of the tap-to-tap time of the primary steelmaking unit,
- Savings in primary energy and utilities,
- Scope for use of low-cost charge material as well as ferro alloys,
- improved co-ordination of all units involved in the production sequence

One of the important developments is the incorporation of oxygen blowing as part of the process. This innovation, inspired by the VOD process developed specifically with stainless steel demands in view, has enlarged the role of these units in ultra-low carbon steel development and faster processing cycles.

The use of gas stirring with porous plugs has also been an important aid in ensuring uniformity of temperature and composition, production of cleaner steel etc.

Available Configurations

The popularity of secondary treatment of steel has led to numerous innovations and thus options with specific objectives. A number of combinations of these extensive process steps may be utilised, depending upon the end requirement and their technical and economic objectives. These can be classified as Open and Closed treatments. The processes and systems now available are:

Open Treatments

- Ladle Furnace (LF)
- Ladle Treatment Station (LTS)
- Chemical Heating Station (CHS)

Vacuum Treatments

- Vacuum Degassing (VD)
- Vacuum Arc Degassing (VAD)

- Vacuum Oxygen Decarburisation (VOD)
- Vacuum Circulation Process (VCP)
- Vacuum Circulation Process Top Blown (VCPTB)
- Vacuum Circulation Process Powder Blown (VCPB)

Refer Figure 7-14.

Process Outlines

A brief outline of the various popular processes (which are marketed under the different names by different process suppliers) is given below:

Ladle Furnace

The ladle furnace is a simple ladle heating set up similar to the arc furnace power support and carried out with no vacuum. Ladle furnaces have been installed with heat sizes of up to 400tons.

The demand for greater temperature control of the liquid steel also rose rapidly with the adoption of continuous casting of the liquid steel. A ladle heating installation was obviously the easier solution for temperature compensation. The use of degassing results in significant losses in steel temperature. This temperature loss has to be compensated either by superheating in the melting unit prior to tapping, or by heating metal in the ladle. This led to the cementing of the position of ladle furnace as a vital production unit in the manufacturing chain in all modern steel melt shops.

The metallurgical requirements imposed by the current competitive steel market include more precise analysis tolerances, minimum level of detrimental elements, improved cleanliness, and equilibration of temperature and composition. These final steps of composition adjustments and quality assurance are achieved by treatment in the ladle furnace.

The application of the ladle furnace now encompasses:

- Electric heating
- Desulphurisation by metal/ slag reaction
- Alloying/fine trimming
- Slag management
- Shape control homogenisation of ladle content
- Buffer function between melting and continuous casting units to ensure sequence casting

Chemical heating Station

An effort at optimising the need for additional energy use in the secondary steelmaking, led to the adoption of chemical heating. The exothermic reaction energy created by the oxidation of aluminium (or silicon) is used for chemical heating. The process is run under atmospheric

conditions and features a refractory-covered bell or ring. The bell or ring is partially immersed into the liquid steel bath, so that the entire process is performed under inert gas conditions. This technique is an effective method for attaining clean steel and precise chemical composition. Oxygen blowing also provided greater flexibility and reach of the process.

The process has largely been made popular by the Japanese steel industry. The process has generally become popular in BOF shops due to the faster processing and easier operations and cost advantage. CHS process applications include

- Chemical heating
- Alloying/fine trimming
- Shape control
- Homogenisation of steel quality and temperature, and
- Desulphurisation by metal/ slag reaction

Ladle treatment stations

Need for specific process focus in high productivity steelmelt shops has provided the opportunity to install ladle treatment stations. These newer nuances are inspired by the benefits of chemical heating along with the desire to provide simpler solutions to liquid steel treatment.

Ladle treatment has also acquired a new and enlarged dimension with the need for hot metal treatment for optimised iron and steelmaking. LTS therefore have now two clear areas of application namely hot metal pretreatment and liquid steel treatment.

LTS process applications for liquid steel cover:

- Deoxidation by the addition of aluminium or micro-alloys
- Adjustment of chemical composition by wire feeding and alloy additions
homogenisation of liquid steel by bottom purging or lance stirring
- Desulphurisation by addition of synthetic slag or by powder blowing
- Addition of cooling agents for temperature adjustment serving as a liquid storage buffer prior to casting.

The hot metal pre-treatment include :

- Desulphurisation of hot metal
- Desiliconisation of hot metal
- Dephosphorisation of hot metal
- Deslagging
- Homogenisation of hot metal quality and temperature

Hot Metal Pre Treatment Station

Pre-treatment of hot metal, is becoming more and more popular - almost mandatory. While some of these operations are carried out in Torpedo ladles, open- top ladles particularly the steel transfer ladles in steelmelt ships are used in very many cases. The introduction of co-injection technologies has also enlarged the use of these.

Tank Degassers

This is one of the earliest developments in ladle treatment. The tank- degassing process was installed in alloy and special steel plants producing large forgings. At its present state, it has proven its high availability and its suitability for the production of high-quality steel grades, in EAF and BOF shops, and with heat sizes of over 300 tons. The key requirements of this process step are:

Sufficient freeboard in ladles to counter the high level of agitation due to the reactions with introduction of vacuum. Slag-free liquid steel from the melting unit is another key requirement. Uniformity and homogenization is achieved through the use of a porous plugs at the ladle bottom for inert gas stirring

VD process applications cover:

- Degassing (hydrogen and nitrogen removal)
- Decarburisation to lowest levels
- Desulphurisation by metal/ slag reaction
- Efficient alloying/fine trimming with high accuracy
- Slag management shape control
- Homogenisation of ladle content

VD/VD-OB

One of the major developments in enlarging the use of vacuum treatment of steels, has been the successful introduction of oxygen blowing in the ladle through appropriate blowing lance systems (VD-OB). The application of oxygen blowing has enabled higher levels of decarburisation an essential for the production of Ultra-Low Carbon (ULC) steel grades.

Vacuum lift processes

Full ladle treatments as in the earlier processes made demands of bigger ladles, large vacuum capacity, and extended treatment times. The development of the vacuum-lift processes was a development to counter this. In these processes only part of the liquid steel from the ladles is drawn into the vacuum chamber for treatment at a time. Thus, there is a circulation of liquid steel in a cycle connecting the ladle and the treatment unit as one. The suction and discharge is through what is known as Snorkel designed to ensure vacuum. In case of the DH process one snorkel was used whereas the (Ruhrstahl Heraeus) RH process used twin snorkels.

Due to the smaller volumes treated at a time in a separate vessel, the need for high free-board in ladle units was avoided. This also provided more efficient treatment and faster process. The Rh process soon overtook and eclipsed the DH process and has become the lone vacuum lift process for steel plants at present.

RH process

The RH recirculation degassing process can be considered to be the bed rock of the fast vacuum treatment times as proven by its eminent suitability for operations requiring short tap-to tap times. Most of these units have been built mainly in BOF shops as it efficiently meets the high-speed requirements adequately and with heat sizes of up to 400 tons. Key attributes of this process are:

- Short treatment times
- Highly efficient hydrogen removal
- Efficient decarburisation
- No special slag measures
- No major ladle free board dictates
- No ladle stirring support such as porous plugs at the bottom

The current installations are equipped with supporting alloying/fine trimming support, fast vessel-exchange system for increased availability duplex-vessel installation for increased availability etc. The introduction of oxygen lancing has increased the capability for the ultra-low carbon levels. This process now is largely applied for flat products to enable mass productions of IF and deep drawing grades with very low contents of carbon. In addition, the unit is used to produce low hydrogen, nitrogen with precise control of chemical analysis and temperature of steel.

Selection of process

With the plethora of options, the selection of an appropriate process for ladle treatment demands careful evaluation. The selection of RH or VTD for steel plant is determined by steel grades covered by the product mix.

The very powerful decarburization capability of the RH unit makes it an automatic choice for steel plant which focus on production of ultra-low carbon steel grades (e.g. IF steel for automotive industries). Desulphurization can be better conducted on VTD due to the top slag. In case of RH plant, the sulphur needs to be removed before Rh treatment, e.g. by hot metal desulphurization, better scrap control on BOF and further desulphurization on LF or by powder injection facility. Small degree of desulphurization in Rh by powder blowing is becoming an option. For example, the Non-Grain Oriented Silicon Steels (NGO steel) requires ultra-low carbon and huge amount of alloying to be added. Sulfur removal can be conducted by powder blowing as the temperature of molten steel is high enough after silicon addition to compensate temperature drop during desulphurization.

Greater vacuum levels, oxygen blowing and Lime injection for deep desulphurization have provided extraordinary potential for high quality steel production using secondary treatments. Recirculation Degasser (Rh-TOB) and Tank Degasser (VD/VOD) together with deep lime injection can produce steel having carbon <20ppm, Sulphur <20ppm and hydrogen < 2ppm. For bulk of the other general applications both the processes are suitable options.

Flat products

A Rh or Rh-TOP unit can manage metallurgical tasks like decarburisation, degassing, deoxidation or analysis and temperature adjustment with very high accuracy. For steel grades that do not require any vacuum treatment, but nevertheless have a necessity of high steel cleanliness and excellent castability, a ladle furnace fulfils metallurgical tasks like slag management, desulphurisation and homogenization as well as buffering. For flat steel producers with their main emphasis on the production of low carbon and ultra-low carbon grades, the installation of a Rh or Rh-TOP unit between melting and casting allows the production of extra deep drawing qualities (EDD), improves steel cleanliness and enables the steel producer to optimise the economic mass production of these grades.

Long products

Metallurgical work like adjustment of chemical composition, top slag desulphurisation and deoxidation in case of bulk of the non-flat production is carried out at the ladle furnace at a defined temperature, supported by inert gas bubbling. Further refining steps, as there are degassing and removal of deoxidation products is determined by product specific demands,

Long products with the main emphasis on steel cleanliness, e. g. bearings, springs, forgings, pipes or high alloy structural steels, will require a highly sophisticated refining technology. Ladle furnace and tank degasser (with or without oxygen blowing lance) are significant investments to optimise secondary metallurgical refining techniques for the production of these clean steels.

Stainless steel products

For melting and refining of stainless steel grades, there are many different process routes (DUPLEX, TRIPLEX etc) . The individual choice is influenced by raw material availability, desired final product, existing shop logistics and capital economics. A VOD plant is thus an important part of this line as it enables appropriate process steps for very low carbon, sulphur or nitrogen contents in the final product.

Secondary Treatment Options

The secondary treatment options for steelmaking as discussed above are summarized in Figure 7-8. Refining functions carried out in secondary treatment units shown in Table 7-16 summarises the process capabilities of the different secondary treatment units.

TABLE 7-16 SECONDARY TREATMENT PROCESS CAPABILITIES

	LF	LTS	CHS		Circulation Degassing			
			CASOB	CASOBPB	RhOB	RhPB	Rh Inj	DH
Steel Treatment								
Heating	***		***	***	***	***	***	
Composition Adjustment	***	***	***	***	***	***	***	***
Desulph	***	***	***	***		*	***	
Deox		***		***	***	*	***	**
Decarb					***		***	**
Dehyd					***		***	
Clean Steel	***		***	***	***	*	***	
Buffer Function	***	***						
HM Treatment								
Deslag		***						
Desulph		***						
Desil		***						
Dephos		***						
Homogenisation		***						

CONTINUOUS CASTING

Among the top three most significant and game changing developments in steel technology has been the establishment of continuous casting of liquid steel. Though the concept had been in the offing for considerable length of time, it got real fillip in the late sixties/early seventies.

Background

The two oil shocks (1973 and 1978) brought global focus on energy conservation. This led to the popularization of continuous casting in integrated steel plants propelled by the practices of hot charging. Improvements in the casting practices, mould designs, improved mould powders, efficient cooling systems and practices provided high surface quality and crack-free slabs. These developments encouraged and enlarged the prospect of casting-in line rolling which reduced the energy consumption from casting to product by over 50% in many cases.

Alongside of these developments, the enlargement of the grades that could be continually cast also grew many-fold in the eighties. Improved refining practices, extensive adoption of ladle treatment, Oxide free casting with shielded tundish, heating in tundish, electro-magnetic stirring etc. helped in achieving this.

Concept

In this technology, liquid steel was cast into semi shapes instead of the ingots using copper moulds. The process provided the following advantages:

- Reduction in the process steps of steel processing. The three steps of casting liquid steel into ingots, reheating of ingots and rolling them down to semis (slabs, blooms and billets) were eliminated and a single step for the production of semis became a reality.
- The other major consequence of this was the enormous increase in overall yield from liquid steel to products. An improvement ranging from 8 to 15 % was achievable.
- The energy saving arising out of the reduced processing stages was very large and this alone was adequate to justify the adoption of continuous casting as an automatic choice by the late seventies. The Energy saving could range from 50 to 70 %
- This approach had extraordinary impact on the production cost which helped steel to cement its position further as a material of choice in large applications.
- By its very nature, the process resulted in much improved qualities of steel.
- The steelplant layouts and operations thus became considerably simplified with minimised process steps. This besides reducing the intermediate stage inventories and work-in-process also led to much reduced processing cycle time. This capability enabled the markets to be addressed on a faster track and provided benefits at the user level as well.

Product focus

While the initial development was based on billet casting on a small scale, continuous research, process and equipment improvements, and development of operational expertise led to the application of continuous casting across all the product segments. Thus, casting of billets, blooms, and slabs all became part of the normal steel processing.

Initially continuous casting was adopted in mini-mill EAF shops due to the easier matching with the process cycles. However, in the seventies it found huge interest in BOF shops due to the developments in high-speed casting, sequence casting, improved productivity, easy mould changes, improvements in submerged nozzle lives, reduced machine down times etc.

Near net shape casting

The highly positive impacts of casting semis near to the product dimensions sustained the approach towards near net shape casting as the potential future. By late eighties-early nineties almost all product feeds could be served by near net shape cast semis. These included besides billets, blooms and slabs, new shapes such as beam blanks, midi thick and thin slabs, rounds, etc.

Near net shape casting has become one of the fundamental pillars on which led to the concept of casting and in line rolling without intermediate reheating, a reality in all product areas namely bars and rods, sections as well as hot rolled coils This obviously paved the way for extraordinary energy savings and changed the time concepts of steelplant scheduling.

Sequence casting and Capacity Enhancements

Once the casting technology and stable equipment performance got sustained by the early seventies, the concept of sequence casting took roots. In this approach efforts are made to continue the casting operation as long as feasible. The increase in sequence casting has the following advantages:

- Caster productivity is highly enhanced.
- The yield of cast semis is improved as the end cropping is only required at the last of the sequence.
- Quality improvements due to stable and sustained operations with the introduction of larger tundish volumes.
- The overall steel melt shop productivity also goes up (BOF as well as EAF shops).
- Provides the important starting point for the continuous production of products with casting and in line rolling.

This development made possible significant capacity increase in casters. For example, current day casters can handle 30 heats or even more in a day. Supported by the consistent increase in casting speeds (upto 3 to 3.5 mpm in billets, 2.5 mpm in slabs and 7 to 7.5 mpm in thin slabs) the casters have also been able to match larger heat sizes upto 300 tons and more.

Impact on Plant designs

The modern-day plant designs have enormously benefited from the key role played by continuous casting. This has led to the following major benefits:

- Land area required for integrated steel plants is reduced substantially.
- More compact layouts could be resorted to take advantage of energy savings offered by casting and in line rolling. This has now become par for the course for rolling both flat and non-flat hot rolled products.
- Plant logistics are simpler and faster.
- The requirements of plant utilities also reduced considerably.
- The level of process wastes in steelmaking and casting combine reduced considerably making the operations more environment friendly.

Billet Casting

Billet casting, initially the heart of the mini steel installations (upto 500000 tpy) enabled that section of the industry to address the large commodity market of the rebars. However, the improvements in the casting technology such as shrouded casting, secondary metallurgy, and improved refining practices enabled meeting the demand for higher product qualities in bars and rods as well. The increasing quality requirements from the rebar segments along with high strength rebars have prompted technology improvements in billet casting. The alloy and special steel segments also adopted continuous casting in a large way to benefit from its cost

impacts. Multi-strand casting and appropriate linkage with the downstream rolling units provided the leapfrog required to suit the high productivity BOF shops in integrated steel plants. Thus, the unqualified use of 6 and 8 strand billet casting machines became common place.

The higher casting speeds and sequence casting have improved the casting capabilities to 2.5 to 3.5 mpm and per strand productivity to nearly 40 tons per strand per hour. Thus, managing heat sizes upto 300 tons with 8 strand caster is now a reality.

High-speed casting technology is characterised by:

- Open stream casting equipment, wherever permitted by the quality levels, including Flying Nozzle Tundishes allowing a casting sequence up to 50 heats and more with the same
- Submerged casting equipment, including mould electromagnetic stirrers to maintain casting parameters consistent with reliable and good internal billet quality and a real time quality control tracking system for the production of quality steels
- Efficient and highly controlled Primary and secondary cooling systems to control the billet cooling and the consequent metallurgical properties.
- Well-designed long copper moulds with lengths upto 1,000mm which provide optimized solidification and good surface quality.
- Very large tundishes (more than 20 % of the ladle quantity) which besides buffering minimise the temperature differential between strands and increases the proportion of clean steels in the cast products.
- The billet sizes have been constantly evaluated for providing the required optimization between the mill demands (lowest technically acceptable size for quality and reduction ratios).
- Billet hot charging and inline rolling in high-capacity continuous mills is now an integral feature of steelplants. The facilities and layout as well as the link between the Caster and the mill are designed appropriately to meet this requirement. In line equalising/heating/holding furnaces are also adopted where required by the quality demands, higher input sizes etc.
- Steel grades in billet caster now cover the full range of Low, medium and high carbon steels, rebars of ultrahigh strengths, high strength alloy and special steels, stainless steels, specific qualities such as boron steel etc.

Successful integrated operation with the BOF and high productivity EAF shops now enable casters to handle 8000 to 9000 heats per year (similar to the main steelmaking unit). Plant designs based on a six-strand billet caster productivity of over 200 tph are now a reality. Here, the ability of most the mini-mill rolling installations to accept larger input sizes (150 mm to 200 mm) driven by quality and product mix as well as productivity demands, has played a very significant role.

Bloom Casters

While the mini mill industry was a source of impetus for billet caster popularity, the blooms segments were driven by the alloy and special steel industry and the forging segments. The initial reactions of use of continually cast semis for use in alloy and special steels were quite highly conservative particularly related to the reduction ratios, segregation, internal quality etc. The adjustments required in steelmaking (particularly increased tapping temperatures) were also slow in coming.

With sustained efforts at improved equipment, operational practices and user support the use of continuous cast semis reached near full acceptance for most of the applications by the eighties. Thus, the efforts to cast bigger sizes got considerable attention. In line heating also provided flexibility in enabling larger size inputs across applications.

Initially these were blooms both for rolling bars and rods as well as for the sections. Over time the possibility of casting rounds became a reality providing the seamless steel tube mills a source of high-quality inputs at economic costs. The mould designs, cooling systems, withdrawal systems, handling facilities, automation have all contributed to enable casting of rounds as well. A record breaking 1000 mm size, comparable in size to the traditional ingots, is now being continuously cast.

Similarly, the section mills are now served with limitless feed sizes from casting machines. The use of rectangular blooms with thicknesses upto 600 mm are now a reality.

Billet/bloom casting and hot charging

The maturing of casting technology and reliable equipment performance prompted the adoption of hot charging for the production of bars and rods. The potential energy savings and the improvements in yield and productivity were very attractive and justified the additional equipment, operating practices as well as operational discipline.

The productivity of the existing reheating furnaces went up significantly with hot charging temperatures reaching even upto 600 deg C.

In newer installations, it is possible to conceive an in-line heating facility with a compact layout avoiding multiple transfers as well. The increased billet requirements of the high-capacity bar and rod mills (reaching over 250 tph) have been adequately met by the billet/bloom casters. The chief areas which have ensured this matching are:

- High speed casting and strand productivity.
- Multi-strand casters (up to 8 strands in billet) using very large tundishes provided enough capacity to match the mill demands. The caster productivity has now reached near 30 to 40 tons per strand depending upon the size and grades.
- Larger product campaigns in the mills help in scheduling the caster for adequate campaigns with benefits of long sequence casting.
- With the mills being designed for high productivity using larger input sizes (150 to 220 mm) the caster operations are more stable and also quality capable.

Beam Blank Casting

A major offshoot of bloom casting was the development of near net shape cast semis for section rolling particularly beams. Heavy sections were primarily produced by integrated steel mills in the 1980s using rolled blooms. With the introduction of beam-blank casting, the technology became available to allow heavy sections production to be incorporated into the minimill concept.

The initial beam blanks had a relatively thicker flange, the near net shape blanks have a flange thickness much less than 100 mm, usually with a lower limit of 50 mm in practice. Near-net shapes to enable Jumbo beams production 1200 mm deep and more are now in wide use.

The economic advantages of the beam blank casting can be largely attributed to both the primary rolling as well as the rolling the section mill. Direct casting of small size blanks significantly reduces the number of passes. Usually starting from a standard bloom nearly 15-16 passes are required for conversion to the product whereas the same is reduced to 5-6 passes with net-shape casting. Rolling technologies particularly the universal rolling has enabled production of wide sizes of beams through rolling with only one beam blank in many instances.

Due to the above, the overall yield of beams improves by 12 to 20% as compared to the conventional practices. There is also the energy saving due to the reduced stages of operation. Even greater savings in costs are experienced in the section mill particularly at the roughing stage such as:

- Reduced investment in roughing mill (Power, Mill size, auxiliaries) may be even upto 30% lower
- Increased mill productivity (10 to 20%)
- Energy savings due to fewer rolling passes at the roughing stand
- Improvement of yield at the roughing mill 1%- 1.5%
- Elimination of intermediate storage for blooms and related costs

Combi Casters

The increasing dependence of many steel mills on single caster operations and need for flexibility has driven development of the combi-casters. These casters are designed to produce billets/blooms/rounds and near-net shapes, as required. The combi-caster can cover a variety of sizes, and shapes of semis.

Slab casting

The slab casting developments have kept pace with the increasing demands of the flat products. Improvements in machine design, high quality steel refining practices and stage-wise automation and controls for integrated operations have made the slab caster as the automatic choice.

As a result of development of technology that allows stable and high-speed casting, maximum casting speeds of 2.7 m/min is realizable for casting low-carbon steels and 2.4 m/min for ultra-low-carbon steels. The choices of slab thicknesses have also highly enlarged to enable selection appropriate to specific requirements such as the overall production level, hot strip mill optimization, plate mill demands, special quality dictates etc.

The large units are considerably standardized in terms of slab thickness (which enable stable and undisturbed continuous casting machine operations and sequence casting). However, quick size changes are now common with the resultant flexibility. In terms of capability slabs are now cast for specific application even at 400 mm thicknesses.

Automatic width adjustments have enabled better hot strip mill scheduling and overall plant operations. The width ranges of slabs cast have also grown substantially to suit the wide plate mill demands. Slab widths of more than 3 m are now a reality.

Owing to the combined effect of new casting technologies, superior machine designs, and better and cleaner steels, the level of intermediate conditioning is reduced to less than 10 % even in high-quality demands for producing steel sheets. The key advantages of this aspect include improved yield, better plant scheduling and reduction in the inventories of slabs. The other major spin-off of this, is the high level of energy-saving, which can be achieved by direct charging of hot slabs. The savings can be as high as 50 % of the normal consumption.

The slab caster productivity is slated to produce even up to about 3Mt/yr on a single casting machine, covering a wide range of steel grades including low, medium and high carbon, IF, high strength low alloyed, peritectic, Multi phase, silicon, pipeline and AP grades etc. Heat sizes of upto 400 tons are readily supported by the configurations available.

Hot charging for rolling

The successful adoption of this practice has led to better integration of operations between steelmaking and rolling, and overall energy optimisation. In older plants the slabs are often transferred hot either through insulated carriers or through roller tables which are covered with insulation hoods. In the newer plants it is possible to design the layout for direct-feed from the caster to the furnace in the NF Mills/hot strip mill through the shortest movements.

CASTING AND IN-LINE ROLLING

A key factor for energy conservation is the integration of discontinuous process flows. Over the last two decades great advances have taken place in this direction. The major outcome of this approach is the revolutionary Endless Casting and in Line rolling without losing the available heat in the cast section (termed as ECR) which is now largely feasible for both the non-flat as well as flat rolled hot-rolled products.

The chief advantages of this technology over the conventional billet/slab production and rolling are:

- Much Higher energy efficiency. Against an estimated energy consumption for reheating of about 1.2 GJ/t for cold semis, 0.8 GJ/t for hot charging at about 600°C, the

ECR can enable hot charge the rolling mill at a temperature in excess of ~850-950°C, leading to energy savings of up to 1GJ/t (over 80%).

- Substantially reduced equipment and facilities as process integration is the key. The biggest enabler for this concept has been the development of high-speed continuous casting, which can keep pace with the production capability of the large capacity and fast rolling mills.
- Both the above aspects led to much reduced space requirements
- Much lower Capex as a consequence of the above.
- Reduced Opex due to energy savings, improved yield and higher productivity.
- Large and extremely fast production cycles
- Avoiding intermediate inventories of semis.

The concept has now been adopted for both the Non flat as well as flat production. The individual requirements nuances and scale have also got tailored to the specific requirements. These are indicated in detail in the following paragraphs.

ECR FOR NF PRODUCTS

The major attributes which enable the success of this concept for non-flat semis (billets/blooms/near net shapes) are:

- Fast continuous casters (Multi-Strand with minimum strands)
- Compact layout and fast transfer to rolling mill with insulated covers
- Use of induction heater to provide fast heating with no emissions (Refer table)
- Billet welder to provide scope for complete endless rolling.
- Improved product quality with fine grains. Scope for reducing micro-alloy additions.

Emission	Value (g/t)	
	Conventional Reheating	Induction
NO _x	7-12	none
SO _x	7-12	none
CO	5-10	none

Bar and Rod Rolling

The bar and rod rolling technologies have also made substantial progress to match the ultra-high demands for unit capacities, energy optimisation and product diversity.

Sustaining Technologies

Technological developments in the bar and rod manufacture have covered all areas such as mill capacities, flexible and a number of plant configurations, operational flexibility, product

improvements, productivity, equipment designs and capabilities, energy efficiency, environmental friendliness: These are briefly outlined in the following paragraphs.

Capacity Improvements

The normal mill capacities today range from 500000 tpy to over 1.2 MTPY as compared to the average capacities of 250000 to 600000 tpy a few decades ago. This has come about as a consequence of integrated capacity planning covering steelmaking casting and rolling, stable multi strand mills, continuous mill configurations, sequence casting and in line hot charging for rolling.

Flexible Plant Configurations

The mill configurations and products have become quite flexible with amenability to tailor to specific demands. Thus, Rebar mills, Bar and light section mills, Wire rod mills, combination bar and rod mills can be configured to meet the capacity as well as product ranges as required.

Product Quality

While the major contribution to the improvement in the quality of bar products has come from the improvements in steel making and continuous casting technologies, the rolling mills have provided commensurate processing ability. The main technologies that have enabled this are:

- In-line Water quenching for rebars is now well established and adopted in all rebar mills providing the capability to produce high strength rebars.
- A related development is the ‘cold skin’ rolling (for the production of rebars), which involves intensive cooling of the wire rod surface before the last rolling passes to produce a very fine surface microstructure and enhanced final mechanical properties.
- Thermo-mechanical treatments, particularly in the wire rod mills during coil cooling and collection. Precise treatment cycles and controls aided by high level of automation has enabled product range and quality to be enhanced.
- Extensive use of thermo-mechanical treatments and rolling including on-line patenting enabling most installations to roll wide range of steel grades. These include low medium and high carbon steels, HSLA steels, Alloy and special steels for automotive and engineering applications, Stainless steels.

Productivity

The key elements that have enabled high productivity are:

- The push for sequence casting and in line hot charging helps improved productivity, yields, and operational efficiency.
- Ability to accept larger input billets. Mills now can be designed to use 200/250 mm sq billets even for small sized products.
- Establishment of continuous rolling as a new normal even in smaller capacity mills.

- Very large product range - from single installations, which can range from 5 mm to over 40 mm including coil weights going upto 3 tons and above
- Larger product campaigns have now become possible with rationalized pass schedules and roll profiles and minimal changes in settings. The modular design permits the use of compact stand cassettes in all configurations, Horizontal, vertical, and universal.
- Modular stands and automated roll changing have reduced the outages on this account substantially. Multiple-drive concepts, use of robot for fast changes are also now possible.

Impact of sizing blocks

The near universal use of sizing blocks in present day mills is inspired by the original Kocks block as well as the high-quality products from the finishing blocks in wire rod mills. The key benefits are:

- Scope for reducing size changing times through rationalised and integrated roll-pass design.
- Consistent quality
- Excellent dimensional tolerances

Pre-finishing block (PFB)

The introduction of pre-finishing blocks and sizing blocks has provided cutting-edge finishing-rolling technology for producing high-quality wire rod and small bars at ultra-high speed. Speed records of over 125 m/min on 5.5mm rounds have been reported. Cold skin rolling also has been possible due to the additional of blocks.

High-speed Compact Sizing Block (CSB)

The CSB was created to improve dimensional tolerances and finished product quality, and increase rolling speed from 110 to 130m/s,

A significant development in the high-speed wire rod process is the use Twin- Module-Block to achieve ultra-high finishing speeds for wire rods. An interesting adaptation of the rolling and sizing blocks concept introduced by Danieli centers around Two Pre-Finishing 2-stand Wire rod Blocks (WRB), One 8-stand WRB acting as pre-finishing mill and One 4-stand high-speed finishing sizing block.

The production range from the mills includes 5.5-25mm rounds, 6-12mm rebar, 19-51mm bar-in-coil rounds and 16-51mm hexagons, all weighing up 2,700kg (even 3000 kg) and round bars. Steel grades include cold heading quality, low, medium and high carbon, spring steel, bearing steel, micro-alloyed grades and free-cutting grades. Maximum speeds are 115m/s on the wire rod line and 13.5m/s on bar-in-coil line.

Thermo-mechanical Treatments

Increased use of thermo-mechanical treatments and improved equipment designs and precise controls through automation have enabled temperature trimming to suit the grade

groups and quality. This provides opportunity for energy optimization as well. The downstream processing for high quality products also benefits from the tailor-made attributes (strength, grain size, microstructure, precise chemistry, large size of coils).

Environmental impact

Reduction in the energy use reduces the environmental impact as well. Low Nox burners are now a normal feature. The level of scale generation is lower due to the lower heating requirements (as low as 0.5%). Induction heating has brought along with it very low emissions and much higher efficiency.

Endless Bar rolling

Endless bar rolling is made possible by the billet-welding line installed at the exit side of reheating furnaces. By automatic continuous on-line head-to-tail flash-welding of billets, this process enables uninterrupted rolling in the mill, resulting in higher material yield, higher production capacity, better production planning, and lower production costs. Product Yield has increased upto nearly 99.5%.

Endless rolling enables coil weights to be freed from the limitations of individual billet weights. Thus, heavy and extra heavy coils can be produced using low weight starting billets.

Spooler Concept

A significant development towards optimization of the production chain of bars (including the downstream users) is the Spooling process. This technological innovation has introduced a major change in bar-in coil production by avoiding off-line uncoiling, stretching and re-coiling operations. It provides significant benefits for both hot rolled coil producers and for the downstream coil users.

The spooling process consists of twist-free coil formation by regular distribution of the hot rolled and on-line control-cooled bar for producing a highly compact and regularly shaped coil. The coil fill factor improves to nearly 0.7 against 0.3 of Garret coilers and near 0.1 for wire rod coils).

This development coupled with Endless Rolling provides a unique combination of benefits with customised coil sizes featuring cobble-free uncoiling.

The advantages for the producer are:

- Improved mill productivity with High finishing speed (35m/s) and freed from coil weight limitations.
- Considerably Higher material yield
- Improved mill utilization

Slit rolling

The slitting technology as applied to continuous bar mills enables the production of two or more strands from one billet. Slit rolling has been in place for quite some decades. But it got considerable boost due to the developments in guides and practices to suit high speed rolling

and the efforts towards enlarging product range with reduced equipment (no of stands in rolling mill). Slit rolling has enabled production of small sized bars (upto 5 mm) in high-speed mills.

The process gives the following benefits:

- Enlarged product range
- Reduction in the number of rolling stands
- Substantial increase in production rates

The rolling process for slit rolling uses special roll passes and guides to prepare, shape and longitudinally separate the incoming billet into two or more individual strands (4 and more) for further rolling into the finished size.

Wire rod Mill in Perspective

One of the most significant aspects of current day options for rolling bars and rods is the high level of flexibility in mill configurations. The concept of having exclusive wire rod mills with maximum product size restricted to 12.5 mm has now become a thing of the past. There is a meeting of Bar mills and wire rods into one composite catering to the conventional two specific product segments. The product ranges can now go upto 50 mm and more, coil sizes upto 3 tons and above and mill features enveloping the entire product range. These features enable single mill installations with range of capacities upto 1.2 MTPY.

For example, a bar mill in Japan produces straight bars of 18–120 mm in diameter and bars in coil of 18–52 mm in diameter from a single installation. .

Automation and process control

This has been at the core of many improvements towards higher mill speeds, productivity, quality, planning etc Functions covered include Material tracking, automatic labelling, consumption accounting, in-line non-contact inspection and quality monitoring, and condition monitoring of equipment

On line measurements, temperature controls etc have enabled Optimisation to the minimum tolerance, Reduction of cobbles, improved guide life.

Section Production Leapfrog

The introduction of near net shape casting particularly the beam-blank casting provided great fillip to section rolling. The use of Continuous mills for smaller and midsized sections and universal rolling in case of large sections including rails has introduced a wider scale and plant capacities, productivity and quality of products.

State-of-the-Art Section Rolling Mills

The heavy section mill capacities can go upto 1.2 million tonnes per year with a wide range of sections (beams, rails and sheet piling sections). Mill configurations can now include a breakdown stand, tandem reversing group instead of the usual mill stand arrangement, a universal roughing/edging stand and a separate universal finishing stand. The mills can be operated both with universal and 2-high roll sets with quick product changing facilities.

The near-net-shape beam blanks are getting constantly better with a web thickness of as little as 50 mm against the 120 mm of the conventional dogbones.

Thermal treatment of rolled products

Efforts at Thermo-mechanical rolling are still in the making on a scale. The online cooling section allows various heat treatments to be performed. Improved straightness during cooling, especially in the case of asymmetric sections, facilitates handling on the cooling bed and admission into the straightener. Residual internal stresses significantly reduce the amount of a beam's admissible stressing.

Modern Rail Production

Current processes commonly used for the production of rails include rolling on 2-high reversing stands or 3-high stands and universal rolling. Tandem reversing mill and universal rolling are now preferred. The increasing use of high strength rails (using high alloy steels) and extra-long rails (over 250 m long) have also demanded corresponding adjustments/ technologies in the casting and rolling practices and facility layouts and logistics.

Beam Blank Casting and in line rolling

A major leap forward in section production to enable improved productivity, cost savings and shorter production cycle is the casting and in line rolling of beams and sections along the lines of the thin slab casting and in line rolling. Direct linking of continuous caster and rolling mill enables this solution.

ECR FOR FLAT PRODUCTS

Thin Slab Casting and In line Rolling (TSIR)

A revolutionary step forward in the area of near net shape casting was the development of thin slab casting and in line rolling in 1989 (over 30 years ago) as an effective alternative to the conventional slab casting and rolling. The casting and in line rolling processes are integrated real time. The principal objectives of development namely reduction in energy consumption, space reduction, faster processing and reduced inventory have been more than met.

The chief advantages of this technology over the conventional slab production and rolling in hot strip mills are:

- High energy efficiency
- Substantially reduced equipment and facilities
- Much reduced space requirements
- Much lower Capex
- Tailoring capacity to specific requirements
- Extremely fast production cycles
- Avoiding intermediate slab inventories

Some of the key metallurgical aspects of this technology include:

- Rapid solidification of thin slab compared to conventional products
- Improved dendritic structure and help to more homogenous structure
- Improved isotropic properties during rolling
- Prevents early precipitation of dissolved elements added micro alloys) due to high temperature before rolling.
- High temperature of slab prevents the formation of transverse cracks during bending.
- Direct transfer of slab to rolling mill is the key factor in reducing energy consumption.

Development Road Map

The implementation of TSCR concept did not achieve any success till mid-eighties due to numerous technological challenges associated with the technology namely high speed casting, limitations in product quality and scale of production. The first breakthrough in this direction was achieved in October 1985 by SMS Schloemag-Siemag when the first thin slab of 50 mm thickness was cast in a pilot plant in Kreuztal-Buschhütten. This success was achieved with a patented funnel shaped 7 mould and an optimized submerged entry nozzle. SMS Schloemag-Siemag gave this technology the name of “Compact Strip Production (CSP)”. The first CSP plant was ordered in late 1987 and was commissioned at Nucor Steel, Crawfordsville, Indiana in July 1989. The length of this plant was 260 m the basis of so-called Compact Strip Production. Almost at the same time, the In-line Strip Production (ISP) was under intensive development by Mannesmann Demag and Arvedi group. Development of ISP started in 1988 based on an Arvedi-Mannesmann patent. In 1992, the prototype ISP plant was built by Arvedi at its Cremona works, with most development carried with the plant. In 1994-95 the prototype plant completed the first phase of its development. Later based on the ISP technology, Acciaieria Arvedi has developed a new thin slab casting/continuous rolling process under the brand name Arvedi ESP. Voest Alpine (VAI) of Austria (Now Primetals) and Danieli of Italy have also developed thin slab casting and rolling technologies.

There were other initiatives as well by Sumitomo, Armco, Tappin etc which were in the mid-thick range a-la Arvedi.

With the successful establishment of the technology and its linkage with the primary steelmaking units, the emphasis on scale took center stage. The development of multi strand casting and coordinating with the hot strip mill was achieved through innovative solutions such as the moving ferries. Today three single strand casters to support single strand rolling operation is a reality. This resulted in the scale going up to the present over 3 to 4.5 MTPY

Outline of the Options

CSP (SMS-Group)

CSP was a pioneering development by SMS Siemag who in cooperation with Nucor of USA installed the first thin slab casting in line rolling at Crawfordsville Indiana, USA on a

commercial scale. The features and the highlights of this technology as available today are outlined below.

In this system, a Tunnel Furnace is used to maintain the homogeneous temperature in the slab before rolling. The hot thin slab then enters the finishing mills and is rolled into hot strip as per required thickness. The hot strip after rolling enters the run-out table where it undergoes cooling to the coiling temperature. The CSP process has matured over the last two decades and presently most of the steel grades including low, medium & high carbon, HSLA line pipe grades and steel grades for automotive application including IF grades, AHSS grades, and electrical steels are produced using this technology. A very significant achievement has been the production of Silicon steels (CRNO) in these lines in selected installations.

SMS Group has modified its traditional approach and extended the conventional CSP concept with introduction of liquid core reduction in the area between the caster exit and the pendulum shear in front of the roller hearth furnace. Up to 100 to 120mm thick slabs can be reduced to 40 to 60 mm thickness. The roller hearth furnace is retained to provide the flexibility in rolling practice; this is supplemented by an induction heating section required for rolling the ultra-thin sizes. This process thus provides capability for efficient limited endless rolling for the production of ultra-thin strips. Adding a flying shear and the second coiler allows endless rolling of strip thickness below 1 mm. The arrangement enables the operation in batch mode as well as in semi-endless and endless modes.

Casting higher thicknesses has necessitated their resorting to Vertical Liquid Bending in the caster which enables Liquid core reduction (LCR) in reduction stands to sizes suitable for feeding the hot strip mill. The CR stand/s enables slab thickness reduction without any loss in productivity.

CSP FLEX(SMSGroup)

The concept called CSP Flex, where the casting thicknesses and the mill configurations have been adapted to meet the above requirements. Vertical Liquid Bending (VLB) and introduction in-line induction heating as an addition to Tunnel furnace are key features of this development. The claims for the flexible options are:

- A production capacity up to 4 million t/year in two-strand operation mainly made possible by increasing the casting slab thickness with appropriate casting machine and LCR technology.
- Product range covering IF steels, DP grades, AHSS grades, medium- and high-carbon steels, HSLA and API pipe grades, stainless steels, as well as high silicon electrical steel grades.
- Capability to produce pipe grades (e.g. API X70) up to 20 mm thickness driven by appropriate caster design, mill design and provision for in line induction heating.
- A flexible hybrid plant concept for semi-endless and batch operations for ultra-thin strip, and batch operations for other products.

- Optimization of energy consumption due to the improved process and components

DANIELLI APPROACH

Danielli offers three variants of the Thin Slab Casting and Rolling concepts namely: QSP (Quality Strip Production), FTSR (flexible Thin Slab Rolling) and ETR (Extra Thin Rolling). The plant capacities can range from 1.5 MTPA per strand to 2.2 MTPA. Currently, they claim that one of the installations under implementation may have a capacity of 2.7 MTPA with a single strand. Danielli also claims to be able to ramp this up to even 3 MTPA per strand.

QSP Concept

The use of 100mm slabs with eight rolling stands can be installed. (2RM + 6FM) to produce a complete range of products including light gauge strip down to a thickness of 0.95mm in batch rolling mode. The QSP process consists of:

- Thin slab casting in a vertical curved caster
- Heating the slab through a tunnel furnace, linking the caster to the mill
- Roughing mill comprising a high-pressure descender, top driven vertical edger, and one or two roughing stands
- Finishing mill comprising five or six 4-high finishing stands

The Danielli concept has also matured well and has the capabilities similar to the CSP as far as product mix, grades that can be produced, markets addressed, minimum thickness and ultra-thin HRC are concerned. A very significant achievement has been the production of Silicon steels (CRNO) in these lines in selected installations.

Flexible thin slab rolling (FTSR)

A more compact version of QSP, is the FTSR configuration aimed at reduced investment cost and production capability. Nominal slab thickness is usually 70mm (with the possibility of reaching 85mm). The plant is shorter than the QSP, as it has the RM and FM coupled to work in tandem. The product mix can be considered in the medium-high quality range and can cover most market requirements, including soft API grades. The absence of two-step rolling only creates a limitation in special grades requiring a true thermo-mechanical process, such as pipeline grades like API X70-X80 for arctic applications.

Extra Thin Rolling (ETR)

This extremely compact configuration makes the plant suitable for a fully endless rolling process to produce thin and ultra-thin gauges down to 0.8mm. The mandrel box represents the core of the process, making it possible to disconnect the roughing from the finishing phase, thus it is possible to obtain standard finishing mill speeds of conventional hot strip mill finishing units, with benefits in terms of process temperatures and surface quality. The mandrel box can be used as a buffer in case of delays in the finishing mill.

Endless rolling (DUE)

In DUE (Danieli Universal Endless) mode, caster, roughers and finishers are directly linked and the mandrel box is bypassed. An induction heater has been added which enables thin as well as ultra-thin rolling. With a slab thickness of 80mm and a high casting speed of ~7m/min, production can exceed 2Mt/yr of hot rolled coils. The DUE® line is very compact requiring an overall footprint of approx. 290 m x 90 m from TSC turret centerline to second down coiler axis.

ARVEDI-PRIMETAL APPROACH

ISP (In-line Strip Production)

The In-line Strip Production (ISP, developed by MDH) process was developed at Arvedi, Italy along with Mannesman Demag since 1992. The ISP in its present form is an extension and further development of the concept of midi thick casting and in line rolling. The key differentiator in this case is the adoption of liquid core reduction from the beginning. This has enabled higher slab thicknesses to be considered with the consequent advantages. This process adopted coil to coil rolling technology.

This development was focused on the adoption of casting thickness to suit the exacting demands which could not be addressed due to the very thin slab size used in CSP. The higher slab thicknesses have consequent advantages such as better cast product, product quality with requisite metallurgical properties due to the possible higher reduction ratios and better surface quality.

ESP Arvedi

A further development by Arvedi in contract with Siemens-VAI as principal process and plant supplier in 2006 is the endless rolling concept. The current approach is based on in-line induction heating of the reduced bar from Heavy reduction mill and rolling in line, enabling the reduction of the overall length of the installation by almost 200m to 250m. The provision of the induction heater also enables the ultra-thin HRC production without having to take recourse to any additional heating.

This configuration has the focus on extra-thin rolling upto 0.8 mm and lower. Developed by Acciairia Arvedi and designed and manufactured by Primetals, it has revolutionised the extra-thin sheet space with the overall mill requirement of 180m.

ESP-ISP Combine

ESP/ISP Combi-plant ESP enables production of a wide range of steel grades, from carbon grades to special-steel grades in thicknesses ranging from 0.8 to 12.7 mm and from minimum to maximum width at full productivity. The main reason for investment in ESP is the capability of producing high volumes of ultra-thin and wide strips. The Cremona furnace is bypassed in order to operate the ISP/ESP Combi Plant in the ESP mode.

LAYOUT AND CONFIGURATIONS

The various configurations and their layouts are shown in the following Figures.7-15 to 7-20. Typical Layouts of Various TS rolling Options

Fig 7-15 Thin slab technology with Compact Strip Production (CSP) Conventional (SMS)

Fig 7-16 Thin Slab Production with CSP® flex concept (SMS)

Fig 7-17 QSP Technology (Danieli)

Fig 7- 18 QSP DUE (Danieli)

Fig 7- 19 IN-LINE STRIP PRODUCTION (ISP) (Arvedi)

Fig 7- 20 ESP ARVEDI (Arvedi-Primetal),

STEEL PRODUCT UPGRADES

The introduction of thin slab casting with cast thickness of 50 to 60 mm was essentially directed at commodity segments initially. However, the numerous potential advantages including costs widened this approach to cover a larger range of steels.

The various epoch-making developments in the thin slab casting technologies, thermo-mechanical processing of steel in line coupled with appropriate steelmaking modifications have enabled steel products to achieve unheard of competence levels, whether it be UTS, Ductility or Formability etc. The supporting steelmaking developments have made the process achievements even more significant considering the extraordinary benefits that are endowed with a view to provide the applications with the most optimal products.

The demanding requirements of the automotive applications, (high and ultrahigh strength steels, extraordinary surface quality) have led to the IF steels, Multi phase steels, Peritectic steels etc. Silicon steels, API grades at high thicknesses and strengths etc. with controlled metallurgical properties.

