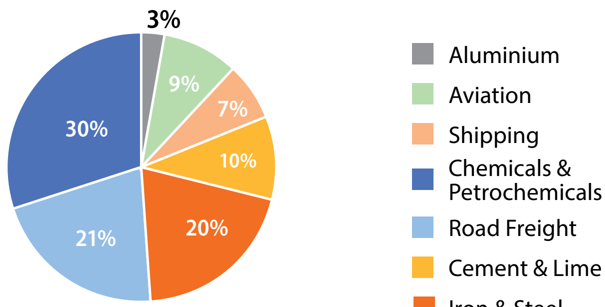
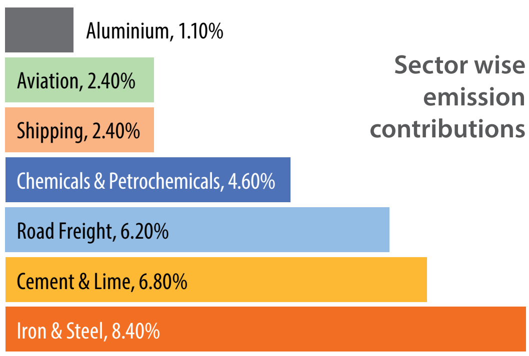
Energy Transition & Clean Technology In Metals: *IRON & STEEL*

The world is on a warming pathway of 2.8-3˚C, and the Paris accord, 2015 requires all nations to act aggressively to restrict temperature rise below 2°C above pre-industrial levels within this century. As of November 2020, the European Union and 194 countries, including India, signed the Agreement and expressed commitment to carbon neutrality. However, under current and planned policies, if fossil fuels such as oil, natural gas and coal would continue to dominate the global energy mix, the world would exhaust its energy-related "carbon budget" (CO_2) to keep the global temperate rise well below 2°C (with 66% probability) within 20 years.

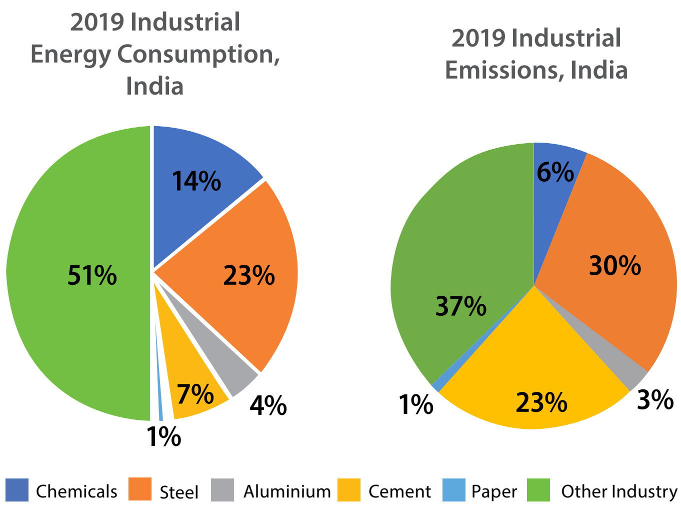
Industry accounts for about 45% of the global energy consumption and 32% of total CO_2 emissions with varied contribution across seven major sectors:



% Energy Consumption



Figures below give the distribution in India:



Technologies are being deployed for a transition in energy systems starting with generation & use of renewable energy sources and moving towards hard to abate Energy-intensive and Emission-intensive industries such as Power, Metals (primarily Iron & Steel and Aluminium), Cement, Refineries.

Although aluminium takes a lower position in cumulative contribution, primary aluminium production is very energy-intensive. Emission intensity is around 4.8 tCO_2/t of aluminium against the global average of 2.2 tCO_2/t of crude steel. The energy source is primarily electricity. Majority of the power consumption is from inhouse power generation, primarily based on coal (~60%). Work on improvements in CO_2 emissions is in improved recycling, flexibility to adopt renewable power, and development of non-carbon consumables such as inert anodes.

At around 1.9 billion tons of global steel production per year and about 19 gigajoules (GJ) (0.45 tonnes of oil equivalent) of energy required per ton of crude steel, the industry emits around 2.6 Gt direct CO_2 emissions annually.

Similarly, Steel Industry stood highest as a single sector in industrial energy consumption and CO_2 emissions in India in 2019.

