Steel Industry and Climate Change

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ABSTRACT

The carbon dioxide emission from steel plants has been recognized as an important concern globally. In the past two decades steel industry has reduced CO₂ emission by 15-20% by adopting newer technologies and improvement in processes. Further reduction by 15-20% is expected in next decade by implementation of newly developed techniques and controls. Drastic reduction CO₂ emission is only possible by adoption of technologies like plasma heating, CO₂ recovery, BF and CO gas injection in Blast Furnaces and use of hydrogen on commercial scale in iron ore smelting. Increased use of recycled steel will also play an important role. Life Cycle Assessment (LCA) for steel products to improve product quality and strength including weight of product will enhance consumer confidence besides reducing the environmental burden. Further reduction of CO₂ in the steel plant globally can come only through adopting flexible mechanisms and CO₂ trading.

This paper describes present scenario, technologies in practice, trends and drivers and flexible mechanisms to reduce CO₂ emission in steel industry. The paper also presents the scenario at Tata Steel and various actions initiated to address the issues related to energy conservation and reduction in CO₂ emission.

Key Words: Iron & steel industry, green house effect, clean technologies, energy taxes.

INTRODUCTION

The earth absorbs radiation from sun at its surface and this energy is then redistributed to atmosphere and ocean and reradiated to space. Some of this reradiated energy is absorbed by Green House Gases (GHG’s) present in the atmosphere. The energy thus absorbed by GHG’s is reradiated in all directions downwards and upwards. The upward radiation is lost to the space. This radiation is from higher and colder level of the atmosphere. As a result the Earth’s surface loses less heat to space due to presence of GHG’s in the atmosphere and its temperature is gradually increasing. This phenomenon is known as Green House Effect, mainly responsible for climate change. The carbon dioxide, a gas, emitted during burning of fossil fuels, agriculture and deforestation is considered as main culprit for the climate change. The carbon dioxide emission is the direct result of non-renewable energy usage. Carbon dioxide levels in atmosphere during industrialization period of two centuries have increased from 280 parts per million (ppm) to 370 ppm resulting in global temperature rise of more than 0.6°C. It is expected that in 21st century this rise will be 6°C and ocean level will
increase by nearly a metre. A metre rise in sea level will inundate nearly one percent of Egypt, 6% of Netherland, 17.5% of Bangladesh and 100% land of small island countries like Maldives, Mauritius, etc. [1]

Large amount of CO₂ is emitted to atmosphere because of natural and human activities. About 190 Giga Ton of carbon equivalent CO₂ is emitted by natural processes annually and only about 6-8 Giga Ton is emitted by human activities including industrial plants. The man made emission is only 3-4% of the total emission. The atmosphere contains total 750 Giga Ton of CO₂ as carbon, a quarter of which circulates each year in natural carbon cycle. It is estimated that atmospheric levels are increasing by 3.5 Giga Ton of CO₂ per year as a result of human activities. [2]

The international importance of climate change means that industries are under increasing pressure from Governments to reduce CO₂ emissions. Steel industry being major energy consumer and CO₂ emitter faces a serious pressure from Governments and green consumers. Steel industry has responded well so far and reduced CO₂ emission by more than 20% during past two decades. Current technologies in use will help reduce CO₂ emission further to the tune of 15-20% in the next decade. The cost to reduce CO₂ emissions drastically is very high and therefore, flexible mechanisms are being viewed as a solution to this problem. Several countries have imposed or are considering the imposition of energy taxes. Discussions on flexible mechanism are taking shape and issues like, trading of CO₂ is being considered seriously.

This paper describes present scenario, technologies in practice, trends and drivers and flexible mechanisms to reduce CO₂ emission in steel industry. The paper also presents the scenario at Tata Steel and various actions initiated to address the issues related to energy conservation and reduction in CO₂ emission.

IRON & STEEL INDUSTRY – GLOBAL SCENARIO

The Iron & Steel Industry has been recognized as a major source of CO₂ emission. The steel industry globally emits approximately 356 million tons of CO₂ as carbon from cradle-to-gate [3]. The carbon in steel industry is required as a chemical feedstock (reductant) and for energy units (direct or electricity generation). The range of CO₂ emission from steel plants reflects a part of the factors like, iron making and steel making practices, energy efficiencies, national power mixes and the complexity of finishing operations. These factors represent the basis for CO₂ reduction strategies. For example, in Blast Furnace operations the most significant improvements are likely to come from coal injection, coke dry quenching, coke moisture control etc. These factors are likely to save 8-10% of the total energy input. In Electric Arc Furnace, the energy savings arise from use of alternate energy sources to electricity, such as oxygen and coal injection and utilization of waste gas for scrap reheating etc.