High-strength steel sheets (high strength sheets for automotive use, high-burring workability sheets, Tinplate free of non-metallic inclusions, interstitial-free (IF) steels. bake-hardening (BH) high-strength rails, high-performance electrical sheets are some of the striking examples. Similarly new steels directed to specific uses have become necessary such as cryogenic steels, steels resistant to hydrogen-induced cracks (HIC), high-workability steel sheets corrosion-resistant sheets, high-yield-point plates for shipbuilding), high-purity steels for bars and wire-rods (for auto components, tyre-cords, bearings etc. AHSS steels are now gaining popularity due to the further advantages that they bring in automotive lightweighting and product optimization. The developments which have enabled this progression can be seen from Figure 7-21

CURRENT STATUS OF TSIR

The developments in process technology, equipment, plant design, integrated operations and consequent improvements have covered production capacity, uniform product properties

and a wide range of different steel grades. High energy efficiency along with optimisation of operating costs and high plant availability,

The original discrimination brought about by the different approach to cast thicknesses by the different developers has now nearly vanished. The diversity and range in cast slab thickness as a vital factor for the quality requirements is well appreciated and this is now a common feature. Similarly certain essentials of thermo-mechanical rolling (covering High level pipe grades, AHSS, Ultra-thin strip etc) are now par for course in all solutions. These include the VSB (Vertical Solid Bending) as well as VLB-(Vertical Liquid Bending) casters, in line core reduction, introduction induction heating at the finishing mill entry side, additional crop shear etc.

In terms of rolling practice, the provision of the features enables the plant to be operated on a batch, semi endless as well as end-less modes. This flexibility will enable much easier plant scheduling to suit the specific product ranges and customer demands. For capacities upto 4 MTPY, this may become an automatic choice, with the conventional HSM being necessary for capacities beyond this level upto 6 MTPY. The EAF-TSIR combination has placed the mini steel plants also in a position to effectively compete with the ISP's.

Energy Optimisation

The flexibility due to electric induction heating or a combination of tunnel furnace with induction heating improves energy optimization further. The temperature adjustments to suit the operation modes grades and dimensions is the key. This can lead to considerable savings in energy.

Product range

Configurations can now address product ranges from 0.8 mm to 25 mm and even higher if required. Steel grades practically the entire gamut of applications covering IF steels, Peritectic steels, TRIP steels, DP grades and Multi-phase steels, AHSS grades, API pipe grades, stainless steels, as well as high-silicon electrical steel grades can now be part of the product mix.

Impact on Plant Design

The wide range of improvements that have come about in the last two decades have placed the thin slab casting and in line rolling technology as the key solution for economic hot strip production. The adoption of these technologies in new installations provides the opportunity to reach extraordinary levels of optimization in plant design covering the following aspects:

- Highly compact steelmaking and rolling combine demanding less than 50 % of the space required in conventional approaches.
- Capability to address diverse product mix ranging from ultra-thin hot strip to super thick strip (0.8 to 25mm)
- Much reduced utilities requirements due to reduced number of operating units providing easier plant design as well as saving costs and space.

- Flexibility to choose plant capacities ranging from 1.2 million tons per annum to over 4 MTPY.
- Hot rolled strip replacing the cold rolled feed in many applications. Including galvanized strip leading to lower cost of production.

Sustaining Technologies

At the core of present-day thin slab casting and in line rolling with wide ranging capabilities are the following important technologies:

- Machine design and features and configurations to enable a range of slab thicknesses, and in line core reduction.
- High casting speeds to ensure the requisite mass flow conditions demanded by higher productivity and the thin gauge production demands in hot strip mill. Thus, design speeds upto 8 mpm are now feasible.
- Ability to increase the casting thickness toward what can be called midi-thick, (90-100 mm or even 125 mm) to address quality demands effectively along with the in-line thermos-mechanical treatment support. Dynamic soft reduction known as CR (Core Reduction) both solid and liquid core has now been perfected also provides an efficient tool to balance Caster productivity, Steel quality demands, Mill optimization and product demands.
- Wide-ranging thermo-mechanical treatments appropriate to the steel segments are now realizable with flexible heating and rolling and cooling practices. This has enabled the requirements of tailoring internal quality of strip (phase stipulations, microstructure) mechanical properties, wide thickness range of products 0.8 to 25 mm) to allow production of a wide range of steels and sizes.
- Induction heating of strip on-line provides very low emissions, energy optimization and much finer control being a key to successful grade and size diversity.

Flexible plant design

TSIR developments such as Flexible Casting Slab thicknesses, reliable sequence casting with very long campaigns, induction heating in-line and robustness in plant facilities and equipment design have enabled a flexible plant design which addresses the following objectives very well.

- Optimising investments in the TSIR facilities and seamless stage-wise capacity developments,
- Addressing diversity of the market as well as optimal scheduling
- Flexible operation modes with a combination of the following:
- Coil to coil rolling, Semi endless rolling, and Endless rolling

ENDLESS CASTING & ROLLING

A logical fallout of the Casting and in-line rolling production chain is the development of sustainable endless rolling. With improvements in the casting machine designs, logistics and quality of refractories and coordinated operations of the entire production chain, sequence casting has extended to extraordinarily long campaigns both in the conventional as well as thin slab installations.

The limitations of the campaign duration are introduced by the market driven scheduling requirements, caster availability, roll changes in the mill, need to avoid excess inventories etc. Besides these the diverse product grades and sizes will also require fine tuning the operating practices and parameters to suit each segment. This can lead to differential production rates which may be difficult to balance with the caster scheduling.

The concept of endless rolling as a basis of plant design of a TSCR facility has been introduced as ESP by Primetals. The major thrust in this case is the predominance of thin and ultrathin hot strip (0.8 mm and lower) in the product mix of HRC. The extraordinary benefits of this successful development are:

- Ability to produce ultra-thin hot strip in the most efficient manner.
- Highly compact plant (180-m-long) with reduced investments for land, buildings, piping, cabling and construction volumes.
- Compactness leads to reduced strip-temperature losses.
- With endless production, an average yield of more than 98% is achieved from liquid steel to the coiled product.

Endless rolling implications

The main benefit of endless strip production is the scope for better plant productivity, consistent quality, and yield. The continuous operation provides the possibility to maintain uniform process conditions through stable operating conditions and the accordingly constant levels of product quality over the entire length of the strip. The adoption of endless rolling option as a total plant concept with consequent benefits would also be accompanied by the following demands:

- Higher casting speeds is essential in order to ensure requisite mass flow in the total plant in case of predominance of the thin and ultra-thin gauges in the product mix.
- Very high availability and consistent operation at high casting speeds are required for meeting the demands of ultra-thin sizes of strip.
- Reduced plant flexibility as the work-roll changes in the mill cannot be performed as a background task, with sole provision of induction heating.
- Scheduling in plants with diverse hot strip ranging from thin and ultra-thin to the highest thicknesses (0.8 mm to 25 mm) would be a major challenge.

CAPACITY LEVELS

Establishment of the TSIR on a good technological and economic platform has opened up the possibility of installing optimum plant units for Hot strip as required. Capacity range of 1 MTPY to 4.5 or even 5 MTPY with diverse product range is now realistically feasible. Capacity-optimization with minimum number of units is also feasible as the Casters can now reach productivity of nearly 2.5 MTPY per strand with well-honed sequence casting practices and scheduling.

Approaches to TSIR

TSIR initiatives which have matured and come to stay are as follows:

- CSP-CSP-flex: Thin-slab casting and in-line rolling (SMS Group, Germany)
- QSP & Variants: Thin/Midi-Thick slab casting -- in-line rolling (Danieli, Italy)
- ISP: Midi-thick casting & in-line rolling (Arvedi Primetals, Europe and Japan).

An overall comparison of the three approaches is summarised in Table 7- 17.

TABLE 7- 17 TSIR OPTIONS FEATURES

Sl No	Parameters	DUE (Danieli)	ESP (Primetals)	CSP (SMS Group)
1	Casting Thickness	Higher slab thickness an advantage for higher quality grades.	Higher cast slab thickness provides scope for higher quality	Standard configuration focus on fit for purpose thickness CSP Flex with larger slab thickness for higher grades
2	Rolling modes	Flexible coil to coil, semi endless and endless as required.	Design focused on endless rolling and thin and Ultra-thin gauges.	Flexibility to operate in coil to coil, and semi endless modes as required.
		Adoption of endless rolling with the addition of induction heater		Semi endless concept-flexible for scheduling. Endless rolling with additional induction heater
3	Endless rolling benefits	In line induction heating required	In line induction heating enables better control for thermo-mechanical rolling	In line induction heating required
			Oriented to thin and ultrathin rolling largely.	
			Elimination of Tunnel furnace may offer Capex savings	

4	Tunnel Furnace Benefits	Provides buffer for maintaining coordinated production.	Induction heating more environment friendly	Provides buffer for maintaining coordinated production flow.
		Provides uniformity of temperature,		Provides uniformity of temperature,
5	Operating Scheduling	Modes Changeover can be seamless	Change over in modes a challenge. May demand higher capex.	Changeover to different modes can be seamless
6	Additional Strand add-on	Feasible if planned	Not feasible	Feasible if planned
7	Tunnel Furnace implications	Space for tunnel furnace required.	Smaller area demanded by induction heating	Space for tunnel furnace required.
		Additional Capex of building, EOT crane, Utilities etc.	Large power demand and higher cost	Additional Capex of building, EOT crane, Utilities etc.
		Additional induction heater for ultrathin required.		Additional induction heater for ultrathin required.
	Caster range			VLB and LCR required for midi thick for higher quality/capacity demand.
	Operating Practice		Endless process economical in the thin and ultra-thin gauges.	
			Provisions made for endless rolling remain underutilized in case thicker products are higher in product mix.	
		Casting rates to be suited to ensure uniform mass flow in thin/ultrathin mode	Casting rates to be suited to ensure uniform mass flow	Casting rates to be suited to ensure uniform mass flow in thin/ultrathin mode.

STEEL AND DIGITAL APPLICATION

The steel industry has been at the forefront of the development and application of various automation and computer-based technologies over the last 5 decades and more. Large scale use of computers in order processing, production planning and inventory management have been well recognized and adopted in most modern installations. Integrated control systems

linking the various locations involved in this entire chain have been in existence for long. The emergence of better communication has improved their efficacy.

Similarly, plant level and equipment level instrumentation and automation systems, now designated differently in line with the (emerging jargon) digital industry. Sensors for signaling as well as collection of various process data on a real time basis and their processing on line in the production processes have been in existence in most of the critical applications of the steel manufacturing chain. These have led to improvements to graduate to zero-defect manufacturing, consistent and repeatable quality levels reduction in the variation bands of different qualities and properties (temperature control, gauge control, continuous monitoring and feed-back controls, creation of data bases for statistical evaluation) etc. Adoption of AI in BF operations has been in vogue for quite a few years. Model based automation with real time processes control such as the adoption of sub-lance and dynamic control in BOF are well established uses in steel manufacture. Full in line automation and process control, material tracking, Data acquisition and Statistical analysis have been par-for the course for over three decades.

Digital Disruption

The following reality of the steel industry (largely) has to be taken into account in evaluating the possible impact and the contribution that large scale digitalization. A critical analysis of each of these areas will indicate the following reality as far as Indian industry is concerned.

Predictive Analysis

The key focus of digitalization is on predictive analysis based on high volume data. This aspect has always been a strong focus of the steel industry which is highly asset-intensive as well as multi-speciality based. Thus, large number of integrated asset management systems, condition monitoring tools along with automated data acquisition and transfer, predictive maintenance techniques with reference data bases and other approaches have been developed and matured over time.

That the Blast furnaces and related units operate uninterrupted for 350 days a year on 24x7 basis is an indication. Similarly, the current day Steelmelt shops including continuous casters also operate on similar lines. That available operating time in rolling mills is now over 7200 hours per year as against the earlier accepted 5000 to 5400 hours in another pointer.

Automation

The integrated steelplants have state-of-art process monitoring and control systems in all parts of the chain. As these are generally part of the respective units, there is a wide diversity in terms of level of technology, sources of manufacture, software platforms etc. A large number of applications (AGC, On-line inspection, Material tracking) are integral parts of the respective relevant process systems. This reality would indicate that indiscriminate implementation of current technologies may be fraught with large scale disruption (huge investments for revamps and additions for ensuring compatibility with existing equipment and systems, large scale disruption risks, time for transition, reskilling, etc) and associated risks. Also with the

increased digitalization, the need for higher qualified manpower and its higher costs have also to be factored in arriving at the potential improvements.

Discrimination Required

Most narratives on Digitalisation and emerging digital technologies look upon steel industry as a monolith amenable to one approach. The approaches are also primarily focused on Business aspects. Whereas the reality of steel manufacture on the ground is significantly different. There are three/four vital and nearly independent constituents of the manufacturing chain operated by different organizations in many cases. These are:

- Raw materials as delivered to the steel plant
- Steel manufacturing chain within the steel plant premises
- Downstream value addition units for products
- User segments

Raw Materials

This segment is now globally controlled and operated. The companies that develop and deal with their distribution are independent companies with their own strategies. Except for quality coordination and commercial contracting, they have no direct role to play in the steel manufacture. Thus, the entire manufacturing chain as depicted by many as needing end- to-end integration may not be relevant.

Similarly, logistics is also an independent business and the steel industry may not have any control or link to it except as a service provider.

Direct Manufacturing Chain

All activities and related strategies within the industry ambit are included. Traditionally, the steel industry is based on an integrated outlook given the integrated nature of the chain itself and the need for hot processing on a very large scale. The dominating narrative on steel derives from its numerous and diverse technologies, variety of equipment, large scale, need for consistent quality and improved products demanded by the user industry. The level of adoption of technologies including automation therefore is quite high in the industry.

Downstream Units

Integration with the downstream as well as end users is only selective and based on local factors (Locational, Ownership, business links). These are largely independent and in most cases the steel plants do not have a role in the way they operate and manufacture. The picture here could change depending upon the manner in which the Circular Economy initiatives take shape in the future.

Labour Productivity

With regard to India, the disruption that can reduce employment potential has to be evaluated in context of need for productive employment of the large population at economic costs. The impact of labour costs on steel production costs will vary from location to location.

For example, in an advanced nation with wage of over USD 40- 50 per hour, and a labour productivity of about 1 mh ton, the cost contribution is US \$ 45 at the least. This would be about 8 to 10% of the production cost. Whereas in India, in spite of the so-called lower productivity of nearly 2.5 mh per ton, the labour component would be less than 3 to 4% of the cost.

Chapter 8

STEEL AND ENERGY USE

Iron and steelmaking is a highly energy-intensive process, more so through the iron ore-based conventional route. It accounts for around 8% of global energy demand and 7% (2.6Gt CO₂) of total emissions from the energy system largely stemming from the sector's high reliance on coal, which supplies 74% of its energy inputs. Energy constitutes a significant portion (20% to 40%) of the cost of steel production. The energy aspect of the steel continues to attract significant attention due to the environmental impact from the GHG gases that are emitted during its use.

ENERGY INPUTS FOR STEELMAKING

Coal and coke from it are the main sources both for reduction and for energy input for iron making in the blast furnace. Use of energy in the iron and steelmaking process serves two purposes - one of iron ore reduction and the second as energy input for iron and steelmaking making process.

Currently the Gas-based DRI is the principal process based on the use of natural gas, which also serves the twin purposes. Electrical energy forms the other major energy source with EAF steelmaking being largely electricity based.

Coke, made by carbonising the coal (i.e. heating in the absence of oxygen at high temperatures), is the primary reducing agent of iron ore. Other fuels such as Injection coal, Natural Gas, Coal Tar etc are able to substitute a portion of coke due to their reducing ability.

Up to 75% of the energy content of the coal is consumed in the blast furnace in the integrated steelmaking. The direct reduction of iron ore into sponge iron (DRI) consumes nearly 2.4 Gcal of energy per ton of DRI. In case integrated DRI-EAF is considered, then about 60 % of the energy is from natural gas and the rest from electrical energy. The coal-based processes popular in India consume nearly one ton of coal per ton of DRI.

In case of electric furnace steelmaking (using scrap mainly) nearly 75% to 85% of the total energy is in the form of electrical energy. The balance is formed by carbon, natural gas and oxygen (where applicable)

The current overall energy sources for integrated iron and steelmaking facility are generally as follows:

From Coal (Coking as well as non-coking coal) About 50%

From Electrical energy About 35%

From Natural gas About 5% and

From Other gases About 5%

Refer Figure 8-1.

Energy end-use in the steel industry

Fired heaters like blast furnaces and other furnaces use the majority of the energy involved in the iron and steel making process, consuming about 81% of the final energy. Motor systems 7%, Facilities 3%, Steam 7% and Others 2% consist the balance. The energy end use in steel production is shown in Figure 8-2.

Energy Intensity

The energy consumption of the different plants, is in some ways unique, as each plant has specific issues and realities. The energy intensity of the different plants, are likely to vary considerably not necessarily due to plant inefficiency or inadequacy of technologies alone. The raw materials and their specifications, which vary widely in the different locations play a very important role in overall energy consumption. Type of energy, type and age of equipment, level of technology and adoption of latest developments, operational efficiency and legacy issues (layout, operating practices etc) also play a significant role. In many areas, a level of estimation is also involved due to the local limitations of systems. Thus, the overall figures are not to be treated as absolute and are more of a guide of the levels that can be expected to be reached. An overall appreciation of the energy levels that can be considered as near optimal for the different steelmaking routes helps in establishing achievement benchmarks as well as future road maps for improvements. This also provides a guide for the planning of new installations in terms of energy planning and facility selections. Typical Sub-Process wise energy consumptions in steel production considered as benchmark levels is shown in Table 8-1 and Figure 8-3.

TABLE 8-1 ENERGY INTENSITIES OF PROCESS ROUTES

Process Route		BF-BOF	SR-BOF	Coal DR-EAF	Gas DR-EAF
Process	Stage	GJ/tcs	GJ/tcs	GJ/tcs	GJ/tcs
RM Processing	Sintering	2.1			
	Pelletising		0.8	0.8	0.8
	Coking	1.0			
Ironmaking	BF	11.8			
	SR		17.0		
	DRI			12.6	9.5
Steelmaking	BOF	1.0	1.0		
	EAF			5.6	5.6
	Refining	0.4	0.4	0.4	0.4
	ConCast	0.1	0.1	0.1	0.1
Total		16.4	19.3	19.0	16.4

Stage-wise Energy Demand

BF Ironmaking in the integrated steel production route is most energy intensive and energy consumer accounting for nearly 70% of the total consumption. Typical stage-wise share in energy consumption is shown in Tables 8-2 and 8-3. (Figures 8-4, 8-5 and 8-6)

TABLE 8-2 STAGE-WISE STEELMAKING ENERGY SHARE

Process / Sub-process	% of total energy consumption (Typical)		
	BF BOF	DR-EAF	EAF- Scrap
Coke making	15		
Sinter making	9		
Blast furnace	45		
Total iron making	69		
Direct Reduction	-	50	
Steel making	9	35	75
Rolling	12	10	15
Others	10	5	15
Total	100	100	100

TABLE 8- 3 STAGE-WISE FUEL AND POWER REQUIREMENT

Process Stage	Fuel	Electricity
	GJ/t Product	Kwh/t Product
	Typical	Typical
Sinter	1.9-2.2	25-30
Coke	1-1.2	20-40
BF	11.8-14	10-15
BOF	0.7-1.0	30 to 40
EAF	2.4-3	350 to 550
CC	0.1	5 to 10
HRM	1.8	90-150

Stage-wise Energy BAT

The stage-wise energy requirement levels as per available BAT are given in Table 8-4.

TABLE 8- 4 STAGE-WISE ENERGY REQUIREMENT AS PER BAT

Process	BF-BOF	SR-BOF	CDRI-EAF	GDRI-EAF	Scrap-EAF
	(GJ/t)	(GJ/t)	(GJ/t)	(GJ/t)	(GJ/t)
Coking	1.0	-	-	-	
Sintering	1.9	-	-	-	
Pelletizing	-	0.6	0.6	0.6	
Iron Making					
BF	11.8				
Smelt Reduction		17.3			
DRI			11.7	10.7	
Steel Making					
BOF	-0.4	-0.4	-	-	
EAF	-	-	2.7	2.6	2.4
Refining	0.1	0.1	0.1	0.1	0.1
Continuous Casting	0.1	0.1	0.1	0.1	0.1
Hot rolling	1.8	1.8	1.8	1.8	1.8

Total	16.3	19.5	17.0	15.9	4.3

Review of one of the Best Available Technology (BAT), indicates the SEC upto the hot strip production of 14.8 GJ/t through BF-BOF route, 17.8 GJ/t by the smelt reduction (COREX)-BOF route, and 16.9 GJ/t in the gas based DRI-EAF route and 2.6 GJ/t for Scrap EAF (Table 8-5).

**TABLE 8- 5 ENERGY INTENSITIES OF PROCESS ROUTES
(UPTO HOT STRIP PRODUCTION)**

	GJ/t
BF-BOF-TSC	14.8
COREX-BOF-TSC	17.8
GDRI-EAF	16.9
Scrap-EAF-TSC	4.3

Energy Equivalent KWh(Overall)

Typical overall energy consumption of the different process routes in terms of equivalent electrical energy in kwh and the carbon impact are given in Table 8-6.

TABLE 8-6 ENERGY & CARBON IMPACT PROCESS ROUTEWISE

	Energy	CO ₂
	Equivalent Overall kwh/tls	kg/tls
	Typical	Typical
BF BOF	4600	1960
EAF 100 % Scrap	1650	440
EAF 80 % CDRI	5100	1160
EAF 80 % HDRI	4600	1080

Energy Optimisation Status

Energy is important from the economic competitiveness of the steel industry as well as environmental angles. The global steel industry has for ever been conscious of the energy impact on its costs and as a result this aspect has received continued attention in all its facets. The current energy consumption levels are nearly 40 % of what was consumed in the sixties as will be evidenced from Table 8-7. (Fig 8-7).

TABLE 8- 7 REDUCTION IN ENERGY USE

Year	Energy Consumption Index
1960	100
1965	97
1970	91
1975	89
1980	83
1985	76
1990	69

1995	57
2000	50
2005	49
2010	43
2015	40
2020	Lower

Energy Losses in Steelmaking

The major losses are in the processes where a substantial energy is taken away in wastes, waste gases and emissions. One estimate puts the useful part of the energy around 30% to 35 % of the total energy input to the steel plants as directly useful energy. Balance 65 to 70% is dissipated as heat through waste gases (30%), cooling water (20%), hot slag (5%) and others (10-15%). The above includes significant energy losses at different stages of operations. For example, while, motor systems account for a relatively small proportion of energy use, at around 7% it has been estimated that up to 70% of the energy consumed by these motors is lost due to system inefficiencies. It is estimated that over 23% of the energy that enters the plant being lost to inefficiencies in equipment and distribution. (Figure 8- 8).

ENERGY SAVING AND RECOVERY AVENUES

The sustained industry efforts and the consequent innovations have led to a multitude of energy saving process technologies, operating practices as well as avenues for recovery of waste heat. A summary of the measures that have been adopted in the steel industry are presented in Table 8-8.

TABLE 8-8 ENERGY SAVING/RECOVERY IN STEELPLANTS

	Direct Measures	Energy Impact
Coke making	Use of COG as fuel	Fuel, Power Generation
	Coke Dry Quenching	Water saving, Power from
	Coal Moisture Process control	
Sinter Plant	Blowers – VVVF	Reduced energy
	Automation	
	Waste gas recycling	Energy optimisation
Blast Furnace	Waste heat recovery	Power Generation
	Main exhaust gas recovery (EOS)	Potential for heat recovery
	Full Use of BF Gas	Fuel and power generation
	Top Gas Recovery Turbine	Scope for power generation
	Stove heat exchanger	Power Generation
	Efficient Blowers	
Steel making	Heat recovery from slag	Potential for future
	BOF Gas recovery and use	Fuel and power generation
	BOF Gas Sensible heat recovery	Potential for heat recovery
Continuous	WHR from Slag	Potential for heat recovery
	Near net shape casting	Energy saving and

	In line strand reduction	Energy saving and
	Sequence casting	Energy saving and
Casting & rolling	Hot Charging	Energy saving and
	Net shape Casting & In line rolling	Energy saving and
	Thermo-mechanical rolling	Energy saving and
Drive Systems	Energy efficient Drives	Reduced energy
	Indirect Measures	
Productivity	Improved productivity, better raw material inputs, process efficiency	Increase yield, reduced slag, Energy saving
Scale	Optimization of usages	Greater energy efficiency
Operations	Process continuity, Sequence casting, endless casting and rolling	Energy savings
Products	Enlarged size ranges Thin and ultra-thin hot strip, and smaller bar and wire rods.	Reduction in overall energy consumption downstream.
Equipment Design	Greater efficiency, Lighter construction, Optimum sizing	Reduced facilities, savings in energy and utilities for operation

It will be noted that the above includes already well-established practices as well as those with the potential for the future. Many of the improvements and innovations hold great potential even now for old plants awaiting modernization and upgrade. Concurrent improvements in heat recovery systems including recovery of sensible heat from molten slags is also an area which has the potential to assist steel industry in large way.

Gains So Far

The areas where efforts have been directed for energy recovery and optimization with considerable success and the currently available technologies are outlined below under the following heads:

- Process optimization
- Facility and Equipment design
- Use of off gases as fuel
- Use of off gases for power generation
- Energy recoveries at different stages in the processes.

Process optimization

The iron and steelmaking processes have been consistently improved with the use of better and prepared raw materials, operating practices and their standardization, automation and AI systems. These have led to the increase in productivity and scale of operations with resultant efficiency and energy use improvements. The overall energy consumption per ton of steel production has reduced by over 60% over the last 6 decades.

Process integration, utilizing available sensible heats, has catapulted the savings in energy requirements for the processing of hot rolled products. The casting and in-line rolling of thin slabs, billets and blooms has resulted in energy saving to the tune of over 40%. Adoption of large-scale sequence casting has also enabled higher productivity and reduced energy consumptions.

Facility and Equipment Design

Improved equipment designs have enabled reduced energy consumptions (better performing drives, use of VVVF drives, reduced utility requirements), better performance and higher productivity. Technologies such as near net shape casting and in line core reduction have greatly reduced the energy demand for processing.

Off gases as fuel

Coke Oven Gas

The coke oven gas resulting from the coking process is used as a fuel in Integrated steelplants. Approximately 360 Nm³ coke oven gas is generated per ton of coal, with a calorific value of about 19-20 MJ/Nm³. Approximately, 40 percent of the COG is used as heating fuel in coke ovens itself, the remaining used to fuel equipment such as turbine driven equipment and boilers that supply steam for electricity generation, and for process heat, reheat furnaces etc.

Blast Furnace Gas

The blast furnace produces a low calorific gas, blast furnace gas at a rate of about 1200 to 2000 Nm³ per ton of pig iron. The energy content of blast furnace gas typically varies between 2.7-4.0 MJ/Nm³ depending on its CO concentration. The gas consists of 20-28% of carbon monoxide (CO) and 1-5% hydrogen (H₂), both potential energy sources and thus measures can be taken to recover this energy. After cleaning, blast furnace gas is used as a fuel. Total export from the blast furnace is approximately 30% of the gross energy consumption of the blast furnace. BF gas is often enriched with coke oven gas or natural gas for increasing the calorific values to suit most applications, prior to use as fuel.

BOF Gas and Sensible Heat

Recovery of BOF gas is the single most energy-saving improvement in the BOF process, making it a net energy producer. Carbon monoxide rich BOF gas (70-80% CO) produced during oxygen blowing leaves the BOF through the converter mouth and is subsequently caught by the primary ventilation. This gas has a temperature of approximately 1200°C and a flow rate of approximately 55-110 Nm³/ton steel. The gas has a heating value of approximately 8.8 MJ/Nm³. Typically, shops recover 100 Nm³ of LD gas with a calorific value of 1750 kcal/Nm³, i.e 0.175 GCal energy per ton of liquid steel.

Heat recovery methods are classified as a combustion method or as a non-combustion method. Non-combustion method facilities are designed to recover about 70% of the latent heat and sensible heat. The sensible heat of the off-gas is first recovered in a waste heat boiler, generating high pressure steam. The gas is subsequently cleaned and stored. The recovered

converter gas can be used as such or mixed with other by-product gases (coke oven gas, blast furnace gas).

Waste heat boiler, combustion type steam recovery system, in which the CO contained in the gas is completely burned using air and the sensible heat is recovered provides a steam saving of about 292.9 MJ/ton of steel. The suppressed combustion type gas recovery system, in which the CO contained in the gas is not burnt, but is recovered as latent heat can amount to 836.8 MJ/ton of steel. The total savings- potential can vary between 0.5 and 0.9 GJ/ton, depending on the way the steam is recovered.

The predominant use of BOF gas is as a fuel in reheating furnaces and for steam generation, either directly or blended with BFG. BOF gas and BFG have also been used in gas turbine–combined cycle units, The energy recovery would reduce CO₂ generation from the use of natural gas and electricity by approximately 0.05 ton of CO₂/ton of steel, which would offset a significant portion of the unavoidable generation of CO₂ from steelmaking estimated at 0.11 to 0.16 ton of CO₂/ton of steel.

ISP Fuel Balance

The off gases discussed above have been a major source of fuel in many of the ISP's, meeting the needs of reheating, and process support largely avoiding in the process need to purchase fuel from external sources.

In the current modernized concepts for ISP with the adoption of BAT's in all potential areas from Raw materials to Product processing, the by-product fuels have the potential not only to meet the entire heating requirements but also have the potential to support additional power generation adequate to meet the major loads. This is discussed in the following paragraph.

Cokemaking

Dry quenching of coke

Dry quenching of the coke, in place of wet quenching, can be used to recover sensible heat that would otherwise be lost from the coke while reducing dust. The steam recovery rate with this equipment is about 0.5 MMBtu/ton (0.55 GJ/ton) coke. In addition, typical experiences show that the use of coke manufactured by dry quenching can reduce the coke consumption in the blast furnace by 0.24 MMBtu/ton (0.28 GJ/ton) molten iron.

The sensible heat of coke (temperature of about 1000°C) can be recovered by circulating non-oxidizing gas in a closed loop. The heat recovered can be used to generate steam or electric power by means of a heat exchanger (energy saved = 334.72 MJ/ton of coke). In comparison with conventional wet quenching, this process can improve the coke quality and environmental performance of the industry

For instance, CDQ with 200t/h cooling capacity can generate approx. 36MW of electric power. To generate the same output with a heavy oil firing boiler, 12 tph heavy oil is required which can result in 36 tph CO₂ emission to the atmosphere. Thus in- case of a steel work with 10 MTPY crude steel production, requiring nearly 3 MTPY of coke, approx. 0.5 million tpy

CO₂ emission can be reduced if all coke is quenched with CDQ and the electric power is provided from it.

Coal Moisture Control

Waste heat from the COG can be used to dry the coal used for coke making, which may reduce the fuel consumption in the coke oven by approximately 0.26 MMBtu/ton (0.3 GJ/ton).

The use of programmed heating instead of conventional constant heating of the coke ovens can help ensure optimization of the fuel gas supply to the ovens during the coking process. This measure can result in fuel savings of 10 percent, or approximately 0.15 MMBtu/ton (0.17 GJ/ton) of coke.

Variable-Speed Drive COG Compressors

The use of variable-speed-drive (VSD) COG compressors can reduce the energy required for compression of the low-pressure gas for transport.

Single Chamber Coking System

Single chamber system coking reactors (formerly called Jumbo Coke Reactors) are coke ovens with large coke oven volume and widths, between 17.7 to 33.5 in (450 to 850 mm). Single chamber system coking reactors enable an improvement in thermal efficiency from 38% to 70%, but the technology is still under development.

Non-recovery Coke Ovens

In the non-recovery coking process, raw COG and other by-products released from the coking process are combusted within the oven, offering the potential for heat recovery and cogeneration of electricity. A typical plant produces 500,000 tons of coke per year while producing 200 tons/hr of steam.

Sinter Plants

Heat recovered from the sinter plant can be used to preheat the combustion air for the burners and to produce high-pressure steam, which can then be used to generate power. Typical fuel savings reported are about 0.47 MMBtu/ton (0.55 GJ/ton) of sinter, and increased electricity generation of 1.4 kwh/ton (0.0056 GJ/ton) of sinter.

Waste heat recovery from sinter cooler

The temperature of exhaust air from the sinter cooler is 300-350°C and the energy content of its sensible heat is equivalent to approximately 30% of the energy input into the sintering machine. The sensible heat can be recovered by following ways:

- Recirculating Fans:

Use of hot air to the ignition furnaces as combustion air (energy saved = 20- 42 MJ/ton of sinter).

Use of hot air to the raw material layer for preheating (energy saved = 42 - 84 MJ/ton of sinter).

- Waste Heat Boiler:

Produce steam for processes, or provide steam to feed the turbines for power generation, (steam saved = 125 - 200 MJ/ton of sinter).

Steam generation with sinter cooler gases using a waste heat boiler has a potential to recover 0.22 MMBtu/ton sinter (0.25 GJ/tonne).

Emission Optimized Sintering

This process developed by Outokumpu Technology in the 1990s reduces the off-gas volume by 50% to 60% through housing the entire sinter strand, re-circulating off-gases, and using its CO content as an energy source. Reduced off-gas results in savings in gas cleaning energy and coke,

Reduction of Air Leakage from the sintering plant can reduce fan power consumption by approximately 2.0 to 3.6 kWh/ton (0.011 to 0.014 GJ/ton) of sinter.

Blast Furnace

PCI In Blast Furnace

Pulverized coal and natural gas injection replace coke, thereby reducing coke production and saving the large amount of energy consumed in coke-making. However, increasing fuel injection requires energy for the oxygen and coal injection, electricity, and equipment to grind the coal. Still a fair amount of coke is still used as support material in the blast furnace. The energy savings in the blast furnace due to coal injection have been calculated at 3.23 MMBtu/ton (3.76 GJ/ton) coal injected. Coal injection rates above 200 kg/ton of hot metal are becoming the aim.

Natural Gas Injection

Natural gas injection is an alternative to coal injection, and its selection depends on the price of natural gas versus coal and its ready availability. Replacement rates for natural gas may range from approximately 0.9 to 1.15 ton NG/ton coke. Energy savings for a typical process were estimated to be 0.8 MMBtu/ton (0.9 GJ/ton) of hot metal.

COG and BOF Gas can also be injected into blast furnace to reduce CO₂ emissions, since these gases contain less carbon than coke. The maximum level for COG injection at the tuyere-level is thought to be 0.1ton COG/ton hot metal. The equivalent replacement rate of coke is about 1 ton of COG for 0.98 ton of coke.

Hot-blast Stove Automation

This measure can reduce energy consumption of the stoves by running the operation more efficiently and closer to optimum conditions. Energy savings typically range between 5 and 12 percent and may reach 17 percent. The sensible heat of BF hot stove gas can be re-used to preheat the combustion air and fuel gas. For a specific medium type waste heat recovery device (consisting of two heat exchangers), a recovery rate of sensible heat of 40 to 50 percent and a reduction in heat consumption of about 0.108 MMBtu/ton pig iron (0.126 GJ/ton) produced has been reported.

Top gas Pressure recovery turbine

The blast furnace top gas exits with a sufficiently high pressure which, after cleaning, may be expanded through a suitable recovery turbine to generate electricity. Up to 50% of the electrical energy required for blast compression can be recovered by this method. The turbine may produce approximately 14 to 36 kWh/ton (0.054 to 0.14 GJ/ton) of hot metal. Typically, a modern 4000 cum Blast furnace producing 10000 tpd of hot metal has the potential to generate about 18 MW of power from the pressure energy of BF gas using a Top Gas Recovery Turbine (TRT)

One of the studies conducted by OECD has indicated a potential energy saving in the iron and steelmaking units of nearly 3.2 GJ per ton of hot metal as shown in Table 8-9. (Figure 8-9).

TABLE 8-9 POTENTIAL ENERGY SAVINGS IN STEELPLANTS

	GJ/thm
Coke Dry Quenching	0.80
Sinter heat recovery	0.55
Top Gas Recovery Turbine	0.77
PCI	0.70
BOF Gas recovery	0.40
Total	3.22

WSA has placed the potential for energy savings through improvements towards benchmark operations at 20% of the current levels.

Casting and Inline Rolling

One of the most striking developments in steel processing in the last 3 decades has been the development of Near Net-shape casting and in-line rolling. This approach has paved the way for huge energy savings from casting to finished products by using effectively the sensible heat in the cast product. Near net-shape has also enabled optimization of the energy use by adopting the least semis dimensions consistent with qualities for reducing the processing loads in the rolling mills.

The technology has so far covered Hot strip, Bars, Wire Rods as well as Structural sections. The energy reductions have been more than 70% from the conventional practices in many cases. The reduced fresh energy demand in the process stages has also enabled reduction in the emissions substantially. Increased use of electricity in supportive heating during processing has provided the potential for reduction in the fossil fuel use as well. The magnitude of savings with the adoption of this concept have been extraordinary as can be seen from the typical example of the energy savings given in Table 8-10 with the adoption of different routes of casting billets and in line rolling. (Figure 8-10)

TABLE 8- 10 POTENTIAL SAVINGS DUE TO ECR FOR BILLETS

	Conventional Practice	Casting and hot charging	High speed casting and in line rolling	Endless casting and rolling
Base	100	%	%	%
Reheating cost savings		55	82	91
Savings in yield and scale		36	46	69
Opex Savings		6	12	23

Similar results are experienced in rolling hot strip as well. In the case of thin slab casting, the steel is cast directly to slabs with a thickness between 30 and 60 mm instead of slabs with a thickness of 120 to 300 mm. Thin-slab casting is estimated to reduce energy consumption for processing by 4.2 MMBtu/ton (4.9 GJ/ton) of crude steel which is nearly 20% of the total energy consumption in efficient steel production and processing through integrated route.

Equipment Designs

Energy Efficient Drives

High energy consuming drives are now installed in numerous applications in the steel plants. Large drives are used for large capacity blowers, compressors, Ventilation fans at various locations.

Variable speed drives have been effectively used in these applications for energy optimisation and obtaining overall savings. High-efficiency alternating current (AC) motors can save 1 or 2 percent of the electricity consumption of conventional AC drives.

Recuperative Burners

Recuperative burners can reduce fuel consumption by 10 to 20 percent compared to furnaces without heat recovery. Although actual savings will be facility-specific, one estimate placed energy savings at approximately 0.6 MMBtu/ton (0.7 GJ/ton) of product,

Flameless Burners

Flameless oxy-fuel gives high thermal efficiency, higher levels of heat flux, and reduced fuel consumption compared to conventional oxy-fuel. Typical experiences include 60 percent reduction in the furnace's total fuel consumption compared to the original air-fuel operation. The technology also reduced the furnace's annual NO_x emissions output by 92 percent and annual CO₂ emissions by up to 60 percent below the prior air-fuel operating levels.

GHG Emissions

The major consequence of the dominance of fossil fuels in iron and steelmaking is the carbon impact where a ton of steel production through integrated steelmaking contributes to nearly 2.5 tons of CO₂ per ton of crude steel. Of this nearly 80 % is attributable to the energy use. The emission intensive stages are in iron making, where the sintering stage accounts for

about 0.3-0.4 t-CO₂ and the blast furnace intensity range is between 0.7-1.1 t-CO₂ to produce new steel using the best technology. The repositioning of the steel industry from a sustainable perspective presented in the later chapters factoring the energy angle is, therefore, an important element of Carbon reduction.

OVERALL POTENTIAL FOR ENERGY SAVINGS

As per the IEA report “Iron and Steel Technology Roadmap Towards more sustainable steelmaking “, Energy performance improvements to existing equipment are important, but by themselves not sufficient for a long-term transition. The energy intensity of state-of-the-art blast furnaces is already approaching the practical minimum energy requirement. For inefficient equipment the gap between current energy performance and best practice can be much larger, but with energy making up a significant proportion of production costs, there is already an incentive to replace the least efficient process units. Improvements in operational efficiency, including enhanced process control and predictive maintenance strategies, together with the implementation of best available technologies contribute around 20% of cumulative emissions savings in the Sustainable Development Scenario.

In the Indian context, this scope will be substantially higher as the performance indicators of the Indian industry are considerably above the global benchmarks. The NSP envisages a reduction of over 30 % at the industry level aiming about 5 Gcal/t steel production.

STEEL INDUSTRY SCENE

The steel industry energy scene including the scope for transition particularly as relevant to India could be generally summed up as follows:

- Carbon is the most efficient abundantly available and economic reductant used by the industry. The use of hydrogen as an alternative is feasible subject to its availability at economic prices - unlikely in the near and mid-term scenarios due to high energy inputs for hydrogen production and its impact on costs as well carbon foot prints.
- Of the Green energy options, Solar energy would be the most appropriate in the Indian context. The recent cost indications also point towards this as a cost competitive option as compared to fossil-based power. Implication of the same such as restricted time availability, absence of large-scale storages, need for flexibility in distribution systems, impact of partly used supporting generation capacities need to be satisfactorily resolved.
- The use of natural gas as a clean energy has serious limitations in Indian context as the same will be largely imported. The volatility in price as well as availability and the infrastructure costs make this option risk prone.
- India is endowed with huge coal reserves albeit with high ash contents. But its large-scale use has been ensured with beneficiation, and effective ash management. It has the potential to be cost effective, compared to competing energies such as oil, Natural gas

etc. The proper use of coal with appropriate carbon management support will therefore be a national imperative which cannot be ignored.

- It is generally understood that even with the zero-carbon initiatives, the RE (Green energy including green hydrogen with massive energy demand)) contribution may still be around 40 % of the total demand. To believe that the steel industry can become 100 % green would be a pipe dream. Besides coordinated efforts on energy use reduction and increased use of RE, carbon management would have a critical role in achieving the higher objective. Here, CCSU with its huge demands on facilities, infra-structure and sites would ultimately determine the level of success.

Energy composition

Currently, typically about 55 to 60% of an integrated steel facility's energy input comes from coal, 35% from electricity, 10% from Oil, natural gas and other gases. One of the redeeming features of the modern ISP based on BF-BOF is the large scale and efficient recoveries of by product energy from its processes and the efficient use of this for generation of power as well. The level of dependence on external energy support (primarily electricity) thus can be less than 20 %. Whereas in the case of the alternative with emphasis on DRI-EAF process the external support can go upto nearly 100%.

Considering the EAF capacity in India by 2040 to be around 150 million tons (near 50% of the production) the external power demand of the steel sector will be quite high (About 300 to 350 MW for a 2 MTPY unit). Besides, the, electrical energy will also be required in massive quantity for hydrogen and oxygen generation in case these become viable popular options in the future.

The extraordinary fallout of this approach outlined above, is the gigantic role of external energy particularly electricity. Non-availability of requisite electrical energy at economical costs could, therefore, have a major disrupting potential in the process transition in steel for reducing carbon footprint and sustainability.

Process Routes and Metallics Impacts

A comparison of energy requirements and corresponding CO₂ emissions for various ironmaking/steelmaking routes, from the conventional blast furnace (BF)/BOF and Direct Reduction Process direct reduced iron (DRI)/hot briquetted iron (HBI)/EAF routes is shown in Tables 8-12 and 8-13.

Besides a comparison at the process levels, the likely impact of the type of metallics and their shares in the charge are also indicated. The alternative metallics for steelmaking include hot metal/pig iron, hot DRI, Cold DRI, Hot High carbon DRI, Cold High carbon DRI, HBI and Steel scrap.

TABLE 8-12 STAGewise ENERGY - STEELMAKING OPTIONS (KWH/T)

	BF pellet	DR pellet	Sinter	BF HM /thm	CDRI HDRI	HBI	BOF (LS)	EAF (LS)	Total Kwh/tls
80% BFHM	503		546	3397			911		4624
80% CDRI		529			2695			1949	5065
80% HDRI		529			2570			1634	4592
80% HC CDRI		529			2795			1956	5124
80% HC HDRI		529			2670			1633	4766
50%CDRI		529			2795			1907	3893
50%HBI		529				3341		1924	4204
50%BFHM		452	546	3485				1003	3284
100%Scrap								1647	1647

TABLE 8-13 TOTAL ENERGY & EMISSIONS - STEELMAKING OPTIONS

	80 % AIU		50 % AIU	
	Total Energy	CO ₂ Emissions	Total Energy	CO ₂ Emissions
	Kwh/tls	CO ₂ /tls	Kwh/tls	CO ₂ /tls
80% BFHM	4624	1959		
80% CDRI	5065	1163		
80% HDRI	4592	1065		
80% HC CDRI	5124	1195		
80% HC HDRI	4766	1066		
50%HCCDRI			3893	912
50%HBI			4204	991
50%BFHM			3284	1507
100%Scrap			1647	441

Figures 8-9 and 8-10, show the energy savings and consequent emissions reduction in the production methods. Figures 8-11 and 8-12 show the impact on total energy required to produce the liquid steel, with varying metallics inputs. The units of energy are given in kWh/t of liquid steel, and the emissions are given in kgCO₂/t liquid steel. The results are divided into two graphs which represent the 80% AIU, and 50% AIU usage, respectively.

The main results of this study indicate that:

- For 80% iron ore-based steelmaking facility, DRI consumes slightly more overall energy but produces significantly less carbon emissions than the BF/BOF technology because of its use of natural gas for iron ore reduction.
- The EAF production routes, which utilize greater amounts of scrap, have lower total energy and carbon emissions than the conventional BF/BOF route.

- To minimize total energy consumption and CO₂ emissions, scrap use must be maximized.
- Since many steel products cannot be made with a 100% scrap feed, a portion of alternative iron is charged to the EAF to meet quality requirements.
- As the amount of AIUs charged to the EAF increases, so do the total energy consumptions and CO₂ emissions.
- AIUs produced by natural gas-based reduction (DRI & HBI) promote lower total energy consumptions and significantly less CO₂ emissions than (cold) pig iron.
- In the 80% AIU group, HiC HDRI & HDRI have lower CO₂ and EAF energy, and compare equally for total energy with the BF-BOF route.
- In the 50% AIU group, use of BF HM has the lowest total energy and EAF energy, but with the highest CO₂ emissions.
- Use of steel scrap provides the optimum solution both from the point of energy use as well as CO₂ emissions. This positions the use of steel scrap as the principal alternative for steel industry sustainability

Indian Scene

By 2050 almost one-fifth of the steel produced globally is expected to come from India, compared to around 8% today. A diverse technology portfolio emerges in India to tackle an array of challenges.

The Indian steel sector is currently highly energy and carbon-intensive, consuming around 23% of the total energy use and directly emitting over 300 Mt CO₂ accounting for over 12% of the nation's total fossil fuel combustion emissions. The sector also resulted in an additional 75 Mt CO₂ of indirect emissions to generate the power and imported heat it consumes.