Consequently, steel players across the globe are increasingly facing a decarbonisation challenge. Three key developments drive this challenge:

- Changing customer requirements and growing demand for carbon-friendly steel products. A trend that has already been observed in various industries, including the auto industry.
- Further tightening of carbon emission regulations manifesting in carbon dioxide reduction targets and rise in carbon dioxide emission prices.
- Growing investor and public interest in sustainability. For example, the Institutional Investors Group on Climate Change, a global network with 250-plus investors, has raised expectations for the steel industry to safeguard its future in the face of climate change.

With substantial projected capacity additions (100 – 140 MT) by 2030-31 in India and high reliance on coal, green/clean technology is very relevant for iron & steel industry even in India.

Steel is mainly produced by two routes:

Iron ore-based steelmaking and Scrap-based steelmaking.

In total, 70% of the world steel is made BF-BOF route, where iron ore is reduced in Blast Furnace and then converted into steel in Basic Oxygen Furnace (BOF). Raw materials are mainly iron ore, coal, limestone and steel scrap. Electric Arc Furnace produces balance (EAF) wherein scrap steel, or Direct Reduced iron (DR) is mainly used as raw materials and electricity as the energy source. In FY2020, share or crude steel BF-BOF route was 44%, EAF- 26% and IF (Induction furnace) was 30% in India. Global average carbon emissions from above routes:

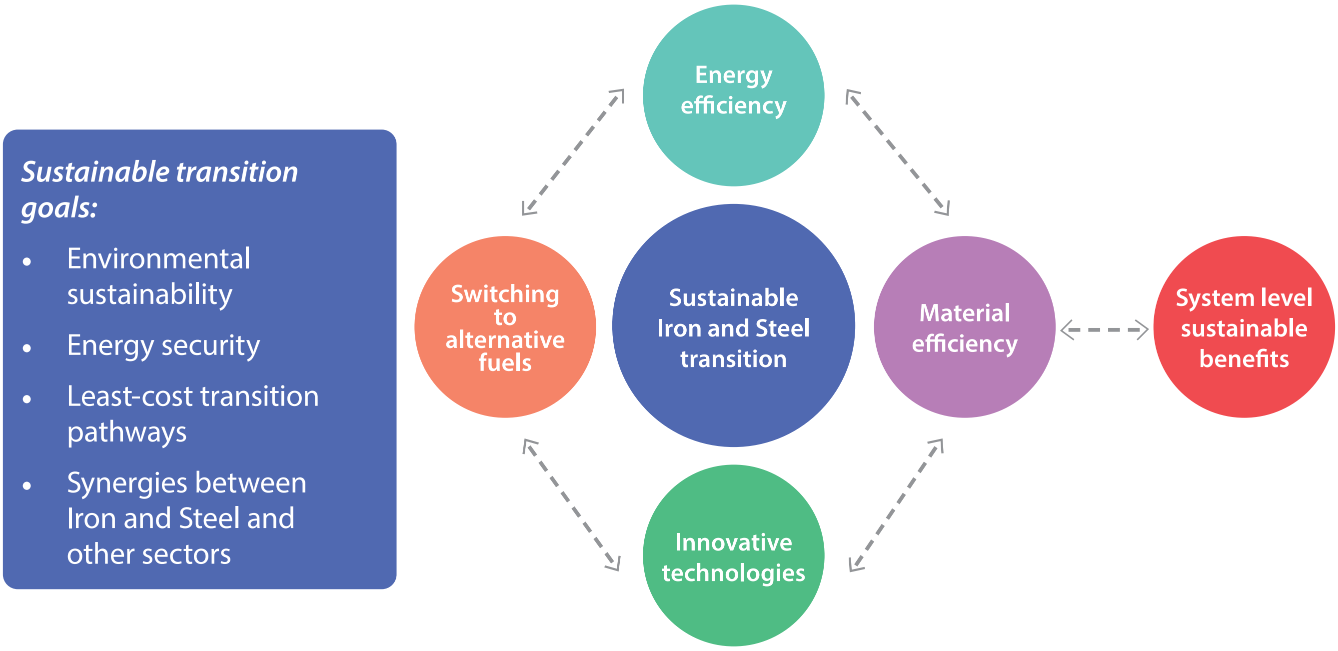
BF-BOF	*Natural Gas based DRI-EAF*	*Scrap based DRI*
CO_2 Emissions (Direct + Indirect*)		
2.2 t CO_2 / t cs (1 + 1.2)	*1.4 t CO_2 / t cs (1 + 0.35)*	*0.4 t CO_2 / t cs (0.04+0.35)*