New processes and technologies which have been developed in the recent past show a great potential for CO₂ reduction after commercialization. Some of these technologies are direct reduction methods (MIDREX, HyL, FIOR, SLRN processes etc.) and smelting reduction technologies like, COREX, ROMELT, CCF, HISMELT etc. Comparison for various processes with regard to CO₂ emission is given in Table 1.
Table 1: Trends in CO₂ emission for various proven processes

<table>
<thead>
<tr>
<th>Sl. No.</th>
<th>Process</th>
<th>CO₂ Emission Ton/Ton of Steel</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>BF-BOF Route</td>
<td>1.9</td>
</tr>
<tr>
<td>2</td>
<td>COREX</td>
<td>1.7</td>
</tr>
<tr>
<td>3</td>
<td>Direct Reduction (DR)/EAF Route</td>
<td>1.2</td>
</tr>
</tbody>
</table>

Challenges for Steel Industry

Following the Kyoto protocol on the reduction of greenhouse gas (GHG) emissions by industrialized countries, the signatory governments are in the process of developing ways and means to implement such reductions. The order of magnitude of these reductions exceed by far the 5.2% average reduction from 1990 levels agreed upon, since potential increases due to economic growth by 2012 are also to be accounted for.

The policy makers who are to develop strategies that could lead to such reductions will address different target sectors of the economy, which are likely to include:

- The industrial sectors and particularly the energy intensive ones, of which steel making undoubtedly is a part, will see pressure to become less GHG emitting in their manufacturing processes. There will be a demand for:
  - More energy efficient manufacturing processes.
  - Development of manufacturing techniques with reduced GHG emission potentials.
  - Clean technologies i.e. technologies with the highest possible recycling rates.
  - The development of products and consumer goods which both at manufacturing and during their useful life, generate lesser quantities of GHG.

- The consumers will be led to choose more sustainable products, including:
  - Products from clean production techniques.
  - Products, which require low energy during manufacturing.
  - Products, which require low energy during their useful life.

These options offer great challenges to steel industries to reduce CO₂ emission. A simulation study carried out for a Modern Steel Mill in France [4] shows the potential for CO₂ reduction for various technological options as illustrated in Table 2.
Table 2: Simulation of CO₂ emission in the various Model Steel Mills.

<table>
<thead>
<tr>
<th>Process Route</th>
<th>Input in Blast Furnace (kg)</th>
<th>In Steel Shop</th>
<th>Electricity</th>
<th>CO₂</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Sinter Pellets DRI Coke Coal</td>
<td>Iron (pig/ton) kWh/t (kg/t steel)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Ref. Blast Furnace</td>
<td>1357 103 331 153</td>
<td>1000 187</td>
<td>2111</td>
<td></td>
</tr>
<tr>
<td>BF 100% sinter</td>
<td>1600 331 153</td>
<td>1000 191</td>
<td>2156</td>
<td></td>
</tr>
<tr>
<td>BF 200 kg PCI</td>
<td>1290 168 290 200</td>
<td>1000 186</td>
<td>2088</td>
<td></td>
</tr>
<tr>
<td>BF 250 kg PCI</td>
<td>1290 168 250 250</td>
<td>1000 184</td>
<td>2084</td>
<td></td>
</tr>
<tr>
<td>BF + Pellets + DRI</td>
<td>1217 112 94 269 189</td>
<td>1000 185</td>
<td>2052</td>
<td></td>
</tr>
<tr>
<td>BF 900 kg hm/tcs</td>
<td>1357 103 331 153</td>
<td>900 174</td>
<td>1904</td>
<td></td>
</tr>
<tr>
<td>BF gas recycling</td>
<td>1357 103 224 0</td>
<td>1000 1696</td>
<td>1264</td>
<td></td>
</tr>
<tr>
<td>CFC’s-Reduction</td>
<td>1000 319</td>
<td>2212</td>
<td></td>
<td></td>
</tr>
<tr>
<td>EAF 125 kg pig iron</td>
<td>1357 103 331 153</td>
<td>125 499</td>
<td>323</td>
<td></td>
</tr>
<tr>
<td>EAF 160 kg pig iron</td>
<td>1357 103 331 153</td>
<td>160 478</td>
<td>396</td>
<td></td>
</tr>
<tr>
<td>Redsmelt 250 kg hm/tcs</td>
<td>250 574</td>
<td>639</td>
<td></td>
<td></td>
</tr>
<tr>
<td>EAF 830 kg DRI</td>
<td>798 500</td>
<td>500</td>
<td></td>
<td></td>
</tr>
<tr>
<td>EAF 244 kg hm/tcs</td>
<td>1357 103 331 153</td>
<td>244 468</td>
<td>611</td>
<td></td>
</tr>
<tr>
<td>Corex + Midrex + EAF</td>
<td>500 632</td>
<td>1639</td>
<td></td>
<td></td>
</tr>
<tr>
<td>EAF Scrap</td>
<td>0 458</td>
<td>68</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Some sectors of the steel industry might be more affected than others by the new scrutiny on ‘sustainability’ of their products. Short life steel products, such as food packaging, might be most affected by the new requirements and new consumer preferences for sustainable products. In addition, since consumer goods producers (appliances, automobiles, etc.) will be increasingly challenged to reduce the energy component of their product, the energy demand during its service life and to extend the products useful life, the consumers will demand more sophisticated and less
‘weighty’ steel qualities or they may prefer to step away from steel. While strengths of steel lie in its excellent structural performance and durability, steel products with long service lives might be less under pressure.