According to a recent assessment by TERI, the emissions are projected to jump to 837 MT by 2050, in response to the quadrupling of energy demand for steel, resulting in the steel industry contributing more than a third of the nation's total fossil fuel combustion emissions

Of the direct emissions, most come from coal (90% of total emissions), mainly used in coke ovens, blast furnaces and coal-based direct reduction units. Much of the remaining direct emissions are process emissions resulting from the use of lime fluxes and ferroalloy production, with only small contributions from gas and oil consumption.

After coal, electricity is the second largest energy commodity consumed in the sector (10%). EAFs and induction furnaces account for about half of the electricity input to steelmaking in India. This electricity consumption results in indirect emissions. In the Stated Policies Scenario of IEA, both the energy consumption and CO₂ emissions of the Indian steel sector are projected to more than triple by 2050.

The Indian steel industry is currently one of the most energy intensive in the world, with energy use of around 30-40% higher than the global average. The trend in SEC in the Indian industry can be from Figure 8-10.

The NSP has set down a Specific Energy Consumption of 5.0 – 5.5 Gcal/tcs by 2030 (over 15% to near 60% in different installations from the present levels). It needs to be mentioned here that the emission intensities at the industry level are significantly diverse with some of the poorer installations contributing more than 3 tons of CO₂ per ton of crude steel.

The Indian steel industry technology scene is also quite muddled as it is a mix of highly outdated as well as the most modern technologies. High level of fragmentation and use of inefficient practices and resources builds in huge diversity in terms of energy consumptions and fossil fuel use and consequently. Unreliable results of actual energy consumptions are also issues which impact the conclusions at the industry level.

A concerted approach is, therefore, required to place the industry on an efficient level in case the Global BAT levels of energy optimization are to be achieved. A section of the industry (nearly 30 to 35 % of the production, particularly the ISP's) has made great strides in the past 2 decades towards this objective.

The all-round implications of energy in steel production would also encourage the tenet “Doing more with Less”. A holistic outlook at the effective use of steel (consequently reduced demand) would demand serious attention. This has to be strongly supported by the improvement in the efficiencies of power generation and distribution, and the increase in the share of the renewables.

A key factor in terms of efficiency of overall energy management in ISP's would be the following:

- Full use of available excess by product gases (CO, BF and BOF) as essential fuel as well as power generation.
- Maximising waste heat recoveries at all stages of processes and use as a steam or power input.

Adoption of the optimized technologies and processes and equipment, it may well be that the external purchased energy may be restricted to well below 20%

Steel and Energy Transition - Indian Scene

The steel sector remains heavily dependent on coal even in the Sustainable Development Scenario projected by IEA, although its share does drop from 85% to 60% of final energy consumption by 2050. Continued Coal use is thus required for the foreseeable future.

Energy Transition

A key factor that needs to be recognized for decisions on evolving steel industry scenarios is the likely impact of the push for energy transition away from fossil fuels to green and renewables. An energy sector transition to net-zero CO₂ emissions by 2070 of the kind

depicted in the Sustainable Development Scenario (SDS) of IEA requires a radical technological transformation of the energy sector.

While energy efficiency and renewables are central pillars, additional technologies are needed to achieve large-scale decarbonization and towards net-zero emissions. The key technology value chains that have to contribute to CO₂ reduction in steel industry are:

Carbon capture, Utilisation and storage (CCUS),

Hydrogen and hydrogen-related fuels,

Renewable energy including Bio-energy

The energy transition in steel industry is inextricably linked with the evolving energy scene of the nation as a whole. Replacement of coal, increasing use of renewables, and greening efforts are all conditional on availabilities in terms of scale, economic costs and uninterrupted availability. Reduction in coal use so vital for carbon reduction driven by the possibility of use of hydrogen as the energy as well as reducing source would demand massive increases in use of electricity making huge demands on power infrastructure and consequent investments.

The relevance of the ambitious Net Zero objective has to be critically evaluated in the Indian context and its energy scene. Given that the use of coal would continue to merit attention due to its abundant availability as well as economics, and its efficient and environmentally appropriate optimized use would be a priority.

Possible Road Map

Considering the above reality, the following approach may be of interest:

- Increased use of EAF with scrap as the principal raw material would deserve highest priority as it is attendant with multiple benefits. In the Indian context availability of scrap would be a big poser. This will also be critically dependent upon ready and reliable availability of purchased Electricity and its CO₂ contribution.
- Increased use of renewables to the maximum extent (Purchased electricity) would be inevitable. This may account for 40 to nearly 100 % of the energy requirements depending upon the route adopted (BF-BOF, DRI-EAF or Scrap EAF). Overall energy policy of the nation would have to address this aspect appropriately.
- The existing gas-based DR processes have nearly perfected the process of DRI manufacture with the syngas compositions reaching near 90 % hydrogen. Effective use of even blue hydrogen in emerging processes as well as in supplementing the existing processes would be an optimal approach. This will also insulate the industry from the impact of likely high costs and issues associated with the green hydrogen.
- Once the technology for the use of H₂ exclusively as the reductant gets established, captive on-site Hydrogen installations may be the way to go for the large sized steel units provided requisite unit sizes can be appropriately supported on the energy front

- The use of coal will necessarily have to receive simultaneous attention (at last in the near and mid-term) which can be can be through gasification to Syngas for DRI production, supported by appropriate CCUS. This will reduce the adverse impact of coal substantially.
- With the progress made in gas-based DRI where numerous options for reduction source have become available such as off gases (Coke oven gas, Corex gas, Coal gas) dependence on natural gas which is not available on scale in India can be avoided.

Chapter 9

STEEL AND ENVIRONMENT

Being energy-intensive and carbon-dependent for chemical reduction, there are inevitable environmental impacts in the form of emissions, effluents and overall climate concerns arising from the steel production. The development of mitigation measures over the decades and the future road map for ensuring environmental compliance and friendliness are discussed in this chapter.

STEELMAKING VIS-A-VIS POLLUTION

The integrated process of steelmaking gives rise to pollution in three forms at every stage of its production namely solid, liquid and gaseous besides aspects such as noise, aesthetics etc.

The GHG emissions in steelmaking are generated as one of the following:

- Process emissions, in which raw materials and combustion both may contribute to CO₂ emissions;
- Emissions from combustion sources alone; and
- Indirect emissions from consumption of electricity (in EAF steelmaking and in finishing operations such as rolling mills at both Integrated and EAF plants).

The arisings include co-products as well as wastes, some of which are polluting. The critical, from the environmental angle, are the gaseous emissions which have adverse effects on the environment. Liquid effluents have a limited impact but can be a matter of great concern when they are allowed to discharge into public waterways (rivers, natural drains and soils). The solids have two aspects, one dust and fugitive emissions which are environmentally damaging, and the second solid waste.

The polluting elements also have impacts on human well-being and have been responsible for quite a few on long term health. Similarly, the work environment demanded by each of the processes is also challenging in terms of ambient temperature and ambient air quality (toxic, dust laden). Human safety is another environmental aspect which is of concern. Noise levels in many of the installations (boiler houses, blower houses, turbine stations, large drives and fans) are quite high and damaging to the humans.

Historical Perspective

Fig 9 - 1 shows the steel industry environmental control journey. It will be clear that the steel industry recognized the adverse impact of its operations fairly early as can be seen from

Figure 9-1. It also took initiatives in line with the demands of the emerging global energy scenes as well as global climate control objectives.

Impacts besides the direct pollution such as waste disposal also got quite an attention and newer technologies to mitigate this aspect have been under development for a long time.

Magnitude of Pollution

The magnitude of the pollution from the steel industry is quite daunting due to the carbon intensive energy use, multiple and huge quantities of raw materials and process stages and variety of equipment used for steel making. This assumes a very large dimension due to the scale of steelplant operations (ranging from 1 to 15 million tons and more in one location).

Pollution Arisings

The pollution arisings at every stage of steelmaking are shown in Figures 9-2 to 9-7 as follows:

Figure 9-2 Pollution arising in cokemaking

Figure 9-3 Pollution arising in sintermaking

Figure 9-4 Pollution arising in ironmaking

Figure 9-5 Pollution arising in steelmaking (BOF)

Figure 9-6 Pollution arising in steelmaking (EAF)

Figure 9-7 Pollution arising in rolling and finishing

Overall Emissions in Steel Manufacture

The level of emissions as well as pollution varies significantly from process route to process route. The overall gaseous, solid and liquid arisings (emissions included) and wastes in integrated steelmaking (BF-BOF Route) as well through the EAF route are shown in Fig 9-8 and Fig 9-9 respectively.

Typical CO₂ emissions in a steel mill and their proportions in the overall emissions are given in Fig 9-10 and 9-11. The blast furnace is the main CO₂ emitter in steel production accounting for over 73%.

Steel and environment in perspective

The environmental concerns on steel production can be clearly divided into three categories as follows:

- Process Emissions which have adverse impact on environment and climate control.
- Effluents which can have damaging effects on public water streams, outfalls and soils.
- Waste arisings as part of the process which have adverse impacts on land use, resource optimization and on environment if unaddressed effectively.

It is important to recognise that the environmental impact of steel production is considerably less than competing materials such as aluminium and plastics, carbon composites etc (Fig 9-12). It is this attribute of steel which will continue to make it sustainable. However, its aggregate impact appears high due to the high volume of steel production of over 1.6 billion tons per year and still growing.

INDUSTRY INITIATIVES

The steel industry actions to combat/reduce/neutralize the adverse environmental impacts have been quite far reaching so far. The major steps include:

- Improvements to existing process technologies to reduce impacts through reduced material usages, better quality inputs, innovative processes, reduced energy and water consumptions, circular economy, and life cycle perspectives.
- Better plant and equipment design, operational efficiencies and innovations to provide adequate control of Pollution arisings.
- Effective waste management focused on reducing waste generation, and conversion of waste to useful inputs/products.
- Breakthrough technologies for dealing with issues related to carbon reduction, both for reduced usage/elimination as a reductant and also use of alternative reductant and energy sources.

The details of the various technologies have been dealt with in detail in respective chapters at different places. A brief overall recap here would put the issue of mitigation in perspective.

Process improvements

Considerable development of processes used for integrated as well as secondary steelmaking has been driven by the need to reduce energy intensity, material uses, as well as process arisings as explained in different parts of the earlier chapters. The notable developments are recounted here in Table 9-1 processes stage-wise. (Figure 9-13)

TABLE 9-1 PROCESS DEVELOPMENTS VS ENVIRONMENTAL IMPACTS

	DEVELOPMENTS	ENVIRONMENTAL IMPACT
Coke making	NR coking	Avoidance of pollution
	Coal moisture control	Energy saving
	Coke dry quenching	No water usage, scope for power generation
	Improved by-product recovery	Desulphurisation
Sinter plant	Emission optimised sintering	Reduction of pollution
	Waste heat recovery (cooler)	Energy optimization and carbon reduction
Blast furnace	PCI and auxiliary coal injection	Reduced coke use
	Top gas pressure recovery	Energy optimization and carbon reduction

	Cast house slag granulation	Converting slag to useful material, saving land fill
	HBS (heat recovery)	Energy optimization and carbon reduction
Steel making		
(BOF/EAF)	BOF off gas recovery	By product fuel and carbon reduction
	Dry gas cleaning	Reduced water usage, avoidance of wet sludge, efficient dust collection for reuse.
	Granulation of slag (BOF/EAF)	Converting slag to useful material, saving land fill
	Off gas waste heat recovery (EAF)	Energy optimization and carbon reduction
	Scrap preheating	Energy optimization and carbon reduction
Continuous casting	Continuous casting	Reduced process steps, energy needs and waste arisings, improved yield
	Near net shape casting	Energy optimization and carbon reduction. Material saving
	In line strand (core) reduction	Energy optimization and carbon reduction
Hot rolling	Hot charging	Energy optimization and carbon reduction
	Thermo mechanical rolling	Energy optimization and carbon reduction
	Casting and In line rolling	Major energy saving and carbon reduction

Recycling and Waste Reduction

Steel industry focus on waste reduction and improved resource utilisation has been driven from financial, environmental as well as social priorities. Steel's inherent capability for recycling has been a source of great impact. The value embedded in the coproducts has been a source of major incentive for its processing and recovery. Adverse environmental impacts and wasteful landfills have also been at the core of the technologies for avoiding indiscriminate dumping of the waste arisings.

The recycling strategy of the steel industry envelopes the following:

- By product energy recycling for in-house needs
- Process scrap as well as obsolete scrap recycling for steel production
- Recovery of co-products and making them suitable for other user industries/applications.
- Assisting in recycling wastes from other sources such as plastics and tyres.

Steel recycling

Steel by its very nature is an environmentally compatible material. By its complete recyclability, environmental impacts are minimized and it enables establishment of a truly closed loop manufacture with reduced demands on fresh raw materials. This aspect has been dealt with in detail in other chapters. Some of the key aspects with relevance to environmental control are presented here.

Recycled steel is projected to form nearly 30% of the global steel production, over 0.5 billion tons annually by 2030. Thus, technologies for efficient collection, classification, reuse strategies, and preparation for use in steelmaking are aspects that are being effectively addressed in the secondary sector. Recycling attribute of steel is also the fundamental to the easier adoption of circular economy in steel with zero waste approach.

Recycling of co-products

While recycling of scrap steel is an age old and established practice, increasing efforts are now directed towards the recycling of other co-products, which besides improving economics also acts as an important pollution control measure. Typical scenario of the recycling of co-products of steelmaking industry is given in Table 9-2. It will be observed that the recycling rate of the major co-products (slags, process and other iron bearing wastes) is near-total, thus establishing a sustainable manufacture.

Recycling of other industry EOL products/Wastes

Recycling other industry end of life products/wastes is also an area where the steel industry plays a significant role resulting in indirect environmental control. For example,

- Sludge resulting from paper-making processes and the dross generated in the production of aluminium are used as heat-insulating materials and as chemical agents in refining steel,
- Nickel catalysts used in oil refining and food processing are recycled as raw materials in the manufacture of stainless steel,
- Iron powder collected as a residue in the waste acid recovery process in the different areas is also used as raw material for steel making.
- Tyre recycling is used as a recovery tool for the steel and carbon.
- Waste plastics recycling as an additive in coke making.

Nearly the entire process waste arisings and coproducts are currently recovered /recycled as can be seen from table 9-2

TABLE 9-2 RECOVERY FROM WASTES & RECYCLING

CO PRODUCTS	RECYCLING RATES	INPUTS TO PRODUCTS/PRODUCTS
Blast furnace slag,	100 %	Cement, concrete aggregate, roadbed
Steelmaking slag	Over 95% possible	Process additive, concrete additive, roadbed, soil additive, sea bed preparation
Dust	Over 98% possible	In-house use and zinc refining
Rolling oil and coating materials wastes	Over 65% possible	Reuse in-house
Refractories	Over 80% possible	Recovery and reuse, input for remanufacture

Figure 9-14 outlines the steel industry initiatives towards energy & material recycling.

Pollution control still vital

Besides the process emissions, dust arisings in handling and transport of raw materials is a major area of focus due to the magnitudes. The issue of fugitive dusts is addressed as follows:

- Use of better raw materials
- Equipping bulk material handling systems with dust collection facilities.
- Use of closed conveyors for transport of the raw materials to the units and dust collection at numerous points on line.
- Reduction/elimination of particulate matter by installing extensive dust collectors at all facilities and points of arising.

Measures to improve logistics

The transportation component of steel manufacture as well as its distribution is a major consumer of energy (over 20 % of the overall energy consumption). Thus the adoption of energy-saving measures to reduce CO2 emissions generated by this sector is also a vital area of focus. Examples of environmental impact reduction measures including energy savings in logistics include:

- Increased use of green transport equipment (EV's)
- Promotion of energy conservation
- Reduction of transport distance
- Improvement of loading rates and more efficient payloads
- Increased Coastal transport

Waste water and Effluents

The sources of water pollution in steel production are shown in Figure 9-15. Quantitatively, the ironmaking segment accounts for the larger consumption as well as pollution due to its focus on using virgin raw materials for the production of iron. Environmental preservation of water measures through reduced discharge of effluents, near 100% reuse of process water, reduced water consumption, improving the treatment efficiency waste water treatment facilities.

Facility and operation aspects

A holistic approach to pollution has now come to be adopted in industry. A coordinated view of technology, optimized energy use, waste management and extensive pollution control equipment in manufacturing plants is now par for the course right from design through the production stages.

Key Pollution Control Measures

The key aspects of pollution control adopted at present in iron and steel production are given in Table 9-3.

TABLE 9-3 KEY POLLUTION CONTROL MEASURES

	CONTROL SYSTEMS	ENVIRONMENTAL IMPACT & ACTIONS
Coke making	Charge emission control and FES	Control of dust arisings and efficient collection
	Pushing emission control and FES	Control of dust arisings and efficient collection
Sinter plant	Closed material handling	Control of dust arisings and efficient collection
	Very efficient ESP and bag filters for exhausts and secondary arisings	Control of dust arisings improved dust collection for reuse.
	Dry dedusting systems	Reduction in water usage. Avoidance of sludge.
	Secondary dedusting of the unit	Safe and better work environment
Blast furnace	FES systems in stock houses cast houses	Control of dust arisings and efficient collection
	Runner covers and exhaust systems	Control of fumes and related dust arisings. Safe and better work environment
	Highly efficient ESP and bag filters for exhausts as well as	Control of dust arisings improved dust collection for reuse.
	100 % cast house slag granulation	Conversion of waste to wealth
(BOF/EAF)	Effective gas recovery	Reduced emissions, carbon footprint reduction through reduced energy purchase, avoiding flaring of off gas
	Dry gas cleaning systems	Reduction water usage. Avoidance of sludge.

	Highly efficient ESP and bag filters for exhausts as well as secondary arisings	Control of dust arisings improved dust collection for reuse.
	Secondary dedusting of the unit	Safe and better work environment
	Slag granulation	Conversion of part of the slag to ready use construction material and input for other processes.
CC	FES for fumes.	Control of fumes and steam arisings.
	Secondary dedusting of the unit	Safe and better work environment
Hot rolling	Secondary dedusting of the unit	Safe and better work environment
Water Use	System separation	Fit for use optimisation
	Closed loop systems	Reduction of losses and need for make up
	Rainwater harvesting	Reducing external fresh water demand
	Zero discharge	Avoidance of pollution of surrounding land and water bodies
		Reduced make up water demand

PRODUCT DEVELOPMENT

Steel is one of the most efficient modern construction materials. It offers the highest strength-to-weight ratio of any commonly-used material and is exceptionally durable. Improved material usage through better quality steels is an important aspect that the industry has been pursuing on its own initiatives as well as on the demands of its principal users. Better steel products, Effective recycling, Circular Economy, and Life Cycle leverage have now come to be the foundation on which the future of steel sustainability will rest.

The industry is thus, also addressing the environmental aspect through the development of low impact environmentally friendly products in all its uses. This approach has been a hallmark of the industry focusing on specific products for specific uses, which has resulted in thousands of grades of steel in various forms are now readily available. The environmental impact aspect is explained in the following paragraphs.

Steel products to lower environmental impact

The basic principle underlying the development of products with low environmental impact (“eco-friendly products”) is the minimization of environmental impact in all the phases of the life cycle of steel. This is sought to be achieved covering the following:

- Use of ecological processes which save energy and have low environmental impact at various stages involved in the manufacture of steel products (from raw materials to products).
- Reduction in processing at the downstream stages with consequent optimization in overall manufacturing chain in terms of processing, energy use, waste generation etc.

- Developing steels for enabling optimization in using products to realize weight reduction, high efficiency and long life.
- Avoiding harmful substances with environmental impact to ensure environment friendly disposal of steel-using products at the end-of-life stage.
- To make and offer steel products which are easy to re-utilize at the stage of recycling.

With the above approach, new and sophisticated environmentally-responsible production processes have been introduced. New steel applications continue to replace conventional materials. This has contributed to the reduction of greenhouse gas emissions when the total life cycle of the application as follows:

- Reduction in quantity usage for given applications (automotive, transport, construction, consumer durables)
- Materials with specific properties induced. (corrosion resistance, electrical properties, higher strengths, optimised sizes and shapes)
- Products and properties to suit optimized downstream processing. (reduced process steps, reduced energy use, reduced carbon foot print overall)

A brief account of the environment friendly steel uses in the different sectors is given below:

Steel in automotive

Steel makes up nearly 50% of today's vehicles. Advanced high-strength steels (AHSS-HTS sheets) with high strength, weldability, and toughness are now used for nearly every new vehicle design. And this makes possible lighter, optimised vehicle designs that enhance safety, improve fuel economy and reduce lifetime greenhouse gas emissions (Emit less CO₂). This saving in emissions is more than the total amount of CO₂ emitted during the production of all the steel in the vehicle. About 2.2 tons less greenhouse gas is produced over the total life cycle of a typical five passenger vehicle when it is transformed from conventional steels to new AHSS grades and optimised design techniques.

The other notable steels include trip steels that are soft before being fabricated but become hard afterward induced transformation, lead-free aluminum- or tin-zinc-coated sheets, chromate free coated sheets lead-free free-cutting steels, electric motor materials (thinner-gauge, low core loss electrical steel sheet) all contribute to make the automotive use environmentally better.

Steel in rail transport

Rail transport has an increasingly vital role to play in mass as well as bulk transportation as it is substantially more economical, fuel efficient and environmentally friendly option as compared to the automotive

Steel is the lifeline for rail transport. It is widely used in the trains (passenger as well as freight), for the rails and infrastructure covering overhead power lines, bridges and stations and buildings etc. High strength and wear resistant rails have helped in enabling high speed

trains with consequent advantages. Innovations such as longer and straighter steel rails (250 m and beyond) mean that trains can now reach much greater speeds more safely. Thus, there is carbon savings from the displacement of alternative transport options throughout the lifetime of the track. By recycling the steel track at the end its life there is a significant reduction in the environmental impact and energy cost associated with the material.

Steel in shipping

Special grades and products with much higher tensile strengths, greater corrosion resistance etc find uses in ship building and a number of related industries resulting in reduced material usage. Large ships have played a significant role in economic transport of bulk materials, and in increased use of containers in safe, economic and faster transport.

Steel in construction

Steel usage in construction is in two distinct forms. The major use is in steel constructions such as buildings, bridges, and other infrastructure. Steel forms the core of reinforced concrete construction which includes low rise buildings, dams, and other infrastructure.

High strength and optimized rolled steel sections (jumbo beams, universal sections) enable reduction in steel usage saving resources. Specific grades, shapes and sizes address effectively the demands of modularised designs, factory manufacture of prefabricated buildings and structures, fast track construction. High strength and corrosion resistant steels improve the life of the infrastructure providing huge savings in carbon foot print over the life cycle. High strength rebars including special grades reduce material usage and concrete volumes for given applications. Recyclability enables the steel structures to be reused and also recycled for fresh production, thus preventing environmental impacts.

Steel in consumer durables and appliances

Pre-painted steel sheets for household electric appliances, endothermic service coated sheets, high efficiency electrical steels for motors are eco-friendly products used in appliances.

Steel in energy

Development of advanced steels (high strength rebars, HTS, AHSS, boiler pipes, OCT uses, special application-oriented steels etc) have also found applications in the host of other steel applications such as, power plants, renewable energy systems, energy transport, tanks and pressure vessels engineering and many others. The development of specific products suited to each of the segments with reduction in material consumption in all these applications and their amenability to recycle at the end of life make steel a highly environment friendly material.

Overall impacts

The overall positive impacts of these developments are summarized in Table 9-4 below:

TABLE 9-4 environmental impact of eco products

Key objective	GHG reduction	Waste reduction & recycling	Environmental improvement /preservation
Approach to applications	Better products and processes	Longer life impacts	Environmental (no/reduced impacts)
Effects	Reduced material usage	Waste reduction and improved recycling	Multiple areas
	CO2 reduction and energy savings		
Sector	Eco steel products	Positive sustainable impacts	Other impacts
Automobiles weight reduction and safety	High strength steel sheets rods and wires High efficiency grain-non-oriented electrical steel sheets Vibration restraint steel sheets Heat resistant stainless steels Lead-free coated steel sheets for fuel tanks	Reduced steel material demand Reduced waste Easier recycling Longer life due to high corrosion resistant steel sheets	Fuel economy Reduced noise and vibrations Improvement of exhaust gas purifying capacity No environmentally damaging substances
Rail transport high strength, wear resistant extra long	Special rail steels High strength steel	Longer life due to high wear resistant steels. Reduced material usage in cars and wagons	Higher safety greater comforts
Ship building	Special grades High corrosion resistance High strength steels	Longer life and safety Reduced material usage in ships and containers	Better payload
Cans & containers weight reduction	Ultra-thin tinplate, polypropylene -laminated steel sheets	Reduced material usage	
Electrical machinery & appliances improvement of motor efficiency formability elimination of painting process	High efficiency electrical steel sheets Lubricant film treated steel sheets Pre-painted steel sheets chromate-free galvanized steel sheets	Reduced material usage	No environmentally impacting substances Measures against noise, measures for magnetic shields

	Lead-free coated steel sheers Vibration absorbing stainless steel sheet		
Power and energy improvement of generation efficiency transformer efficiency	High efficiency grain-oriented electrical steel sheets High corrosion resistant steel pipes for boilers corrosion resistant heavy plates for smokestacks environmentally-friendly oil-well pipes	Measures for electric power generation with refuse-derived fuel	Overall reduced environmental pollution
Buildings and engineering improved construction efficiency	Hyper beams High strength structural steel High tensile strength steel wires Steels for high weld-heat input Corrosion resistance marine weather resistant steels High corrosion resistant steel Clad steel sheets (composite, titanium, stainless steel etc) -	Life span extension Reduced material usage	Environmental preservation (surplus soil, noise, vibrations, etc.) Sound absorbing panels, steel framed houses Substitution for polyvinyl chloride laminated steel sheets

Refer Figure 9-15.

WASTE MANAGEMENT

WASTE MANAGEMENT IN STEEL INDUSTRY

The waste arising in steel production include:

- Solid wastes such as slag, scale, dust from raw materials handling and processing, dust in process emissions.
- Liquid wastes such as process effluents in by product plant in coke ovens, process water wastes (process equipment cooling, quenching and material cooling, granulation, descaling)
- Gaseous waste (off gases, emissions)

Steel industry approach to waste

The steel industry has grappled with the problems of wastes arising out of processes and other areas from three angles:

- Recovery and reuse of iron content in wastes
- Conversion of wastes into useful products and additives to other uses
- Combating pollution with waste reduction in processes

There are fairly well-established technologies and operational protocols for waste management in steel industry at present. The utilization of wastes is approached from the following angles.

Conversion of waste

To make one-ton of crude steel with good raw materials and efficient operations, 5 tons of air, about 2.8 tons of raw materials and 2.5 to 3 tons of water are required. These will produce in addition to 1 ton of crude steel, 8 ton of moist laden gases and 0.5 to 0.8 ton of solid wastes. Typical waste generated in the production of one ton of steel is given in table 9-5 below:

Table 9-5 solid waste generation in steel manufacture

PROCESS WASTE	Typical	RANGE
	(KG/TCS)	(KG/TCS)
Coke breeze	80	80 - 100
BF slag	300	200-400
BOF slag	120	75-120
EAF slag	100	100-150
Mill scale	12	10-25
Dust/Sludge		
Sinter plant dust/sludge	35	10-60
BF flue dust and sludge	25	8-48
BOF sludge/dust	20	10-40
EAF sludge/dust	15	5-25
HRM Sludge	5	2-6
CRM Sludge	18	15-20
CRM Iron oxide	6	6
Refractory waste	5	5-6

It will be observed that over 75 to 88% of the total waste consists of slags. Thus, the priority for its effective management is the highest in good steel plant operation.

Slag utilisation

The principal wastes - slag arising in ironmaking as well as steelmaking together range from 350 kg to over 700 to 800 kg per ton of steel depending upon the processes used, raw materials and operating practices. Maximum attention has been received by the slags in iron and steelmaking as the improvement/recovery of these has multiple effects (environmental, economic as well as operational efficiencies). The blast furnace slag is now granulated in the cast houses on tapping from the blast furnace. The granulated product is an ideal raw material for cement making. Thus, nearly the entire (more than 98%) arising is used for cement making in most locations.

BOF slag requires stabilization due to the presence of free lime and thus has to be held in storage for extended periods. Technologies such as accelerated cooling and steam aging are now adopted to reduce the demand for dumping for natural cooling. The cooled slag is processed and converted to road and railroad ballasts, as fertilizer addition and as a chemical source. Effective use of the steelmaking slag is increasing and is currently over 70 to 90%. However, granulation techniques (with water as well as atomising air) are now getting popular as they enable the slag to be converted to a building material (cement additive, sand and aggregate replacement) the granulated slag has uses such as construction material, precast paving and related products adoption of this system enables reduction in land use, land degradation and storage and disposal impacts. About 50% of the hot and liquid slag arising can be granulated.

Dust

As a measure towards improvement in process efficiency and eco-friendliness, the industry has progressed considerably in maximizing the reuse of these arisings. The dust generation in integrated steelmaking is about 40 to 100 kg/t. The fine dust generated in material handling as well collected in the dedusting systems (ESP/bag filter) is difficult to handle. Current day dedusting systems are equipped with efficient collection and pneumatic transport to meet this requirement. Briquetting is a technique which provides the opportunity to convert the fine dust into more easily handled product.

Sinter plant is the key process unit which accepts the recycled iron-bearing wastes in good quantities. Direct use instead of as a sinter feed would result in energy saving, better quality feed and in some cases even improvements in the productivity of the furnaces. Refer Table 9-6.

Table 9-6 Iron bearing waste recovery and use

UNIT	WASTE ARISING	CURRENT/POTENTIAL USE	PROCESSING POSSIBILITY
Coke plant	Coke breeze	Sinter feed	Briquetting fine-dust
Material handling	Ore fines	Sinter feed	
	Flux fines	Sinter feed	

	DES dust		Briquetting
Sinter plant	Ore fines	Sinter feed	
	Flux fines	Sinter feed	
	Sinter fines	Recycle in sinter	
	DDS dust	Sinter feed	Briquetting
Blast furnace	Ore fines	Sinter feed	
	Flux fines	Sinter feed	
	Sinter fines	Sinter feed	
	DDS dust		Briquetting
	GCP sludge	Sinter feed	Dewater and dry
BOF shop	GCP dust	Sinter feed	
	DDS dust	Sinter feed	Briquetting
	GCP sludge	Sinter feed	Dewater and dry
CCM	Scale	Sinter feed	
Hot mill	Scale	Sinter feed	

A composite product is possible in briquetting which also provides the opportunity to use the briquettes in higher process stages such as the blast furnace and BOF. It will be noted from Table 9-7 that most these being iron bearing are being recycled after requisite processing.

Table 9-7 Process dust recovery and use

CATEGORY	ARISINGS	RECYCLING AND MITIGATION
Blast furnace dusts	7–45 kg of dust thm;	Briquetting and in-process recycling
Coke plant dusts	Varies (approx> 1 kg	Additives in sinter plant
Ferrous raw materials	Varies (upto 5-8%)	Briquetting and in-process recycling as well as auxiliary additives in the BF and EAF.
Basic oxygen furnace	14–143 kg dust/t	Briquetting and in-process recycling in BF/BOF.
Electric arc furnace steel	15–20 kg dust/t	Briquetting and in-process recycling.

Recycling levels of Waste and byproduct are shown in Figure 9-16.

Liquid waste and effluents

Water used at different process steps and operations gets polluted due to various causes. The different sources of water pollution in steelmaking is shown in Figure 9-17.

The sludge is a waste from processes using water as a medium for cooling as well as dust suppression such as gas cleaning in coking, sintering, ironmaking and steelmaking processes, hot rolling etc. Chemically laden process-effluent waste arise in units such as the by-products plants, pickling plants, coating units etc.

Current-day installations have effective filters which reduce the water content of the sludge, making it easier to handle. The direct use of sludge without drying is also being practiced in some installation where it is added in the proportioning area.

Process water waste (cooling as well as dust suppression and cleaning, process arisings) is the major effluent in steel production. The strategy adopted for containment in this area by the industry are:

- Usage reduction through equipment design and process improvements.
- Cascading is adopted to ensure optimized usages. Cooling water is largely recirculated after cooling.
- Once through water is subjected to recovery and reuse to the maximum extent to reduce demand of fresh water for makeup.
- Extensive effluent treatment for safe disposal of harmful chemical elements and also incidentally recover waste water to the extent feasible.
- Adoption of zero discharge objective as far as possible.

Waste Management Strategy Focus

Adoption of circular economy

The role of circular economy in steel industry has been dealt with in detail in Chapter 6. Its key role in terms of mitigation of pollution and reduction carbon foot prints as a consequence can be summarized as follows.

i. Its adoption provides an environmental-friendly manufacturing loop for the industry. In this context, the infinite recyclability of steel, and durability are dominating quality attributes

ii. At the process and technology level the industry efforts are directed to the following potential areas for obtaining incremental benefits:

- a. Improved charge materials (blending, agglomeration) to reduce overall materials used.
- b. Reduced slag production (less gangue in raw materials)
- c. Reduced material use through better use of arisings. (recycling of solid wastes such as dust, flue dust, scale, scrap etc).

- d.Process improvements for reduced slag generation (multistep processing in steelmaking including hot metal pre- treatments)
- e.Leveraging life cycle benefits for steel use optimization

Potential zero waste processes for the steel industry

Since waste arising in steelmaking still has a substantial share in manufacture, the industry efforts are focused on its reduction and ultimately a zero-waste prospect. It is neither reasonable nor economical to attempt to make every process within a steel plant into a zero-waste process, since the thermodynamics and kinetics of some reactions and also the nature of raw materials mitigate against achieving absolute zero waste. The key is to choose those areas with the greatest potential to make an immediate environmental and economic impact. Coke making, DRI production, iron making in blast furnace, steelmaking and hot rolling areas hold the greatest potential for economic waste minimization.

Process waste minimization, "zero waste", concept of the steel industry envelops a structured approach to minimize waste generated either directly or indirectly by

- i. Appropriate manufacturing process,
- ii.Reduce energy consumption,
- iii.Reduce air emissions, and effluents emissions.

The details of these aspects are discussed in other chapters at relevant places. Briefly these are:

i.Coke-making: One zero waste option is the development of new coking processes that reduce emissions at the source. The NR coke-making processes, sealed coke manufacturing processes such as the "jumbo coking reactor" and the Calderon coking process may nearly eliminate all coke oven emissions, approaching a true zero-waste process.

ii.Ironmaking: There are several processes for the production of direct reduced iron or the treatment of iron bearing wastes which use iron oxide fines as raw material:

- The Lurgi-Circofer (coal-based) and Circored (hydrogen based) processes use iron ore fines to produce DRI.
- One option which produces a true zero-waste process is a combination Corex and DRI plant. The excess fuel generated by a Corex plant is sufficient to produce DRI at 60% or more of the hot metal volume. In addition, the oxide and metallized iron fines generated in the DRI plant could be fed to the Corex melter-gasifier.
- "Super-Sintertm (secondary-fuel injection technology for energy reduction)" is a technology in which part of the coke breeze normally used in the sintered ore production process is replaced with a hydrogen-based gas, such as natural gas or the like, which has a lower CO₂ emission load than carbon-based coke.

- In case of blast furnace ironmaking which has minimal scope for further reduction due to the high level of optimization already reached in the process, incremental savings may be possible through some of the following steps:
 - i. Top gas recycling
 - ii. Tailoring hot metal quality and composition to derive overall system optimization (Reduction in slag volume, Improved steelmaking).
 - iii. Steelmaking: The Japanese steel industry has made great strides in zero slag steelmaking using pretreatment of hot metal as well as appropriate process adjustments. Multi-step refining for steel making is a step in this direction.
 - iv. Casting and in-line hot rolling: Near net shape casting and in line rolling with utilisation of the sensible heat in the cast steel semis is another area which has revolutionised processing with enormous reduction in the energy demand and consequent reduction carbon footprint. The level of waste generation in terms of scrap, scale also gets reduced due to more efficient heating practices including induction heating online, faster processing, highly optimized and controlled temperature regimes for processing,

Exploitative Potential

The level of success that has been achieved so far in recycling and resource optimization in steel works is typified by NSC, one of the world's leading steel producers, is shown in Table 9-8.

Table 9-8 RECYLING LEVELS IN STEELPLANTS

BY PRODUCT	RECOVERY AND REUSE	AREAS
BF Slag	100 %	BF cement, fine aggregate, road base
SMS SLAG	98 %	Road base, civil engineering material, fertiliser
DUST	80-100 %	Raw material in house use, zinc refining
SLUDGE	80-90%	Raw material in house use
COAL ASH	100 %	Cement Raw material, construction material
furnace& MILL SCALE	.90 %	Reuse
OTHERS (Refractories etc)	Varies	

Typical level of solid wastes generated in steelmaking are shown in Figure 9-17.

Steel industry Recycles other Industry wastes

Two of the major items of common use namely plastic and tyres have received considerable attention for recycling in steel industry as a part of its social sustainability.

A Waste plastics recycling process using coke oven is now used. Waste plastic after crushing, removal of foreign matter and agglomeration from part of the charge. As a result, the waste plastic is thermally decomposed into coke (about 20%), tar/light oil (about 40%) and coke oven gas (about 40%). These products obtained by the carbonization of waste plastic have their own uses:

- Coke is used in blast furnace,
- Tar and light oil are used as raw materials for various plastics, etc.
- Coke oven gas (COG) is used as clean energy at thermal power stations,

Adoption of this technology helps in resolving the waste plastics problem, conserves resources and save energy by recycling and the reduction of carbon dioxide emissions.

Recycling of waste tyres

Nippon Steel has developed technologies for the recycling of used tyres in steelworks. They are used as a partial substitute for scrap iron and coal in the scrap melting furnaces. In the scrap melting furnace, the steel cords contained in the tyres are melted and recycled as high-quality steel and the heat-generating properties of carbon derived from the melted tires aid in the melting process as a substitute for coal. In addition, exhaust gas formed during the same process is used in another downstream process of steel making.

Human Impacts

A number of measures in steelplant designs, layouts and operations and maintenance are directed at human safety, comfort and well-being. These include: Safety compliances in layout, equipment and practices. Specific risk prone areas are addressed with special equipment, precautions and safety protocols which also include on site monitoring and tracking.

- The plant design focuses on environmental imperatives through dust extraction systems, ventilation and air cooling and conditioning systems.
- Noise levels are controlled through appropriate equipment design ad control features, protection equipment, monitoring and sustained maintenance.
- Disaster management protocols are made mandatory and are tailored to suit the individual areas, criticality, constraints of plant layout etc.
- Orientation, training and fail-safe compliance are ensured through employee orientation, regular updates, seminars and special training sessions.
- Community level sensitivity is ensured through compliances on (emissions, effluents, noise levels, transport regulations and stakeholder involvements).

Life cycle approach

The life cycle approach has been dealt with in detail in Chapter 7. This approach considers the emissions associated with steel products over its entire life cycle from raw material extraction to manufacture, fabrication and use and recycling.

Steel has a very long service life and as a result its contribution to carbon reduction through extended life which results in reduced new demand for virgin raw materials and processing. The energy efficiency of buildings, plants, machinery and transportation is also highly improved with the new steels developed for the specific uses. Avoided CO₂ emissions from the use of high-grade applications are on average 6 times higher than the CO₂ emissions from the production of these advanced steels.

Therefore, viewing the issue of carbon consumption in steel production from the narrow standpoint of materials production alone can be highly misleading. The real societal demand is to minimize the emissions of CO₂ for performing the various economic functions, such as transportation, housing, construction etc. Each of these functions will lead to emissions, only part of which (in some cases very small) stem from the materials used to accomplish them.

Required approach

The steel industry needs to sustain a holistic Environmental Management approach. This involves multiple measures within the steel industry, coordinating developments with other stakeholders, and addressing climate, health and social concerns effectively. In this context the industry measures required in different areas is shown Table 9-9.

TABLE 9-9 STEEL INDUSTRY APPROACH DESIRED

KEY AREA	INDUSTRY MEASURES
Pollution prevention	i. Reduced carbon dependent technologies. ii. Efficient Emission control iii. Improved efficiencies iv. Waste reduction v. Eco friendly layouts and plant areas
Global warming prevention	i. Reduced carbon dependent technologies ii. Energy transition to RE iii. Use of Hydrogen
Effective recycling	i. Improved collection ii. Technologies for conversion and reuse
Circular economy	i. Holistic approach across supply chain ii. Overall technology coordination iii. Logistics optimisation
Life Cycle Thinking	i. Focus on durability and special products ii. Coordinated actions in line with policies

Research and development	i. Improved Processes ii. Improved products iii. Improved equipment
Social outreach	i. Hinter area ecology development and maintenance

Chapter 10

EMERGING TECHNOLOGIES

As explained in earlier Chapters, there are inevitable environmental impacts in the form of emissions, effluents and overall climate concerns arising from the steel industry. Though huge improvements have taken place over the years in all their facets of the primary technologies of steelmaking enabling sustainability so far, the larger Climate issues have brought the steel industry into focus being a significant contributor (nearly 8 per cent) of the global emissions. It is in this context that the emerging technologies in steel production are discussed in this chapter.

The global industry has undertaken massive efforts in numerous installations and institutions for improving the emissions impact scenario.

Emerging Technologies

Incremental improvements in the existing processes as well as in the type of raw materials and energy usage have provided some relief. But the essentiality of Carbon input for steel production still continues to remain central. Drastic changes in the role of the fossil fuels, therefore, demand break-through technologies to enable the industry to remain sustainable in the future. An outline of the emerging technologies has been presented here primarily focused on the stage of their development, and relevance to the future iron making scenario and ability to offer viable alternative solutions. A recapitulation of the currently available established ironmaking technologies and their present status are shown in Table 10-1.

TABLE 10-1 ESTABLISHED IRONMAKING TECHNOLOGIES

	Reaction Vessel	Production Stages	Reductant	Process status
Liquid Iron Processes				
Blast furnace	Shaft	Single	Coke & coal	Established, Widely used
COREX	Shaft-Melter Gasifier	Two	Coal	Established,
FINEX	Fluidised Bed -Melter Gasifier	Two		Established,
DR Processes				
Midrex	Shaft	Single	Natural gas	Established, Widely used
HyL	Shaft	Single	Natural gas	Established, Widely used
SL-RN etc	Rotary Kiln	Single	Coal	Established, Widely used

Blast furnace iron making has held sway in reduction of iron ore for over 7 decades, accounting currently for over 70% of the steel production globally. Consistent efforts on technology improvements, raw materials flexibility, energy efficiency, equipment performance, and scale have placed the Blast furnace in the commanding position that it is today. However, the large Carbon impact is one single factor (over 70 of the energy in iron and steelmaking is consumed at the Blast furnace stage) that has demanded an appropriate alternative for decades.

Promising Hot Metal Technologies and Promising DRI Technologies are shown in Figures 10-1 and 10-2, The TRL levels of these are shown in Figure 10-3.

Technology Development Focus

The primary impetus for the developments of alternatives to the Blast furnace so far have been:

- Need to reduce the carbon footprint of iron and steelmaking
- Avoiding use of coking coal and use of abundantly available non coking coal.
- Use of low-grade iron ore and coal inputs
- Utilisation of fines as well as plant fine wastes
- Increasing use of hydrogen as a replacement for carbon.

Promising Ironmaking Technologies

The results of various approaches have provided prima-facie many options as can be seen from Table 10-2. The entire gamut of processes of interest is shown in Appendix 10-1.

TABLE 10-2 STATUS OF PROMISING TECHNOLOGIES

	Reaction Vessel	Production stages	Reductant	Process status
Liquid Iron Processes				
Hisarna	CC- SR	Hot coupled	Coal	Pilot plant trials over Commercial scale unit awaited.
Fastmet & Fastmelt	RH-EIM	Two	Coal/Other	Proven. Awaiting larger use
Solid Iron Processes				
ITMK 3	Rotary Hearth	Single	Coal	Proven. Awaiting larger use
DR Processes				
Circofer	CFB and FB	Two	Coal	Proven. Awaiting larger use
Circored	CFB and BFB	Two	Natural gas	Proven. Awaiting larger use
Ulcored	Shaft	Single	NG/Coal gas	Evolving.

It will be noted that the alternative production processes for Hot metal and Steel as well as DRI in some cases are all still coal/natural gas based.

LEADING PROCESSES

Of the numerous options available today, the most successful so far in terms of graduating to commercial scale and stable operations are:

Corex Process

Finex Process

ITMK 3 Process

Potentially Well-placed Processes

Processes which have gone past the initial pilot plant stage and also have made advances towards commercialisation are:

Hisarna

Circofer and Circored

Fastmet and Fastmelt

Status of the Potential Processes

COREX PROCESS

The coal reduction process (COREX), was developed by Voest-Alpine industries (VAI) and DVAI. This is a two-stage operation in which DRI from a shaft furnace is charged into a final smelter-gasifier. COREX uses approximately one ton of coal per ton of hot metal, with approximately 45% of the total energy input used in ironmaking and the rest going to export fuel gas. The hot metal produced has carbon and silicon contents similar to blast furnace hot metal, however the sulfur content is much higher because nearly all of the sulphur in the coal enters the slag and hot metal.

Commercial scale installations are in successful operation in South Africa, India, S.Korea, China etc. The unit size has also been scaled upto 1.5 MTPY. The successful operation of the COREX plants has confirmed that the Process is a proven alternative to the conventional blast furnace technology. A COREX C-3000 plant with an annual capacity of 1.5 million tons of hot metal at Baosteel, China is the latest addition. The key attractions of Corex are:

- Single process without the need of coking or sinter plant
- Direct use of non-coking coal and low-quality nut coke as reducing agent
- Usage of oxygen generates a high valuable, nitrogen free export gas

Corex process can lay claim to be among the most successful initiatives as an alternative to blast furnace so far for avoiding use of coke. Since a COREX plant produces large quantities of a clean off-gas, effective use of which is at the core of its economics and profitability. The off-gas can be used for power generation as well as a substitute to natural gas. Its possible use

for direct reduction has provided a new dimension in the context of Carbon reduction and sustainability.

A holistic exploitation of this process by some of the plants that established commercial scale units in the last two decades has provided optimism in its being a viable alternative. Non-use of coke, use of non-coking coal, and effective use of off gas are attributes which are attractive in the Indian context. The increasing energy costs and the scope for using the off gas in a productive and economical and environment friendly manner may be strong enough reasons in the future for preferring this process in a larger way.

FINEX PROCESS

Finex is the ironmaking technology developed by POSCO in collaboration with Siemens VAI. A cascade of fluidized bed reactors to heat up and to pre-reduce the ore is provided. A briquetting machine is used to compact pre-reduced ore and coal thus enabling usage of low grade and fine raw materials.