**Indirect emissions include emissions from the required electricity and other energy imports. Coal-based DR kilns emit three times that of direct emissions by gas-based DRI.*

While energy intensity and carbon emissions are closely linked, the path towards energy transition in iron and steel sector can be divided into three segments:

- ***Reduce the energy intensity of current processes:*** Energy efficiency improvement with waste heat utilisation, Process efficiency improvement
- ***Replace fossil fuels for production***: Electrification and use of Renewable energy, low carbon Hydrogen, Biomass utilisation
- ***Develop new production pathways with low carbon footprint:*** Process intensification with hybrid technologies, Improved Scrap recycling and utilisation.

The path can be represented by the following figure also:



Available Technologies in Energy Transition and Decarbonising programmes for Iron & Steel Industries

The following section discusses the available technologies wherein Technical systems are either complete & qualified or very promising to have a significant impact in future:

- ***Technologies related to energy efficiency measures***
  Energy efficiency in industry has resulted in energy savings of around 40% per product unit (EEA, 2019). There is a remaining potential for estimated additional savings of 15-25% by 2050 using system design changes such as Coke Dry Quenching, Top Pressure Recovery Turbine, Waste heat recovery from different available sources, recuperative and regenerative burners, process improvements, etc. TCE has managed many such projects successfully.

- ***BF/BOF efficiency programs***
  Such programs improve efficiency and/or decrease production losses in different ways, for example
  - optimising the BF burden mix by maximising the iron content in raw materials to reduce the usage of coal as a reductant
  - increasing the use of fuel injection through, for example, pulverised coal injection (PCI), natural gas, plastics, biomass, or hydrogen (as an additional reagent on top), or
  - using coke oven gas in the BF as an energy source.

  These processes may decrease carbon dioxide emissions without eliminating them, but do not offer fully carbon-neutral steel production.

- ***Technologies dealing with electrification***
  There is a growing potential for emission reduction in the steel industry by switching from fossil fuels towards electricity, thanks to growing availability of strong transmission grid and economical renewable power including rooftop solar, waste energy utilisation, etc. supported by storage solutions.

  As indicated earlier, the EAF route is a well-established technology having substantially fewer emissions with a major share of indirect emissions. The use of electricity often offers considerable efficiency benefits, such as applying heat pumps for low-temperature heat. Several commercially available technologies can be implemented to substitute fossil fuels for heat demand: Electrode boilers, Electrical resistance heating, Heat pumps, Steam recompression, etc.

  However, the integrated steel plants run with an established gas and steam balance. Thorough knowledge and case to case basis study are required to evaluate the techno-economic benefits.

- ***Increase share of scrap-based EAFs***
  EAF producers are more environmentally friendly and flexible to demand ups and downs. Increasing the share of EAF-based steel production will play a key role in decarbonising the steel industry.

However, this role will be dependent on the regional availability of high-quality scrap. Therefore, it could be limited in regions with an inadequate supply of high-quality scrap, making other technologies a must.

Increasing demand for high-quality scrap will also lead to extra cost for EAF-based steel production.

- ***Transition to gas-based DR-EAF route***

  Another matured alternative is the gas-based DRI EAF route. In case a carbon-neutral reduction gas is used, such as green hydrogen, the steelmaking process can be mostly carbon-neutral and fueled by renewable electricity in the DR-EAF route.

  Currently, Iron ore can be reduced to iron by reduction with Natural Gas (NG). NG can play an interim role in the transition phase by implementing the DR/EAF production route.

  DRI-EAF route based on NG would result in a ~40% CO2 emission reduction compared to the BF-BOF route. In the long term, use of green hydrogen in place of NG will lead towards carbon neutrality. However, this is mainly dependent on the availability of required gases.

- ***Biomass reductants***

  This process uses biomass, such as heated and dried sugar, energy cane, or pyrolysed eucalyptus, as an alternative reductant or fuel. It is regionally dependent and mainly crucial in areas where the biomass supply is guaranteed, like in South America or Russia.