Its key components include fluidized-bed reactors, a coal briquetting plant, a hot DRI compactor, and a melter-gasifier. Commercial scale Finex plants are in operation in S. Korea at Posco, Pohang.

The separation of the iron-ore reduction and melting processes in the reactors and the melter-gasifier as different from the Corex, makes operational control simpler. The reducing gas generated by coal combustion with pure oxygen in the melter-gasifier is channeled to the fluidized-bed reactors to reduce the iron.

A demonstration plant with capacity of 0.6 Mt/year was erected in 2003, followed by launching in 2007 of the first commercial plant with capacity of 1.5 Mt/year at Pohang Works. More advanced FINEX plant with simplified design and capacity of 2 Mt/year was launched in January 2014.

The best result achieved corresponds to 97% of average fuel consumption in a blast furnace (combined with coke-making and iron ore agglomeration). The environmentally friendly nature (much reduced SO_x, NO_x, and dust emissions as compared to the ISP's) of the Finex process is one of the factors that would be in its favour in the future. It is expected that better process control will help to reach in the nearest future the level of 90% CO₂ emissions compared to blast furnace.

ITMK3[®] PROCESS

Kobe Steel, Japan has developed the ITmk3[®] Process, which produces high-purity granular iron (nuggets) by utilizing iron ore concentrate and non-coking coal. The ITmk3[®] Process is distinctive with reduction, carburizing, melting and slag separation occurring promptly at lower temperature.

The effective utilization of low-grade iron ore has now acquired a global dimension as an important action towards virgin resource optimization and sustainability. In the ITmk3[®] Process, iron ore concentrate and non-coking coal are mixed together and

agglomerated into green pellets. These pellets fed which are converted into granular iron in a rotary hearth furnace (RHF), through a single stage reduction.

Since the Process utilizes non-coking coal as the reductant, issues related to coking coal and coke in the BF are circumvented leading to reduced environmental impacts and emissions.

The nuggets produced by this process can have a potentially attractive role due to their excellent physical and chemical and environment friendly attributes. These are:

- i.The high quality of nuggets equivalent to pig iron, with total Fe of 96-97%, make them an excellent raw material for steelmaking.
- ii.High density and small size of nuggets make them highly suitable to steelmaking including possibility of continuous feeding. This can have a significant place in the context of the use of EAF in a far wider manner in the future due to the increased scrap recycling foreseen.
- iii.It is easy and safe to handle transport and store. There is no re-oxidization.
- There is no significant fines generation which makes it environment friendly as well as amenable to effective use.

Commercial scale demonstration plants are in operation at Kobe steel in Japan, and at Mesabi Nuggets and SDI in USA. With the emphasis on recycling as a major direction of decarbonisation, EAF steelmaking will take center-stage in the future. In this context, this process offering an alternative high quality metallic source will be of interest to steelplants.

HISARNA

Hismelt process, a smelt reduction process had shown considerable promise. In this process a bath smelter segment had been coupled to a circulating fluid bed pre-heat/pre-reduction step using iron ores. A commercial Hismelt plant (0.8 MTPY capacity) started up in 2005 in Kwinana, Australia and operated till the end of 2008. The plant was producing (at > 75 % capacity in early 2008) merchant pig iron using Australian higher phosphorus iron ore. However, the plant was shut down and later dismantled and reportedly moved to China.

Hlsarna Process is a Smelting Reduction process concept incorporating a cyclone for heating and melting iron ore and a bath smelter, akin to the SRV of Hismelt. Hlsarna, a hybrid of the Cyclone Converter Furnace (CCF) and Hismelt, is being developed by Tata Steel in IJmuiden (The Netherlands) in Europe as the part of the ULCOS project in collaboration with Rio Tinto and several other steelmaking and engineering companies.

The innovative aspect of Hlsarna is that all core processes are directly hot-coupled. This means that the iron ore can be melted and reduced to hot iron without any intermediate gas treatment, cooling or dedusting. This iron-making process allows the direct use of fine ore and non-coking coal, In this process iron ore is processed almost directly into liquid iron (pig iron) with ore melting and pre-reduction in the CCF and the final reduction stage to liquid iron taking place in the SRV in a continuous, once through process.

All the off-gases produced are fully combusted in the melting cyclone before they leave the vessel. Therefore, the remaining top gas is concentrated CO₂. This makes CO₂ capture possible without the need for additional separation steps. The process generates more direct CO₂ than a blast furnace but thanks to phasing out of coke-making and sintering, the aggregate CO₂ emissions are 20% lower compared to conventional primary steelmaking. Sensible heat of the off gases is recovered in a waste heat boiler, from which electricity is generated in a power plant.

The key objectives of the process are multi-fold as can be seen from the following:

- 20 - 35% CO₂ reduction from the present level in ironmaking
- 80% CO₂ reduction with CCS
- Use of Low-cost raw materials
- Maximum Recycling waste oxides and scrap

A potential reduction of more than 50% CO₂ emission reduction is projected with HIsarna technology, without the need for carbon capture technology by replacing part of the coal for sustainable biomass and using steel scrap in the process. Together with the use of biomass or other waste materials to replace part of the coal and CCS, it is projected to achieve a reduction of ~80% compared to the CO₂ footprint per ton of crude steel produced from a conventional BF. Hisarna has the potential to be a preferred process for a greenfield steel mill site, once its viability has been demonstrated at scale from the present pilot plant stage.

The road map so far has been:

2011 First metal tap

2012 First long operating period

2013 High energy efficiency

First metal delivered to BOS plant

2014 Recycling of high Zn waste oxides

Recycling of scrap

2015 - 2017

- Major plant expansion (20 M € investment)
- CO₂ reduction target of 35%
- Long duration testing of process and equipment

CIRCORED AND CIRCOFER

Circored and Circofer processes of ironmaking are fluidized bed-based iron ore fines reduction processes. Both the processes have been developed by Lurgi Metallurgie GmbH, Germany (now Outotec Oyj, Finland) for the production of direct reduced iron (DRI) from

iron ore fines. For both processes, capacities above 1 million tons per annum are possible in a single production unit.

CIRCOFER

Circofer is a coal-based process that produces DRI. Iron-ore fines and recycled char are preheated by off-gas in two stages, initial reduction in the circulating fluidized-bed (CFB) and the final reduction in a fluidized-bed reactor. The DRI is briquetted.

The process has been designed with operating temperatures of around 950oC without the production of any excess gas. The DRI produced by Circofer process has greater than 93% metallization. The process has flexibility to produce HBI, a saleable product, or can be transferred to a smelting furnace for producing hot metal.

The key Process advantages are –

- Proven DRI technology
- Possible Use of any iron bearing material
- A closed energy system with minimized primary energy demand
- No excess energy
- No hazardous waste
- Environment friendly with low emissions

CIRCORED

This is a natural gas-based process similar to the Circofer for reduction of iron ore. It uses a two-stage fluidized bed process in order to achieve a high degree of metallization. The first reduction stage is a circulating fluidized bed (CFB), the second reduction stage is the bubbling fluidized bed (BFB) reactor. For heating up of the fine grained DRI product to briquetting temperature, a flash heater is used.

The final product contains no carbon because the reductant is pure hydrogen produced from the natural gas, instead of methane. The fines reach a final metallization of 92 to 93%. Off gas from BFB is fed as secondary process gas to the CFB. The gas exiting the recycle cyclone of CFB is cooled and passed through a multi-clone for the recovery of part of the dust particles, which are recycled into the flash heater. The off gas is then scrubbed and quenched simultaneously for the final removal of dust and water product during reduction. For the recovery of the scrubber dust, a micro granular process is adopted. In this process, ultrafine particles are agglomerated to micro granules with the addition of a binder to an average size of about 350 micrometers. Micro granulation can also be applied in case of ultra-fine ores such as pellet feed are to be processed.

The process produces highly metallized DRI or Hot briquetted iron (HBI) for direct feed into EAF for steelmaking. The product leaves the FB reactor at about 630-deg C, is then heated to about 680 deg C and briquetted. The special the process are:

- Direct use of iron ore fines without prior agglomeration such as pelletisation or sintering.
- Operation with pure hydrogen as reducing gas enables reduction with very low CO₂ emissions and allows lower reduction temperatures. Hydrogen is produced by means of Natural Gas reforming, but H₂ from other sources (except steam reformer) such as water electrolysis can also be used.

The Circofer EAF route is estimated to emit about 50% of the CO₂ emitted by the conventional BF-BOF route, assuming Hydrogen is generated by conventional steam reforming. If H₂ is generated by water electrolysis and electrical power for EAF are based on RE, CO₂ emissions can be decreased by 90%.

The first commercial Circored plant was built by Cliff Associates at Point Lisa Industrial Complex in Trinidad in 1998. The plant has a capacity of 500000 tpy of HBI. The plant is presently not working.

ULCORED

This process is the Worldsteel ULCOS solution for making iron based on natural gas rather than coal. A shaft furnace is used. The process involves conversion of at least 90% of the CO in the cleaned off-gas from the shaft reactor to produce H₂ and CO₂. The CO₂ is then separated using VPSA or PSA and sent for storage. The tail gas contains only CO₂ which if linked with Carbon Capture can lead to an environmentally attractive alternative. It is expected that the emission levels can be reduced by 70 % as compared to the conventional. A demonstration plant of this technology to produce 1 t/day DRI is installed at LKAB's experimental DR unit at Lulea, Sweden. ULCORED would probably be a candidate for retrofitting in existing direct reduction plants, once its viability has been demonstrated at pilot and then demonstrator scales.

FASTMET & FASTMELT

Midrex and Kobe Steel have developed two processes, FASTMET and FASTMELT, at the core of which is the focus on conversion of Steelplant wastes particularly in the sinter plant/coke oven area of ISP's. It has also provided a solution to Zinc management in scrap-based EAF waste.

FASTMET Process converts iron oxide pellet feed, oxide fines and/or steel mill wastes into metallic iron using, when necessary, pulverized coal or other carbon-bearing material as a reductant. In cases in which steel mill wastes are the primary feed material, the wastes can be briquetted, which are charged directly into the rotary hearth furnace for production of DRI (80~90% metallization). In operations, where the primary feed is virgin ore, concentrates and ground reductants are pelletized and dried before being sent to the RHF.

The flue gas leaving the RHF is fully combusted and partially quenched in the flue gas conditioner. Heat exchangers use the thermal energy in the flue gas to preheat combustion air or a cogeneration facility for production of electricity from energy contained in the RHF flue gas can be installed.

The FASTMELT Process uses the DRI, which is a feed to an electric melter known as an EIF), to produce a liquid iron known as FASTIRON.

Thus, FASTIRON has the potential to provide high purity metallic (hot metal) comparable to good hot metal from BF. Very low fines generation in the process results in high zinc content and very low iron content of the secondary dust, which can be treated to become a product.

FASTMET and FASTMELT Plants can be designed for applications from 50,000 to more than one million tons per year. These could be a solution in the context of the increasing costs of disposal of harmful wastes and the related costs along with the stringent compliance. The recovery of iron units can provide a basis for its commercial viability and furthering the Circular Economy approach.

Gas-based DR without Natural Gas

A possible game changer towards carbon reduction, but with the continued use of coal as the basic reducing agent is the production of Syngas, through coal gasification. The syngas is a gas mixture consisting of hydrogen, carbon monoxide and carbon dioxide resulting from the gasification of a carbon-containing input. Coal gasification as a technology is well established for decades. Plant scales are also quite large and thus enable optimal sizing to suit the different requirements. Gasification can be an option in new installations (both greenfield as well as existing plant expansions).

The use of steelplant export gases for the production of DRI offers the existing steel plants an opportunity to move towards lower carbon impact through reduced dependence on BF iron making exclusively. The introduction of gas based DRI can also be consistent with the future emphasis on increasing share of steel production through scrap recycling. The availability of EAF thus would also be an appropriate complementary steelmaking gateway using DRI.

The use of alternatives to natural gas for DRI production has reached commercial levels of plant scale at present. The use of Corex off gas (technically syngas from coal) in DRI production was practiced at Arcelor-Mittal Steel South Africa and at JSW in India. Jindal Steel & Power Limited (JSPL) has built the first MIDREX® Direct Reduction Plant based on commercially available coal gasification technology in Angul, Odisha, India. The plant uses indigenous coal and iron ore to produce both hot and cold direct reduced iron (DRI).

Coke ovens generate an off-gas containing hydrogen and carbon monoxide. Midrex and Praxair have partnered to develop the technology that will reform COG for use in a DR unit. Partial replacement of the natural gas through COG has been achieved at JSW Ispat in India.

SUSTAINABILITY THE KEY

New steelmaking processes are critical, but there is no one right answer. Also, the state of the development of the various initiatives indicates that most them are more long term, ten to twenty years from now.

Existing Facility Upgrade

Therefore, in the developing technologies the ones with large short-term gains, reduced demands on resources and easier transition, would be vital. This necessarily requires process upgrades, introduction of incremental technologies and use of alternatives to carbon in the existing installations. These are discussed in the following paragraphs.

Technologies vs CO₂ emission-abatement potential

Increased scrap usage with EAF offers the optimum solution for the reduction of CO₂. But in the Indian context, availability of scrap is a big question. Therefore, it cannot be relied upon to form the backbone of the strategy in the near term. Technologies related to gas injection in BF, and CCUS have lower impact on CO₂ emissions when applied individually but are the closest to industrial development for adoption. The direct-reduction technology ensures a significant CO₂ abatement in the short term via the natural gas-based direct reduction (NG-DR). In the Indian context Hydrogen rich Syn gas supplemented by CCUS offers a compromise. It also paves the way for the adoption of H₂-DR technology within a short time frame due to decent level of development and feasible results of H₂ usage and very high CO₂ abatement potential even in the medium term.

It would be clear that several technologies can be combined to raise the overall CO₂-mitigation potential above their individual limits. In the current context, the desired sequence would probably have to be on the following lines:

- Addressing existing brown-field installations for retrofitting incremental technologies and improvement steps including CCUS.
- Capacity increases (brown-field expansions) through technology upgrades (carbon reduction focused), addition of new and optimized facilities
- New Green installations.

Innovations in technology and better equipment have enabled the TSC process route to achieve substantial energy savings and consequent carbon reduction. Typically, the ISP/ESP installation (Primetal-Arvedi) has reported the following results. Table 10-3.

TABLE 10- 3 IMPACT OF TECHNOLOGY IMPROVEMENTS ESP vs. Conventional process (3-mm HRC, from liquid steel to coil)

ESP			CONVENTIONAL		
		KOE		KOE	
kWh/t	130	24.3	90	16.8	
Nm3 NG	0		36	29.5	
Total		24.3		46.3	
CO ₂ (kg)	42.5		98.6		
Advantage for ESP		-48% KOE -57% CO ₂			

ESP (1-mm HRC) vs. Conventional process (1-mm Cold Rolled from 3-mm HRC)

ESP			CONVENTIONAL		
		KOE		KOE	
kWh/t	56	10.5	90	16.8	
Nm3 NG	2.5	2.05	37.5	30.8	
Total		12.5		47.6	
CO ₂ (kg)	23.1		101.5		
Advantage for ESP		-74% KOE -77% CO ₂			

The above would confirm that the adoption of some of the incremental technologies in steelmaking, casting and inline rolling hold considerable potential in many respects (Energy consumption, Carbon impact and environmental impacts)

Process Modifications and New Processes

Adjustments to the conventional BF-BOF ironmaking process would obviously be major target in the short term given the major share of carbon from BF. Modified GDRI with EAF would also be an attractive avenue. A step-by-step improvement strategy could include the following:

- Existing Processes with required modifications with potential to provide sustainable benefits in the immediate term.
- New processes which are environment friendly, sustainable and commercially proven but require scale up and large adoption.
- Breakthrough Processes which would demand longer term efforts and consolidated actions.

Blast Furnace

Incremental technologies have been developed and are under stages of implementation for ensuring carbon reduction. These include BF top gas recycling, reduced carbon usage in BF Conversion of off gases to fuels and chemicals etc.

BF Top gas recycling using vacuum pressure swing absorption is a potential step towards reducing carbon emissions by about 10% from the present. The process incorporates a CO capture system that separates the CO₂ from the BF top gas and thus also produces a reducing gas, which is re-injected (recycled back) hot into the furnace. Pure oxygen, rather than hot blast and pretreated BF gas, is used to avoid nitrogen getting trapped in the recycling loop. At the pretreatment stage, the BF gas is separated in a CO₂-rich and a CO-rich-gas by vacuum pressure swing adsorption (VPSA). The CO-rich gas stream is fed into the furnace and the CO₂-rich stream, which still contains CO and H₂, is used for preheating the CO-rich stream. Due to the recycling of CO to the furnace, coke demand drops by 45% compared to the conventional blast furnace. ULCOS-BF is considered the fastest ULCOS route to be implemented in steel industry, because of its relative maturity and because it is a retrofit.

The first commercial plant for Converting off-gases to fuels began in 2018 in China by Lanza Tech, Shougang Group and TangMing; it produced 30 million litres of ethanol for sale in its first year of operation. A second large-scale plant with a capacity of 80 million litres of ethanol is under implementation in Ghent, Belgium under the Steelanol/Carbalyst project by ArcelorMittal and Lanzatech.

A consortium of European partners is piloting steel off-gas conversion to methanol (1t/day). The Carbon2Chem pilot plant in Germany initiated by Thyssenkrupp in 2018 has produced ammonia and methanol from steel off-gases; it is aiming for an industrial-scale plant by 2025. Carbon4PUR, a project by a consortium of 11 partners across Europe, is piloting converting steel off-gases to polyurethane foams and coatings (20 t/yr).

The TKS project in Germany involving replacement of coal by hydrogen in BF is likely to be installed in 3 blast furnaces to decrease the emissions from steel production by 20%.

CO₂ Ultimate Reduction in Steelmaking Process by Innovative Technology for Cool Earth 2050(COURSE 50) is a national research program of Japan aimed at developing the technologies to reduce CO₂ emissions from the blast furnace and to capture, separate, recover CO₂ from blast furnace gas (BFG). The initial objective is

- Development of new technologies that can reduce CO₂ emissions from blast furnace, including reforming technology of coke oven gas to increase hydrogen concentration,
- Reaction control technology to reduce carbon reducing agent by using hydrogen
- Technology for manufacturing high-strength and high-reactivity coke suitable for hydrogen reduction reaction

The other objective is to develop

- Technology for separating and recovering CO₂ through chemical and physical adsorption methods using waste heat available within the steelworks,
- Development of chemical and physical absorption device for absorbing CO₂ from blast furnace gas, the novel amine-based absorbents and catalysts, and a system combining chemical absorption and physical adsorption,
- Technology that utilizes waste heat resources from steel mills to reduce the energy required to separate and recover CO₂.

Japan's COURSE 50 project has completed the first experimental testing phase; the second phase aims to reach full commercial scale by 2030. It can be deployed with CCUS. It is predicted that the industrialized application can be realized by 2030, and the export and transfer of the technology can be realized by 2050.

The COURSE 50 project of the JISF involves two main technologies –

- Hydrogen-rich reduction and CO₂ capture and recovery from BF exhaust.

- Use of reforming technology of coke oven gas (which increases the hydrogen content from 55% to 63-67%) and a novel coking method for obtaining high-strength coke utilizing CO₂ absorption technology for utilizing waste heat are the main features.

A total reduction of emissions by 30% consisting of 10% by Hydrogen use and 20% by CO₂ recovery are being aimed at. Japan expects to operate the first blast furnace with Hydrogen reduction to reduce coke use by 2030.

In S. Korea, a full-scale plant trial is expected in 2025 with 2 Blast furnaces by 2030. The CO₂ emission target is 16% by 2030 and a further 8.7% by 2040 through complete hydrogen iron making in BF. POSCO's low-carbon ironmaking technology in South Korea includes the following aspects:

- Low-carbon ironmaking technology—FINEX. Previously, two FINEX plants have been operating in a stable manner. In 2014, another FINEX plant with an annual capacity of 2 million tons was put into operation.
- Pure hydrogen blast furnace ironmaking technology. The short-term goal is to use the by-produced gases produced in the steel production process to produce hydrogen that can be used to reduce iron ore. The medium-and-long-term goal is to develop the technology that can produce high-purity hydrogen in large quantities at low cost.
- Carbon capture and separation technology. The technology of absorbing CO₂ with the ammonia from blast furnace gas and using low-and-medium-temperature waste heat generated during steelmaking process as energy to absorb CO₂ was developed to reduce cost.

Blast Furnace with Carbon Capture

This concept is also developed by ULCOS. The main difference to the BF-GR is that the BF gas is separated by chemical scrubbing in an almost pure CO₂ stream (>99.99%) and a CO-rich stream is led back to the blast furnace. Because the CO₂-rich stream has no heat value, it cannot be used for preheating the CO-rich stream. Therefore, natural gas is used for the preheating of the stream, as well as for the additional thermal energy demand of the CO₂-separation unit via chemical scrubbing. To avoid CO₂ emissions to the air, the pure CO₂ stream must be geologically-stored or used as a feedstock for chemical products or synthetic gases.

According to the data on ULCOS, the coke demand drops 30% lower than in the conventional process. The net energy demand of the blast furnace with carbon capture is higher because of the lack of BF gas for preheating the air or the recirculated gas, and the additional thermal and electrical energy demand of the CO₂ separation unit. However, the direct CO₂ emissions from the furnace are very low (382 kgCO₂/tpig iron) because of the separation of 867 kgCO₂/tpig iron. Even taking into account the CO₂ content of the exported BF gas, the emissions are 392 kgCO₂/tpig iron and thus less than in a conventional blast furnace and the BF-GR.

Existing DR Processes with Potential

One of the major areas, which holds great potential is the Gas-based DR processes. Hydrogen, as part of the reduction process in combination with other components, has been in use for decades in the gas-based direct-reduction processes. The existing technologies already use a mixture of CO and Hydrogen (about 55% by Volume). The existing well-established direct-reduction technology, is thus the most prospective avenue for furthering the use of hydrogen in the steel industry. Efforts over the decades have confirmed the possibility of raising the hydrogen proportion upto 90% successfully even in existing installations with minimum modifications. The key requirement for enlarging this action is the availability of green/grey hydrogen on a large scale at economic costs. The carbon impact reduction can be as high as 60 to 80 % of the current levels.

Hydrogen based DRI processes such as Circored have the basic attribute of environment friendliness. But the scale at which this is at present is far from what can meet the integrated industry demands/expectations. Unless these can be scaled upto at least a million-ton level their technological potential maybe difficult to exploit fully.

Bulk of the other process developments are still coal/NG dependent and thus can only provide a limited succor if supported by palliative technologies for carbon management. The carbon capture has presented itself as an option but comes with needs for considerable additional investment, facilities and logistics and with possible site availability, environmental and social impacts.

Natural gas-based DRI plant with CO₂ capture in Abu Dhabi has been operating since 2016 with 0.8 Mt/yr of CO₂ capture capacity, with CO₂ used for enhanced oil recovery at nearby oilfield. Two plants of Ternium in Mexico are operating since 2008 capturing 5% of emissions (0.15-0.20 Mt/yr combined) for use in the beverage industry, with planning underway to upscale capture capacity Commercial Finmet plant since 1998 at Orinoco Iron, Venezuela with amine-based CO₂ separation achieving close to 100% CO₂ concentrations as an integral part of the process, but captured CO₂ is not currently used or stored.

DR Using Hydrogen Rich Gas

Midrex has moved ahead with trials in the reformer-less units for use of gas with 90% by volume of hydrogen and the balance gases consisting of CO, CO₂, CH₄ and H₂O). A demonstration plant at Arcelor Mittal, Hamburg the first of its kind in the world is being implemented with a capacity of 1000000 tpy of DRI using 100% hydrogen for reduction. This project is expected to demonstrate the large-scale production and use of DRI made with 100% hydrogen initially with “blue” hydrogen sourced from natural gas as the reductant. The plant will be the world’s first direct reduction plant on an industrial scale powered by hydrogen, and is expected to be ready by 2030.

Tenova has moved ahead with trials on increased hydrogen usage (upto 90%) in the reformer gas at a demonstration unit in Egypt.

Smelt Reduction

Hisarna pilot plant is currently operating at a Tata Steel plant in IJmuiden, Netherlands (60 kt steel produced, CCS not yet implemented). A demonstration scale (0.5 Mt/yr) plant (TRL8) is expected in 2023-27 in India and an industrial scale (1.5 Mt/yr) plant with CCS (TRL 9) is targeted in the Netherlands in 2027-33.

Initial testing is also underway to integrate full carbon capture and storage into the already commercial COREX and FINEX smelting reduction technologies. These technologies currently incorporate physical CO₂ scrubbing using pressure swing adsorption in order to isolate higher ratios of CO and H₂ for recirculation to the smelting reduction process or for use in a subsequent direct reduction plant. Upgrading to an amine-based chemical CO₂ scrubbing capture system would lead to CO₂ concentrations in the tail gas that are suitable for CO₂ use or storage.

Existing Plant Technology Update Implications

It is very likely that substantial part of main existing process units may be sought to be replaced for the proposed CO₂ mitigation options. Still, it is also realistic to have BF play a fair role (may be upto 30%) in overall steel production in the longer term, due to quality and new product demands. It is therefore imperative that very significant modifications and requisite additional equipment and facilities will be required to combat CO₂ and sustain the operations. The chief areas for BFGR are:

- the blast furnace requires gas injections, which may require significant revamping of tuyeres, gas mains, gas distribution and possibly even blast furnace shell and structure. Additional safety measures, integrated automation and control measures etc will be needed.
- the blast furnace stoves have to be partly or totally revamped to meet the substantially higher oxygen consumption in the blast furnace demanded by the additional energy need associated with replacement of carbon with hydrogen.
- Additional auxiliary facilities such as CCUS units, gas heating/reforming plants, biomass preparation plant etc of significantly large sizes, complexity and requirements (energy, storage, maintenance, etc.) will be required;
- • Energy and gas networks will require significant adaptations.

One estimate puts the cumulative potential for decarbonisation through the combined adoption of the above at nearly 30 to 40 percent of the present levels in the BF-BOF plants. Gas injection in the blast furnace (including the energy required for preparing the gas) is projected to have potential of 15-20%. This along with a carbon capture of about 40% from the process gases and other smaller measures could provide a platform for a fairly high level of decarbonisation.

Similarly, the possibility of Hydrogen injection in the BF will also demand substantial modifications and new equipment.

Process integration (PI) Key

Besides the introduction of new equipment and modifications to existing equipment and systems (including energy systems), major overhaul of process regime may become inevitable. This could prove to be the key to successful carbon reduction through existing facility upgrade.

Process Integration will thus be the key to successful adoption of the incremental technologies and process upgrades in the integrated production chain. Adopted technology routes will need to integrate the newer components into the full process chain, including upstream operations (conversion of raw materials into intermediate steel products) and downstream applications (production of final shaped and coated products). This will require a holistic approach covering:

- Equipment upgrade/replacement
- Requisite Utility systems upgrades and additions
- Appropriate layout modifications and logistics support without compromising on safety and efficient operations.
- Modernisation of the support areas
- Tailoring and trimming technology needs covering raw materials and operating practices demanded in the context of the technological upgrades and long-term requirements.
- Optimising investments and operations ensuring returns for sustainability.
- Ensuring definitive timer frames for implementation, startup and stabilization of production

MULTI-DIRECTION APPROACH

The main conclusions of the current status of the developing technology scenario may be the need for multi-directional approach recognising the following:

- Many break-through incremental technologies are not available for industrial deployment in the short term (at least until 2030/2040),
- There are some technologies currently available which enable short-term deployment with limited R&D need and investment effort, but their mitigation potential is limited, and
- All technologies need certain framework conditions, with the most important one being sufficient renewable energy as a replacement for Carbon support at competitive costs.

It is now clear that CO₂ management (CCUS) and use of Hydrogen as a replacement for carbon in the steelmaking process are the two areas which hold maximum potential and scope for successful transition.

The steel industry has responded well to the global need to reduce CO₂ emissions and to this effect it has achieved about 20% reduction in the past 20 years.

Possible Options

The following breakthrough technology routes are of major interest at the present stage of their development:

- Conventional BF-BOF-HR route the technology route upgraded with applications of several PIs and/or carbon capture and usage, or storage (CCUS) for fast and high CO₂ mitigation.
- DRI (H₂ intensive)-EAF route, with significant modifications of existing Gas based DR plants, can achieve high CO₂ mitigation without large scale need for CCUS.
- EAF share increase through scrap-based production.

Obvious Opportunity

Recycling of steel offers the optimal, fast track and least cost (in many cases) option for enabling steel industry meet the demands of climate control. Typical Carbon levels of the different process options that can be targeted are shown in Table 10- 4.

TABLE 10-4 POSSIBLE CARBON IMPACTS (PROCESSWISE)

	CO ₂ Impact t/tcs	
	Current	Possible target
BF BOF	2.3	
BF BOF TSC		1.8
EAF DRI		0.96
EAF Scrap	0.462	
EAF Scrap CCPG ⁽ⁱ⁾		0.38
EAF Scrap TSC ⁽ⁱⁱ⁾		0.275
EAF Scrap TSC ⁽ⁱⁱ⁾ CCPG ⁽ⁱ⁾		0.1

Note:i.Combined Cycle Power Generation: Efficiency improvement of power generation from 0.35 to 0.45.

ii.Thin-slab casting and in-line rolling

Thus, greater attention in ensuring return of obsolete and long-term scrap into the system can be a sustainable solution. However, it cannot be an exclusive solution due to the limitations of the recycling levels. Most optimistic projections place this share at 50% by 2050, which would mean that the alternative processes based on virgin resources have to play an equal part. It is here that Hydrogen-intensive DRI would also deserve major attention as it would be the complementary metallic source for EAF.

BREAKTHROUGH TECHNOLOGIES

Deep emission reductions are not achievable without innovation in technologies for near-zero emissions steelmaking. Hydrogen, carbon capture, use and storage (CCUS), bio-energy and Electrolysis, and Maximising share of green energy all constitute avenues for achieving deep emission reductions in steelmaking

There is, therefore, an urgent need to fast track the development process of the appropriate breakthrough technologies to enable the ambitious zero emission by 2050/2070. The potential ones are discussed in the following paragraphs.

Electrolysis (SIDERWIN)

Electrolysis is widely used in the metal industry to produce aluminum, copper or zinc. Although not used in the Steel Industry, electrolysis could in principle be applied in different ways to Steel production. From a carbon perspective, Electrolysis of iron ore could be a game changer. The technology might prove attractive as there is no direct CO₂ emission from this process and if the carbon content of electricity is sufficiently low then a really green solution could be in the making. The process has reached the scale of a small-scale laboratory pilot plant (4 kg of pure iron). Ten years of work will still probably be necessary before a good scale pilot can be designed, erected and tested.

SIDERWIN (Previously ULCOWIN) is the more mature embodiment, based on room-temperature electro-winning of an alkaline solution in which ore particles are dispersed. As per studies at MIT the energy requirements range from 6400 kWh/t or 23 GJ/t (electrolysis + annealing), and 3800 kWh/t or 13.7 GJ/t for the electrolysis and 1300 kWh/t or 4.7 GJ/t for the subsequent production.

HYDROGEN OPTION

Hydrogen has remained a potential alternative to Carbon for reduction of iron ore. Hydrogen use has come into great focus with the Carbon footprint and climate control debate and the role expected from the steel industry. But the energy issues, need for massive amounts of green energy for its production, distribution issues and costs etc are involved issues that beg resolution and thus may make this solution a long term one (possibly by 2050).

Hydrogen gains greater importance due to the carbon capture not being a highly sustainable solution on many counts such as the following:

- Difficulty in establishing the massive carbon storage sites commensurate with the demand.
- Huge additional investments in creating requisite infrastructure.
- Adverse impact on steel cost to factor in this additional process step.
- Scale mismatch
- Unknown social impacts in the future

- Potential technical challenges in large scale adoption

Hydrogen-based steel production using an EAF is considered technically feasible today and is in strong contention to be part of a potential long-term solution for steel industry decarbonizing on a large scale. The question is not whether but when and to what extent this transformation will happen.

Potential Hydrogen Alternatives

The prospective Hydrogen metallurgy development besides the existing process improvements in direct reduction and numerous other initiatives are:

- i.HYBRIT
- ii.H2FUTURE by Voestalpine (Austria); and

In this process technology, 100 % Hydrogen is used for direct reduction. SSAB(Sweden) and Vattenfall are cofounders of the project Trials have shown the following results (Table 10 -5)

TABLE 10-5 HYBRIT TEST RESULTS

	Hybrit	Blast Furnace
CO ₂ emission Kg/thm	25	1600
Bio-mass energy consumption kwh/thm	560	
Fossil energy consumption kwh/thm	42	5231
Electric Power consumption kwh/thm	3488	235
Total energy consumption kwh/thm	4090	5466

It will be seen that the CO₂ emission in Hybrit is lower by 98.44 % and energy consumption by 25.17% compared to the BF. Refer Figure 10-4.The project includes three pilot plants, a hydrogen production-Direct Hydrogen Reduction Steelmaking unit in Lulea, a non-fossil pellet plant, and a hydrogen storage plant. The HYBRIT project began operation of a pilot plant in August 2020 using 100% electrolytic hydrogen from non-fossil fuel sources, and a demonstration plant is being targeted by 2025.The first lot of green steel product was sent by Hybrit to an automaker in August 2021 for user application and trials.

H2FUTURE (Voest Alpine)

The project as the largest hydrogen reduction plant in the world, aims at coke replacement by hydrogen with ultimate reduction in CO₂ emissions by 80% by 2050.

SALCOS (Salzgitter AG)

This approach, a combined initiative of Salzgitter AG and Tenova to gradually convert a Conventional Carbon-Intensive BF into a DR-EAF process and use surplus hydrogen for

multiple uses. Waste heat from the processes in steel plant is used for generating water-vapour to produce green-electricity for use in electrolysis for hydrogen and oxygen production. Hydrogen can be used for direct reduction.

Salzgitter steelworks has undertaken MW-scale electrolyser demonstration in Germany and a feasibility study for integrating a hydrogen DRI plant into the existing site, as part of the SALCOS project.

ULCORED & CIRCORED

As earlier indicated, there are also emerging options referred earlier such as Ulcored (ULCOS initiative) and Circored. The Ulcored concept involves separating CO₂ out of the process gas, and is therefore also dependent on CCS. ULCORED would probably be a candidate for retrofitting in existing direct reduction plants, once its viability has been demonstrated at pilot and then demonstrator scales, which may be 2 decades away.

Circored was one of the earliest direct-reduction initiatives in hydrogen use. A commercial scale plant in Trinidad with a capacity of 400,000 ton/year of DRI was started up in 1999 but shut down in 2001. In the Circored process, the requisite hydrogen is produced from natural gas by an external steam reformer. It is also possible that the hydrogen is produced by water electrolysis. However, in this case the purchased electrical energy demand of 12.5 GJ/tls and natural gas for the heat will lead to total CO₂ emissions of 2407 kg/tls, which are two-times higher than in the case with hydrogen production via the steam reforming of natural gas, having CO₂ emissions of only 409 kg/tls.

The various Breakthrough Technologies Projects In Steel Industry are shown in Figure 10-5.

Scale of H₂ and CCUS Demand

In a Sustainable Development Scenario (SDS) projected by IEA, the deployment of one hydrogen-based DRI plant per month is required globally, following market introduction of the technology, and raising electricity demand by 720 terawatthours by 2050, equivalent to 60% of the steel sector's total electricity consumption today. Thus, parallel developments in energy supply and distribution will be critical to Hydrogen introduction and scaling.

Similarly, the concurrent deployment of CCUS-equipped plants is estimated to require around 0.4 Gt CO₂ capture globally in 2050, equivalent to the deployment of one large CCUS installation (1 million tons CO₂ capture per year) every 2-3 weeks from 2030.

READINESS OF EMERGING TECHNOLOGIES

It would be observed from the foregoing that a wide array of technologies directed towards lowering emissions are in the pipeline. The acceleration of their commercialisation hinges on a substantial increase in R&D efforts and supportive policy and the availability of the required inputs (renewable electricity and hydrogen) and infrastructure (CO₂ pipelines and storage facilities, grids, hydrogen networks). Availability of commensurate financing is a very major issue given the fact that the green hydrogen would demand massive green energy supply. All

this is time consuming and fraught with diverse risks which will determine the time frame for the successful use of the solutions. The status of the different technologies is discussed in the following paragraphs.

Technology Development and Time Frame

The status of the various technologies in terms of TRL, ballpark investments and the carbon abatement potential are summarised in Table 10-6.

TABLE 10-6 EMERGING TECHNOLOGIES' STATUS

Technology	TRL By			Ballpark Investment		CO ₂ Abatement Potential
	2020	2030	2050	TRL 9	Full scale	
MAIN TECHNOLOGIES				Mio US\$	Mio US\$	%
H-DR (100% H ₂)	6-8	7-9	9	200	300	95
HPSR	5	6	9	250	600	95
AIE	4	5-8	9	600		95
IBRSR	6	8	9	Near billion		20-80
BF Gas Injection	5-9	8-9	9	500	750	20-60
Biomass usage	2-7	8	9	20		30-100
Increased scrap usage	6-7	7-9	9	100		50-70: 100 with CCS
SUPPORT TECHNOLOGIES						
CCUS	5-8	9	9	500	Near billion	
CO ₂ Capture	5-6	8-9	9		500	
Water Electrolysis	5-8	7-9	9	100		
Green Hydrogen	5-6	8-9	9			
INTEGRATED PROCESS						

Optimised BF BOF Route	7-9	9	9		4-5 billion	95 (with CCS)
DRI-EAF (improved)	7-9	9	9		2- 2.5 billion	95 (with CCS)
DRI-EAF (H2 rich)	7-8	9	9		3- 3.5 billion	95
Improved SR	7-8	9	9		1- 1.2 billion	85 (with CCS)
Iron Electrolysis	2-5	3-6	?	500		95

Present Status

The different technology solutions (Existing upgrades as well as new processes) from the various specific initiatives by the different agencies worldwide which are at different stages of trials are expected to be available by 2025-30. A projected time frame of each is given in Appendix 10-2. Their status is summarised in Table 10-7 (as per IEA analysis in report of 2020).

TABLE 10-7 Status of main emerging decarbonisation technologies

Technology	TRL	Year available	Deployment status
Blast furnace			
Off-gas hydrogen enrichment and/or CO ₂ removal for use or storage	5	2030 (Very high)	i. Japan's COURSE 50 project; Demonstration scheduled for 2030 and commercial implementation 2050. Can be deployed with CCUS ii. ULCOS Top-gas recycling using VPSA proven. iii. ArcelorMittal site in Dunkirk, France relies on using the DMX™ CO₂ capture process. Launched in May 2019 and will end in May 2023. Plan for a first large CCS implementation on a full-scale unit (1.5 Mt CO₂/year) and a future CCS cluster in the North Sea. iv. IGAR Industrial-scale demonstration reforming with plasma torches likely to be completed by 2025-27.

			ROGESA pilot testing H₂-rich coke oven gas in a blast furnace in Germany, Implementation in two blast furnaces . v.STEPWISE project in Sweden to decarbonise blast furnace gas for use in power production (14 t/day CO₂ removal)
Converting off-gases to fuels	8	Present (Medium)	i.TangMing China produced 30 million litres of ethanol for sale in first year of operation (2018) ii.Large-scale plant with a capacity of 80 million litres of ethanol in Ghent, Belgium by ArcelorMittal and LanzaTech. iii.Project by Baosteel and Lanzatech to produce ethanol from the steel mill off-gases. iv.FReSMe: Capture of CO₂ and H₂ from the BF gases to produce methanol. A 50 kg/h using a blast furnace gas input of 800 m³ /h. planned.
Converting off-gases to chemicals	7	2025 (Medium)	i.Carbon2Chem pilot plant in Germany by Thyssenkrupp to produce ammonia and methanol from steel off-gases; Industrialscale plant by 2025. ii.Carbon4PUR, project in Europe, for converting steel off-gases to polyurethane foams and coatings (20 t/yr)
DRI			
Natural gas-based with CO ₂ capture	9	Today (Very high)	i. 0.8 Mt/year of commercial CO₂ capture capacity connected to a steel mill. operating in Abu Dhabi, since 2016 for enhanced oil recovery (EOR). ii.Finmet plant operating at Orinoco Iron, Venezuela, with amine-based CO₂ separation achieving close to 100% CO₂ concentrations
Smelting reduction with CCUS			
Hisarna (Under ULCOS)	7	2028 (Very high)	i.Demonstration-scale (0.5 Mt/yr) plant (TRL8) is expected in 2023-27 in India and an industrial-scale (1.5 Mt/yr) plant with CCS (TRL 9) in the Netherlands for 2027-33

FINEX			Initial testing of amine-based CO ₂ scrubbing
HYDROGEN			
Blast furnace: Electrolytic H ₂ blending	7	2025 (Medium)	i. Since 2019 Thyssenkrupp has been testing use of hydrogen in a blast furnace in Germany, replacing a proportion of injected coal
DRI: Natural gas-based with high levels of electrolytic H ₂ blending	7	2030 (High)	i. Tenova tested 90% hydrogen use in Mexico (scale of 9 kt/yr DRI production) ii. Salzgitter steelworks is undertaking 6MW-scale electrolyser demonstration in Germany SALCOS iii. Thyssenkrupp planning to build commercial DRI plants incorporating hydrogen by the mid-2020s
DRI: Based solely on electrolytic H ₂	5	2030 (Very high)	i. SSAB LKAB Vattenfall Pilot plant of HYBRIT in operation in Sweden targeting 1Mt/yr demo plant by 2025. Aim - 100 % fossil-free DRI-EAF steelmaking with 100% H ₂ and alternative fuels, such as bio-oil or pulverized biomass. The planned time frame is: Pre-feasibility Study 2016-2017 , Feasibility Study Pilot plant trials 2018-2024, Demonstration Plant Trials 2025-2035 ii. Pilot plant at existing DR plant by ArcelorMittal, by 2030 at Hamburg iii. Thyssenkrupp planning to transition towards eventual full hydrogen reduction. To replace pulverized coal with hydrogen gas in all three blast furnaces from 2022.
H ₂ plasma reduction (Smelting reduction)	4	--- (Medium)	i. SuSteel research project at voestalpine plant in Austria; (50 kg batch operation, H ₂ plasma-based) H ₂ future is green hydrogen ii. Flash ironmaking technology under development at University of Utah,
Electrolysis			
Low temperature	4	--- (Medium)	i. ULCOWIN process (electrowinning),

High temperature molten oxide	4	--- (Medium)	ii.First prototype cell commissioned (more than 1 t of metal produced
Bio-energy Blast furnace			
Torrefield biomass	7	2025 (Medium)	i.Testing use of bio-coal to partially substitute coal in ArcelorMittal's plant in Ghent
Charcoal	10	Present (Medium)	ii.Used primarily in Brazil

Refer Figure 10-6. Which shows the elements covered and the current status of the options

Hydrogen Challenges

Green steel production through Hydrogen would demand the following:

1. Hydrogen infrastructure:

A robust infrastructure for hydrogen production, storage, and distribution is fundamental and critical to operating a hydrogen-based steel plant. This will include investments in electrolyzers capable of efficiently generating green hydrogen from renewable energy sources such as wind or solar power.

2.Hydrogen based technology:

Introducing hydrogen as a reductant in blast furnaces is likely as an add on. This would call for substantial revamp of the existing process and equipment and some of the systems to address the requirements imposed by Hydrogen. This will demand substantial investment as well as time for transition and stabilisation of the process. It is generally believed that about 30% of the coke requirements of the Blast furnace could be replaced by Hydrogen.

Direct reduction using Hydrogen holds the prospect of 100% use of Hydrogen. This is due to the head start that this process has with the sue of reduction gas with high hydrogen content and the success achieved in using higher proportions of Hydrogen upto 90% and more. Thus, the direct reduction for the production of DRI offers a greater scope as well as possible lower demands of investments and operational needs. Large scale decarbonisation may be readily facilitated by this option.

3.Steelmaking process Adaptation

DRI being a solid product would demand use of EAF as the steelmaking option as compared to the Blast furnace the BOF would be the choice due to the liquid iron production. Use of EAF being almost solely dependent upon electrical energy would add to the demand of RE substantially. Thus, the criticality of energy at affordable prices as well reliability in supply will be the deciders of the ultimate success of this route. A major added advantage of the EAF is its ability to accept steel scrap as well as the metallics source. Thus, with increasing role of

recycling in the future, the process scene in steelmaking would be substantially undisturbed upto 100% scrap as charge.

4.Integration of renewable energy sources

It is highly likely that the chosen steelplant locations and the RE locations would be far apart in the Indian context. Thus, the storage and distribution of the RE is a major area of concern, as it would involve substantial costs in creating requisite infrastructure adding to the energy costs.

5.Carbon capture and utilization (CCU):

Implementing carbon capture and utilisation technologies to enable steel plants to capture CO₂ emissions generated during the steelmaking process and convert them into valuable products or transport them would be essential. By coupling CCU with hydrogen-based steel production, plants can further enhance their environmental credentials and contribute to carbon neutrality goals. This however will also add to the costs besides the resolution of the related issues of suitable sites/technology for conversion of CO₂ etc.

6. Supply chain integration:

Successful Working methodology with suppliers, particularly the RE sources, is key to a sustainable and reliable supply chain of hydrogen in a green steel plant. This will involve partnering with renewable energy providers, and hydrogen producers, a new dimension for the industry.

7.Investment and Cost Impacts

The most crucial aspect of the proposed transition is the impact on the cost of production of the steel. Various estimates (varying based on the assumptions made in regard to the investments for RE and the final cost RE to the steel plants including that for Hydrogen production) from 30 to 50% of the current levels are in circulation. Obvious recourse to Green Steel premium including carbon tax seems to be in favour. In the Indian context, this aspect must be evaluated critically as the steel input is vital for the growth of the economy and abnormal increases in steel prices could have serious cascading effects on nearly every sector.

Hydrogen Based Process Implications

Hydrogen-based processes have considerable potential due to their greater amenability to adaption in the steel process chain. The maximum potential for its use is in the production of DRI where it is readily amenable to adoption with minimal modifications to the existing systems and technologies. However, the successful introduction of Hydrogen as a replacement of coal/natural gas would have numerous challenges which need to be overcome. These relate to

- Process modifications and equipment features.
- Type of raw materials and their impacts

- Type of energy for needs other than iron making and the appropriate green supply systems
- Waste energy and recovery systems
- Dismemberment of sections of manufacturing chain and their impacts.

Raw material Impact

A major shift in the production technology of steel would have to accompany the introduction of hydrogen as the reductant. To switch production from BF/BOF to DRI/EAF using hydrogen, raw material changes will be essential with huge increase in demand for DR grade pellets. This can affect both the economics as well assured raw material availability for the industry.

DRI Process Energy Balance

With such a large amount of hydrogen, the energy balance of the shaft furnace is affected by the absence of the exothermic carbon monoxide reduction to balance the endothermic reduction. Thus, it is necessary to add energy to the shaft furnace to carry heat in the burden.

Carbon in DRI

Pure Hydrogen-based DRI will have 0% carbon. Carbon in EAF charge, either in metallic charge materials, such as DRI, HBI and pig iron, or even as pure carbon creates a significant amount of heat, helping in reducing electricity consumption and enabling faster melting. Current DRI can have 1 - 4.5% carbon depending on the process, the type of reducing gas, and DR plant operation. Changeover to Hydrogen-based DRI would necessitate addition of hydrocarbons at some place in the process to achieve the desired carbon level. This added carbon will then be converted to CO₂ in the EAF.

Existing Plant Systems

Replacement of millions of tons of BF-BOF capacity by the EAF would have serious implications on existing steel plant systems, layout, utilities and operations as well. This will demand huge investments in replacements and adaptation which must be planned for effective transition. Considering the issues involved in Hydrogen manufacture, and use on a large scale a step-by-step process transition would be appropriate for the industry. The DRI process transition fits in well with this approach as well. Factoring flexibility in plant design to adapt to the changes required for hydrogen transition would thus be a major requirement for long term sustainability as well.

Purchased Energy Role

Purchased energy would be center-stage in the hydrogen-driven operations as the byproduct fuels and the electricity generated in the ISP's will no longer be available. The introduction of EAF as the primary steelmaking unit is also totally electricity based. Thus, availability, stable supply and quality of supply at competitive prices is a vital necessity.

The absence of byproduct gases would also necessitate the purchase of fuels for the various operations currently served by them. The entire energy and utilities distribution systems in the existing plants will demand reconfiguration retrofitting.

Retrofitting Challenges

The proposed changes are highly disruptive of the entire existing plant facilities in terms of layouts, material flows, energy and utilities, transport systems and process linkages. Implementing the schemes would be a major challenge in terms of Planning, design as well as construction. Large scale revamp of these aspects would require meticulous planning, high level of construction expertise (dismantling, rebuilding, new addition integration), careful phase-wise planning, safety in execution and minimizing disruptions.

Revised plant and unit designs, estimation of facility needs, dismantling and construction volumes, disposal strategies, reconstruction volumes and appropriate construction strategies will require well researched efforts demanding time and money. Cost estimates will also have to be in adequate detail to ensure inclusion of the different aspects.

Energy Key to Hydrogen

In the event electrolysis is considered as the option for the production of Hydrogen, energy availability will be the decider. With 50-55 kWh required to produce 1 kg of hydrogen, and 50 to 60 kg of hydrogen required to produce 1 ton of steel, for adding 100 million tons of steel capacity, it would require an estimated 250 terawatt-hours (TWh) of renewable energy to fully decarbonise the annual production.

SMART PLANT CONCEPT VS STEELPLANT

The introduction of major new processes and modifications with impact on the overall manufacturing chain may offer an excellent opportunity to move the plants towards smart operations in a planned manner. Besides ensuring that the new facilities incorporate the demands of smart plants right at the beginning, their implications on the other systems as well on the supply chain can be evaluated and appropriately tailored for enabling this. So far, the thrust of the Smart plant Concept generally covers:

- Condition monitoring/Predictive Analytics
- Interoperability among systems & equipment.
- Plant Operations Management from Mobile Devices
- Intelligent Data acquisition devices
- Mobile Workflow Management

Steel industry & Industry 4.0

Industry-4.0 essentially revolves around promises of productivity improvements and operational efficiency enveloping the above requirements. With the explosion of data around involving equipment, plant and overall management, advanced data analytics and use of AI

have a key role in enabling informed decision-making particularly related to design, equipment performance and the root causes. The digital industrial technologies such as Artificial Intelligence are increasingly focused on Model-based process automation systems, Energy optimization, ongoing maintenance of production line machinery and equipment, Unplanned down-time reduction, Failure prediction, Visual Inspection and Acoustic Analysis etc.

The next generation of industry 4.0 solutions may increasingly necessitate

- Emphasis on software requiring Hybrid systems
- Collaboration in supply chain (horizontal digitalization) for superior demand visibility, better coordination, effective CE introduction
- Standardization of data exchange & compatibility
- Information security

Seamless and real-time information flow between the (IT) Information Technology layer (ERP at the enterprise level and systems at the plant level) and the (OT) Operational Technology layer (SCADA, PLC, and Control devices at the shopfloor level) is an aspect which has to be ensured at the design stage itself.

Industry Uniqueness

The important factors that set the steel industry apart from the many in making installations smart plants are:

- The mind-boggling diversity of the steel plant as it encompasses besides the numerous and complex steel related process and manufacturing technologies, areas such as Energy recovery, Waste energy (multi) Power generation and distribution, Large-scale Water treatment and efficient usage, Massive Gas plants for Oxygen, Nitrogen, Compressed air, 50 to 75 km of railway tracks, 30 to 50 km of roads and drainage, By product chemical recovery such as Sulphur, Benzol, Tertiary chemicals etc.
- The various processes, operations and operational units, therefore, cannot be grouped under a single class for general approach nor as a single integrated entity.
- Large integrated steel plants are served by existing multiple automation, instrumentation and control systems, most of them tailored to specific requirement (Process and equipment related) and in many cases integrated with the process equipment. There would be considerable diversity in the systems as these are evolved over years of research and its applications by the vendors and developers in close co-operation with the steel plants.
- Considerable privacy and restricted-use is maintained on data. This is a striking difference in approach in development of IT related technologies which tend to provide generalised solutions that can be applicable across the board.

- Steelplant equipment require diverse competent maintenance resources. Equipment and systems have also to be designed to equip them with Condition monitoring and automatic data collection facilities in selected areas.
- Systems forming part of the process equipment would be on a real time, feed forward, feedback modes. Whereas the Integrated Production Control system would have a different scale. As a practice, the analysis of the real time data is already built into the respective local units and are accessible to the users of the relevant steelplant area.
- Remote supports which have emanated from the IT industry requirements may be applicable only in very selective cases and that too for advisory modes only. Whereas the maintenance demands inside a steel plant (particularly in case of unscheduled outages) need to be attended forthwith. Outsourcing for such services would generally be restricted to deployment of outsourced skilled manpower inside the plant premises.

APPENDIX 10-1 CLASSIFICATION OF DIFFERENT PROCESSES

BY PRODUCT TYPE		
Liquid Iron/Pig Iron		BLAST FURNACE
		COREX
		Hisarna
		ITmK3
		REDSMELT
		TECNORED
		FASTMET/FASTMELT
		HISMELT
		DIOS
		ROMELT
		AISI
		CCF
Direct reduced iron (DRI)		MIDREX
		HYLSA
		SL/RN
		CIRCOFER
		FINMET

		INMETCO
		CIRCOFER
		Iron carbide
BY APPLICATION DEGREE		
In Commercial production		BLAST FURNACE
		MIDREX
		HYLSA
		COREX
		SL/RN
		ITMk3
		IRON CARBIDE
		CIRCOFER
Semi Commercial production		
Trial operation		TECNORED
		Hisarna
		HISMELT
		FASTMET/FASTMELT
		DIOS
		ROMELT
		CCF
BY CHARGE MATERIAL		
Lump ore, pellets, iron-bearing waste		COREX
		Finex
		Hisarna
		MIDREX
		HYLSA
		SL/RN
		FASTMET/FASTMELT
		TECNORED
		REDSMELT

		INMETCO
		AISI
Small-grained ore		FINMET,
		CIRCORED
		CIRCOFER
		HISMELT
		DIOS
		ROMELT
		CCF
		IRON CARBIDE
BY REDUCING AGENT TYPE		
Coke: metallurgical coke ore semi-coke		Blast furnace
		TECNORED
Coal: non-metallurgical coal		COREX
		Finex
		Hisarna
		TECHNORED
		SL/RN
		FASTMET/FASTMELT
		REDSMELT
		INMETCO
		CIRCOFER
		AISI
		CCF
Natural gas		MIDREX
		HYLSA
		CIRCORED
		FINMET
		IRON CARBIDE
Mixture of coal and natural gas		HISMELT

		DIOS
		ROMELT
BY SMELTING FURNACE TYPE		
Shaft furnace		Blast furnace
		COREX
		MIDREX
		HYLSA
		TECHNORED
Rotary kiln/ Hearth		SL-RN, ACCAR
		ITmk3
		REDSMELT
		FASTMET/FASTMELT
		INMETCO
Fluosolid reactors		
Fluidsed bed and Melter Gasifier		Finex
		FINMET
		CIRCORED
		CIRCOFER
		IRON CARBIDE

Chapter 11

DECARBONISATION AND INDIAN STEEL INDUSTRY

Carbon dependence of steelmaking on a large scale, being one of the key contributors to the emissions, has prompted huge efforts towards finding carbon reduction/elimination alternatives which can provide greater environment friendliness and long-term sustainability. In this context, a new action area that has evolved is the “Decarbonisation Strategies for Steel Industry”. The approach to decarbonisation, status of appropriate technologies for decarbonisation, and preliminary contours of transition road map with Indian steel industry in view are outlined in this chapter. Decarbonisation strategies can have a major and far-reaching effect on approach to design of the future steel production facilities.

It may be noted that some of the details presented in this chapter may be a repeat in some aspects, but it is considered important to maintain the contextual relevance. Further the narrative is in the specific context of decarbonisation as a critical objective.

STEEL AND CARBON FOOTPRINT

As already indicated, the major section of the global steel production (over 70%), because of its significant reliance on coal and being one of the largest volume industries in the world, is among the large contributors of greenhouse gaseous emissions.

The magnitude of the carbon emissions varies from the steelmaking processes adopted with BF/BOF emissions of 1.6 - 2.9 t CO₂/tcs with a typical level of about 2.2/2.3 tcs. Coal can also be used in DRI-EAF production, with average emissions of about 1.8t CO₂ / tcs for the COREX/FINEX process and upto 3.2 t CO₂ / tcs for the rotary kiln process. Natural Gas-based DRI paired with an EAF has the CO₂ emissions of 1.1 – 1.6 kg CO₂/kg steel. Hydrogen-based DRI-EAF production results in an average 0.70 t CO₂ / tcs. Recycled scrap-based EAF typically has a carbon footprint of about 0.3 to 0.6 t CO₂/tcs.

In 2020/2021/2022/2023, on average, every ton of steel produced led to the emission of 1.88/1.91/1.91/1.92 tons of CO₂, respectively. The total global direct emissions were of the order of 2.6 billion tons, representing between 7% and 9% of global anthropogenic CO₂ emissions, and about 11% of the CO₂ emissions. Over 90% of emissions from the steel industry come from iron production in nine countries or regions: Brazil, China, EU-27, India, Japan, Korea, Russia, Ukraine, and the USA.

The overall Emission intensity rose by +0.6% from 2019 to 2023 and total CO₂ emissions by +1.8%.

However, the Indian scene is a matter of concern as the contribution from India has grown significantly over the last 30 years as will be evident from the following.

	1990	2000	2005	2015	2020	2022	2023	OfWorld total
	Mton CO ₂ Eq	Mton CO ₂ Eq	Mton CO ₂ Eq	Mton CO ₂ Eq	Mton CO ₂ Eq	Mton CO ₂ Eq	Mton CO ₂ Eq	%
India	1383.06	1845.45	2120.89	3302.49	3433.62	3897.21	4133.55	7.80

In this context, a well nuanced decarbonisation strategy for the steel industry is one of the essential priorities for India and the globe.

APPROACH TO DECARBONISATION

A 3-pronged approach to decarbonisation is considered appropriate recognizing the current state of the industry, its composition and level of preparedness for disruptive change. These would be:

- Incremental actions on improving current operations and facilities with focus on carbon reduction.
- A transition road map for shift in the process shares in steelmaking with move towards low carbon options.
- Introduction of new breakthrough technologies which can drastically alter the carbon dependence and management.

Specific actions for decarbonisation are required to be multi- dimensional and across technology platforms. Besides the aspects directly forming part of the steelmaking process, other areas to be addressed in this regard are:

- Energy type and use
- Carbon management post-process
- Replacement of carbon as a Reduction agent
- Feasible out of box options

STEEL INDUSTRY INITIATIVES

The overall direction for steel industry actions for Climate Control are outlined in the approach outlined by Worldsteel. The same is shown in Figure 11-1. (FIG 11-1 Industry Actions On Climate Impact Reduction). It will be evident from this that a multi-pronged approach is inevitable to achieve the desired levels of decarbonization of the steel industry.

The steel industry actions so far to reduce/neutralize the adverse environmental impacts have been quite far-reaching. The details of the various technologies that have enabled considerable progress in this direction have been dealt with in detail in respective chapters including Chapter 9 at different places. The areas of the initiatives can be summarized as:

- Improvements to existing process technologies to reduce impacts
- Process Innovations and operational efficiencies for reduced energy consumption
- Wider adoption of Circular economy,
- Eco-friendly Product developments
- Life cycle perspectives.
- Addressing Pollution arisings through better plant and equipment design, operational efficiencies and innovations and waste management strategies.
- Breakthrough technologies for dealing with issues related to carbon reduction, both for reduced usage/elimination as a reductant and also for capture of CO₂ and its usage.

CURRENT REALITIES

Huge efforts have been directed to the above areas by the various global agencies with considerable success so far. The current status of the initiatives along with the progress made so far and likely future horizons in the direction of decarbonisation are presented in the following paragraphs.

Energy Impacts

Obviously, energy occupies the center-space for any actions related to decarbonisation, due to the fact that carbon sources in steel production are primarily the fuels (as energy and reductants).

Specific carbon emission of different primary energy sources used in steel industry is shown in Table 11-1 below. Why the coal narrative is vital for steel decarbonisation can be appreciated from the table.

TABLE 11-1 CO₂ EMISSIONS OF PRIMARY ENERGY SOURCES

	Specific CO ₂ Emission		Reference
Steel Production - Fuel Sources	kgCO ₂ /GJ	kgCO ₂ / Gcal	
Coal (Coking / BF injection / Steam	95	398	IEA
Coke	108.2	453	WSA
Coal (SR/DRI)	95	398	WSA
Natural gas	56	234	IEA
Steelplant By-products			

Coke oven gas	44	184	WSA
Blast furnace gas	27.01	130	WSA
LD gas	180	754	WSA
Coal tar	92	385	WSA
Benzol	83	348	WSA

The process and technology developments over the decades having been introduced in modernized sections of the existing units as well in the newer installations have enabled significant achievements - primarily reduced energy use, reduced coal usages, and better energy efficiency. The current energy consumption levels are about 40% of what was in existence about 4 to 5 decades ago. In the last 50 years, the steel industry has reduced its energy consumption per ton of steel produced by over 60% as can be seen from reiteration in Table 11-2. (Fig 11-2)

TABLE 11- 2 REDUCTION IN ENERGY USE IN STEELMAKING

Year	Energy Consumption Index
1960	100
1965	97
1970	91
1975	89
1980	83
1985	76
1990	69
1995	57
2000	50
2005	49
2010	43
2015	40
2020	Lower

The impact of reduction in energy use is reflected in the consistent reduction in CO₂ levels during the past decades as shown in Table 11-3.

TABLE 11-3 CO₂ EMISSION TREND IN STEELMAKING

Decade	CO ₂ emission	Reduction
	Kg/tls (Avg)	d-on-d %
1950 's	3800	-
1960's	3500	8
1970's	3200	9.15
1980's	2800	8.75
1990's	2400	14.3
2000's	2200	8.3
Overall so far		42%

Energy efficiency Measures

Besides optimization of direct energy use in the processes, Waste heat recovery at the different process stages is an area of focus due to its large share in total consumption. The major successful areas which are now part of the normal in steelplant design and operation are given in Table 11-4.

TABLE 11-4 ENERGY RECOVERY IN STEELPLANTS

Action Area	Energy Recovery Measures	Impact
Coke making	Use of COG as fuel	Fuel Self-sufficiency, Reduced Power purchase (indirect carbon reduction)
	Waste heat from CDQ	Power generation (indirect carbon reduction)
Sinter Plant	Cooler Waste heat recovery	Reduced emissions, Improved efficiency
	Main exhaust gas recovery - EOG	Potential for Reduced emissions future
Blast Furnace	Full Use of BF Gas	Fuel Self-sufficiency, Reduced Power purchase (indirect carbon reduction)
	Top Gas Recovery Turbine	Power generation (indirect carbon reduction)
	Stove heat exchanger	Reduced emissions, Improved efficiency
	Heat recovery from slag	Reduced emissions Potential for future
Steel making (BOF)	BOF Gas recovery	Fuel Self-sufficiency, Reduced Power purchase (indirect carbon reduction)
	BOF Gas Sensible heat recovery	Power generation (indirect carbon reduction)

	WHR from Slag	Reduced emissions Potential for future

Potential scope for further reduction

It would be noted that nearly 70 % of the energy and consequent CO₂ emissions are in the iron making (hot metal, DRI- Coal as well as NG). Thus, the major focus of decarbonisation efforts is in this segment

A recent Worldsteel study shows that the average energy intensity for steel production is 20 GJ/t crude steel with a potential for improvement of 15-20%. While, policies to encourage improved energy efficiency and reduced CO₂ emissions through energy performance, improvements to existing equipment may appear to be a prospective solution even at this stage, the same by themselves are not sufficient for long-term decarbonisation objectives.

For inefficient equipment in India, the gap between current energy performance and best practices can be much larger than the 20% referred above. With energy making up a significant proportion of production costs, there is also an incentive to replace the least efficient process units for ensuring viability. Improvements in operational efficiency, including enhanced process control and predictive maintenance strategies, together with the implementation of best available technologies have a potential to contribute over 30% of cumulative emissions savings in the Indian context.

TECHNOLOGIES IMPACT

Incremental technology measures have played and will continue to play a significant role in carbon reduction through process improvements, and energy efficiencies as can be seen from the various measures adopted by the industry, with consequent CO₂ reduction potential. The energy intensity of state-of-the-art blast furnaces is already approaching the practical minimum energy requirement in many installations globally. However, there are still large number of units which are old and technologically well behind. These provide scope for much improvement. A summary of the impacts of the technology developments and their impact on CO₂ reduction are given in Table 11-5. Figures indicated are typical.

TABLE 11-5 IMPACT OF ENERGY EFFICIENT TECHNOLOGIES ON CARBON EMISSION IN STEEL INDUSTRY

Technology	Description	Est. Reduction Typical	
		Energy Consumption	CO ₂ Emission
Cokemaking		MJ /t dry coke	kg /t dry coke
Controlled program	Lower temperature of coke and coke oven gas by 150°C.	262	13.4
Carbonisation control		60	3.2

Coke oven gas	Recovery of sensible heat from 650 to 800°C	300 MJ	15
Coke dry cooling	400 - 500 kg by product steam/t	1.44 GJ	73
Super coke oven	Rapid preheating, compact coke better energy efficiency.	410	21
Coal Moisture control	Energy saving (8-12% to 4- 6%	300	15
Sintering		/t gross sinter	/t gross sinter
Segregation of raw materials	Coke saving 4 kg COG saving 0.5 Nm/t	10 MJ	0.5 kg
Sinter cooler exhaust	Waste energy 500°C to 700°C to 100 to 150°C,	156 MJ	8 kg
Curtain flame ignition	Curtain-flame, line & slit burners	15 MJ	0.8 kg
Reduction of air leaks	Main exhaust system	38 MJ	2 kg
Fan Capacity	Optimisation	13 MJ	0.7 kg
Sinter main exhaust	Waste energy in exhaust gas reduction of 100 to 150°C	129 MJ/t	7 kg recovery gas
Blast Furnace		MJ /thm	kg /thm
Raw material	Improved raw material reduced slag, save coke	44	2.3 kg
TRT	Top gas Pressure recovery	108	5.5 kg
PCI	Save coking energy	4 GJ	205 kg
BF stove	Waste heat recovery	300	15.4 kg
BOF Steelmaking		MJ /tls	kg /tls
BOF gas recovery	Full BOF gas recovery	700	36
Combined blowing		140	7
BOF gas	Steam from the sensible heat	920	47
		MJ /tcs	kg /tcs
HM ratio	Increased scrap use	200	10
Heat recovery	Sensible heat from hot slabs	290	15

EAF		MJ / tls	kg / tls
Hot DRI/HBI	At temperature of ~600°C	1.5 GJ	77
EAF Off- gas heat recovery	Steam from the sensible heat	900	45
Scrap preheating	With EAF off-gas	800 MJ/t	41 kg / t
Casting & rolling		MJ /tcs	kg /tcs
Endless bar rolling	Direct rolling, Induction heating	650 - 800	32 to 40
Thin slab in line rolling	Direct rolling, Induction heating	930	47
Hot/warm charging		320	16.4
Evaporative cooling	Skid cooling in RHF	370	19

The potential for carbon reduction due to the various measures as per studies conducted for European commission, USEPA on State-of-the-Art Steelmaking Technologies and applicable BAT's, is shown in Table 11-6.

TABLE 11-6 EFFICIENT TECHNOLOGIES AND REDUCTION OF CARBON EMISSION IN PROCESS STEPS

Process Units	Technology Description	Reduction of CO ₂ Kg.CO ₂ /t product
Coke ovens	Coke dry cooling	27.5
Sinter Plant	Waste heat Recovery	57.2
	Use of waste fuels for sintering	19.5
Blast Furnace	Use of high-quality ore	15-80
	PCI	34.7-47
	NG Injection	54.9
	Improved control systems	24.4
	Hot blast stove automation	22.6
	TRT	
Direct reduction	Coal gasification	High
BOF Steelmaking	Energy recovery from BOF gas	46

	Increased efficiency by automation	15-16
EAF Steelmaking	Scrap preheating	35.2
	Improved process control	17.8
	Transformer efficiency	10.0
	Bottom stirring/gas injection	11.7
Casting	Thin slab casting in-line rolling	25-40 % energy saving
Rolling	Automated monitoring	35.3
	Recuperative burners	35.2
	Hot charging/direct rolling	30.2
	Process control in HSM	15.1
Other	Combined heat & power generation	82.1
	Energy monitoring and management	35.7

It would be evident that the adoption of these measures and introduction of the efficient technologies through retrofitting to the extent feasible in the existing installation would be a sizable contribution.

PROCESS IMPACTS

Typical stage-wise carbon emission contributions in the BF-BOF route are shown in Figure 11-4 from which it would be clear that the ironmaking (upto BF) in the ISP's is the overwhelming contributor. The overall CO₂ levels from different process routes and metallics choices are shown in Figure 11-5.

Steelmaking & Process- Route Impact

In spite of BOF steelmaking being a net CO₂ saver with its focus on chemical process energy and the use of its off gas as fuel, its key requirement of liquid hot metal (iron from BF) makes the integrated process highly carbon-intensive. It is thus obvious that the real solution for effective decarbonization would be in reducing the carbon intensive BF-BOF route dominating steel production globally. EAF steelmaking with scrap on the other hand requires most energy as electrical energy but consumes less than 30-45% of the total energy of the BF-BOF route with a CO₂ impact (Scope 1) of less than 30%.

In this context, developments in the last three decades in converting and processing liquid steel into usable products leveraging the sensible heat in the crude steel (continuously cast semi) have made big contributions to energy optimization and to overall carbon reduction as well. (Table 11-7, and Figures 11-6, &11-7).

**TABLE 11-7 IMPACT OF TECHNOLOGIES IN PROCESS ROUTES
(Energy and Carbon Contribution)**

BF-BOF Route	Energy Intensity Index	Carbon Contribution Index
Continuous Casting with Conventional hot rolling	100	100
Thin Slab Casting with in-line hot rolling	80-85	95
Near Net shape Casting with in-line hot rolling	80-85	95
SR-BOF Route		
Continuous Casting with Conventional hot rolling	98	105
Thin Slab Casting with in-line hot rolling	78-83	100
Near Net shape Casting with in-line hot rolling	78-83	100
DR-EAF Route		
Continuous Casting with Conventional hot rolling	105	105
Thin Slab Casting with in-line hot rolling	85-90	100
Near Net shape Casting with in-line hot rolling	85-90	100
SCRAP -EAF Route		
Continuous Casting with Conventional hot rolling	55	40
Thin Slab Casting with in-line hot rolling	35	38
Near Net shape Casting with in-line hot rolling	35	38

CARBON REDUCTION INITIATIVES

Carbon Capture and Use

The most direct approach would be to capture the CO₂ and find ways of usefully utilizing the same as effectively as possible. Figure 11-8 shows the areas of interest in this regard. These are in Oil fields, in Direct applications and recycling by converting the CO₂ into useful chemicals.

Worldsteel

Worldsteel, the nodal steel industry lighthouse has outlined possible directions under which the carbon reduction initiatives are being pursued globally. The focus is on developing technologies and their adoption in the steel industry. Innovative carbon management incorporated as a part of the process unit, and /or with new technologies is also a major initiative. These are:

- Coal

Coal would continue to be used as a reducing agent for the near-term foreseeable future for want of a feasible alternative. Thus, there would be no other alternative but to manage CO₂ and storage particularly in the existing BF-BOF based units in order to effect decarbonisation. The approach is similar to the power industry's effort to cut emissions from fossil fuel power plants, although the steel production solutions propose in-process CO₂ capture.

- Ironmaking solutions

These range from the blast furnace, deeply modified to accommodate CCS (the new field of carbon capture and storage) as in the ULCOS 'top gas recycling blast furnace to smelting reduction processes such as Hisarna, Finex, etc. These are dealt with in detail in the appropriate chapters. The technology initiatives and their key elements are shown in Table 11-8.

TABLE 11- 8 DECARBONISATION TECHNOLOGY INITIATIVES

Programme	Key Players	Focus Area	Key Elements	CO ₂ reduction
ULCOS BF and Similar	Worldsteel, TKS, Posco	TGR, CCS, H ₂ in BF	Hydrogen, Oxygen use	10 + 20%
Course 50	JISF	H ₂ reduction in BF	Internal hydrogen	10+20 %
Super Course 50	JISF	H ₂ reduction in BF	External hydrogen	Zero Carbon aim
H ₂ reduction ironmaking	Midrex-AM, HyL-Tenova, VAI, SAAB	DRI - H ₂ reduction without BF	Hydrogen	Over 90%
CCS	Various	Recovery of CO ₂ from BF gas etc	Capture technology	Tailored
CCU	Various	Value addition options (Carbon-to-chem. etc)	Internal as well as external	Tailored

The Technology Pathways for Carbon Reduction In Steel Industry are summarized in Figure 11-9. These include:

- Process Integration with Reduced Carbon Use (CCS)
- Carbon Valorisation and Carbon Capture (CCU*CCS)
- Carbon Direct Avoidance (HYDROGEN USE)

The various decarbonization projects which are at different stages of implementation and maturity enveloping the above broad approach are shown Fig. 11-10.

Worldsteel Approach and IEA Projection

IEA has been in the forefront in critically assessing the energy scene vis-à-vis steel industry and the decarbonisation impacts. IEA has made significant and important recommendations in its report on Energy in 2020. This also covers the emerging role of hydrogen, its large-scale adoption and related impacts.

Worldsteel is adopting a 3-way approach in the context of the IEA SDS projections as per their report of 2020. These are Worldsteel Step up, Maximise scrap use and Use of Breakthrough technologies. Worldsteel approach is comprehensive as can be seen from Figure 11-1.

Increase in the proportion of scrap in BOF, and 100 % scrap based EAF are ready avenues for scrap use increase. There are three sources of scrap namely Home scrap, Prompt Scrap and Obsolete scrap. Home scrap, being what is generated by the steel producers, has already found efficient use inside the steelworks itself in most cases. Prompt scrap which is the generation in fabrication and manufacture of steel-based products can be aggregated with a well organised and coordinated system and returned to the manufacturing chain. Obsolete scrap which is generated by the end-of-life uses is the major source and its reuse calls for a well nuanced strategy involving policies, scrap aggregators, processors and traders

BREAK THROUGH TECHNOLOGIES

Breakthrough technologies include the push towards Carbon Capture as well as use of hydrogen. It is well recognised that the aim of Carbon Neutral/Zero Carbon intensity may not reach 100% through exclusive carbon-free process developments as carbon is a multi-application contributor in steelmaking and an important element in steel. Therefore, the transition road map has to find effective solutions for legacy ridden issues as well. Thus, prospective breakthrough technologies include post process management of carbon as an important area of focus. These are:

- Carbon capture and storage (CCS)
- Carbon capture and utilization (CCU)
- Hydrogen based options

A brief outline of the technologies involved and the issues arising out of the solutions are given in the following paragraphs in the context of and with focus on steel industry.

CARBON CAPTURE AND USE

Steel industry has introduced numerous technologies to manage most common emissions (SO_x, NO_x, dust, heavy metals etc.) to meet increasingly stringent regulatory requirements. However, mitigation of CO₂ emissions still eludes the industry. as ore-based processes, rely heavily on use of carbon and (to a smaller extent Natural gas) for reduction of iron oxide to iron at high temperature. CO₂ is also emitted in calcination for fluxes such as limestone and

dolomite Ferroalloy production is also carbon based (coke, lime and from the carbon-containing electrodes). EAF process CO₂ emissions are largely through use of graphite anodes

The use of carbon capture and use, as a part of the decarbonisation strategy, is likely to be a necessary precondition to the continued use of fossil-fuel based reducing agents in steel production. This emerging technology could be based on various capture and storage options, some of which only need to be adapted to the steelmaking context, while others still need basic research. This can generate a clean and concentrated CO₂ stream that can be captured and stored. The process involves retrofitting steel plants with capture technology and requires the development of transportation networks and access to storage sites.

Considerable efforts have been directed to this aspect in the last decades and a measure of success has been achieved so far. The primary objective has been to enable carbon inputs and yet avoid their environmental impact by avoiding emissions to the atmosphere. Storing the captured CO₂, instead of flaring, would immediately lower CO₂ emissions. Successful adaptation of this option could provide much relief immediately to the industry, particularly in the context of the uncertain time frame for hydrogen adoption and its implications on commercial scale.

The daunting issues associated with Carbon capture (sites/infrastructure) and the associated costs have forced approaches towards Carbon capture and utilization (CCU). In this approach, carbon-dioxide (CO₂) is captured for recycling to useful chemicals/fuels. CCU thus avoids the need for permanent geological storage

Carbon Capture Technologies

Carbon capture and storage involve separation and capture of CO₂ from the flue gas, pressurization of the captured CO₂, transportation of the CO₂ via pipeline, and finally injection and long-term geologic storage of the captured CO₂. Several different technologies, at varying stages of development, have the potential to separate and capture CO₂, some of which only may be adapted to the steelmaking context. The concentrated stream of CO₂, with a purity of 95% or more, is produced by separating the gas out of the flue gas or process gas (the top gas of a blast furnace in the case of steelmaking) by using chemical or physical technologies (adsorption, absorption, membrane separation, cryogenic separation, etc). Various storage options for the CO₂ are indicated below.

Carbon dioxide sequestration

A potentially attractive solution for carbon-intensive activities is CO₂ sequestration. It can be carried out, in principle, in a variety of ways, although all remain at concept level, as the experience so far is limited and restricted to small scale. These are:

- **Chemical sequestration**

This consists in storing CO₂ as a chemical compound. Industrial systems exist at the scale of several hundreds of tons of CO₂ per day, which is an order of magnitude less than what would be needed for treating the emission of one blast furnace. The cost of such option is estimated at 40 US\$/t of CO₂.

- **Physical sequestration**

This means either trapping CO₂ in underground reservoirs, such as aquifers or empty gas or oil deposits, or injecting it to the bottom of oceans, where the pressure beyond a depth of 500 m liquefies CO₂. The storage capacity available worldwide is estimated at 63 Gt of CO₂, or roughly 10% of the anthropogenic emissions per year. A technology for injecting CO₂ into oil reservoir already exists, as it is being used by the oil industry to improve the recovery of oil. An oil or gas field, nearing the end of its life or already depleted; coal seams, containing methane, that will never be mined or have already been mined are the potential options.

- **Sea sequestration**

A deep saline aquifer isolated from the surface and not communicating with sub-surface aquifers containing drinkable water. The site can be on-shore or off-shore, underneath the sea floor.

CO₂ is injected under pressure, either in a gaseous or supercritical phase, depending on local conditions. When using aquifers, CO₂ replaces water and slowly dissolves in it until geochemical reactions occur with the embedding rock and minerals precipitate. This has in principle a potential several orders of magnitude larger than underground reservoirs and is expected to be effective for at least one century. The Norwegian power industry has shown that one third of the power of a fossil fuel power plant would be used up by the injection.

- **Biological sequestration**

A possible option in the future is using CO₂ either directly (for example, in the food industry) or as a feedstock in chemical processes that produce valuable carbon containing products or fuels. New biological processes currently under development make it possible to convert CO₂, CO and H₂ contained in steelmaking waste gases into fuels with a lower CO₂ intensity per unit of energy relatively to fossil fuels.

This means that C or CO₂ are accumulated in living organisms, the energy necessary for the process being derived from solar energy by natural photosynthesis. The compensation of emissions by planting trees has been put forward as a realistic solution for carrying out biological sequestration.

CO₂ Capture Options

The potential methods of CO₂ capture which could enable its use in various downstream applications are:

Chemical Absorption

Physical Separation

Membrane Separation

Chemical Looping

Calcium Looping
Direct Separation
Conversion to fuels
Conversion to Chemicals
Building Materials
Crop Yield Boosting with CO₂

Chemical absorption

This operation includes two stages, one for the absorption and the other for releasing pure CO₂ and regeneration of the chemical solvent. Chemical absorption using amine-based solvents is the most advanced technique TRL 9-11. It has been widely used for decades and is currently applied in a number of small and large-scale projects worldwide in power generation.

Physical separation

Physical separation of CO₂ is based on either adsorption, absorption, cryogenic separation, or dehydration and compression. After capture by means of an adsorbent, CO₂ is released by increasing temperature (temperature swing adsorption [TSA]) or pressure (pressure swing adsorption [PSA] or vacuum swing adsorption [VSA]). Physical separation is currently used mainly in natural gas processing and ethanol, methanol and hydrogen production (TRL 9-11).

Membrane separation

Membrane separation is based on polymeric or inorganic membranes with high CO₂ selectivity, which allow CO₂ pass through but act as barriers to retain the other gases in the gas stream. In natural gas processing, they are mainly at the demonstration stage (TRL 6-7). Membranes for CO₂ removal from Syngas and biogas are commercially available. Membranes for flue gas treatment are currently under development.

Calcium looping

Calcium looping is a technology that involves CO₂ capture at a high temperature using lime (CaO) as a sorbent to capture CO₂. The CaCO₃ is subsequently regenerated to lime and a pure stream of CO₂. The lime is then looped back to the first reactor.

Calcium looping technologies, currently at TRL 5-6, have been tested, for coal-fired fluidised bed combustors and cement manufacture. Two European projects are developing calcium looping capture technologies in steel (C4U) and cement production (CLEANKER) at pilot and pre-commercial scales.

Chemical looping

Chemical looping, a similar two-reactor technology has led to the development and operation of around 35 pilot projects (TRL 4-6) with capacity up to 3 MW for coal, gas, oil and biomass combustion.

Direct separation

Direct separation involves the capture of CO₂ process emissions from cement production by indirectly heating the limestone using a special calciner (TRL 6). Low Emissions Intensity Lime and Cement (LEILAC) pilot plant has been developed by Calix at the Heidelberg Cement plant in Lixhe, Belgium.

Supercritical CO₂ power cycles, use supercritical CO₂ (i.e. CO₂ above its critical temperature derived from combusting a fuel with oxygen to provide a flue gas composed of CO₂ and water vapour.

Two supercritical CO₂ power cycles are currently in operation: NET Power's Allam cycle and the Trigen Clean Energy Systems (CES) cycle (TRL 5-7).

CO₂ UTILISATION OR CARBON RECYCLING

Several unique properties of CO₂, such as its large heat absorption capacity, stable and nonreactive nature, and its ability to act as a solvent have enabled its use in a range of products and processes. Some of the key areas are food and beverages, metals fabrication, cooling, dry cleaning, healthcare, water treatment, fire suppression, and the injection in oil reservoirs to enhance oil recovery (CO₂-EOR). CO₂ is also increasingly used to enhance yields from industrial processes, such as methanol production and crop cultivation in greenhouses. A potential use of CO₂ is in supercritical power cycles, where CO₂ would replace water as a working fluid, increasing the efficiency of electricity generation. Fig 11- 8 CCU (Carbon Capture and Utilization): CO₂ recycling

Fuels Production

The carbon in CO₂ can be used to convert hydrogen into a synthetic hydrocarbon fuel that is easy to handle and use. The production of such fuels is highly energy-intensive and is most economically viable where both low-cost renewable energy and CO₂ are available. Currently George Olah facility in Iceland, converts around 5,600 t CO₂ per year into methanol using hydrogen produced from renewable electricity. CO₂ can be used to produce fuels and chemical intermediates through several conversion routes. Biotech solutions are already in use to transform Carbon-monoxide to Ethanol for transport

Chemicals Production

The carbon in CO₂ can be used in production of polymers and primary chemicals such as ethylene and methanol, which are building blocks to produce an array of end-use chemicals. An example of is Covestro, a company active in the field is operating a facility to produce around 5000 t of polymers per year in Dormagen, Germany. CO₂ substitutes up to 20% of the fossil feedstock normally used in the process.

The off gases in the steel plants rich in CO offer the opportunity for use in chemical manufacture as a replacement of the present practice of gasification or steam reforming for CO production from coal, oil, or natural gas. Typical chemical industry processes that can utilise CO directly, or after converting to hydrogen with shift reaction, are

- Methanol, ammonia, and urea are the potential largest volumes.
- Acetic acid, formic acid, and methyl formate are also simpler to produce directly from CO.

The results of a study show that carbon dioxide emissions caused by steel industry can be reduced by selling CO gas, from blast furnace and basic oxygen furnace, to chemical industry. As this CO gas is currently utilised in the steelplants for producing energy, the replacement electricity has to be bought from the markets. In order to meet the environmental requirements, this electricity must originate from sustainable sources.

A number of challenges are also associated with this use. These are:

- Conversion costs are relatively high.
- A large amount of carbon-free hydrogen is required for chemical conversion (reduction) since CO₂ is chemically stable.
- Except for mineralization, the storage is temporal and the CO₂ is eventually re-released into the atmosphere through combustion and decomposition.
- The amount of chemicals and fixed amount of CO₂ is limited.

Building Materials

CO₂ has potential use in the production of building materials to replace water in concrete, called CO₂ curing, or as a raw material in its constituents i.e. cement and construction aggregates. The CO₂ is reacted with minerals or waste streams, such as iron slag, to form carbonates, the form of carbon that makes up concrete. This conversion pathway is typically less energy intensive than for fuels and chemicals and involves permanent storage of CO₂ in the materials. A few applications, such as the use of CO₂ in concrete mixing, are already commercially available in some markets today. Two North American companies, CarbonCure and Solidia, are leading the commercialisation of CO₂-curing technology, with CarbonCure now operating some 175 facilities in the United States and Canada. The British company Carbon8 is among the companies using CO₂ to convert waste materials into aggregates as a component of building materials. It is currently operating two commercial plants.

Crop Yield Boost

CO₂ can enable enhanced yields of biological processes, such as algae production and crop cultivation in greenhouses. The application of CO₂ with low-temperature heat in industrial greenhouses is the most mature yield-boosting application today, and can increase yields by 25 per cent to 30 per cent. Netherlands has an estimated annual consumption between 5 and 6.3 MtCO₂.

CCU LEADS TO MANY OPPORTUNITIES

The foregoing approaches thus provide wide-ranging ways to use carbon, while decreasing and avoiding CO₂ emissions. Their dictates may well establish a high level of industrial symbiosis.

Its success will largely depend upon the evolution of appropriate policy framework, legal provisions, adequate incentives recognising the level of developmental efforts and costs, climate control as well as need for being competitive against conventional processes, fuels and materials.

In the light of numerous issues related to Hydrogen, Renewable energies, requisite infrastructure, and actions for meeting the massive additional demands, pending resolution, a holistic collaborative approach and a suitable policy framework will be inevitable. This could provide a level and equitable basis for sharing the responsibilities for decarbonization chain as well as enable the various stakeholders to retain their industry/sector viability.

CCS IMPLICATIONS ON STEEL INDUSTRY

The use of CCS will involve major retrofitting in steel plants supported by the development of suitable transportation networks and access to storage sites. If all related technical, financial and cost barriers are overcome, then CCS could be more widely deployed in the steel industry. The issues to be dealt with in this approach are:

Scale

A very major challenge is the scale of CO₂ capture to match the steel industry demand. This is quite daunting as can be seen from the IEA's core 'Sustainable Development Scenario' (SDS), by 2070, where about 75% of all the CO₂ produced globally in iron and steel needs to be captured. For this to happen, an average of 14 steel plants operating with CO₂ capture need to be brought into action every year from 2030 to 2070, amounting to over 15Gt of CO₂ being captured cumulatively by 2070. Currently, installed CCS capacity accounts for 0.0007GT/year.

In the Indian steel industry context, with a current level of CO₂ emissions at about 300 million tons per year, the storage demand would be completely out of line with the possible storage availability. This gap will only continue to increase in the future. The CCS infrastructure required and its retrofitting to the extent required in existing installations would demand huge investments and considerable additional risks to sustained production.

Storage Sites

Another challenging aspect of CO₂ capture in steel production is the availability of supporting sites for its storage. The major steel capacity particularly in India is inland and away from the Sea coasts. Also, there are hardly any abandoned oil wells (as Oil and Gas production in India is still very low) available for use. The mines (particularly iron ore) are also distant in most cases. In case the sites for carbon storage are far away from the steel plants, then the cost of transportation and creation of infrastructure in outback areas would be substantial. This could act as a major deterrent for its adoption in the steel industry. It is understood that today, only six large-scale storage sites (with a capacity of over 1 MT CO₂/year) are in operation in the world and the inventory of candidate sites and their capacities is still sketchy around in the world, as geo storage requires a complex validation and permitting process on a case-by-case basis.

There are also socio-economic issues which arise as part of their introduction which will demand serious attention.

CO₂ Transport

Currently, the CO₂ stream is transported to the storage sites in a pipeline or in boats, barges or sea vessels. The process of capturing and transporting CO is highly energy-intensive, which in turn decreases the overall efficiency of the system the CCS technology is applied to. This results in high operating costs, on top of the huge initial investment costs. Should these issues be resolved, CCS could play an important role in mitigating CO₂ emissions in the future. One projection places this potential at up to 19% of global emissions by 2050.

Additional Energy Load

The current CCS opportunities typically are believed to have a substantial parasitic load requirement that they will place upon the system from which they are capturing the CO₂ for sequestration. As a result, it is expected that CCS can lower the energy efficiency of the overall process by as much as 30 percent. This could also be higher in the Steel industry context considering bulk of the steel capacity (at least in India) are likely to be considerably distant from the storage sites extracting additional energy and infra demands. This scenario creates higher operating costs and lower energy efficiency while attempting to sequester GHG emissions.

Economics

It is reported that equipping blast furnaces with CCUS can theoretically reduce crude steel production emissions up to 63% per ton of steel in blast furnaces with suitable configurations. The application of CCU/S in natural gas-based DRI can lower the average emissions intensity of steel production by 59%. At present, CCUS has yet to be adequately demonstrated at industrial levels and proven economically.

The IEA found that innovative process routes (including CCS on the blast furnace, smelt reduction and gas-based DRI) can be expected to cost 10-50% more than conventional technology within a given regional context, noting this cost increase significantly exceeds profit margins from steelmaking today. Typical estimates indicate that carbon capture and storage (CCS) would only be viable at a cost of €100 per ton of CO₂ emitted. This would then increase the price of a ton of steel by up to €185, nearly 40 per cent increase from the current levels. How this could be compensated is a matter of vital significance not only to steel industry but to the global economies in general.

HYDROGEN PERSPECTIVES

Hydrogen use has come into great focus with the Carbon footprint and climate control debate and the role expected from the steel industry as it is potentially the most attractive, environmentally compatible reducing agent for iron and steelmaking and a replacement for the fossil fuels. Thus, many decarbonisation approaches particularly in the steel industry are quite dependent on its ready availability.

Hydrogen-based steel production, using an EAF, is considered technically feasible today. It is in strong contention to be part of a potential long-term solution for steel industry decarbonizing on a large scale due to the proposed EAF share going upto may be over 50% by 2050 to facilitate recycling on scale. The question is not whether but when and to what extent this transformation will happen.

Hydrogen Advantage

Hydrogen gains greater importance due to the carbon capture not being a highly sustainable solution on many counts such as the following:

- Difficulty in establishing the massive storage sites for CO₂ commensurate with the demand.
- Huge additional investments in creating requisite infrastructure.
- Adverse impact on steel cost to factor in this additional process step.
- Scale mismatch
- Unknown social impacts in the future
- Potential technical challenges in large scale adoption

Potential Issues with Hydrogen

While Hydrogen has taken center stage in the decarbonization debate, more particularly related to the steel industry, there are a number of highly significant issues the resolution of which will be a primary requisite for its adoption.

The major challenges associated with its production and distribution are:

- Hydrogen production is energy-intensive, which at the present moment is largely from fossil fuels.
- High cost of manufacture currently is due to high energy costs and low scale units needing large investment.
- Efficient and economical storage of hydrogen is still awaiting large scale development
- Hydrogen transportation is a major challenge given its very low density.
- Need for Scale commensurate with the demands of large capacity steel industry and its units.
- Energy support progress is the key to Hydrogen success. Green hydrogen or Zero carbon achievements are critically dependent upon the renewable (carbon-free) energy availabilities in massive scale as well as affordable costs.

These are generally discussed in the context of the Indian steel industry in the following paragraphs.

Energy vs Hydrogen

About 96% of global hydrogen production presently is reported to be produced from fossil fuels – nearly half of which from natural gas, nearly a third from oil, and just under a fifth from coal. Called ‘grey’ hydrogen, this is largely generated and consumed on the same site and so is not traded or transported.