  In Europe, biomass availability is likely not enough to reduce carbon emissions on a large scale. This is used as reductant and may replace coal.

- ***Use of Hydrogen in Blast Furnace***

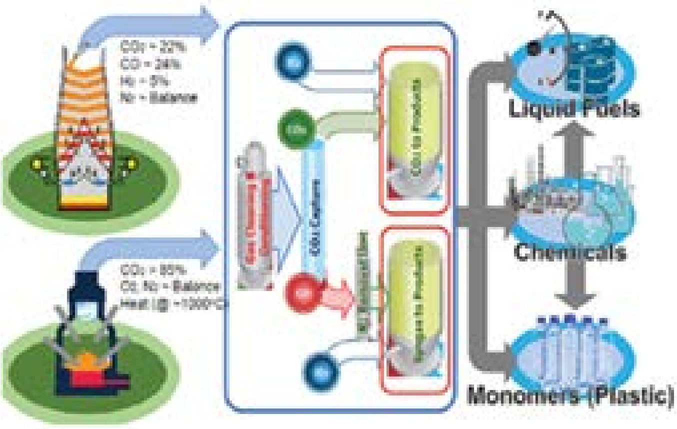
  Hydrogen reduction is not yet proven at industrial scale and is currently more expensive than the BF-BOF route. However, it also depends on the availability of hydrogen.

  Green Hydrogen generation requires intensive renewable electrical energy, and with the availability of economical solar & wind power, green hydrogen is expected to be affordable by 2030.

Following hydrogen-based technologies are promising and will have a huge impact once made commercially viable:

- ***HYBRIT:*** Direct reduction of iron into steel using hydrogen and renewable energy generates water as a by-product instead of carbon dioxide.
- ***COURSE-50:*** This involves reforming coke oven gas using catalysts and utilising unused heat to increase its hydrogen content (from 55% to 67%). This hydrogen-enriched gas is then used for the reduction of iron ore in the blast furnace.
- ***SUS STEEL:*** Based on hydrogen-based DR-EAF steel making (Hydrogen Plasma Smelting Reduction: HPSR process).
- ***SALCOS:*** The SALCOS technology uses hydrogen-based DR-EAF steel making
- ***FLASH OXIDE SMELTING:*** The process would use inexpensive NG (or hydrogen) to heat the ore and remove oxygen, in converting the ore into metal.

Technologies for Carbon Capture, Utilisation/ Storage (CCU/S)



In addition to the above shift in energy systems, carbon dioxide capture with permanent sequestration (CCS) / viable utilisation (CCU) prepares to play a significant role in defining the future energy systems.

New technologies such as the HIsarna process generate CO_2 rich emissions for economic capture other than 20% emission reduction by replacing Coke making and agglomeration processes. However, the commercial transformation will require time.

A summary of various available & emerging Technologies is tabulated below with broad segregation on technology readiness between a pilot and commercially availability:

TECHNOLOGIES ON ENERGY OPTIMISATION, REDUCTION OF EMISSION & DECARBONIZATION				
PROCESS	BF-BOF ROUTE		DRI -EAF/EIF ROUTE	
	PILOT	COMMERCIAL	PILOT	COMMERCIAL
Sintering	-	Waste heat recovery	-	NA
Sintering	-	High-Efficiency Coke Oven Gas Burner in Ignition Furnace	-	NA
Sintering	-	Increasing sinter bed depth	-	NA
Sintering	-	Improvement in segregated charging of sintering material	-	NA
Cokemaking	-	Coke Dry Quenching (CDQ)	-	NA
Cokemaking	-	Coal Moisture Control (CMC)	-	NA
Cokemaking	-	Automated Combustion Control of Coke Oven	-	NA
Cokemaking	-	Partial fuel substitution in the coking plant	-	NA
Ironmaking	COURSE 50	Top pressure recovery turbine (TRT)	SALCOS	Use of iron ore pellets in DRI kiln/ BF.
Ironmaking	FLASH OXIDE SMELTING	Preheating through WHR from Hot Stoves of Blast furnace	SUSEEL	Waste Heat Recovery from Sponge Iron kiln.
Ironmaking	HISARNA	Pulverised coal injection (PCI)	HYBRIT	-
Ironmaking	-	Injection of coke oven gas	-	-
Ironmaking	-	Recovery of blast furnace gas	-	-
Ironmaking	-	Stove flue gas recycling	-	-
Ironmaking	-	Use of iron ore pellets in DRI kiln/ BF	-	-
Steelmaking	-	Converter gas heat recovery device	-	Charge or scrap preheating
Steelmaking	-	Converter gas recovery device	-	Scrap densification or shredding
Steelmaking	-	Heat recovery from steelmaking slag	-	Coherent Jet Gas Injection Technology
Steelmaking	-	Increased use of recycled steel scrap	-	Improved process control
Steelmaking	-	-	-	Ultra-high-power transformers
Steelmaking	-	-	-	Waste heat recovery from EAF
Steelmaking	-	-	-	Ecological and Economical Arc Furnace
Steelmaking	-	-	-	Oxy-fuel burners or lancing
Steelmaking	-	-	-	Slag Foaming, Exchangeable Furnace and Injection Technology
Steelmaking	-	-	-	Hot Charging DRI
Steelmaking	-	-	-	Increased use of recycled steel scrap
Casting and Refining	-	Oxygen burners system for ladle preheating	-	Near net shape casting
Rolling	-	Regenerative burners in reheating furnace	-	Direct rolling
Rolling/ Furnace	-	Rotary Hearth Furnace (RHF) Dust Recycling System	-	Hot charging of slab
Rolling/ Furnace	-	-	-	Installing VVVF drives to electrical motors

Financial Improvements/ Government funds applicable in India

Current Indian Govt. policies and programmes that could enable progress towards low emission steel making are given below:

- ***PAT (Perform, Achieve, Trade) Scheme:*** Aims to reduce industrial specific energy consumption using a market-based mechanism.
- ***Steel Scrap Recycling Policy:*** Increasing the steel recycling rate is the primary goal of the Steel Scrap Recycling Policy (Ministry of Steel, 2019c), promoting the 6Rs: Reduce, Reuse, Recycle, Recover, Redesign and Remanufacture.
- ***Promotion of R&D in Iron & Steel Sector Scheme:*** Govt of India through the Ministry of Steel has supported several R&D projects under this scheme with a total cumulative budget of more than USD 17 million over five years (Ministry of Steel, 2019a).
- ***Promotion of R&D in Iron & Steel Sector Scheme:*** Regarding public-sector funding, the Indian government through the Ministry of Steel has supported several R&D projects under this with a total cumulative budget of more than USD 17 million over the past five years (Ministry of Steel, 2019a). Private companies in India such as SAIL, RINLS, Tata Steel, and JSW, invest cumulatively USD 83.3 million in R&D per year.

Conclusion and Way Forward

Metallurgical industries in General and Iron & Steel Industry in particular, are energy-intensive and generate a significant amount of Green House Gas. Innovative approaches in Energy optimisation, Waste heat recovery, Scrap recycling, Gas based EAF will support shift towards green. Carbon capture and utilisation/ storage and the use of green H2 for the reduction process offer prospective solutions. Still, adoption reality depends on the socio-economic thrust and availability of required resources, including a considerable quantity of renewable energy, technology maturity for commercial adoption.

Adopting the fast development in digitalisation, artificial intelligence and machine learning offers a considerable prospect in unfolding detailed information on the processes and optimisation in energy consumption. While coming years will bring out the techno-economically sustainable solutions, an open-minded, informed and progressive approach in developing the configuration for a greenfield project and prioritising the sustainability projects in a brownfield installation may be a key to adopt and align with future.

Each system needs to be evaluated in terms of Input, Internal Process, Output and Recycling capacity to arrive at a suitable carbon footprint, integrated into overall plant product. The plant's success appears to be dependent on effective collaboration across sectors of power, chemicals, digitalisation, automation, and environmental control measures, other than the core process optimisations & development.

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References:

- Energy-intensive industries Challenges and opportunities in the energy transition- Technical Report July 2020
- Iron & Steel Technology Roadmap – IEA
- IEA Technology Roadmap- Global Iron and Steel Sector -OECD Steel Committee Paris 22nd March 2019
- Towards a low carbon steel sector- The Energy and Resources Institute 2020