It is expected that renewables such as Solar, Wind, Water, Marine and Geo thermal energy will emerge in the long run to replace this and make the hydrogen production green with Zero Carbon emission called Green Hydrogen. However, the progress in these areas leaves a lot of uncertainties. Thus, a more realistic and feasible solution to this end would be warranted at least for the near and mid-term future (maybe even after 2040)

In the Indian context, the evolving energy scene (higher demand due to the growth projections) may dictate the graded replacement of coal as the principal energy source. The utilization of coal gasification along with CCS for hydrogen production may well be a reality providing an opportunity for utilising easily available coal resources is also a real possibility.

Production of hydrogen thus needs to be supported by scale as well as compatible alternatives of power supply, more so with green energy. Producing the necessary amounts of hydrogen for a full decarbonisation of the steel industry would require an increase in electricity production which could even far exceed the current total energy generation in most countries of the world.

Steel industry Scale vis a vis Hydrogen

As far as steel industry is concerned, one of the key concerns in regard to hydrogen will be the scale of its operations and availability. The magnitude of global steel production is in billions of tons, the current level being in excess of 1.5 billion tons projected to increase to near 2.5 billion tons by 2050. Even assuming that recycling in the most efficient manner can meet 50% of this demand in the future, the steel capacity needing attention to decarbonisation will still be 1 to 1.5 billion tons annually. The requirements of hydrogen, if established to be a viable adaptable alternative, would be extraordinarily high as compared to the current levels of hydrogen manufacture. Therefore, any narrative on Carbon replacement in iron and steelmaking has to recognise this reality and nuanced approaches will be inevitable.

The Indian steel industry is projected to be on a high growth path for the next 30-40 years with the steel demand reaching a level of about 450 to 500 MTPY by 2050. The current emission levels of about 300 million tons in Indian steel industry will more than triple by 2050 at current levels (near billion tons/year), if the projected 500 MTPY steel demand were to be realized.

Therefore, for Hydrogen to be a sustainable option for the Indian steel industry would require to have a scale which can support individual steel installations with capacities of 3 to 15 million tons per year. Even at 50% of the capacity getting decarbonised as per climate objectives and goals would mean nearly 250 to 300 MTPY by 2050. With a hydrogen demand of about 60 to 70 Kg/t DRI, the metallics supply for this part alone would require 18 to 20

million tons of Hydrogen capacity. Besides this there are additional energy needs to be filled in by Hydrogen both as a need for its successful; use in the existing process as well as replacement of fossil fuel in other areas.

It is conservatively estimated that a million ton of steel production using hydrogen will require 75000 tons of hydrogen. The power demand for this expected to be about 900 MW or more. A large Gas-based DRI Plant producing about 1.8 million tpy of DRI could require the power generated by more than 200 large offshore wind turbines.

The current unit capacities of the various hydrogen solutions for tackling emissions are quite small and will thus necessitate multiple number of units for each large consumption prospect. Current modern technologies for hydrogen production, such as proton exchange membrane (PEM), generate about 200 Nm³ per hour of hydrogen per MW of power. Consequently a 20 MW plant – at the upper end of the size range at present – could generate 4,000 Nm³ per hour of hydrogen.

In this context, Siemens have made considerable progress in scaling the PEM modules. The currently largest SILYZER 300 model consists typically of 24 PEM electrolytic modules that together can draw 17.5 MW of power to produce up to 340 kg/h of high purity hydrogen with no CO₂ emissions. The system is claimed to operate at 75 to 88% efficiency depending on the load. Its modular design leverages use of scaling effects to minimize investment costs for large-scale industrial electrolysis plants. This could mean a capacity per unit of about 2500 tpy, requiring 35 units to serve a single DRI unit of 1.8 MTPY capacity. This is one of the highest output rates of any electrolyser currently on the market. Although still short on scale as per optimal steelplant unit capacities, such a system has the potential to pair with DRI production, as the high output rate of hydrogen is better-suited to the requirements of the direct reduction shaft. The DRI energy consumption using hydrogen is placed at about 3000 kwh per ton of DRI.

Hydrogen Storage and Transport

Currently storage of hydrogen is a major limitation in efficient utilization of hydrogen. The present methods include high pressure gaseous storage, cryogenic liquefied storage, organic and liquid storage porous material storage. The high- pressure gaseous storage and cryogenic liquefied storage are the most feasible.

Hydrogen has a high energy-density by weight, but a low energy-density by volume, when not compressed or liquefied. Thus, the cost of infrastructure for storing and transporting hydrogen can be a major obstacle in its development. Pipelines for transporting hydrogen have been in use for almost 80 years. Use of existing networks, wherever available are also a possible solution but its feasibility will be a major concern (condition, hydrogen embrittlement of steel, safety, community impacts).

As far as the steel industry is concerned, a captive installation may be a must, given the criticality of uninterrupted supply for ensuring required production. While the infrastructure (land, utilities, power linkage etc) could be shared with the steel plant, the power supply to

Hydrogen units (if on electrolysis) has to be on a guaranteed uninterrupted availability basis (24 x 7).

STEEL INDUSTRY DECARBONISATION IN PERSPECTIVE

Globally the steel industry contributes about 7-9% of the emissions, in spite of the massive volumes of steel used in the economy. As per the Energy Technology Perspective Report of IEA, it is expected that in BAU scenario the steel sector, global CO₂ contribution can go to 3.3 Gt by 2050, nearly 10 % of the global emissions. The climate action plan for 2 deg C scenario demands that this be capped at 1.3 Gt, i.e a reduction of over 60%. Thus, there is a yawning gap between aim and actual, demanding high priority actions on decarbonization. The demands in other industries such as the Cement etc are lower (about 25%).

In the Indian context, the current emissions account for about 12% of the total emissions. By 2050 the gross emissions is projected to triple as per BAU. In this case also there is a need to neutralize 60 % of the added emissions.

It is obvious that the requisite availability of carbon free energy, and steelmaking technologies based on green hydrogen and carbon free energy are vital requirements for the high level of decarbonization that is demanded of the steel industry.

NET ZERO AND STEEL INDUSTRY

The various decarbonisation projects related to steel are shown in Fig 11-10. The Technology Potentials and status and the actions to Net Zero are shown Fig 11-11. The most critical issues that can make or mar this objective are:

- Developing Hydrogen Scenario (Scale, Costs, Availability)
- Reliable RE grid power supply Scenario (Quantum as well as 24X7 supply)
- Affordable Cost of RE Power on a sustainable basis.
- Adequate R&D efforts from the industry for making the process and energy transition successful.

Successful resolution of all the above can put the Indian steel sector on a trajectory towards net zero by 2050.

This would mean:

- Establishing on scale commercial H₂-DR technology in India by 2030.
- Industrywide deployment of the same.
- Additional availability of over 700TWh of reliable electricity supply
- Electrolyser Capex of Rs 25000 to 30000/kw by 2030
- Decarbonisation of the grid fossil-based electricity

INDIA SCENE AND DECARBONISATION CAUTION

The India steel growth story is quite unique, having a major role when the rest of the world sees steel in a declining perspective. This is dictated by the economic growth imperative of the highly populated country and is an uncompromisable objective.

The huge cacophony around coal use as the principal cause does not represent the complete true picture whether Global or local. Natural gas and (both fossil fuels) have equal if not larger share in the energy scene. While the aim of carbon emissions reductions is the need of the hour, the pathways can be wide-ranging and diverse specific to local realities. Energy security is again non-compromisable and the various actions have to be sync with this requirement as well.

Global Reality

In evolving a strategy for decarbonization of the Indian steel industry, there is an overriding need for evaluating the current status of energy transition in the developed world where the initiatives have been on a roll for over a decade. Experiences in implementing the various decarbonising actions as well as in scaling up the requirements to meet the immediate 2030 objectives of energy transition would provide an appropriate guide to optimal decision making.

Energy Concerns

The areas of current concerns include the entire gamut of Decarbonisation paths such as Renewable energy, Electrification (EV's, heat pumps) CCUS, Hydrogen and Sustainable fuels. There are also serious issues related to finding appropriate financial commitment and support for the different areas. A coordinated and time bound action plan with clear steps is also not yet visible on industry scale. Time frames for the availability of mature technologies as well as energy supports are quite blurred. The policy pronouncements so far are indicative of the directions for future, but the concrete integrated steps (covering the multiple fronts both inside and outside the steel and energy fronts) are yet to take shape.

Gap in Finance Commitment

The process of financing the various decarbonisation measures has met with an extraordinary challenge in terms of the time being taken for obtaining committed financial support/investment. It is reported that in USA (the largest spender in Climate control space) more than 1000 green or blue hydrogen projects have been announced in 2015. Less than 15 % have seen financial investment decision (FID) so far.

Similarly in case of Solar, Europe is seen to be falling short of the 2030 target of 600 GW by a third. Also, less than 20% of about 114 GW of additional capacity slated to go on line by next year have reached FID. In USA around 60 % of the solar announced capacity to come on line by 2030 is pending FID.

Even the current indications (2025) are also that numerous commitments made for the Hydrogen development are getting cancelled/put on the back burner. Too few projects are reaching the FID stage and beyond.

Such uncertainties are also dogging the CCUS, Hydrogen and Sustainable fuels as most of the technologies in the above space remain largely untested in scale and have very low FID level. Only about 25% of the planned capacities are likely by 2030 as per present status. Balance need FID.

The key factors of concern seem to be:

- CCUS Technology Maturity,
- Lack of reference projects
- Long permitting procedures,
- Raw material shortages (lithium)
- Geo political uncertainties.

FID Demand

It is now emerging that requisite finance is getting highly challenging due to

- Viability concerns
- Impact on Cost competitiveness for the user segments
- Many technologies have not yet reached the commercial scale tested stage
- Relatively reduced speed of policy commitments as well as projects taking shape due to global uncertainties as well as financing challenges.

All the above issues are creating major concerns and uncertainties about the effectiveness of the solutions being pursued.

INDIA APPROACH TO FACTOR

The global experience so far on decarbonization of the steel industry raises the following red flags for India to take note:

- While there are substantial exchanges in terms of various aspects for going forward such as Technology, Role of RE, Desired road-maps for Hydrogen, reality checks on its countrywide status and realistic targets and firm time frames are elusive.
- Step-wise approaches with firm cost and time lines are still not clear as the decisions on transition are highly laden with concerns on existing asset implications including demand meeting ability, costs of replacement, and carbon management policies.
- Energy transition, one of the key elements, being a multi-sector issue requires a highly coordinated and well committed road map at the national as well as industry sector level. In case of steel industry, the power sector (even fossil based) has a more than readily imaginable role in ensuring success. Thus, clarity on the power projections and their availability in time is a critical necessity

- It is well accepted that overall about 40 % or near global energy demand would only be from RE, whereas the rest has to be from alternatives. India is no exception. Therefore, a firm supply and cost picture has to be in place supported by reliable uninterrupted supplies.
- Carbon capture as an initial step and as a sustaining part of the decarbonization strategy is fraught with multi-directional competing demands. Power sector is one of the major candidates. Clarity on the level of support that could be reliably considered has to be established.
- The key takeaways for India from the current global realities are:
 - Strong financial back up is a vital factor for plans to fructify.
 - Technology selection has to favour substantially well-proven and commercially tested and operating alternatives.
 - Cost competitiveness for the user (which decides the demand as well as the sustained marketability) must be at the core.
 - Optimistic assumptions without adequate convincing evidence on scale, future-linked cost optimisations, and uncertain policy environments can be a negative for the FID.

Indian Steel Industry Imperatives

The backdrop and major challenges for the large-scale repositioning of the Indian steel industry are:

- India is at the cusp of the take-off for becoming a very large economy in the next three decades. Steel is a vital part of the growth story as it is the most preferred and economical material of construction and engineering serving the interests of huge populations. Replacement of steel in scale therefore is far-fetched.
- Major capacity additions have taken place post industry liberalization over the last 10 to 25 years. A large number of existing assets are thus fairly new and some not even investment returned fully at present. Ensuring maximum returns from the investments already made and ensuring no disruption to the supply chain would obviously be a high priority.
- The experience of the Western economies (mostly made of numerous smaller countries with limited population and having reached a level of saturation in consumption would not be highly relevant in the Indian context. Further, these well-developed economies have benefited from the earlier high consumptions to access much larger amounts of end-of-life scrap than the consumption starved developing countries. Therefore, the narrative of EAF has a significantly different connotation in the Indian context. It is relevant due to the prospect of DRI share increase in overall steel production.

- Quite a few of the current expansion projects (under implementation at different stages) have been part of earlier master planning by the various players. Disturbing this programme would be disastrous both in terms of loss of investments as well as shortfall in planned future capacities.
- Steel industry is capital-intensive and requires a large life cycle for its economic viability. The technology upgrades, modernizations and replacements have to be seen in the context of the level of investment demanded, ability to finance the same and their feasibility and affordability. Current leverage status of potential players will also be key.
- Carbon continues to be the most economic reductant for iron ore and with not many equivalent alternatives in sight.
- The new low carbon technologies (read Hydrogen) have their development challenges, scaling issues and above all investments for commercial exploitation, commercial viability and affordability in terms of manufacturing costs. These demand long times for development and massive resources. Even optimistic views tend to place quite a few solutions only by 2050.
- The challenges of resource mobilisation (additional investments, transition management costs, impact of reduced profitability) dictate that the investments are based on most optimal solutions, with fast-track returns and minimum disruption.

Green Energy Realities

The clamour for green energy as the ultimate in the efforts at decarbonisation in general is taking away the focus from the following critical realities.

- It is clear that technologies, exclusively Hydrogen-based, are unlikely to achieve full commercial shape earlier than 2045-50 with numerous optimistic assumptions on cost reduction and investments. Whereas the need for decarbonisation with a level of certainty and without serious disruption to steel industry is immediate 2025-2040.
- The green electricity needs of green hydrogen production are so large that it is unlikely that this could emerge as an exclusive sustainable approach. Even as per the various projections the share of green energy nationally is slated to be about 35 % by 2050. The balance will therefore have necessarily to be coal/fossil fuel based.
- Costs and RTC of green RE is in any case a daunting reality without clarity at this stage on what lines this will finally emerge.
- Global output from low-emissions sources of electricity, including all renewable energy technologies, nuclear, fossil fuels with carbon capture, hydrogen and ammonia, increased by 4800 TWh from 2010 to 2023, but global electricity generation increased by nearly 8400 TWh. Global coalfired generation as per IEA increased by almost 2000 TWh (+23%) from 2010 to 2023 and gas-fired output

increased by over 1700 TWh (+36%). This was dictated by the need to meet the increasing electricity demand.

- Specifically in the Indian context, the green power growth achievements in the last two decades are remarkable, with RE contributing near 50 % of the total power currently. However, the industrial share of this power has not made significant impact due to the various issues pending resolution/solution.

Technological challenges and required external conditions

While a lot of efforts and resources are getting deployed in trying to evolve and commercialise technologies that can enable large scale decarbonisation of the steel industry, there a number of critical externalities which have to play a key role in ensuring the ultimate success. These are:

Hydrogen injection into BF

- Implementation of CCU and CCS
- Large scale supply of carbon-free hydrogen

100% hydrogen use in direct reduction (Shaft furnace etc.)

- Large scale supply of carbon-free hydrogen
- Enabling coal gasification to facilitate Hydrogen production, adequate support in the form of CCUS

Production of high-grade steel in large scale EAF

- Cost-effective fossil-free power
- Quality Scrap availability

Power Supply

Good quality, uninterrupted power in requisite quantity would be a prerequisite for sustaining low emission steelmaking. In case of zero carbon objective, green power support of the required magnitude would be obviously essential. The prospect on this front may not be as bright as one would like to see due the current experiences on moving forward with green hydrogen production globally. Key industries on which the entire economy rests cannot be risked with any uncertainty in this aspect.

Also, it is important to note that the energy mix also changes drastically based on the finally adopted technology scene. It is not realistic to believe that the industry can, forever be, made to rely on critical fuels through imports.

Fig 11-12 and 11-13 show the Decarbonisation Avenues Indian context and the approach.

INDIAN STEEL INDUSTRY AND COAL USE

There is a prevailing perception that steel industry is an exceptionally large consumer of coal and CO₂ emissions. The reality in this regard is quite different as can be seen from the following. The sector-wise coal consumption in India for the period 2011-12 to 2022-23 is given in Table 11- 9. The following realities related to steel industry can be noted:

- Steel industry consumed about 7% of the total coal consumption of the country in 2022-23. This included the share of imported coking coal.
- The coal consumption of steel industry was less than 10% of the coal consumption of the energy sector.

TABLE 11-9 INDUSTRY- WISE COAL CONSUMPTION (Million tons)

Year	Electricity	Steel (incl Coking)	Sponge iron	Cement	Total
2011-12	410.37	47.86		13.18	638.73
2012-13	446.76	51.70		13.11	713.39
2013-14	448.95	53.05		11.94	739.34
2014-15	497.70	56.24		11.36	822.13
2015-16	517.77	57.08	7.76	8.99	836.73
2016-17	535.04	51.98	5.56	6.36	837.22
2017-18	585.49	58.45	8.53	7.71	898.49
2018-19	621.64	64.65	12.09	8.82	968.36
2019-20	626.15	63.74	10.53	8.57	955.92
2020-21	581.23	60.17	9.57	6.75	906.33
2021-22	710.05	66.28	9.02	7.31	1,028.03
2022-23	785.13	70.84	8.06	8,12	1,115.22

Sector-wise consumption of energy sources shown in Table 11-10 indicates that the Manufacturing industries in India including building industry, account for less than 20% of the total consumption.

TABLE 11-10 YEAR-WISE CONSUMPTION OF ENERGY RESOURCES (PetaJoules)

	2011	2012	2013	2014	2015	2016
A. Fuel Combustion	16,04,503	17,04,639	17,74,788	18,71,709	20,55,017	20,92,250
GHG sources						

Energy Industries	9,24,258	10,05,813	10,53,981	11,40,983	11,97,123	12,06,587
Manf industries & constrn	3,38,816	3,43,603	3,56,771	3,51,910	3,94,092	3,97,739
Transport	2,21,202	2,36,020	2,41,253	2,50,173	2,61,517	2,74,434
Other sectors	1,20,228	1,19,202	1,22,783	1,28,643	2,02,286	2,13,490
B.Fugitive emission (fuels)	47,426	43,047	38,771	38,057	37,084	37,179
Solid fuels	16,388	16,086	15,568	16,547	16,614	17,121
Oil & natural gas	31,037	26,961	23,203	21,511	20,470	20,058
Total Energy (A+B)	16,51,928	17,47,686	18,13,559	19,09,766	20,92,102	21,29,428

KEY ELEMENTS OF DECARBONISATION

Keeping the Hydrogen and green energy realities and the India imperatives in the backdrop, a realistic decarbonization plan can still be drawn up. While this may not measure upto the ambitious zero-carbon aims in the projected time frame, it would still ensure that the emission impacts are abated to a very large extent. Supplemented by the areas such as CCU, the benefits could be extended further. The key would be timebound positive actions leading to fast-track results of reduction in CO emissions.

A critical review of the issues that can propel towards effective decarbonisation of the steel industry (discussed in the foregoing paragraphs) indicates that a multi-directional strategy is inevitable for ensuring a successful and economically manageable transition to low carbon. Approaches so far not valued, need to be critically evaluated to establish more fundamentally sound and realistic basis for the industry positioning in the overall integrated economic context. These include aspects which are within the industry domain and those which are outside. The crucial ones which can make substantial contributions from the steel industry decarbonization and sustainability perspectives are:

Demand Optimisation

- Energy Efficiency and Type of transition
- Process Route Shift and Technology

DEMAND OPTIMISATION

An obvious and yet highly significant & important step in effective decarbonization, is now recognized as the need for optimally exploiting steels' exceptional attributes. Effectively, this is aimed at the reduction of overall steel demand in quantitative terms without compromising on the vitals of uses and applications. This provides the most direct approach to

decarbonisation as well for resource conservation and consequent reduction in emissions. This aspect is also substantially within the steel industry reach aided by the downside users and value adders.

Aligning the steel demand to specific applications and its durability and life cycle benefits, economic uses, coordinated design, and efficiency improvements in all user sectors are key to arriving at realistic demand. Steel's demand reduction potential is variously believed to be around 15 to 40% from the traditionally projected levels. The direct fallout of this would be the reduced material and energy use and the consequent avoidance of environmental impact. The major elements that contribute to this are discussed below:

Material efficiency

Material efficiency strategies decrease the amount of crude steel needed per product by decreasing steel losses in fabrication and using less steel in each end use. They include:

- In case of fabrication and infrastructure applications, better manufacturing techniques along with use of automated equipment, improved construction methods, and use of fit for purpose steels (grades, qualities, sizes, shapes etc), and modularized designs) can be a key to optimized steel use and reduced wastage.
- Vehicle lightweighting has been a major area supported by steel with property specific products. (Grades, Strengths, Shapes, Finishes)
- In case of buildings and housing avoiding over specification, use of improved steels and improved techniques for construction, modular approach, pre-fab adoption to the extent feasible, increased preference for steel are approaches which will enable steel use reduction.

In case of the projected demand for steel in India, the above segments cover over 75%. These improvements with coordinated intensive efforts can contribute to Indian steel demand demand moderation in a big way. One estimate places the potential at 15 to 30%. From a sector perspective, one analysis by Material Economics places the carbon reduction potential of 30 to 35% in the building sector alone through effective Waste Reduction, Reuse of building components, Material Efficiency and Sharing.

Life Cycle Perspective

A well nuanced approach in regard to the life cycle approach has huge potential to reduce new product demands. Well-constructed buildings, infrastructure and facilities have a potential life extending to over 75 years (may be 100 or over in many cases). With proper maintenance in its life time these facilities serve more than decades. The life cycle approach now being tapped as potential for many benefits, is a concept which is traditionally part of the Indian culture.

Exploiting this is not only in the interest of demand moderation, it also releases huge resources for the other areas for development.

Circular Economy

Circular Economy concept has now come to be recognized as an essential to the overall planning of materials, manufacture and product use. Adoption of Circular Economy in all its facets has two areas of interest. One is the demand moderation, which is supported by Reuse/ Remanufacture/ Repurpose/ Reconfigure concepts. Industrial machinery, Automotives, Consumer durables all have the potential for renewal. This practice is already in vogue in many areas. This potential is estimated at 20 to 25% of the new demands.

The second aspect of CE is the recycling of scrap as well as the wastes and by products arising during the manufacture of steel and their products. Steel recycling has the direct effect on demand for new resource reduction. The use of wastes as inputs for other industries/applications enable consequent new resource reduction as well. These lead to the overall reduction in the emissions. In case of recycling scrap, the level of difference in emissions between the BF BOF and Scrap EAF is massive (over 70% reduction).

Globally the EOL scrap availability is projected to be nearly 900 million tons by 2050 (Figure 11- 14 Potential Eol Scrap Availability By 2050). The key impact of this besides the significant impact on carbon reduction is the impact on process share where EAF is expected to account for 56%.

One projected impact of Material efficiency on steel demand is a significant near 30% reduction in the demand by 2070 (2 billion in place of 2.8 billion tons).

TABLE 11- 11 CIRCULARITY & SCOPE FOR DEMAND MODERATION
(As per Material Economics)

	Stee demand by 2050		Current Practice		Circular Scenario	
	MTPY	% Approx	MTPY	% Approx	MTPY	% Approx
Overall	2342		2341		1786	
Primary Production	1751	76	1470	63	860	48
Scrap Based Production	591	24	851	37	926	52

Even as per IEA, the extensive adoption of Circular economy coupled with the Life cycle thinking and its application can reduce the future steel demand substantially (nearly 25%).(Figure 11-15 Impact Of Circularity On Steel Demand and Process Share). As per the IEA report, Material efficiency (Better use and reducing steel demand) and Circulation (Recycling) can reduce emissions by 37% in 2050 from what would be with the current practices.

It may, therefore, be logical that with intensive efforts it may not be beyond the steel industry to enable overall reduction levels of 25-35% in the levels estimated using the

conventional approaches. Reduced production would also automatically provide overall emission reduction on same scale.

Transport and steel demand

This is an important area considering the adverse impact of automotive on environment, energy demand and limitations, and urban chaos. This sector typically constitutes 10% of the steel demand. In this context, shared mobility services are projected to have the potential to benefit circularity and material efficiency to the extent of nearly 70% in terms of steel per million passenger kms.

Besides the above, the ULSAB10 project of Worldsteel has shown that a weight reduction of 20% as compared to current industry standards could be brought about by making a more sophisticated use of the variety of available steels. A 25% reduction on the 271 kg body-in-white of a 900 kg car would thus mean a reduction of 5 to 11 g of CO₂ emission per km.

The results of an LCA type of analysis carried out on a passenger car, that has covered 150,000 km in 10 years, with a gasoline consumption of 8l/100 km gives the total energy necessary for producing the car and its fuel and use for 10 years, amounts to 540 GJ, whereas the materials part of this energy consumption of all materials put together, is 32 GJ, i.e. 6% of the total.

In the Indian context a useful life of 20 to 25 years may not be out of place.

ENERGY MIX AND EFFICIENCY

Reduction in energy use is the direct answer to emission reduction. Technology innovations, if adequately harnessed, could have a potentially big role in reducing energy requirements and consequent carbon impacts. A multipronged action for carbon foot print reduction could cover the following:

- Energy efficiency and increased waste heat recovery
- Energy efficient Technology (improvements as well as breakthrough)

The energy transition from fossil-based fuels to green or less carbon-intensive ones is quite a difficult path. Focus on energy efficiency, increased use of scrap-based production, and use of green energy to the extent feasible and economically viable may be the most practical courses. In this context, the scrap- based EAF production assuming a dominating role will demand massive electricity support.

The prospective electrical energy alternative could offer greater RE share. This could also be a positive trigger for increased DRI use paving the way for greater use of hydrogen. But the solutions themselves are highly energy intensive, thus exacerbating the overall energy availability scene drastically. Availability of both these is a key determinant for steel industry decarbonization, in terms of availability, scale, costs and green content.

It has been estimated that the Indian industry has the scope for energy reduction for the current levels to the extent of about 30 to 40 % as compared to the applicable BAT's. Scale is

one of the major barriers to improved fuel efficiency both in terms of gross usage as well as effective utilisation supported by maximum possible waste heat recovery.

Large-scale energy transition, however, will be determined by the energy sector abilities including the green energy supply.

PROCESS ROUTE SHIFT AND TECHNOLOGY

Both from a climate as well as industry sustainability angle, substantial shift from the BF-BOF route is a vital necessity. Currently the BF route is near 50 % of the production, with the prospect of rising to near 70 % in the next 10 years considering the projects in the pipe-line and under implementation. As of now, from the steel material perspective there are certain uses which demand the adoption of the BF- BOF route due to quality demands as well as special processing needs. Therefore, the route has to have a share albeit reduced to the essentials.

It has been seen earlier that the alternative secondary steel production route primarily based on steel scrap would be a critical contributor to decarbonization, besides the other incidental benefits that it can ensure.

In the Indian context, while incremental technologies amenable to retrofitting in existing installations still hold interest as there is a potential of 30 % or more saving in energy and consequently Carbon footprint, this is not a total solution. Add to it the uncertainties of retrofitting in existing installations due to various likely limitations and possible unaffordability, uncertain time frames and viability.

Thus, a process-shift with focus on reducing the BF contribution is an inevitable and important step towards decarbonization and sustainability in steel industry. It could also prove to be the key element in the sustainability objective. This is more so in case of the Indian context where the steel demand is expected to go northwards at least for the next few decades.

Process Route Impacts

The possible impact of process focuses will be clear from the relative CO₂ intensities of the different processes currently used in India along with the potential decarbonisation process options recalled as shown in Table 11-12.

TABLE 11-12 PROCESS vs DECARBONISATION

Process Route	CO ₂ Emission(t/tcs)	
Available Options	Typical Values	
	Indian Scene	
BOF	2.46	Dominant share currently
Coal DRI with IF	2.3-2.8 (even 3)	
Coal DRI with EAF	2.51	

DRI with Natural Gas	1.9	Alternative for carbon reduction
EAF	0.6	100 % Scrap Based production
EAF with zero carbon electricity	0.1	Potential

PROSPECTIVE PATHWAYS

Decarbonisation of the steel industry in India can have 5 concurrent pathways. Obviously, the primary focus should be the existing assets improvements to the extent economically viable and technically feasible, doing more with less, process repositioning and energy transition in the same order. These are:

Energy and Efficiency

- Improved energy efficiencies in existing processes and plants and consequent carbon reduction
- Doing more with less
- CE adoption on big scale

Technology Upgrade

- Reduction in waste generation (slag generation)
- Adoption of energy efficient breakthrough technologies such as casting and in line rolling.
- Raw materials upgrade
- Introduction of technologies for use of Hydrogen in Blast furnaces

Demand Optimisation

- Better and optimal steel use (Innovative building designs that require less material, Section and profile optimisation for better components functionality) Reducing over-specification of structural steel and optimized designs, Increased use of pre-tensioned and precast reinforced concrete
- Waste reduction in manufacture (Improved product manufacturing yields)
- Increased recoveries of steels from wastes and reuse.
- Better steels and application focused properties Use of higher-strength steel leading to optimised members and sections, Area specific steels to benefit from long life cycles as well as optimized use
- Life Cycle thinking focus & maintenance of long -term assets and infra.

Process Route Repositioning

- Increased share of DRI with better technology for coal use (Gasification, Syngas)

- Technologies for better carbon management and discriminating and selective use of CCS/CCU
- Efficient scrap recoveries and Recycling of steel on large scale
- Factoring Hydrogen Prospect in the DRI process with well-strategized energy and reductant transition angles.

Energy Composition

- Reduction in coal share particularly in power generation
- Favouring low/zero carbon purchased electricity

Fig 11-16 indicates these options.

Translating the concurrent pathways indicated to an effective action plan can be on the following lines and priorities.

- Existing industry overhaul with least risk and Incremental solutions for near and short term
- Bold and innovative approach to retrofitting of major technologies can enable energy savings. This may demand radical thinking and will to undertake major modifications.
- Increasing the share of GDRI through the use of Coal Gasification with provision for transition to Hydrogen as it evolves.
- Increased attention to CCUS with an integrated approach at least in the new capacities to be installed.
- Starting energy transition with Blue Hydrogen (coal based) as a first step, with green energy and hydrogen share being increased as practical.

INDUSTRY REPOSITIONING

This is the most challenging aspect of the transition strategies. The multiple actions that have the potential to align with the desired carbon targets are discussed under the following heads:

Facility Closures

The majority of steel plants of the world have a very difficult decision-making scenario in regard to facility retirement and closure. The impact of stranded assets has the potential to completely derail the industry and in turn even the country's economy. A clarity on the need for reinvestment cycles as per the larger plans, whether coal-based furnaces should be prolonged, retrofitted, or replaced with lower-emissions technology and how far the blast furnace can be prolonged without affecting the decarbonisation objectives are issues which deserve detailed analysis and evaluation. Specifically in Indian case what would be the best way of replacing the inefficient coal based DRI (mini and micro scale units)

This is an obvious and essential first step for the Indian industry as well consisting of the retirement of inefficient and obsolete carbon-intensive technologies and facilities, and their replacement with low carbon-based capacity. This can provide immediate relief.

A proper transition road map can be evolved, and wherever feasible the new facilities introduction can be made with operations of existing unit parallelly to avoid disruption in the interim.

A holistic approach is required to ensure minimum disruptions and an effective transition to more efficient and less carbon emitting concepts as a replacement/upgrade of these sectors. This strategy will have to embrace the following:

- A decision not to install high CO₂ intensive capacity in any new facility planned from now.
- Classification of the existing assets into those which are near end of life and those that can have a decent life balance. This would enable the priority for investments to be rational and avoid infructuous investments.
- Classification of the assets into most CO₂ intensive, moderate and technologically adequate to establish the priority for closures.
- Evaluation of technology options with relevance to the Indian context and sustainability as well as the long-term relevance. This will necessarily demand the evaluation of Gas-based DRI as a potential key player in the evolving landscape. Actions required for making Coal gasification a sustainable option will provide a long-term solution as the energy security of the country is highly linked with coal. Even globally over 60 % of the energy is projected from Coal in the future as well.
- A well-planned replacement strategy can pave the way for adoption of energy-efficient and sustainable technologies, and introduction of sustainable scale in the units resulting in reduction of number of units as well as diversities.
- Improved technology and scale will provide the required support for long term viability and sustainability.
- The investments required for replacement can be substantially optimized by leveraging the readily available existing infrastructure.

It is projected that by 2050 around half of the global ironmaking capacity could be considered for end-of-life decommissioning and most will reach the beginning of their investment cycle by 2030.

Current Indian Asset Status

The residual lives of Indian steel facilities may range from less than 10 years to over 40 years. Normal investment cycles for the BF's are around 15–20 years requiring large scale rebuild and introduction of better technologies. Most of the coal-based DRI plants do not have appreciable scope for modernization given the initial mini and micro scales, skeletal equipment

and facilities and essentially make do technology. Majority of the old existing blast furnaces also suffer from a similar reality. They have all been prolonged beyond their efficient operational stage.

Industry Fragmentation

Another critical factor is the high level of fragmentation of the Indian steel industry. The level of fragmentation of the steel industry can be seen from Figure 11-32. The industry includes the carbon and energy intensive secondary-sector of Coal-based DRI and Induction-furnace route and quite a few obsolete facilities in existing integrated steel plants. Besides technology, scale of operations is also miniscule in majority of cases in secondary sector. Typically, the plant capacities are below 40000 tpy for DRI-IF routes with DR units of 50 -100 tpd, and furnace sizes ranging from 2 T to 20 T (Over 1200 units for producing less than 30 MTPY). Rerolling capacities are also wide ranging from 30000 tpy to 100000 tpy (Near 1800 units). Typically, in India such technologies form nearly 30 to 40 % of the current steel production (Coal based DRI and Use of induction furnaces, Mini-blast furnaces and obsolete facilities in older integrated steelplants).

A comprehensive transition plan covering both the integrated steel facilities as well as the secondary sector is the need of the hour. In the majority of the installations (excluding the modern integrated facilities installed nineties and later) the facilities may not be amenable to easy actions for making them compliant with the decarbonization requirements. Phase-wise replacement of these capacities with modern facilities may be the important and inevitable step.

Recognising that many of the units have suboptimal capacities and scale, it may be worthwhile to examine a combination approach. This may provide an opportunity to introduce efficient EAF capacities in place of the mini and micro induction furnaces.

Technology interventions in raw materials

Resource demand is increasing at an unsustainable pace. In 1970, the world consumed 7 billion tons of primary materials. By 2017, worldwide consumption of these materials reached 90 billion tons. By 2050 primary material use is expected to go up to 186 billion tons if current consumption trends continue. There is high inequality in the distribution, availability and use of natural resources and in the exposure to environmental risk factors across world regions and within countries.

Resource efficiency, is thus one aspect which can reduce the speed at which natural resources are depleted. Operating with lower resource inputs reduces the economic vulnerability to price volatility at the global raw material markets and limits the environmental impacts that occur with resource extraction.

Innovation and technology have a critical role in the improvement of resource efficiency. Therefore, it is crucial to ensure the coordinated actions with participation of stakeholders. In order to address the risks and impacts arising out of raw materials availability, price volatility as well as disruption potential in the Indian context, it is necessary to maintain focus on

improving lower grade raw materials currently adding substantially to poorer efficiencies and high levels of wastes and environmental concerns.

Status of Technology Options

The status of decarbonization and carbon reduction technologies relevant for Indian context is summarised in Table 11- 13.

TABLE 11-13 DECARBONISATION TECHNOLOGY AVENUES AND INDIA

Avenue	BF Process Upgrade	Smelt Redn (Hisarna)	Carbon Capture & Use	GDRI with EAF	Scrap EAF	HDRI and EAF	Biomass as reductant
Role	Process upgrade	Process change	Add on	SynGas / Off gas use	Increased recycling	Use of RE for H ₂ and DRI	As coal replacement
Action areas	TGR and H ₂ injection	Commercial Scale trials	Focus areas and Increased use	Coal gasification, CCU and EAF	EAF Improvement	DRI upgrade to 100% H ₂	DRI
						Green H ₂	
Current outlook	Technology available	Commercial scale demo plant under planning	Numerous Technologies available for CO ₂ conversion.	Technology available, Numerous CCU add on possible	Technology available. Hydrogen use to be perfected	Technology can be perfected in short time from GDRI	Technology not yet mature.
Concerns	20-30 % Possible	Still 10-15 years from being a option	Requires multi technology and efforts for scaling	Secondary emissions due to purchased power	Sustained Scrap supply	Hydrogen Scale and costs	Scale ,Area specific availability
	Technology modifications and scaling challenges	Scaling, Carbon Capture support	Integrated outlook vital	Carbon use important for sustainable adoption	Secondary emissions from purchased power	Secondary emissions from purchased power.	Assured availability of biomass
	Hydrogen cost and scale		Retrofitting to existing challenging due to scale and speed of production.	Carbon emissions from Coal usage	Green energy support level and costs	Green energy support level and costs	
					High quality steel production		
TIME SCALE	2 years	2035-40	Variable Possible in part by 2030	Ready for Adoption.	Ready for Adoption.	Blue Hydrogen suitable. Possible by 2035	Studies area wise required
						High H ₂ Syngas possible by 2030	
						Green energy availability, costs	

Recycling Scenario

Recycling which ensures Circularity and leads to resource optimization, reduced costs and technology simplification in production is also the key step towards Process route repositioning. Recycling is obviously linked with the availability of scrap (obsolete as well other). There is a general optimism in the future scrap availability scenarios given the large volume of obsolete scrap, increased focus on CE as well as introduction of more efficient collection and processing. As per World steel projection the global scrap availability may rise to 600 MT by 2030 and 900 MT by 2050. (Fig 11-14). Another highly optimistic projection places the possible scrap generation of 1.55 billion tons against a projected crude steel production of 2.68 billion tons by 2050 or near 60% by 2050.

However, the Indian situation may not be able to follow the western approaches, where traditionally scrap-based production has held a key space. Further with emphasis on exploiting life cycle attributes to moderate demand, scrap generation would also be impacted.

Thus, from derisking perspective, India process-mix cannot rely on scrap route as the key contributor to emission reduction. A level near 20-25 % (not counting the scrap used within the production unit from its own arising) may be a practical aim.

Industry Modernisation

Rapid and radical modernisation of the existing iron and steel industry (in areas where technically feasible) is indispensable for reducing the GHG emissions to the levels required for keeping the global warming within 2°C. Therefore, the adoption of BAT on Large/total scale might be an essential step towards reducing CO₂ emissions in a number of individual countries. Greater energy efficiency can be achieved along with the consequent reduction in Carbon footprint from the following actions:

- Existing facility upgrades for achieving BAT's in energy optimisation, carbon reduction/ capture and hydrogen introduction, in BF-BOF routes.
- Introduction of DR using off gases in ISP's for overall carbon reduction
- Adoption of recycling of steel scrap on scale.
- Introduction of energy efficient processing technologies as alternatives to the obsolete processes in many cases. (Net shape casting, Casting and direct rolling).

Efficiency improvement vs demand growth

The historical trend suggests that efficiency improvement in steel production is important but insufficient to achieve net emissions reduction. One analysis shows that after the 1940s, the largest drop in emissions intensity occurred between 1970 and 1995 (from ~4.5 to 2.6 t CO₂-eq/t steel), due to the improvement in energy efficiency through technological advances such as dominant role of BOF and continued decarbonisation of the electricity grid since the energy crisis in the 1970s.

It is notable that The GHG intensity of global steel production has stagnated at ~2.5 t CO₂-eq/t steel since 1995, (remained at the level of ~2.8 t CO₂-eq/t steel in primary route and ~1.0

t CO₂-eq/t steel in secondary route of production respectively. At the same time, the share of steel production in global GHG emissions increased from 5.2% in 1995 to 7.7% in 2015. World Steel Association's statistics has also confirmed that emissions intensity had been stagnant from 2015 to 2019.

In order to keep pace with the GHG emission growth driven by higher steel demands, the need for rapid implementation of low-carbon technologies cannot be over- emphasised.

Circular Economy Requisites

The priority areas which require to be addressed through the adoption of Circular economy are:

- Improved Material efficiency.
- Process waste reduction
- To approach near zero waste for disposal by converting various wastes to useful process inputs and better use of arisings.

Adoption of Circular Economy in the industry should be based on a holistic map covering the various stakeholders. The key stakeholders in this action scenario will be:

- Steel Industry
- Downstream Users and fabricators
- Energy Supply sources
- Automotive Sector
- Building Design Sector
- Scrap aggregators and processors
- Related Government agencies and Policy Formulators (Energy, Environment, Resources Management, Transport and Infrastructure planning and management, Pricing incentives, etc)

The key areas where a coordinated efforts can result in fast results are:

- Scrap Recycling
- Useful products from steelplant waste

Role Of Coal

The current narratives on Hydrogen clearly point to a fair number of uncertainties associated with Hydrogen as an alternative to coal. In case of steel industry, aspects related to scale, additional energy support for Hydrogen production, and availability of RE in a big way are fraught with numerous challenges. It is, therefore, very unlikely that concrete plans for large scale transition to Hydrogen may be possible to be drawn up in the near term (15 to 20 years).

Net-Zero aim is vitally dependent on the decarbonisation of the electricity sector (major supplies to industry are coal based). Therefore, increasing the use of electricity in place of coal within the steel industry does not serve well the overall purpose of emission reduction if the additional demands are for electricity.

Thus, the role of coal in steelmaking cannot be wished away easily. Viewing coal use positively, it is possible to find optimal solutions (factoring country's reality, and current global experiences). Coal gasification is a well-established technology and has proved itself to be viable and sustainable if supported by adequate CCUS. Use of Syngas through coal gasification offers a ready solution. Even the cost of blue hydrogen under Indian conditions is projected to hover around Rs 150/kg with a coal price of Rs 3000. With CCUS this may increase by a third to around Rs 200/kg. This is a fair level compared to the global Hydrogen costs

The gas-based DRI technology, has already been tested for increasing the hydrogen share in the reducing gas (Syngas) may be upto 90 %. For a scrap starved country like India, and with emphasis on Life Cycle exploitation (which will impact the EOL scrap generation) the only option for steel metallics would be the use of DRI. Also, the transition to Hydrogen, as and when it becomes available on a reliable steady basis at affordable costs, would be possible, may be without major disruption in the plants designed to suit.

ACTIONS FOR DECARBONISATION IN INDIAN STEEL INDUSTRY

Besides the steps for reducing emissions as suggested in the foregoing paragraphs, specific actions focused on decarbonisation of the steel industry can be essentially founded on the following imperatives:

Equipping BF's with part Hydrogen use and TGR with a prospect of about 15-20 % reduction in emissions.

Pushing Smelt reduction with lower emissions using coal supported by Carbon capture to keep the hot metal supply chain alive.

- Evolving a transition plan for moderating the BF share and Increasing the share of EAF with Hydrogen GDRI as the final transition.
- Evolving technologies for Steel production could do substantially with Blue/Grey hydrogen. Green hydrogen at scale and affordable cost level would surely be welcome. But this seems quite long-term prospect.
- Increasing the scrap share (excluding the arisings within the production units) in steelmaking to 20 to 25 %.
- On the energy front, the role of coal needs to get defined clearly with a long-term perspective and the increasing energy needs. Permanent reliance on imported energy would endanger the viability of the steel industry. As technologies coal gasification and Gas based DRI are well established, enabling ready adoption with immediate benefits

(supported by CCUS). It is well recognised that the Hydrogen cost through coal use is far more competitive in the India scene.

It may be prudent to evolve an India specific approach for decarbonization of steel industry recognizing the foregoing imperatives. In order to enable the steel industry to remain viable, the longer life cycles of existing assets albeit with modernisation would also be a necessity.

The multi-dimensional and integrated approach to India's decarbonization programme is broadly outlined in Figure 11 – 16.

IEA GLOBAL OUTLOOK

IEA has factored the various issues and developments involved with focus on energy transition and decarbonisation and arrived at a Sustainable Development Scenario. Role of breakthrough technologies (CCUS and Hydrogen and Green energy) are slated to play a key role along with the contributions from material efficiency to reduce virgin demand. The Sustainable Development Scenario, as per report of IEA 2020 has projected process shares in the future as follows. (Tables 11-17 and 11-18).

TABLE 11-14 GLOBAL STEEL PRODUCTION BY ROUTE
(IEA Sustainable Development Scenario)

	2030	2040	2050	2060	2070
	MTPY	MTPY	MTPY	MTPY	MTPY
Historical Routes					
100% H ₂ DRI		75	250	350	550
Commercial DRI	175	200	150	75	
Commercial SR	25	50			
Commercial BF	1200	900	625	340	75
CCUS for SDS					
Commercial DRI with CCUS	10	15	15	75	125
Innovative SR with CCUS		60	200	325	350
Innovative BF with CCUS		20	40	60	75
TOTAL	1410	1320	1280	1225	1175

TABLE 11-15 GLOBAL STEEL PRODUCTION
Projected Process Shares As Per IEA SDS

	2030	2040	2050	2060	2070
Process Shares	%	%	%	%	%
BF	85%	70%	52%	33%	13%
SR	2%	8%	16%	27%	30%
DRI	13%	22%	32%	41%	57%
CCUS		7%	20%	38%	47%

Emissions

Global iron and steel sector direct CO₂ emissions and energy consumption in the Sustainable Development Scenario, 2019-70 as per report of IEA 2020 are shown in Table 11-16. The aim is at near Zero Carbon achievement.

TABLE 11-16 SUSTAINABLE CARBON TARGETS (As Per IEA)

	2019	2030	2050	2070
Emitted CO ₂ Gt/yr	2.6	2.3	1.2	0.3
CO ₂ Intensity ,CO ₂ /tcs	1.6	1.35	0.7	0.15
Captured CO ₂ ,GT/yr			0.7	0.15
% reduction		16%	67%	91%

As per this scenario, Hydrogen use is expected to be over 25 million tons by 2050, electrolytic hydrogen covering more than 90%. Consequently, the electricity demand for hydrogen manufacture is expected to go to over 700 Twh per year of which the steel industry share is projected at over 600 Twh per annum.

STEEL INDUSTRY & BREAKTHROUGH TECHNOLOGIES

Recognising that large scale reduction in carbon impact under the current industry structure could depend heavily upon the success of the breakthrough technologies, the global steel industry has been investing considerable resources and time in efforts for finding other viable solutions.

Nippon Steel, Japan's Course 50 and Super Course 50 are an excellent example providing a lucid road map of the holistic and stepwise actions that are essential in introduction of breakthrough technologies. These can lead to the potential Carbon Neutral Process in Iron and

Steelmaking over time. Hydrogen is clearly the vital cog in the wheel of decarbonisation with the ultimate objective of carbon neutral process. (Figure 11-17 and Figure 11-18)

The multiple approaches to decarbonisation in steel industry can also be appreciated from the following current realities.

- Shougang Steel, China operates a large-scale facility to convert steel plant process gases to ethanol. Arcelor-Mittal are building a similar commercial facility in Belgium.
- Hydrogen: HBIS is building a 1.2Mt capacity hydrogen metallurgy DRI demonstration project.
- Voestalpine's SuSteel project is looking to apply hydrogen plasma reduction to iron making.
- CCS: At Emirates Steel up to 800kt of CO₂ per year is captured from the CO₂-rich gas stream from the ironmaking plant and stored.
- ArcelorMittal are part of the Norwegian "Northern Lights" CCS project.
- Renewable energy Evraz's Rocky Mountain Steel in Colorado, USA, is transitioning from coal to solar.
- Biomass Aç0 Verde do Brasil is exclusively using sustainably grown biomass for their steel production.
- Electrolysis: The Siderwin project (currently at TRL4), being led by ArcelorMittal, is looking at using low temperature electrolysis using a waterbased electrolyte.

Major Leaps in EAF

A positive step that will enable the steel industry to achieve massive energy efficiency and productivity are the performance of the latest design EAF's. The remarkable features/results are:

- EAF Productivity to match the BOF with heat times below 40 minutes.
- With a dominant scrap mix with about 25 to 35 % liquid hot metal, the power consumption for the production of one ton of steel of less than 250 kwh are being achieved. From the energy perspective this is a quantum leap.
- Utilisation of off gas heat for preheating the scrap, and granulation of slag are measures that improve energy efficiency as well as enlarge Circular economy.
- Integrated DRI-EAF facilities are now possible for a level of 3 to 4 MTPY. A 2 MTPY DRI plant currently under plan/Implementation is planned for transition to 100 % Hydrogen at the opportune time. Plant facilities are designed for transition without disruption. The facilities are designed for maximising energy recovery by hot transfer of DRI for steelmaking, waste heat recovery from the off gases etc. Near-net shape Casting and in-line rolling ensure that the sensible heat is best used and the net

consumption is less than 20 % of the conventional options. These units can be recognised as the future ready sustainable steel plants.

DECARBONISATION PROCESS SCENE

It is important to recall the status of the decarbonization technologies particularly with respect to the TRL level and the time frame for commercial availability.

TABLE 11-17 MATURITY LEVELS OF DECARBONISATION AVENUES

	Technology	TRL	Year Available	Importance for Net Zero	
	Blast furnace: Converting off-gases to chemicals	7	2025	(Medium)	Carbon2Chem pilot plant in Germany initiated by Thyssenkrupp in 2018
	DRI: Natural gas-based with CO ₂ capture	9	Today	(Very high)	Abu Dhabi with 0.8 Mt/year of CO ₂ capture capacity, with CO ₂ used for EOR at nearby oilfield (ADNOC,
	Smelting reduction:with CCUS	7	2028(	Very high)	ULCOS consortium, HIsarna pilot plant currently operating at a Tata Steel plant in Ijmuiden, Netherlands
	Blast furnace: Electrolytic H ₂ blending	7	2025	(Medium)	Thyssenkrupp has been testing use of hydrogen in a blast furnace in Germany,
	Gas-based with high levels of electrolytic H ₂ blending	7	2030	(High)	Salzgitter steelworks as part of the SALCOS project. Thyssenkrupp is planning to build commercial DRI plants incorporating hydrogen by the mid-2020s
	DRI: Based solely on electrolytic H ₂	5	2030(	Very high	HYBRIT: Project; targeting a 1 Mt/yr demo plant by 2025 Thyssenkrupp planning to transition towards

					eventual full hydrogen reduction
	Smelting reduction: H2 plasma reduction	4 --		(Medium)	SuSteel
	Ancillary processes:H2 for high temperature heat	5	2025	(High)	In early 2020 Ovako and Linde completed a successful trial using hydrogen to heat steel before rolling in Sweden
	Low temperature	4	---	(Medium	Siderwin project building on the ULCOWIN process (electrowinning), previously developed by the ULCOS programme
	Electrolysis: High temperature molten oxide	4 -	--	(Medium	ULCOS proposed concept
	Blast furnace: Torrefield biomass	7	2025	(Medium	Torero partnership project is testing use of bio-coal (torrefied waste wood) to partially substitute coal in ArcelorMittal's plant in Ghent, Belgium
	Blast furnace:Charcoal	10	Today	(Medium)	Charcoal is currently used commercially to substitute for a proportion of the coal used in blast furnaces

Additional Capacity India Approach

From a transition technology perspective HDRI could emerge as the long- term option. Use of scrap which is a natural solution for reduction of emissions has limited value in the Indian scene due to the availability issues. Therefore, the proposed plans must factor intermediate emission reduction solutions in a manner that the adoption of HDRI and increased use of scrap is well factored to be able to be effectively exploited when available.

Besides the above, the process repositioning approach suggested in the following paragraphs is essentially based on the reality that Coal cannot be dispensed with totally as easily as is being written about. Also, the Coal based DRI as at present produced and converted to steel in induction furnaces in India has necessarily to be revamped considering emissions, level of coal usage, energy usage scale and product quality. The need for making steel as the long-serving affordable preferred material for the years to come in India cannot be over-emphasised.

From all counts replacing this coal based DRI capacity (about 40 million tpy) with gas based DRI using coal is a ready opportunity with many advantages. The existing infrastructure (power, water, transport), raw material sources (iron ore, coal) locations (land and linkages), trained manpower etc could all be well leveraged to optimize investment. Key would be the introduction of scale (1.5 to 3 MTPY), planning downstream units for carbon conversion to useful products (Ethanol, Methanol etc.), adequate provision for the introduction of Hydrogen in quantity as available and affordable. This would also provide the opportunity to spread the ISP locations and make them more readily market approachable.

BF Role

The current Indian situation in some measure is not so alarming as it would generally seem as can be seen from the actual performance in 2021-22. which was as follows:

BF-BOF contribution was 48 %, whereas the DRI has a share of 32% and scrap 20%. Therefore, a major avenue for process shift could be the replacement of the Coal based DRI (nearly 40%) or about 40 million tons. This capacity could be an ideal starter for the introduction of coal gasification based syn gas DRI. This step would also provide an opportunity to introduce scale in this area as well as do away with the inefficient processes. The capacity planning can factor the prospect of about 30% of the projected production by 2050 (about 120 MTPY) through this avenue. With a target 1.4 to 1.5 t CO₂/ tcs, the overall contribution will be about 175 MT against the nearly 125 million tons at the present level. Supported by CO₂ conversion to useful products this level could be well moderated.

The other critical aspect of the process shares is the future role of the blast furnace. Currently the BF capacity is projected at about 90 MTPY. With some of the large projects in the pipeline already this can be expected to go to about 150-200 MTPY by 2030. It is essential that new capacity beyond this is not created as the need for BF on a continuing basis to meet the critical applications and to provide scale may be pegged at 200 MTPY by 2050 tapering to 150 MTPY level beyond that.

Such an approach would restrict the disruption to the present plans and also enable a comprehensive outlook towards future capacity. This would also provide a clearer picture of the Carbon capture needs of the BF share.

Suggested Transition

A possible process transition (2025 to 2060/70) could be along the line shown in Table 11-18 below. (Refer Figure 11-19).

TABLE 11-18 STEEL PRODUCTION AND PROCESS ROUTE TRANSITION

	2030		2040		2050		2060		2070	
	Prod	CO ₂	Prod	CO ₂	Prod	CO ₂	Prod	CO ₂	Prod	CO ₂
	MTP Y	MT	MTP Y	MT	MTP Y	MT	MTP Y	MT	MTP Y	MT
Improved BF	180	360	90	180	55	110				
Improved CDRI	20	40								
NGDRI	20	24								
CGDRI										
Improved SR	10	18								
Hydrogen Use										
TGR with CCUS in BF	15	27	100	160	100	150	75	112.5	75	112.5
Hydrogen rich NG DRI-CCUS	15	12.75	25	21.25	40	34	40	34	50	42.5
Hydrogen rich CG DRI-CCUS	10	12	60	60	75	75	75	63.75	75	63.75
SR WITH CCUS	10	16	30	48	50	70	75	90	75	90
Scrap EAF	10	5	30	16.5	30	13.5	30	13.5		0
Scrap H2 EAF	10	5	20	7	60	21	80	24	150	45
HDRI-HEAF			20	10	40	10	125	25	175	35
Sub Total										
TOTAL	300	519.75	375	502.75	450	484	500	363	600	389
Emission Intensity (TCO ₂ /tcs)		1.73		1.34		1.07		0.73		0.65
Moderated Realistic Demand	270	468	320	427	360	386.8	400	290	450	311
Emission Intensity (TCO ₂ /tcs)		1.55		1.14		0.86		0.58		0.52

Role of Hydrogen

The decarbonisation plans for steel industry and their timely achievements demand that the Hydrogen role be clearly defined recognising the various realities of the country.

The energy scenario of India and the energy security angle indicate that coal use cannot be suddenly transformed to the demands of the Green Hydrogen option for achieving near Zero Carbon emissions from steel industry. Comprehensive analysis covering availability, costs, affordability, energy security, transition to lower carbon without serious disruption to the steel production, and competitiveness, available technology maturity and adaptability show that the role of coal is required to be for a fairly long periods (definitely over the medium-term and beyond). In such a situation the transition plan has to make a reasonable balance between the conflicting demands.

It is well accepted that Hydrogen production using coal would be the most economical option for India. Therefore, post CO₂ management deserves very serious attention. In this connection conversion to useful products would be an avenue which needs to be pursued strongly. An integrated outlook towards coal gasification (covering energy, Syngas production, Hydrogen production, and CO₂ management) could provide a roadmap towards low carbon (even near zero). In this context the possibility of using the off gases in the integrated steel plants for DRI production would also be an aspect worth pursuing. Use of coal for Syngas (High Hydrogen content) for iron ore reduction can be effectively use economically utilized without resorting to the need of producing just Hydrogen.

Once the starting phases of transition are successfully in place then the large scale move to Hydrogen would be much easier. Green Hydrogen would be governed by the progress in RE capacity and availability and the investment level required.

IMPACT OF PROCESS SHARE REPOSITIONING

The impact of the suggested transition plan on process shares is shown in Table 11-19.

TABLE 11-19 PROCESS SHARES AS PER PROPOSED TRANSITION

	2030	2040	2050	2060	2070
Process shares					
BOF %	68%	59%	33%	30%	25%
EAF %	32%	41%	67%	70%	75%
Total	100%	100%	100%	100%	100%
Metallics Basis					
Hot metal Based	73.40%	59%	33%	30.0%	25.0%
DRI Based	23.3%	28%	47.0%	48.0%	50.0%
EOL Scrap Based	3.3%	13%	20%	22.0%	25.0%

With the expected BF share of near 68% with the maturing of the planned and in pipeline projects by 2030, the share of BF and smelt reduction followed by BOF is reduced to 30% by 2060 and 25% by 2070. Correspondingly, the EAF share would rise from 32% to 70% by 2060 and 75% by 2070. (Figures 11-21 and Figure 11-22).

From a metallics perspective and reducing emissions, scrap is obviously the ready solution being less than 30% in terms of emissions as compared to the BF. However, in the Indian context, availability of scrap would not follow the western world approach. With the focus on Circular Economy and exploiting life cycle attributes, the generation of EOL scrap would also be moderated. Thus, the increase in scrap-share (excluding the in plant arising which would be used up inside the units) has been conservatively projected to rise from about 4% in 2030 to 22% in 2060. Any performance over this dictated by the better scrap availability would only improve the emission scenario.

Potential Benefits

Process shift in steelmaking has also the potential to provide positive impacts besides the carbon angle. The major benefits of shift in process route are:

- Reduction in the Blast furnace contribution and consequent deletion of coke and sinter making facilities in ISP can play an important role in reduction of overall pollution levels.
- Overall virgin resource demand will be reduced.
- Long term sustainability of the industry will be improved.
- The introduction of EAF in all installations will provide the important nucleus for DRI production with increased use of off gases and transition through increased use of hydrogen (possibly 100 % in future).
- The huge efforts and Capex and Opex demanded for pollution control in ironmaking in the ISP's can well be diverted to more productive and sustainable technologies as well as operating practices.
- The steelplant installations will be much more compact and will provide effective use of land as well as easier introduction of some of the crucial energy saving measures such as NNS and In line rolling.

Steel Demand and Emission Reduction

This is an aspect which requires serious attention from multiple angles. The demand growth over the next 4 decades is present in Table below. This would be an optimistic projection with no major changes in the steel use strategy. The projected CO₂ emissions and their intensity is shown for ready reference.

TABLE 11-20 DEMAND MODERATION vs EMISSION REDUCTION

Steel Demand	Crude Steel Demand	CO ₂ Emissions	Emission Intensity	Intensity Reduction
Projected	MTPY	MTPY CO ₂	CO ₂ /tcs	%
2025	200	440	2.20	7%
2030	300	520	1.73	21%
2040	375	503	1.34	23%
2050	450	484	1.07	27%
2060	500	363	0.73	33%
2070	600	389	0.65	16%
Moderated	MTPY	MTPY CO ₂	CO ₂ /tcs	
2025	200	440	2.20	7%
2030	270	468	1.55	29%
2040	320	503	1.14	27%
2050	360	387	0.86	25%
2060	400	290	0.58	32%
2070	450	311	0.42	2.7%

The key takeaway from the above plan is that the gross emissions by 2060/2070 would be near the same levels as current (or slightly lower) in spite of a three-fold increase in steel production. There is considerable scope for reducing the steel demand through better usage, better materials and better designs. If this is given the requisite push, both by the producers and the users, then there is a real possibility of steel demand moderation upto 20%. In which case the CO₂ intensity by 2070 could be about 0.42, nearer the net zero aim projected by IEA. If 50 % of these emissions are subjected to carbon capture additionally, then the net emission would be a decent 0.21t CO₂ pe tcs (may be enough to qualify as near net zero)

Steel Industry as a Catalyst

Steel industry can unlock Decarbonisation in Other Critical Sectors

- Scope 3 emissions from steelmaking include upstream emissions from iron ore and energy production, as well as downstream emissions from the transport, manufacturing, and end-of-life treatment of steel. Especially when factoring in emissions from the natural gas and coal value chains, upstream energy and commodities production and distribution is the largest piece of scope 3 emissions for the steel sector today.

- Steel could provide concentrated demand and certainty of off-take for zero-carbon hydrogen. A single steel plant using hydrogen rather than fossil fuel to reduce iron ore would utilise about 300,000 tons of hydrogen annually.
- Growth of hydrogen-based steelmaking could help drive down the cost of zero-carbon hydrogen production, supporting its use in a wide range of industrial applications where direct electrification is challenging.
- Carbon capture technology applied to blast furnaces also has the potential to support decarbonisation in other industrial sectors. Blast furnace slag is already utilised as a lower-emissions alternative to clinker in concrete production. Captured CO₂ from the blast furnace could provide a valuable source of carbon for the chemicals industry, replacing virgin fossil carbon. However, for these circular use cases to be compatible with a net-zero economy, it is critical that carbon is only used in products where it will be sequestered long-term, such as in construction aggregates, concrete, and in long-lived or recyclable plastics.

Chapter 12

SUSTAINABLE STEELPLANTS- INDIA CONTEXT

The various aspects of the adverse impacts of steel production that have been enumerated in the previous chapters along with the possible desirable approaches to their mitigation provide us the roadmap for the future for ensuring the Sustainability of the steel plants in the Indian context.

Therefore, in keeping with the changes that may be ushered in by the focus on decarbonisation as well as on sustainable technologies, the Steel plants (both existing as well as new) have to reposition themselves in an appropriate manner. The requirements in this regard, if properly factored into the steel plants, would lay the foundation for long- term sustainability of the Indian steel industry. Desirable approaches particularly relevant to Indian context are outlined.

INDUSTRY REALITY

The Indian steel industry is at crossroads and needs to decide on the most suitable future path given the following:

- Having climbed upto be the second largest producer in the world, the country still needs to increase its production substantially in order to meet the demand appropriate to the world's second largest population.
- The adverse environmental impacts of the industry have raised serious concerns and require to be addressed seriously and sustainably.
- The global resource scenarios (particularly coking coal, energy, steel scrap, iron ore etc) are fraught with unmitigated volatility, raising concerns of effectiveness of trade as a sustaining option. The current Russia-Ukraine face-off has serious implications on the global energy and raw materials scenario.
- Grossly inadequate share of R&D in the Indian industry as well as at the nation level has made dependence on external developments endemic.
- Upgrading process routes and operations have become an inevitable necessity given the very high carbon impact of the BF-BOF route.
- Highly fragmented nature of the current industry with domination of very small scale, and considerable technological obsolescence in existing units, makes an integrated and coordinated outlook for the future complicated.

- The prospect of a large role of renewable energies in the country's overall scenario would demand concomitant readjustments of the industry.

STEEL INDUSTRY INDIAN ROLE

Steel A Material Beyond Compare

It is necessary to recall the uniqueness of steel as a fundamental differentiator from any competition. Steel is a unique material with far-reaching uses. Its attributes have enabled steel to retain its preeminent position for decades in spite of great efforts worldwide to find suitable replacements. The inherent qualities of steel described below place it in a pre-eminent position of sustainability.

- i. Recyclable: Steel is infinitely recyclable and it is the world's most recycled material. Steel recycling has both economic and environmental benefits.
- ii. Sustainable: Recycling steel saves energy and natural resources. Steel's contributions to helping achieve the triple bottom line of environmental, economic and societal sustainability make it vital for achieving the needs of today without impacting society's ability to meet the needs of the future.
- iii. Economic Resource Use: Codes and standards for steel construction and use enable designers and builders to utilize more cost-effective and efficient practices, which ultimately improves industry profitability.
- Extended Product Lives: Many steel applications remain in service for decades. This along with other material efficiencies enable reduced mining of virgin ore.

Steel has led the manufacturing growth substantially in India and made significant contributions due to its large linkages and widespread economic impacts. In the Indian context steel is and likely to remain the economic, affordable and environmentally sustainable material for as long as one can see. Therefore, enabling Steel to continue to play a big part in the economic growth in India is not just an economic but also a technical necessity.

Key Concerns

The following must be factored while envisioning the future of Indian steel industry.

- A very large part of the existing industry is old (15 to 50 years) and in crying need of modernisation. This could both be a challenge as well as an opportunity.
- Extraordinary efforts are required to equip the Indian steel industry adequately to address the Climate control objectives due to legacy issues, resource limitations and the conflicting Growth versus the Environmental angle.
- Coordinated development with adequate quality supporting infrastructure (Power, Transport, Equipment manufacture, Construction) will determine sustainable steel industry along with economic development. Optimized use of the common resources is, therefore, an imperative.

- The energy policy and development must adequately address the steel industry demands for (Electricity including RE, Quality Coal, Hydrogen) for ensuring effective carbon reduction.

Another major source of concern is the validity of steel demand to be taken as the basis for planning. Of the projected demand by 2030-31 as per NSP, Infrastructure, Construction and Engineering sector-demands are slated to increase by 188 MTPY, accounting for over 60 %. It will be evident therefore that the projected scenario is critically dependent upon the projected growth in these sectors of the economy. How realistic this projection can be is also an area of concern. In this context the demand review as well as “Doing more with less” also assumes extraordinary significance to guide the development along realistic targets consistent with the Sustainability objectives.

NEW STEELPLANT 'S ESSENTIALS

In the foregoing context, the new steel plants will have to keep Sustainability as approached by the World steel as an overall aim at the planning stage itself. These are as follows:

Environmental Sustainability

Emissions and CO₂ intensity in production at levels compatible with climate change objectives and the overall global approaches including near zero-carbon by 2070.

Optimising Energy intensity and Planning for effective transitions to alternative energies as the developments favour.

Environmental Control in the new facilities through Efficient and adequate pollution control facilities and compliance to the emerging demands.

Material Efficiency

To ensure reduced material usage, total waste recovery and reuse and product improvements. Ensure most appropriate technologies and equipment for the purpose.

Economic Performance

High productivity Performance with high resource efficiency to ensure Profitability

UNSG CHECK

As a proof of its effectiveness towards sustainability, the ground realities would have to be put to test on the sustainability expectations well summarized in the UN Sustainability Goals.

The UNSG provide at present a Comprehensive Outlook to Sustainability and subscribing to this could be an effective answer for the industry. An evaluation system suited to the steel industry enveloping these requirements would provide a good parameter for measurement of the efficacy of the actions taken.

SUSTAINABLE STEELPLANT CONCEPTS

The approach to Sustainability, essentially driven by need for successful decarbonisation of the Indian steel industry suggested in the book is three pronged:

- Increased focus on Gas based DRI production both greenfield as well as in Integrated steel plants (including the existing ones wherever feasible). Planning of facilities to enable transition to Hydrogen in stages
- Partial coal replacement in the existing processes as an interim solution using partial hydrogen as the key, supported by CCU.
- Providing ample scope for use of recycling and Circular economy in action as the prime mover for steel production in the future.

ACTION AREAS

Process Share

Obviously, the heart of decarbonisation pathways is the reduction of the role of blast furnace (45% of the current steel production) to essentials. The blast furnace has reached near theoretical levels of operational parameters and usages. Thus, except Carbon capture and to some extent the introduction of hydrogen there appear no other significant actions that can enable it to be made sustainable with commensurate carbon reduction. A well-considered road map will have to be evolved for phasing out the Mini DR kilns and Induction furnaces as they are also a major contributor in the Indian steel production so far.

Also, the increasing need for enabling higher recycling (upto 50 % of steel production by 2050), the EAF emerges as the core steelmaking option. Thus, the stepwise reduction of blast furnace share may finally be set at about 40 % by 2030 and 33 % by 2040 and lower beyond as shown in Aspirational process shares suggested in Table 12-1. (Figure 12-1)

**TABLE 12-1 ASPIRATIONAL PROCESS SHARES WITH DEMAND MODERATION
INDIAN STEEL INDUSTRY**

			2030		2040		2050	
Process Route	Production CS	Share	Production CS	Share	Production CS	Share	Production CS	Share
	MTPY	%	MTPY	%	MTPY	%	MTPY	%
Hot Metal	54	45	80	40	70	25	60	18.2
GDRI - EAF	12	10	60	30	130*	46	170*	51.5
CDRI IF EAF	42	35	30	15	-			

Total DRI-(IF)-EAF	54	45	90	45	130	46	170	51.5
SCRAP EAF	12	10	30	15	80	29	100	30.3
Total EAF	66	55	120	60	210	75	270	81.8
Total	120		200		280		330	

Carbon Targets

The overall Carbon reduction objectives should form the basis for the target setting in each plant and the improvement as well as new additions should be evolved on the basis of complying with this requirement.

The key advantage of the suggested process share repositioning is that the decarbonisation can be effectively introduced without large scale dependence on emerging solutions where external support and agencies have a very major role. Thus, the sustainability road map can be driven largely by the steel industry itself. Based on the potentials provided by the various processes and innovations, and the other supporting measures suggested in the different sections of the book, and the projected process shares, the following carbon targets (as shown in Chapter 11) appear well within the Indian steel industry reach.

The suggested targets for the gross carbon impact can be sustained at the present level (2020's) even by 2040 in spite of the more than two-fold increase in steel production. It is necessary for the existing industry to reach 2t CO₂ per/tcs and lower as a first step at the earliest. The intensities of carbon impact are also substantially reduced in the years beyond, 20% by 2030, and 33% by 2040 and 24% by 2050. (Table 12-2).(Figure 12-2)

TABLE 12-2 ASPIRATIONAL CARBON TARGETS FOR INDIAN STEEL INDUSTRY

YEAR	Crude Steel Production	CO ₂ Emissions			
		Gross	Intensity	Intensity Reduction	
	MTPY	MTPY	Per tcs	% d-on-d	% from base
Actual			2.35		
Base	120	246	2.05	10*	
2030	200	318	1.53	20	20
2040	280	275	0.98	37.7	50

2050	330	214	0.65	35	68

Major Enablers

The key avenues available for carbon reduction as indicated in earlier chapters are summarized in Table 12-3

TABLE 12-3 CARBON EMISSION REDUCTION POTENTIAL AVENUES

Demand Management	Scope	Priority
Better steel products and extended lives	38 %	I
Greater and better scrap recycling		I
Material efficiency and circularity		I
More intensive use of steel products (sharing)		Requires wider coordination
Energy Efficiency	15-20 %	
BF TGR and others		I Selective
CDQ/WHR		I
Decarbonisation Technologies		
Scrap Based EAF	100%	Phased (external factors govern
Gas Based DRI	50%	I
Carbon Capture and Use	Variable	I Selective
Hydrogen-based DRI	100%	Governed by external factors. Faster developments can help earlier adoption

As per IEA 2020 report, the key drivers for emission reductions by 2030 globally will be technology performance improvements and material efficiency which together will deliver 90% of annual reductions. Even in the 2030-2050 segment, technology performance improvements and material efficiency play a key role accounting for over 60 % of the projected reductions.

Coal gasification is one of the potential areas which can be of vital significance in enlarging the role of GDRI in the Indian context.

Breakthrough technologies are more in the longer term driven by the need for steady availability at economic costs and scale. Hydrogen based DRI would be the most attractive under the Indian scene. The level of use of Green hydrogen will determine the extent of its impact on carbon in steel manufacture. Even lower grade hydrogen is a highly desirable

alternative to Carbon capture given the large number of external issues dogging the CCU. However, smelt reduction preferences driven by local coal considerations, will have to have CCU if the carbon intensity has to be within the acceptable ranges. Coal gasification based DRI if continued would also need CCU support for maintaining low levels of carbon impact.

PROSPECTIVE AREAS

In the Indian context the immediate priorities would be to focus on existing facilities modernization and in ensuring that the new facilities would be fully compliant of the final objectives. The major potential areas are:

- As far as process modifications/interventions are concerned introduction of TGR in the BF supported by CCU will become inevitable in the modernized BF installations for carbon reduction. These impacts along with the potential they offer will need to be critically evaluated versus the SynGas based DRI to arrive at an optimum solution under Indian conditions on a sustainable basis.
- The most prospective Gas-based DRI with coal gasification in the near and mid-term, can have the initial target level of about 1.2 TCO₂ per ton DRI with limited CCU support.
- Another area which can be of interest in carbon reduction is the use of hot metal in EAF's installed in the existing ISP's as a part of its Carbon reduction plans. The EAF can accept 25-40 % hot metal in its charge besides the DRI and Scrap as other metallics. This combination offers substantial reduction in EAF steel scrap demand and energy intensity. The adoption of this would have to be part of the larger plans of each HM based units and their transition and requires individual evaluation to assess its viability and benefits on a case-by-case basis.
- A prospective option for carbon reduction in BF is the use of GDRI in BF charge. It can be seen from Table 12-4 that use of high carbon DRI produced using Syngas with 55% Hydrogen has the potential to reduce overall BF carbon intensity by over 30%.
- Kobe Steel Japan has reported to have achieved the world's lowest coke rate of 239 kg of coke per ton of hot metal (RAR of 415 Kg.thm) using about 300 kg of HBI in the charge. A 20 % reduction in Carbon emission is also reported. (Figure 12-3.)
- Similarly high carbon DRI can also help reduce the intensity of carbon in EAF by over 25% as can be seen in Table 12-5.(Figure 12-4)

TABLE 12- 4 CO₂ IMPACT OF HIGH C DRI USE IN BF

Process	Carbon share (Typical)				
	Overall		BF		DRP
	kg/tls	%	%	kg/tls	Kg/tls
BF BOF	2200	100	100	2200	
Standard DRI/HBI to BF	1980	90	80	1880	100
High C DRI/HBI to BF	1750	82	74	1570	180
High C DRI/HBI to BF + 35 % Hydrogen in DRP	1650	78	74	1570	80
High C DRI/HBI to BF + 55 % Hydrogen in DRP	1500	77	75	1450	50
Figures are typical & vary from location to location.					

TABLE 12-5 CO₂ IMPACT OF HIGH C DRI USE IN EAF

	Carbon Share	
	DR EAF	DRP
	t/tls	t/tls
EAF High C DRI NG 100%	0.58	0.40
EAF High C DRI/ 35 % Hydrogen in DRP	0.30	0.15
EAF High C DRI/ 70 % Hydrogen in DRP	0.21	0.10
Figures are typical & vary from location to location		

STEPWISE INDIA CARBON TARGETS

At a gross 246 MT of CO₂ currently, the current industry level of CO₂ intensity is placed at the level of about 2.4/tcs, whereas the Coal based DRI is near 2.6/tcs. Against this, the near-term overall industry average CO₂ emissions targets are 1.53 by 2030, 0.98 by 2040 and 0.65 by 2050. (Refer Table 12-6 and Figure 12-5).

TABLE 12- 6 TARGET CARBON INTENSITIES

	Current	Base	2030	2040	2050
	CO ₂ Intensity	CO ₂ Intensity	CO ₂ Intensity	CO ₂ Intensity	CO ₂ Intensity
	t/tcs	t/tcs	t/tcs	t/tcs	t/tcs
BF/SR	2.40	2.22	1.8	1.5	1.2

SynGDRI	2.60	1.58	1.3	1	0.6
CDRI	2.60	2.38	2.2		
SCRAP	1.00	0.67	0.6	0.5	0.4
Total	2.35	2.05	1.53	0.98	0.65

The Sustainability of the steel industry can largely be assured if the above targets can be fulfilled successfully as per the time frames envisaged. The indirect contribution from the purchased power is also a critical factor given the increase in the quantum of purchased power in the future. The stepwise actions towards sustainability targets are indicated below.

Step 1 Immediate:

The key actions are related to the improvements in operations, energy efficiency and material efficiency. The current industry levels are quite high as compared to benchmark operations. Actions required for the use of Hydrogen albeit as a part replacement for coal, must begin. These include BFTGR, Syngas (high hydrogen) and Hydrogen use for DRI production

Step 2 Target 2030:

The reduction in Carbon overall is a manageable 25 % given the head room available due to the increase in new capacities focusing on Coal gasification/Off-gas based GDRI. Benchmark operations, energy recovery from EAF off gases and material efficiency must form essential part of GDRI and related EAF facilities right from the planning stage. The use of high carbon DRI in BF charge and its increasing use in EAF are also of major interest. The efforts at increasing hydrogen proportion in syngas will be of immense value in reducing the Carbon impact of Gas based DRI. Use of hydrogen upto 100 % can be made as a provision for future.

New BF capacity additions (fully) and modernization (selected capacity) need to incorporate TGR and CCU.

Step 3 Target 2040:

Consolidation of Gas-based DRI with EAF and start of phasing of old BF's will be the key actions. Introduction of hydrogen upto 100 %, if economically feasible, is a main area of focus. Evaluation of any breakthrough technology with prospect of high decarbonisation (Electrolysis) and plan for adoption also merits attention. Scrap based production must also receive critical attention to place the industry on a realistic transition path.

Step 4 Target 2050:

Enlarging the 2040 focus on Hydrogen and continued reduction of BF to a stabilized level. Plans to include energy transition with long term realities and objectives must be well in place by this time. Scrap based production to be placed on a firm basis with good share (25 to 30%).

Renewable Energy share

As earlier explained the share of Purchased electricity will substantially increase in all the steps given the focus of EAF as the workhorse for steelmaking. The indirect carbon contribution from this aspect can be reduced through increased share of green electricity supply. The current level of 0.7 kg/kwh average (going up to nearly 1 kg/kwh) is far too high for environmental security.

While the onus of ensuring this will rest with the Power supply agencies, and the policy level support from government including larger use and competitive pricing, the steelplants have to be ready for adjustments demanded by the green sources (possible intermittent supplies).

Similarly, use of Hydrogen which can have a major role in case of its being green as well as affordable is also critical in achieving the above objectives.

STEELPLANT STRATEGIES

The sustainable steelplants and their configurations to suit the above stepwise objectives and priorities need to factor the following in their strategies:

- The overall carbon emissions in new facilities has to be lower than 1.5 tcs, if Smelt reduction based. With CCU assist this need to be lowered to 1.2 or lower. The process, raw materials and equipment selections have to be based on this requirement.
- Coal gasification coupled with greater hydrogen in syngas and CCU if required could be an environmentally acceptable option as well. A target of 1.2 tcs and lower with CCU assist as required may be relevant.
- The DRI-EAF route must aim carbon contribution of 1.0 tcs and lower with CCU assist if required. HDRI therefore demands concerted actions.
- Provision for Hydrogen use up to 100 % must be part of the initial planning and enablers. With this the DRI can be ultimately near carbon-free. Use of Hydrogen in EAF would also reduce the purchased electricity share and inevitable process carbon addition.
- The existing facilities (mainly ISP-BF area) modernized, need to target 1.5 tcs assisted by CCU, as required.
- The scale of external energy (read purchased) will be quite high and thus will require critical planning and meticulous execution and operations for good performance. A holistic approach is required with effective interfacing with the developments of Green Energy resources as well as future power capacities.
- Incorporation of CE and waste management as an integral part of the plant system is a must being an effective step towards material efficiency. Facilities for ensuring near 100 % recycling of in-plant iron bearing waste must be made.

- The overall electrical energy consumption in steel industry in India with hydrogen introduction at current costs has the potential to add nearly Rs 8000 to 12000 per ton (after adjusting for coal replacement) or about 12 to 30 % of the production costs.
- It is well accepted that the assured availability of hydrogen in scale commensurate with the steel industry demand is quite long term. This is due to the high level of investments required in installing facilities energy constraints and supporting infrastructure. Scaling remains a very important challenge determining the overall availability as well as providing a competitive price of hydrogen and even more so the green hydrogen. In the Indian context the reliable future power scene is also a critical factor governing the possible extensive use of hydrogen in steelmaking.

Planning Vital

The pathways to Sustainable steel plants are multi-dimensional requiring highly coordinated system for development. Every aspect forming part of this total chain have to be carefully estimated, designed and executed, many in cooperation with numerous external agencies. Thus, meticulous planning with strong commitments on time frames is a vital necessity. The key focus areas are:

- National Level Policies
- Repositioning Strategies to address industry fragmentation
- Plans for Modernisation and Sustainability
- Industry Level New Capacity Approach
- Individual Producer Growth Plans

Of the above the first two are at National policy level including the acceptance of the need for drastic reconfiguration of the existing installations. This may affect about 30 to 40 million tons (about 30%) of existing capacity. The modernization of the larger installations is feasible and possibly a more economical solution. In this the ironmaking capacity can be tailored to the targeted carbon levels and also carbon management features can be introduced from the beginning.

New Capacity Creations

The new plants can be installed right from the beginning on the basis of carbon levels suited for decarbonisation and climate control objectives. The contribution of BF may have to be mandatorily retained at the levels suggested to be sustainable. In the event other smelting processes based on indigenous coal become economically viable and successful in being potentially carbon compliant, these units can be integrated with the EAF's which can provisions for use of hot metal as well, if necessary.

Scale (Greenfield or New Brownfield)

It would be desirable to restrict the new installations to the minimum with the following basic attributes:

- Capacity level of not less than 10 to 15 million tons (Ultimate) generally and 5 to 6 million tons (ultimate) in cases where smaller capacities are inevitable. The level in brown-field installations will be determined by the local realities but their scale preferably being the range suggested.
- Compact plant design and appropriate infrastructure inside the plant.
- Energy parameters equal to or better than international and proposed national benchmarks.
- Incorporation of process improvements with the potential to substantially increase the hydrogen content of the reducing gas (upto 90%) which can easily pave the way for seamless transition to 100 % hydrogen as and when its availability and costs become attractive to the industry.
- Maximizing use of Hydrogen stepwise (if economically priced)

Casting and rolling

Casting and in-line rolling of hot rolled products (both flat as well as non-flat) can be made mandatory for design. This approach has the possibility of reducing by upto 90 % of the energy consumption as compared to the conventional processing practices.

Leveraging Available Infrastructure

The biggest advantage resting with expansion of existing installations are:

- All approvals are in place. Updating to suit the higher level of capacity and production needs will be required.
- Infrastructure links (Power, Water, Utilities) are already in place. Enhancements will be required along with quality improvements in some cases.
- Considerable land area may be released, if the innovative technologies, suiting carbon reduction are introduced. This would make the plant compact as well as provide scope for additional capacity addition if planned.
- Skilled available manpower can be leveraged to retrofit solutions and bring them to optimum levels in the shortest times as compared to Greenfield installation.
- The Capex requirements can be lower by 30 to 50 percent making the investments pay back much faster and more reliable.
- The project schedules can be much shorter.

Chapter 13

EXTERNAL FACTORS GOVERNING SUSTAINABILITY

The earlier chapters have covered a wide gamut of sustainability and the same as applicable to the steel industry. Industry imperatives have also been touched upon. A clear picture emerges that Sustainability is a multi-dimensional issue and requires coordinated efforts from all stakeholders to obtain the avowed objectives.

STAKEHOLDERS (EXTERNAL)

The different stakeholders involved are shown in Figure 13 -1. These include:

Core Steelplant

Energy supply sources

Logistics support agencies

Downstream value adders

Steel user segments

Designers and Constructors

Waste to wealth support agencies

Central and State Governments

Policy making agencies

Statutory Authorities

National Institutions

Social Segment

Serious Concerns

The major multi-dimensional concerns that need to be addressed by the industry as the pillars for its sustainability are:

Climate change

Environmental degradation

Impact on competing infrastructure

Resource depletion

SDG compliance

Neutralising the adverse cost impacts

SUSTAINABILITY POLICY - DESIRABLE OBJECTIVES

Sustainability has a wide role in the national context to ensure that the economic, environmental and social objectives are in consonance with the same and in the larger national and global interests. A clear policy in this regard can provide the overall approach that the industry needs to adopt to remain in sync with the larger national and sustainability aspects.

The key areas which can have serious impacts on the planning and performance of the steel industry in sustainability terms are discussed below:

Land Use

The land use laws can be clearly and unambiguously framed. The particular aspects that have great relevance are the following:

- Locational requirements and restrictions
- Compatibility with Agricultural policies, Urbanisation, town and country planning, environmental impacts,
- Usage efficiency

It is the primary responsibility of the state level governments to classify and earmark areas for industrial development within the overall planning framework of the state. In the Indian context the following approach may be of sustainable benefit:

- Use of fallow and uncultivated land for industrial purposes
- Area suited for integrated hinter area development considering the demographic and economic needs. This is necessary in order to avoid the overriding preference to the already well-developed locations to take advantage of the available infrastructure links and facilities.
- Good connectivity

The industry would also have to factor the following:

- Minimum land use with optimized technologies,
- Efficient layout
- Optimised logistics planning with minimal impact on the hinterland activities.
- A self-evolved industry norm for the different plant configurations in keeping with the global benchmarks and best practices.

Transport

The steel industry is highly transport intensive, both for the assembly as well as for distribution and incurs high costs on this account. In India, the major capacities are inland and

heavily rail dependent. Thus, location and siting must receive coordinated attention. The global oil scene also demands that this issue be very carefully nuanced as the viability of road transport (need for imported energy on a large scale, pollution, increasing costs adversely impacting the industry viability) hangs in balance. The ability of EV to provide a viable and stable option is yet to emerge. Competitive and sustainable road transport is a vital need.

In the Indian context Rail offers the primary alternative followed by road, with the water transport having the possibility of a secondary role. Therefore, the modernization of the rail transport to suit the demands of the industry on a very large scale would merit serious attention, particularly to leverage the prospect of use of green energy in rail transport (Solar in particular) and favourable economics.

Energy

Energy is the center-piece of decarbonisation of the steel industry including its Sustainability. However, its strategies are at a national and global levels today. The energy generation and distribution infrastructure requirements for the additional demands (with focus on green energy - RE) will be massive and will have a major role in the successful management of the same.

This is also probably the most important part of the major impact in terms of air pollution and Carbon footprint which is sought to be mitigated by greater use of green energy. The type of energy and its use is also likely to be governed by the policy outlines forming core of the National energy Transition Policy.

In the evolving scenario, the dependence of steel industry is likely to increase many-fold on purchased energy (particularly electricity) to a considerable extent. This is due to the high electricity demand of EAF steelmaking and hydrogen manufacture. Even carbon capture has quite a large associated energy demand. Since these contribute to Carbon contribution in an indirect manner, the possibility of increasing the share of green energy also demands concurrent attention. Policy guidance in terms of the type of energy use, projections of alternative energy scenarios with firm availability targets, timeframes for transition, Trade off policies etc. need to be taken into the industry scenario.

Water

Water is another area which has a critical role in Sustainability requirement due to the need to optimize its use and let competing demands including human consumptions get priority. That the entire population requires access to clean water is an uncompromisable objective. Policy guidance in terms of priorities, the sources aligned to type of use, industry imperatives for usage and conservation, and storage etc. need to be taken into the industry scenario. National policy on issues such Rain water harvesting, adoption of zero discharge in industries need to provide the contours for the industry to follow.

Carbon Capture and Use

Carbon capture is now being seen as an intermediate solution to decarbonisation. Also, it is clear that the last mile achievements would be heavily governed by the success of this option

for carbon management. Here again the infrastructure demand in terms of sites, storage and distribution and related issues will need to be addressed properly while the designs are finalized. The pricing of carbon and its impact on steel production costs will have to be carefully nuanced to ensure the industry financial health. Environmental and Social Impacts and Disaster Management strategies have to be in place as well.

Considering the steel industry scale and its demand level for Carbon capture, encouraging CCU would be an optimal step. This would require besides the direct players (Steel as well as downstream product producers) policy guidelines on the preferred products (fuel may be a priority special chemical), policy support for fair pricing and support for financing required investments.

Environmental Protection

This aspect has been in focus for quite a while. But the climate control objectives and the seriousness of the situation demands tweaking the policies adequately. Decarbonisation has now become an important part of the overall agenda. Thus, the policies in this regard, the transition strategies, and the time frames will have to be in coordination with the National policies. Policies on upgrades, scrapping of non-compliant segments etc are required to ensure continuity in planning and sustainable performance in this vital area of human concern.

Downstream User Factors

The downstream units of the steel industry have come to occupy center stage in manufacturing strategies. The core steel production in the steel plants is preferred to be upto the hot rolled stage (cold rolled stage also in many existing cases) with further value addition being left to the downstream units specifically focused on the user industries. This approach leads to diverse locations of downstream facilities such as cold rolling complexes, Pipe plants, Galvanising units, Prefabricated structures etc.

Clear policies for integrating these units with the core units for policy compliances are vital for ensuring overall system accountability and greater system efficiency. Regulations specific to such units are also required to remove ambiguities and interpretations from the overall steel industry norms and practices.

User Industry Dictates

The steel user segments such as construction and infrastructure including housing, and automotive have a very important role in ensuring the sustainability of steel. Usage reduction, Optimised uses, improved life cycle perspectives, circular economy linkage, new product development and design innovations all demand coordinated action starting from governmental and industry policies in many areas. National institutions such as the Standardisation bodies, Design related institutions will also govern the steel industry approach in many ways.

Circular Economy Impacts

A very challenging new addition to the policy portfolios is the need for the adoption of Circular economy on large scale. The success of CE is critically dependent upon the

development of an appropriate system (Process chain) consisting of effective multi agency, multi locational, multi technology and multi-disciplinary participants. The success of Circular economy also vitally depends on the downstream manufacturers and users linking with the manufacturing chain in an efficient manner. Significant contributions can be made by the downstream to ensure system optimization in terms of resources, costs and efficiency. Such a framework may be in the making for the first time in the Governmental Establishments. A well debated and researched policy frame work which can serve the composite interest of Circular Economy demands is thus essential. Regulatory changes on a large scale may be warranted for its successful and efficient implementation.

Life Cycle Thinking

As with CE focus, it is now recognized that Life cycle thinking is an essential element of Sustainability particularly when it comes to realistic demand assessment and reduced load on virgin resources. Here again the Governmental and Policy establishments as well as the various producer/user segments will be grappling with the demands of this introduction for the first time. Thus, a well debated and researched policy frame work factoring the multi-agency, and multi-disciplinary participants which can serve the composite interest of Life cycle thinking and associated demands is thus essential.

Common Resource Use

The major areas where the steel industry demands come into conflict in terms of priorities for use are:

- Land
- Selected Raw materials
- Energy
- Water
- Infrastructure (Roads, Rail, Shipping)
- Social and hinterland impacts

Clarity in Capacity planning, national priorities and policies in this regard can provide the guidelines for the industry to comply.

Social and Community Impacts

It may be worthwhile to consider evolving policies for addressing social impacts as an independent segment. This will enable setting clear objectives in this direction and the industry actions to suit. While quite a few of the impacts get dealt with as part of the other area actions (Water, Land, Urbanisation etc), the particular importance demanded by the health and safety aspects will require adequate quality attention in planning and sitting.

The Societal Factors that need to be addressed are:

- Societal interface Policies (Health, Environment and Social well-being)

- Hinter area Social development priorities and areas
- Skill matching and industry linkage
- External Environmental management collaboration

ATTENTION AREAS

Summarising, the following issues will have to be coordinated when planning decarbonisation of existing steel capacity and new capacities in India.

- Realistically Projected industry demand
- Industry preparedness for decarbonisation
- Sustainable Energy alternatives
- Green energy approach and evaluation of scale vis-à-vis steel industry
- Additional Energy Generation, Locations and Distribution impact
- Existing country infrastructure
- Resource conservation and CE/LCA initiatives
- New resources developmental plans and time schedules
- Impact of hydrogen transition on energy demand, quality reliability and competitiveness
- Reliability and cost of Supply (particularly RE)
- Environmental and Social Impacts
- Disaster Management Issues.
- Sensitive Policy platforms

While the steel industry as the performing arm has responsibilities in terms of making best efforts for compliance, the overall framework covering the above is driven by numerous external players namely, Energy and infra producers and suppliers, Central and State Governments, Regulatory authorities etc. Their approach and strategies will have a very large bearing on the way the industry needs to reposition itself for sustainability.

Chapter 14 -

ROLE OF DESIGN IN SUSTAINABILITY

Steelplant Design can and will be required to play a vital role in positioning the industry on an appropriate platform while addressing the environmental concerns and ensuring long term sustainability. The extraordinary demands on the industry for decarbonisation and climate friendliness can only be effectively addressed with appropriate design approach as well as support. Critical analysis of the steel production requirements in terms of suitable assets and appropriate practices and objective techno-economic implications of the evolving technologies need to be highlighted right from the stage of design. Sustainability of the steel industry will also require concerted efforts from the numerous stakeholders with a coordinated action plans.

Design Domain

While there are well-known specific roles of design in “Concept to Completion of the Steelplant”, the extraordinary circumstances created by the climate impacts demands extension of this role substantially. Design has the opportunity to shape the entire decarbonisation strategy (within industry limits and supply and use chain) due to its following unique attributes:

- First mover advantage
- Ability to plan an integrated outlook and identification of the individual issues.
- Enabling optimized solutions factoring the learnings of the industry.
- Competencies available to act as the bridge in comprehensive approach to the multi-domain issues and policies.

Besides the traditional design aspects, the current circumstances demand effective participation of design in the following:

- To provide a veering point amalgamation of the policies and regulations and ensuring plant designs to effectively address them.
- Critical interpretations of energy, water and common resource stipulations and ensuring infrastructure for their stage-wise compliance.
- Factoring effective energy optimization strategies through optimized equipment, technology, layout and process flow. Provide monitoring facilities for measuring carbon impacts on a real-time basis.
- Factoring Circular Economy requirements, implementation and multi-agency coordination across the supply and use chain.

- Ensuring scale and minimization of operating units along with minimal land use for ensuring productivity and efficient operations.
- Factoring impacts on design and layout likely due to Newer and evolving technologies for a possible carbon neutrality and large- scale dependence on Hydrogen in the future.
- Evolving and implementing construction friendly and fast track retrofitting solutions, factoring the specifics of every individual site which are likely to be unique.
- Capex optimization and enabling scope for early payback through optimized designs, effective use of existing infrastructure, modular approach, and fast track implementation.
- Focusing on industry profitability and road map for financial sustainability

Design Imperatives

The end results that are expected from a Sustainably Designed Steelplant will fall under the three heads defined by the Worldsteel. These are:

- Environmental Sustainability
- Social Performance
- Economic Performance

While a large part of the responsibility for these would rest with the operational efficiencies, effective maintenance, performance excellence and business strategies, design will have a critical role in terms of providing the basic enablers in the form of a well-designed and laid-out plant and facilities with required features and flexibilities to meet the demands of the specific area performances. The role that design can play to reach optimal levels can be reflected by the various performance parameters actually achieved. The key measurement parameters and associated facility features are indicated in the following paragraphs.

Environmental Sustainability

The key parameters that design can and must ensure to meet the global/national limits are:

CO₂ intensity: Through proper process and route selection for emission reduction, Building-in ability to minimize carbon use, effective CO₂ collection and reuse.

Energy intensity: Minimising through proper process technology and equipment selection and system designs, Waste heat recovery provisions and avenues for its use.

Environmental: Efficient and adequate pollution control facilities.

Effective monitoring and course corrections with EMS.

Material Efficiency: Incorporating enablers for total recovery and reuse (internal as well as external) from waste and coproducts, adoption of CE. Provide enablers for product improvements through in-line processes, and introduction of new processes & products

Economic: Capex Optimisation through Optimised equipment selection and designs, Compact layouts, Enablers for High productivity and optimal yields in facilities, Effective automation systems and AI assist.

Enablers for raw material input optimization (Quantity as well as costs)

UNSG vs Steelplant Design

The UNSG provide at present a Comprehensive Outlook to Sustainability. An appropriate matrix enveloping these requirements would provide for measurement of the efficacy of the proposed designs.

Similarly, the Inter-linkages between Climate Change and Natural Resources have been aptly presented in 2015, by the International Resource Panel (IRP). The steelplant enablers for the goals set out in both these approaches are broadly summarized in Table 14-1.

TABLE 14 – 1 STEEL PLANT DESIGN VIS-A-VIS UNSG

UNSG No	Requirement	Steel Industry Design Enablers
1 2	Poverty alleviation	Development of affordable housing materials Factor scope for Job creation direct as well as indirect. Coordinated Support to ancillary industries.
3	Good Health and well being	Comprehensive Environmental management Systems Design for Zero discharge adoption. Rain water harvesting to maximum extent Facilities for Special treatments for toxic wastes (Lead and Chromium discharges), and emissions as integrated part of the design.
4	Quality education	Facilities for Employee training and upskilling including vocational training and technology relevance.
5 ,10	Gender equality Reduce inequality	Enabling work environment for Increased women participation Facilities for employment, training and skill development.
6	Clean water and sanitation	Designs suited to minimize demand for fresh water. Maximising recirculation and recoveries from waste water. Design for Rain water harvesting.

		Increased Sea water use where relevant (appropriate steel materials).
	Affordable and clean energy	Design with facilities for Maximising waste heat recovery and 100 % use of off gases as energy. Increased use of clean and renewable energy Design focus on efficient and effective transition to Hydrogen.
8	Decent work and economic growth	Effective and efficient use of lower grade raw materials and technological flexibility in design Beneficiation of lower grade materials for extending resource lives.
9 11	Industry innovation and infrastructure	Innovative steel products and attributes to suit specific applications Economic and safe construction materials (optimal, earthquake resistant, corrosion proof, fit for purpose, minimising fabrication losses) Steels for enabling use of sea water Special Steels for use in hydrogen and associated developments Partner for reduced environmental impacts through conversion of steelplant wastes to useful products. 100 % use of slag as friendly construction material,
12	Responsible consumption and production	Optimised raw material use. Design for waste reduction Increased material efficiency (99 % or more conversion of waste to useful co products. Adopt Zero discharge concepts, Production of Eco-friendly products for wider use
13	Climate action	Design and Technology Focus on Emissions control and carbon reduction, Enablers for hydrogen substitution. Circular economy and Zero- waste
14	Life below water	Special steel products for Coastal soil protection measures. Use of steel slag for improvement of sea bed.

15	Life on land	Effective land use. Afforestation and greenery in plant areas. Avoidance of environmental damage. Safe disposal of toxic wastes and discharges.
16	Peace justice and strong institutions	Conform to standards and compliance norms.
17	Partnership for the goals	Coordinated action covering downstream and users for effective overall system efficiency, Circular economy, Life cycle performance and costs.

PLANT DESIGN OUTLOOK

Production chain linkage

The design has to ensure an integrated outlook in the steel production and processing covering the currently evolved Primary Metallurgy, Secondary Metallurgy, Tertiary Metallurgy which form the core of the steelplant restricted to the Hot rolling stage for flat products as well as the non-flat ISP's.

Besides the above, the impact of other dimensions demanded by downstream processing (Quaternary Metallurgy) including thermal treatments, cold rolling, thermo-mechanical treatments, coating and protection, Pipe making etc need to be recognised.

Decarbonisation approach

A key dimension that design has to infuse in the future outlook is the thorough and dispassionate evaluation of the emerging decarbonisation solutions. It has to be borne in mind that the plethora of approaches being suggested and projected defining parameters may be location-specific and considerably loaded with assumptions. Therefore, the relevance of the local realities and factoring the same effectively in the plant concepts would be the clear responsibility of design. Here again an independent and integrated outlook would be of extraordinary value.

Local factor impacts

In the Indian context, the approach to the various energy options, process adaptations to suit the available energies and evolving economically viable options will be unique. These will require a deep analysis to ensure the emerging solutions compatibility and the required transition strategy. Once the basic decisions on these aspects are built in at the design stage, there would be very little scope for course corrections in the future.

The limited R&D efforts within India, is another factor which calls for caution as perpetual dependence on borrowed solutions could preclude the possible impact of the local realities. This is particularly relevant when evaluating technologies and energy options vis-à-vis raw materials quality, availability and costs. It is important to recognise that the success of the steel

industry in the last three decades is principally propelled by the focus on raw materials quality and consistency. Therefore, parallel upgrade and adaptations in the different external interfaces of the steel industry could prove to be vital for the induction of the alternative decarbonisation solutions on a fast track.

DESIGN AND SUSTAINABILITY

The dictates of Sustainability and related compliances have to be incorporated appropriately in design. New Greenfield capacity as well as un-encumbered grey-field segments have the benefit of being able to factor the carbon targets right from the beginning in all aspects of the facility. Here concepts with high relevance for Sustainability can be preferred. Important aspects to factor into design of the New installations/facilities aimed at sustainability and their major impacts are outlined below.

- Favouring technologies with reduced/no carbon requirement to the maximum extent.
- Compact plant concepts driven by the various technologies and metallics scenarios, and associated technologies could be the foundation for reduced emissions due to the reduced number units and the ease of introduction of pollution control solutions.
- With focus on technologies for maximizing use of sensible heat in steel at stages, amenable layouts and auxiliary supports for failsafe performance would to be center-stage.
- The processing technologies focused on using sensible heat to the maximum would lead to much faster production cycles with huge impact on process inventory and consequent plant design.
- Reduced availability of in-house steel scrap.
- Need for introduction of technologies and facilities for use of low-cost inputs (lower grade ores, waste utilization)
- Auxiliary facilities for enabling maximum waste recovery and use with the aim of 100 % recycle/reuse.
- Reduced utilities and energy demands with possible excess availability of by-product energy in BF-BOF integrated steelmaking chain and related demands.
- Increased dependence on purchased electrical energy on a large scale and need for its optimization as well managing the indirect CO₂ impact.
- Factoring need to maximise the use of alternate water sources such as rain water harvesting. Impact of zero discharge both on make up demand as well as on treatment demands.
- Increased concentration of pollution due to the reduced land area used for the plant.

- Recognition of the vital role of CCUS, and providing their possible adoption in the Concept. Optimisation of common infra facilities and costs could prove to be the clinching factor in many instances.

Desired Industry Framework

The design approach should enable the new as well as the brown-field expansion capacities to benefit from the scale, extraordinary developments in technology, plant and equipment and operating practices. The key points are:

- The new and modernized capacities should be replicable modules in line with the ultimate capacity desired and the phases of implementation.
- In new installations the approach should be to use a single steel melt shop as far as possible for the ultimate capacity. Today it is possible to have 10 MTPY and over single BOF shop for flat products. The non flat shops may be restricted to about 6 to 7 million tons. EAF based shops (DR-EAF/DR-HM-EAF) can consider 5 to 6 million tons due to the longer heat cycles of EAF (due to solid charge) as compared to the BOF. Higher than these capacities may demand two SMS's.
- Desirable Minimum Plant Sizes are:
- The minimum non flat plant final capacities can be 3 MTPY and flat products plant about 5 MTPY. The modules within this could be

Non-Flat Product Module 1.5 - 2.0 MTPY

Flat Product Module 2.5-3 MTPY

The specific demands of the individual units will need to be evaluated to establish the extent to which these overall levels can be considered.

- Number of units required for meeting production levels may be largely one per module.

AREAWISE ATTENTION

The major areas which deserve good design focus are outlined with the specifics of each in the following paragraphs.

Impact of Compact Plants

The key fallout of the major technological developments scale and possible restriction of primary production upto hot rolled products with state-of-the-art technologies in the main steelplants, is that the plants will be highly compact as compared to the experiences so far. Design must address the requirements arising out of this aspect as efficiently as possible as it has the potential to considerably reduce the investment required. The attention areas are:

- Introduction of innovative concepts, systems and equipment with focus on optimizing material handling (raw materials and in process), transport and utilities leads.

- Optimising the number of support units for power, water and utilities distribution and other services and innovation in design will serve cost reduction (Capex as well as Opex) and space optimization.
- Provision for Innovative facilities and technologies and support units aimed at enabling full Circular Economy in action.
- Innovative designs (in facilities, yard utilities and logistics, modular buildings) aimed at savings in space, facility costs and ease of maintenance.
- Provision for effective water and effluent management including rain water harvesting on a large scale.
- Increased pollution intensities likely due to compacted installations and reduced area will have to be mitigated through greater centralization of discharge, and efficient collection treatments and maximum recycling/recoveries.
- Effective use of digitalization concepts for process automation factoring the reduced control locations for energy management, utilities, water etc. Optimization, monitoring and control through coordinated systems and approaches.
- The cumulative impact of these could reflect in reduced operational costs, better plant availability, productivity, and improved overall profitability of the unit.

Minimising Investment

Creating integrated steel capacities is highly capital intensive. It is in the range of about US \$ 1200 to 1500/tcs. In many cases the external infrastructure links also demand investments. Besides the initial investment, the steel plants spend considerable amounts of money on a sustaining basis for ensuring plant availability, regular rebuilds and upgrades, energy optimization, productivity, environmental compliances etc. The demands of pollution control, and lowering carbon impact (with sights on near-zero carbon emissions) have the potential to add considerably to the Capex demand, as much as an additional 30 to 60 % of the base Capex.

These concerns will have to be addressed effectively at the design stage taking advantage of the benefits that the compact concepts, reduced number of units and scope for easier and ultra efficient operations through technology and layout. Thus, technology evaluation on a comprehensive basis and overall techno-economic assessments covering the multiple dimensions assume great significance.

In the Indian context the benefits of brownfield expansions as compared to the green field installations need to be fully recognized and exploited. Preferring brown-field capacity increases has the following major benefits:

- Can reduce Capex demand/ ton of increase in capacity by 40 to 60 %.
- The time-frame for implementation and optimized production levels will be much shorter.

- Existing infrastructure can be more effectively used saving both time and costs and regulatory issues.
- Long term sustainability can be ensured.

This will however need to be supported by well researched solutions, innovative approaches, meticulously planned implementation, use of modern and effective construction methods and tools for fast-track implementation.

In the current narrative, where there is a need for big process shift and introduction of scale, it is possible that large scale or even total rebuilding may be involved in some locations. Here the existing attributes such as effective land use, strengthening external infra linkages, and use of some of the existing equipment and facilities (albeit with repurposing and relocation) would be avenues for cost optimization.

The external elements essential for Greening namely Green electrical energy, Hydrogen, Carbon related infrastructure would also demand huge investment (far more than what the steel industry itself would need) and time for implementation, albeit by other agencies and the governments. These have to be addressed simultaneously in a coordinated manner.

There could be scope for on-site units for hydrogen in case of demand and plant scale matching. In such cases the plant infrastructure could be extended to include the requirements of the hydrogen facility as well leading to optimized investments.

Energy Optimisation

This aspect will demand inter-alia at the design stage the following dictates:

- Well nuanced raw material feed both for BF/Smelting as well as direct reduction.
- Pre-treated hot metal supply to BOF's.
- Hot DRI charging in EAF for steelmaking
- .Net shape casting and in-line direct rolling for products
- .In-line Thermo-mechanical treatments while processing avoiding downstream energy demand.
- Maximum recoveries of waste energy and
- Increased use of green energy.

Raw Materials Demand

With GDRI likely to emerge as a major source of metallics for steelmaking, the demand for iron ore pellets will increase substantially in the future. This can be met by purchase, or through captive plants preferably installed at or near mine sites. Consequently, scope for use of lower grade resources after beneficiation will also be increased substantially.

This aspect will require an integrated outlook from design perspective to ensure resource optimization. Internally, need for reducing process and handling arisings, maximum use of process wastes and collection from the pollution control units will need to be addressed.

Flexibility in design to accept a wide range of raw materials and in plant wastes would be an imperative.

Adoption of Circular Economy

This aspect will require sea change in approach to waste management and conversion of waste to productive use addressing the following:

- Impact of Processes with minimal in-process waste generation
- Well discriminated collection of wastes and their recycling within the steel plant.
- Incorporation of facilities for conversion of byproduct wastes to useful inputs for other products/uses. (Granulation of slags, pelletisation of iron bearing wastes for reuse in the plant) will have to be priority. Such facilities will require to be well integrated even when installed as a part of external partner participation to derive maximum benefits including cost savings.
- Process flexibility for use of multiple metallics inputs for steelmaking and factoring increased scrap recycling for steel production.
- With focus on decarbonization, CCUS also is an element requiring attention. Being a new dimension, the impacts of this aspect has to be evaluated on a comprehensive basis for effective use, optimised system cost and competitive product pricing. Since there is strong possibility and need for external partners (driven by the demand for expertise in manufacture of products/carbon conversion), a well- defined project outline and operating philosophy, utility linkages, cost sharing etc will be essential

Constructibility

This is an aspect which design has to address effectively as it has serious impacts on brown and grey filed additions and on fast-track implementation of green field facilities and the level of investments. The key issues are:

- Nature of solutions.
- Resource requirements
- Locational demands
- Time for construction
- Cost of construction
- Safety in construction

Design, besides addressing above concerns, must also factor the impact of increasing need for modularization, mechanisation and automation. Strategies in this regard will vary from project to project (size, location, complexities, schedules).

BIBLIOGRAPHY AND LIST OF REFERENCES

	Steel Impact Infographic	Worldsteel
	Role of Steel in World Economy	Worldsteel
	Setting the Course for the Healthy steel Industry	Worldsteel GF Sec Paris March 20
	Steel Demand Beyond 2030 Forecast Scenarios	Accenture (OECD Sep 2017)
	Worldsteel in Figures, (Various)	Wordsteel
	Latest Developments In Steelmaking Capacity 2020	OECD Report
	Sustainable Steel Indicators and steel applications	Worldsteel
	Securing a robust and sustainable future for the Indian Steel industry	CII and EY Report September 2020
	A brief history of the Indian iron and steel industry	K. N. P. R A 0 , B.Sc. (Met.), F.I.M.
	Opportunities and Challenges of the Indian Steel Industry in the Context of Future Growth	Asian Steel Watch . Dr. A. S. Firoz Chief Economist, JPC, MoS, Government of India
	Indian Steel Industry Opportunities and Challenges	FICCI Report, Dec 2015
	Progresses and Future Prospects of Steelmaking Technologies	JFE Technical Report No. 22 (Mar. 2017) Oshima Kenji et.al
	The State-of-the-Art Clean Technologies (SOACT) for Steelmaking Handbook	Asia Pacific Partnership for Clean Development and Climate December 2007
	Sustainable Development Goals	UN & GIVE STEEL A/S
	Sustainability Indicators and Our sustainability journey	Worldsteel Sustainable Steel report 2021 & Various
	Nippon Steel Sustainability Report	2019
	Nippon Steel Sustainability Report	2021
	Strengthening Sustainability in the Steel Industry	IFC Worldbank Group
	Industrial Resource Efficiency and CIRCULAR ECONOMY	Department of Environment UNIDO Report
	Towards Circular Economy, A report	Ellen McArthur Foundation
	Building Blocks of Circular Economy	CEPS August 2016 BY IGOR TARANIC
	Circular Economy 4 Rs Steel the Permanent Material in the Circular Economy	Worldsteel
	Circular Economy	UNIDO Report

	Development of recycling industries within the UNIDO circular economy approach	UNIDO Report
	Development of recycling industries within the UNIDO circular economy approach	Department of Environment UNIDO Report
	The Circular Economy: What, Why, How and Where	UCL Institute for Sustainable Resources, University College London
	Towards the Circular Economy	Economic and business rationale for an accelerated transition, EM Foundation
	Circular Economy in EAF Process: How to Make It Sustainable with Zero Waste Project in Ferriere Nord	Loris Bianco* , Sergio Porisiensi, Giulia Baracchini, Laura Battigelli, Carlo Ceschia
	Strategy Paper On Resource Efficiency in Steel Sector Through Recycling of Scrap & Slag	Niti Ayog, GOI
	Mining and metallurgical wastes: a review of recycling and re-use practices	Journal of SA Institue of Mining and Metallurgy, Aug 2018 E. Matinde, G.S. Simate, and S. Ndlovu
	How Steel Makes the Circular Economy Go 'Round	POSCO-WSA 2017/06/23
	How Steel is Helping to Achieve a Global Circular Economy	Clare Broadbent Head of Product Sustainability World Steel Association
	Solid Waste Management in Steel Industry - Challenges and Opportunities	Sushovan Sarkar, Debabrata Mazumder International Scholarly and Scientific Research & Innovation 9(3) 2015
	Steel By Product Recycling & Briquetting	SVAI Presentation
	Artificial Intelligence And The Circular Economy	Ellen Mcarthur Foundation
	Economic and business rationale for an accelerated transition	POSCO and WSA
	Steel's contribution to the circular economy through a life cycle approach	Author: Clare Broadbent World Steel Association
	The circular economy: Moving from theory to practice	McKinsey Center for Business and Environment Special edition, October 2016
	Life Cycle Assessment In The Steel Industry	Worldsteel position paper
	LIFE CYCLE INVENTORY STUDY 2019	WSA data
	Life Cycle Assessment in India (A presentation)	Dr. Rajesh Kumar Singh, Managing Director PE

		Sustainability Solutions Pvt Ltd, India
	STEEL IN THE CIRCULAR ECONOMY A life cycle perspective	WSA Report
	Steel Technology Roadmap	ITP
	Change and Development of Steelmaking Technology	NIPPON STEEL TECHNICAL REPORT No. 101 NOVEMBER 2012
	Using the HYL ZR Process and Coke Oven Gases for Production of DRI	Pablo E. Duarte Danieli SpA
	State Of The Direct Reduction And Reduction Smelting Processes	A.Markoti, N.Doli and V.Truji
	Mesabi Nugget: World's First Commercial ITmk3® Plant	Steve Rutherford Mesabi Nugget LLC Midrex Technologies, Inc
	MIDREX H2: Ultimate Low CO2 Ironmaking and its place in the new Hydrogen Economy	Jayson Ripke and John Kopfle
	Coal Gasification Based DRI Solution for Indian Ironmaking	Rob Cheeley, Markus Leu, Midrex Technologies, Inc
	State Of The Direct Reduction And Reduction Smelting Processes	Journal of Mining and Metallurgy, 38 (3&4) B (2002) A.Markoti, N.Doli and V.Truji
	Future Trends In Ironmaking	Dr. Joseph J. Poveromo Raw Materials & Ironmaking Global Consulting May 2014
	New Ironmaking Processes: Relevance to India	Dr B B Agrawal and A S Mathur RDCIS-SAIL India
	Blast Furnace 2030 - A Vision For Sustainable Iron Production	MPI White Paper The Steel Industry Series Paper No.4 - September 2017
	SIMETAL Corex	J.F. Plaul Siemens VAI Presentation
	Hismelt technology	Hismelt Corp Presentation 2008
	Recent Advances and Future Prospects of Refining Technologies	NSC Technical Report 61, April 1994
	STEEL TEEMING LADLE: Ladle Metallurgical Treatment / Refractory Materials Seminar:	Dipl.-Ing. Hans-Christian Schröter Hüttenwerke Krupp Mannesmann GmbH, and Ing. Andreas Viertauer RHI AG,
	Electric Arc Furnace Innovation - Addressing The Technology Challenges	The Steel Industry Series Paper No.3 - June 2017material Processing Institute

	Future Green Steelmaking Technologies	Sara Hornby Anderson, Gary E. Metius, Jim M. McClelland Midrex Technologies Inc
	High Grade Bloom Continuous Casting Technology	NSC Engineering
	Change and Development of Continuous Casting Technology	NIPPON STEEL TECHNICAL REPORT No. 104 AUGUST 2013
	Development of Continuous Casting Technologies at Kawasaki Steel	KAWASAKI STEEL TECHNICAL REPORT No.35 (Nov 1996)
	Hot Rolling Of Steel – Generation 6.0*	Karl Berger,Franz Holy
	An Introduction To Thin Slab Technologies	Elham Kordzadeh April 2016
	20 Years of Experience in Thin Slab Casting and Rolling State of the Art and Future Developments	C. Klinkenberg , C. Bilgen, T. Boecher, J. Schlüter SMS Siemag AG, Germany Materials Science Forum Vols. 638-642 (2010)
	MIDA endless and direct casting and rolling: the Danieli way to energy efficiency and CO2 reduction	Authors: A De Luca, F Tortul, M Cimolino and S Ronco Danieli SpA
	Arvedi ESP (Endless Strip Production) First Thin Slab Endless Casting And Rolling Results	G. Arvedi , F. Mazzolari , J. Siegl , G. Holleis
	TSCRA Analysis and Status	Own Analysis
	Iron and steel making in the third millennium	CIM Bulletin ; Vol. 95, N' 1063 F. Verdeja, J.P. Sancho and J.I. Verde
	Future Challenges in the Steel Industry and Consequences for Rolling Plant Technologies	Bruno Buchmayr ¹ , Michael Degner ² , and Heinz Palkowski ³
	Survey Of Current Projects And Novel Technologies In The Steel Industry 2020	IETS 2020
	New Technologies for Steel Manufacturing Based upon Plant Engineering	NKK Steel Technology Center Akira Uemura and Masaaki Shirai
	Efficient steelmaking has environmental benefits	AISE Steel Technology March 2003 Torsten Rummler Eric Anderson; Michel Hamy, and Gerhard Bünemann and Jens Apfel,
	Change and Development of Steelmaking Technology	Nippon Steel Technical Report No. 101 Masaki Iwasaki* Michitaka Matsuo November 2012
	Ladle Seminar HKM RHI	PPT Presentation 2018
	Technical Progress in Steelmaking and Casting for Special Bar and Wire Steel at Muroran Works	Nippon Steel Technical Report No. 104 Masato Kobayashi* Kohichi Isobe Masayuki Arai August 2013
	Environmental Case Study rail Steels	Worldsteel

	Weight reduction in Automotive steels using high strength steels Bars and rods	Nippon Steel Technical Report No. 81 January 2000
	Advanced AHSS Steel Guidelines	WorldAutosteel
	JPC Bulletins	Various Issues
	Iron and Steel Technology RoadMap	IEA Technology Report Oct. 2020
	A Review On Energy Efficiency Of Steel Plants In India	Arijit Mukherjee 1 , Soumendra Nath Basu 2 , Sayan Paul 3
	Benchmarking Report for the Iron and SteelSector (Industrial Energy Efficiency Project)	UNIDO/gef Report
	A Study of Energy Efficiency In Indian Steel Industry	S. S. Krishnan Venkatesh Vunnam P. Shyam Sunder J V Sunil A. Murali Ramakrishnan C-Step Report (December 2013)
	Energy Technology Perspectives 2020	IEA
	Energy Efficiency and Sustainability In Steel Production	L.E.K. Holappa
	CO2 Emissions and the Steel Industry's available Responses to the Greenhouse Effect	Jean-Pierre Birat, Jean-Pierre Vizioz, Yann de Lassat de Pressigny, Michel Schneider, Michel Jeanneau IRSID, ATS, Usinor, Sollac
	Steel's Contribution to Low Carbon Europe 2050	BCG Report
	Global Solution for Reducing Greenhouse Gas Emission by Steel Industry ³ / ₄ Search for Low Carbon Society	IEI Annual Technical Volume Edition-2 (Somnath Kumar, Subhra Dhara, S Ghosh)
	Global Solution for Reducing Greenhouse Gas Emissions by Steel Industry ³ / ₄ Search for Low Carbon Society	IEI Annual Technical Volume Edition-2 (Smeeta Kujur, Satyendra Sudershan)
	Global Solution for Reduction of Greenhouse Gas Emissions by Steel Industry ³ / ₄ Search for Low Carbon Society	IEI Annual Technical Volume Edition-2 (Partha Banerjee)
	Production of Green Steel: Global Solution for Reducing Greenhouse Gas Emissions by Steel Industry	IEI Annual Technical Volume Edition-2 B Bhoi, P S Mukherjee et.al
	CEPS – Benchmarking Insights from Steel – Benchmarks and the Environment	Dr.Hans-JörnWeddige ThyssenKrupp Steel
	JISF long-term vision for climate change mitigation A challenge towards zero-carbon steel	Japan Iron and Steel Federation November 19, 2018
	Utilizationof Solid Waste From Steel Melting Shop	Presentation by MECON LIMITED Shri Bikas Pandey ,
	NSC Technical Report	No 81, January 2000
	NSC Technical Report	No 94, July 2006

	Unlocking low carbon investments in the steel sector	Eurofer Presentation January 2018
	Power-to-Steel: Reducing CO2 through the Integration of Renewable Energy and Hydrogen into the German Steel Industry	Alexander Otto Martin Robinius et.al
	Progress and Future of Breakthrough Low-carbon Steelmaking Technology (ULCOS) of EU	Yan Junjie
	Low-carbon production of iron and steel: Technology options, economic assessment, and policy	Zhiyuan Fan1, * and S. Julio Friedmann1, Joule Review
	Steel from Solar Energy A Techno-Economic Assessment of Green Steel Manufacturing	Hydrogen Europe
	Green Steel Through Hydrogen Direct Reduction A Study On The Role Of Hydrogen In Indian Iron And Steel Sector	Primetals-Siemens ,The Energy And Resources Institute
	Iron and Steel Industry Transition	Princeton's Net-Zero America study August 2021
	Pedal to Metal 2021	Caitlin Swalec and Christine Shearer, Global Energy Monitor
	Industrial Decarbonisation & Energy Efficiency Roadmaps to 2050 (Report for the Dept of Energy and Climate Change and the Dept for Business, Innovation & Skills Iron and Steel)	WSP-Parsons Brickenhoff, DNV-GL MARCH 2015
	Decarbonization challenge for steel Hydrogen as a solution in Europe	Mckinsey and Company Report
	NSC Carbon Neutral Vision	NSC Presentation March 2021
	Recycling of Steel	World Steel Presentation ECCA Nov 2020
	Climate Change and production of iron and steel	World Steel Presentation March 2021
	Decarbonising Indian steel industry: Recent trends	Grant Thornton Report
	Net-Zero Steel Sector Transition Strategy	Mission Possible Partnership October 2021
	Emerging Technology Concepts to Fully Decarbonize Ironmaking	Christina M. Chang and Jenifer C. Shafer Patrick (ARPA-E) D. Finch (BAH)
	Mission to reach Net Zero Carbon emissions in Hard to abate sectors by mid-century Sectoral Focus Steel	Mission Possible-ETC Report (2017)
	Towards a Low Carbon Steel Sector Overview of the Changing Market, Technology, and Policy Context for Indian Steel	Report of The Energy and Resources Institute 2020

	A Green Hydrogen Economy for India	Policy Brief CEEW Dec 2020
	Steel's Contribution To A Low Carbon Future And Climate Resilient Societies	Worldsteel position paper
	Steel industry in India: Potentials and technologies for reduction of CO2 emissions	Report for MOEF, ASEN and GIZ by AMCG Unternehmensberatung GmbH Dec 2011
	Understanding the Cost of Deploying CO2 Capture in an Integrated Steel Mill	IEA Report 2013/04 Stanley Santos, Lawrence Hooey, Jeremy Johns , Andrew Tobiesens
	Technology Roadmap for "Transition Finance" in Iron and Steel Sector	October, 2021 Ministry of Economy, Trade and Industry Japan
	Climate change and the production of iron and steel	Worldsteel Policy Paper 2021
	Several Initiatives by MoS GOI to support steel industry	MoS GOI Report December 2019
	A Green Deal On Steel: Making The Eu Steel Industry The Flagship Of Eu Climate Policy	Eurofer Presentation 2010
	A Steel Roadmap for a Low Carbon Europe 2050	Dr.-Ing. Jean Theo Ghenda Steel Institute VDEh(Eurofer)
	Decarbonization of the steel industry. A techno-economic analysis	Amaia Sasiain Conde1,* , Katharina Rechberger1 , Andreas Spanlang1 , Hermann Wolfmeir2 , and Christopher Harris2
	Decarbonizing primary steel production: Techno-economic assessment of a hydrogen based green steel production plant in Norway	Abhinav Bhaskar * , Rocky Abhishek, Mohsen Assadi, Homam Nikpey Somehesaraei
	Potential Roadmaps for Decarbonization of the Steel Sector	Authors: Thomas Adisorn (WICEE) Yoshikazu Kobayashi (IEE, Japan) Study for the GJETC Wuppertal, March 2022
	Setting the course for a healthy steel industry	WSA GFSEC, Paris, 17 March 2020
	Hydrogen's Decarbonization Impact for Industry Near-term challenges and long-term potential	Rocky Mountsin Institute Jan 2020
	The Future of Hydrogen - Seizing today's opportunities	Report prepared by the IEA for the G20, Japan
	Hydrogen Insights A perspective on hydrogen investment, market development and cost competitiveness February 2021	Hydrogen Council McKinsey and Co
	Hydrogen in Steel Production What is happening in Europe	Published on May 26, 2021 by Bellona Europa

	India's steel and cement industries to low carbon pathways	SNAPFI Country Study India Transitioning JULY 2020
	The Decoupling of GDP and Steel Demand: Cyclical or Structural?	Dr. Chung Cheol-Ho Vice President POSCO Research Institute
	Best Available Techniques (BAT) Reference Document for Iron and Steel Production	JRC REFERENCE REPORT Industrial Emissions Directive 2010/75/EU (Integrated Pollution Prevention and Control)
	In (And For) A Decarbonised World Case Study Of The Steel Industry:	The Scenario Analysis Run By Carbone 4 !Strategy Practice January 2019
	Environmental Strategy Design For The Japanese Iron And Steel Industry -A global perspective	D.J. Gielen Y. Moriguchi - DRAFT 21/6/2001 -
	Industrial Transformation 2050 Pathways to Net Zero Emission from EU Heavy industry	Material Economics(2019)
	Overview Of The Current State And Development Of Co2 Capture Technologies In The Ironmaking Process	IEAGHG Report: 2013/TR3April 2013
	Co2 Emissions In The Steel Industry	Metalurgija 48 (2009) 3, 193-197M. Kundak, L. Lazi], J. Rnko
	CO2 abatement in the iron and steel industry	Profiles No 12/1 IEA Clean Coal Centre February 2012
	Combining Steel and Chemical Production to Reduce CO2 Emissions	Low Carbon Economy, 2011, 2, 115-122Jouko Arvola, Janne Harkonen, Matti Mottonen, Harri Haapasalo, Pekka Tervonen
	Short-Term Opportunities For Decreasing Co2 Emissions From The Steel Industry.	Joachim von Schéele Linde AG, Gas Division SE-18181 Lidingö, Sweden
	Power-to-Steel: Reducing CO2 through the Integration of Renewable Energy and Hydrogen into the German Steel Industry	Energies 2017(MDPI) : Alexander Otto, Martin Robinius Thomas Grube , , Sebastian Schiebahn , , Aaron Praktijnjo and Detlef Stolten
	Environmental Sustainability of the Iron and Steel Industry: Towards Reaching the Climate Goals	European Journal of Sustainable Development (2016) Volodymyr Shatokha
	Carbon mitigation potential of Indian steel industry	Mitigation and Adaptation Strategies for Global Change Pooja Pal & Himangana Gupta & Deepak Kapur
	CO2 capture technologies	CTCN (UNEP,UNIDO)

	The Role Of Steel Manufacturing In The Global Economy A Report For The World Steel Association	Oxford Economics-WSA May 2019
	Green Steel for Europe- Investment Needs March 2021	Michele De Santis, Antonello Di Donato (CSM) Tobias Kempken, Thorsten Hauck (BFI) Monika Draxler, Axel Sormann (K1-MET) Paula Queipo (IDONIAL) Wojciech Szulc (IMZ) Danny Croon, Jean-Theo Ghenda (EUROFER) Chuan Wang (SWERIM) Jean-Christophe Pierret, Jean Borlee (CRM)
	Hydrogen Production Costs 2021	Deptt of Business, Energy and Industrial strategy,UK
	The potential of hydrogen for decarbonising steel production	European Parliamentary Research Service: Christian Kurrer December 2020
	Technology Roadmap Carbon Capture and Storage in Industrial Applications	IEA-UNIDO Report 2011
	Technologies and policies to decarbonize global industry: Review and assessment of mitigation drivers through 2070	J. Rissman, et al. Applied Energy 266 (2020) 114848
	Most appropriate treatments to control the environmental impact of effluents in the iron and steel industry	Eurofer Report D. Mirabile J. Hodge et al 2008
	Hydrogen-based steelmaking	Pablo Duarte Tenova HYL
	Ultra-Low CO2 Ironmaking : Transitioning to the Hydrogen Economy	JPC Bulletin Sep 2020

LIST OF ACRONYMS AND GLOSSARY

	BAT	Best available technology
	BAU	Business as Usual
	CPCB	Central Pollution Control Board (India)
	IDA	Industrial Development Authority
	IEA	International Energy Agency
	IEE	Industrial Energy Efficiency
	IISI	International Iron & Steel Institute
	IPCC	Inter-governmental panel on climate change
	LKAB	Luossavaara-Kiirunavaara Aktiebolag
	MoS	Ministry of Steel GOI
	NSC	Nippon Steel Corporation
	NEDO	New Energy and Industrial Technology Development Organisation, Japan
	NSP	National Steel Policy (India)
	NZE	IEA's Net-zero by 2050 scenario (1.5°C by 2050)
	NIST	National institute of standards
	POSCO	Pohang iron and Steel Company
	SDS	IEA's Sustainable Development Scenario (1.5°C by 2070)
	STEPS	Stated Policies Scenario (IEA)
	SDG	Sustainable Development Goal
	SME	Small and Medium Sized Enterprise
	SSAB	Svenskt Stål AB
	SAT	State-of-the-Art Technologies
	TRL	Technology Readiness Level
	UN	United Nations

	VDEh	German Steel Institute
	WSA	World Steel Association
	DRI	Direct reduced iron
	NGDRI	Natural Gas based Direct reduced iron
	HDRI	Hydrogen Direct reduced iron
	HBI	Hot briquetted iron
	HCI	Hot compacted iron
	GDRI	Gas based direct reduced iron
	HMS	Heavy Melt Steel Scrap
	HYFOR	Hydrogen-based fine-ore reduction
	SMR	Steam methane reforming
	RHF	Rotary Hearth Furnace
	BF	Blast furnace
	SF	Shaft furnace
	SR	Smelt Reduction
	BOF	Basic oxygen furnace
	EAF	Electric arc furnace
	IF	Induction Furnace
	SAF	Submerged Arc Furnace
	MBF	Mini Blast Furnace
	LF	Ladle Furnace
	VD	Vacuum Degassing
	CC	Continuous Casting
	TSC	Thin Slab Casting
	TSCR	Thin Slab Casting In line rolling
	BF-TGR	Blast Furnace(s) – Top Gas Recycling
	PCI	Pulverised Coal Injection
	TRT	Top gas recovery turbine
	CDQ	Coke Dry Quenching

	PBCC	Partial Briquetting of Coal Charge
	CHP	Combined Heat and Power
	ORC	Organic Rankine Cycle
	BLT	Bell-Less Top (charging)
	EOS	Emissions Optimised Sintering
	WHR	Waste Heat Recovery
	WHRB	Waste Heat Recovery Boiler
	HRSG	Heat Recovery Steam Generator
	VPSA	Vacuum pressure swing adsorption
	PLI	Plastic Material Injection
	BTT	Breakthrough Technologies and Techniques
	ULCOS	Ultra-Low Carbon Dioxide Steelmaking
	SCOPE	Super Coke Oven for Productivity and Environmental Enhancement
	CCS	Carbon Capture and Sequestration
	CCS	Carbon Capture and Storage
	CCUS	Carbon capture use and storage
	CDA	Carbon direct avoidance
	CCB	Carbon Composite Agglomerates
	CCL	Climate Change Levy
	CE	Circular Economy
	BF-CC	Blast furnace with carbon capture
	LCA	Life Cycle Analysis
	SEC	Specific energy consumption
	EE	Energy Efficiency
	EEI	Energy Efficiency Index
	LHV	Lower heating value
	PV	Photovoltaic
	STE	Solar thermal electricity

	VRE	Variable renewable energy
	AEL	Alkaline water electrolysis
	AIE	Alkaline iron electrolysis
	HTEL	High temperature electrolysis
	MOE	Molten oxide electrolysis
	HPSR	Hydrogen plasma smelting reduction
	IBRSR	Iron bath reactor smelting reduction
	PEM	Polymer electrolyte membrane
	PI	Process integration
	COG	Coke Oven Gas
	BFG	Blast Furnace Gas
	BOFG	Basic Oxygen Furnace Gas
	Syngas	Synthesis Gas
	NG	Natural gas
	NM3	Normal cubic meter
	kg	Kilogram
	MTPA	million tonnes (tons) per annum
	Gt	gigatonne
	Gt/yr	gigatonne per year
	CV	Calorific Value
	MMBTU	Metric Million British Thermal Unit
	kJ	KiloJoule
	GJ	GigaJoule
	GJ/t	gigajoule per tonne (ton)
	GJ/yr	gigajoule per year
	kW	kilowatt
	kilowatt electric	kWel
	Megawatt	MW

	GW	Gigawatt
	KWh	Kilowatthour
	MWh	Megawatthour
	TWh	Terrawatthour
	kgCO ₂	Kilogram of carbon dioxide
	tCO ₂	Ton of carbon dioxide
	GtCO ₂	Gigaton of carbon dioxide
	gCO ₂ /kWh	gramme CO ₂ per kilowatt hour
	MTce	million tonnes of coal equivalent
	tce	tonne of coal equivalent
	MtCO ₂ e	metric tonnes(tons) carbon dioxide equivalent
	°C	degree Celsius
	EV	Electric vehicle
	FC	Fuel cell
	HF Welding	High Frequency Welding
	GHG	Green House Gas
	ppm	parts per million
	PM	Particulate Matter
	HAP	Hazardous Air Pollutants
	ESP	Electrostatic Precipitator
	SEI	Specific Emission Intensity
	PM _{2.5}	particulate matter with a diameter less than 2.5 micrometres
	SO _x	Sulphur Oxides (in emissions)
	NO _x	Nitrogen Oxides (in emissions)
	HSE	Health, Safety and Environment
	HVAC	Heating, Ventilation and Air Conditioning
	H ₂	Hydrogen
	N ₂	Nitrogen
	O ₂	Oxygen

	C	Carbon
	CO	Carbon monoxide
	CO ₂	Carbon dioxide
	SO ₂ e	Sulphur dioxid
	NO	Nitric Oxide (in emissions)
	CH ₄	Methane
	Ar	Argon
	As	Arsenic
	B	Boron
	Cu	Copper
	Mo	Molybdenum
	Al ₂ O ₃	Aluminum oxide (Alumina)
	SiO ₂	Silicon dioxide(Sillica)
	Fe ₂ O ₃	Hematite
	Fe ₃ O ₄	Magnetite
	Fe	Iron
	FeO	Wustite
	Fe ₃ C	Iron carbide
	CaCO ₃	Calcium Carbonate
	CaO	Calcium Oxide
	MgO	Magnesium Oxide
	Li	lithium
	LS	Liquid Steel
	CS	Crude steel
	FSC	Finished steel consumption
	FSP	Finished steel production
	ASU	Annual Steel Use
	AKDQ	(Aluminium-Killed Draw-Quality steel)
	CAGR	Compound annual growth rate

	CAPEX	Capital expenditure
	OPEX	Operating expense
	GVA	Gross value added

GLOSSARY

HSS (High-Strength steel):	Any steel product with initial yield strength greater than 210 MPa or a tensile strength greater than 270 MPa.
AHSS (Advanced High-Strength Steel):	A series of high-strength steels containing microstructural phases other than ferrite and pearlite. These other phases include martensite, bainite, retained austenite, and/or austenite in quantities sufficient to produce unique mechanical properties.
COURSE CO2	Ultimate Reduction in Steelmaking process by innovative technology for cool Earth
Abatement cost	The cost of reducing CO2 emissions, usually expressed in per tonne of CO2
Archetype	A steelmaking production technology paired with its business case—which includes its fuel consumption, emissions, and cost.
Bioenergy with carbon capture and storage (BECCS)	A technology that combines bioenergy with carbon capture and storage to produce energy and net negative greenhouse gas emissions (i.e., removal of carbon dioxide from the atmosphere)
DACC	Direct air carbon capture. The extraction of carbon dioxide from atmospheric air
Technology Readiness Level (TRL) The IEA reference scale, with 11	Describes the level of maturity a certain technology has reached from initial idea to large-scale, stable commercial operation.
TRL increments grouped into six categories	Concept (TRL 1–3),
	Small prototype (TRL 4),
	Large prototype (TRL 5–6),
	Demonstration (TRL 7–8),
	Adoption (TRL 9–10),
	Mature (TRL 11)

Avoided burden	A methodology that credits a system for producing a co-product (for example, scrap) that can be used to displace primary production of a material, thus avoiding the environmental burden of primary production.
BREEAM Method	Building Research Establishment Environmental Assessment Method. Used to assess the sustainability of buildings. The concentration of a greenhouse gas (GHG) that would absorb the same level of infrared radiation as a given concentration of CO ₂
Unit of measuring global warming potential.	cradle-to-cradle A life cycle approach where the material is fully recycled back into the same material, with no loss in quality.
	cradle-to-gate A study in which the impacts are assessed from raw material extraction up to the point where the product leaves the factory gate.
	cradle-to-grave A study which includes all life cycle phases from raw material extraction up to the point where the product is disposed of as waste or recovered and recycled
Downcycling	The process of reusing or recycling materials to create a product of lower quality or value than the original. EN 15804: 2012 European Norm 15804. Provides core rules for construction products
End-of-life (EOL)	Defines the end of the useful life of a product when it is ready to be disposed of or recycled. End-of-life scrap results from the treatment of a product at the end of its useful life. Also referred to as post-consumer scrap.
Environmental product declaration (EPD)	A comprehensive disclosure of a product's environmental impacts based on a life cycle assessment (LCA). EPD See environmental product declaration. function Defines the purpose of what is being studied in an LCA, in reference to a functional unit. For steel, the functional unit covers the production of one kilogram of a steel product to the point it leaves the factory gate.
Greenhouse gas (GHG)	A gas in the atmosphere which contributes to the greenhouse effect by absorbing infrared radiation.
greenhouse gases	The principal greenhouse gases are Carbon dioxide (CO ₂) Fluorinated gases Methane (CH ₄) Nitrous oxide (N ₂ O)
Global Warming Potential (GWP)	The ability of different greenhouse gases to trap heat in the atmosphere relative to carbon dioxide expressed as kg CO ₂ - equivalents.

GHG Protocol	The Greenhouse Gas (GHG) Protocol is the most widely used international accounting tool for government and business leaders to understand, quantify, and manage greenhouse gas emissions.
WEO	World Energy Outlook
ZEV	zero-emission vehicle
HPDs	Health product declaration a report listing the health effects associated with the materials content of a building product. Integrated life cycle assessment A tool for the systematic evaluation of overall sustainability aspects (environmental, social (social LCA), economic (LCC)) of a product or service system through all stages of its life cycle.
LCI / LCIA	Life cycle inventory / life cycle impact assessment
LEED	Leadership in Energy and Environmental Design
Life cycle assessment (LCA) cycle.	A tool for the systematic evaluation of the environmental aspects of a product or service system through all stages of its life
Life cycle costing (LCC) cycle.	A tool that evaluates the costs of a product throughout its life
Recycling	A resource recovery method involving the collection and treatment of a previously used product for use as the same material in the manufacture of a new product.
Remanufacturing	Remanufacturing restores durable used products to like-new condition.
UNEP.	United Nations Environment Programme