The Life Cycle Assessment (LCA) will be used increasingly as a tool for monitoring the performance of materials and products both during manufacturing and in their final use. The rules governing LCA need, however, to be fine-tuned for acceptance throughout the industrial community. In order to be ready to take its stance about its products, the steel industry needs to continue its efforts to highlight all the benefits resulting from their use in all types of applications.

Current Technologies in Steel Industry

The technologies contributing to energy saving and CO₂ emission reduction in steel industry and the prospects of their future spread and effects are summarized below [5]:

Waste Heat Recovery

- **Coke dry quenching (CDQ)**
  CDQ is installed at present for over 80% of all coke ovens in Japan. The use of CDQ may increase worldwide in the next few years. As a result of the decrease in coke production due to the increase in Pulverized Coal Injection (PCI), the effect will be small.

- **CO gas sensible heat recovery**
  Technical developments in this area are necessary. However, there is a problem of space for equipment installation in existing Coke Plants. Therefore, the spread is slow and the effect is small.

- **Sintering waste-heat recovery**
  Equipment installation for main facilities are in progress all over the world. The future spread is small and the effect is small.

- **Dry-type top gas recovery turbine (TRT)**
  Its spread will progress with future relining of Blast Furnaces, but the effect is small because pig iron production will decrease with the increasing use of scrap.

- **BF slag sensible heat recovery**
  Among unrecovered waste heat this heat is considerably large, but technical development is necessary for its recovery. The effect will be medium.

- **BOF gas sensible heat recovery**
  At present this is practiced only in few plants. This may increase as a long-term prospect. The effect is medium.

- **Pulverized coal injection (PCI)**
  The present average use is 110 kg/thm in the plants having PCI facility. This will continue to increase in a long-term prospect. The effect is medium.

- **Coal moisture adjustment**
  The spread is small at present. But this is expected to be adopted by all the steel plants in the near future. The effect is medium. The technology, however, is applicable to Top Charge Batteries only.
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- **Scrap preheating**
  The spread will progress gradually, but the effect is small.
- **Direct hot charge rolling**
  The ratio in the hot rolling process is low at present, this is expected to increase in future. The effect is large.
- **Increase in the efficiency of in-plant power generation**
  This will spread gradually and the effect is large.
- **High-efficiency oxygen production**
  Although technical developments are necessary, the spread will progress gradually and the effect is large.

**Increase in the Efficiency of Production Facilities**

- DC electrical furnace - The spread will progress gradually and the effect is small.
- Continuous Casting - The present CC ratio is medium, and this ratio will increase to 100% in future. The effect is small.
- Increase in the efficiency of reheating furnaces - The spread will progress gradually. Technical development is necessary. The effect is medium.
- Continuous hot rolling - The spread will progress gradually. The effect is small.
- Continuous annealing - The spread will progress gradually. The effect is small.

**Technical Development**

- Next-generation coke ovens (Non recovery type, Continuous Coking, Jumbo Ovens etc.) - Technical developments are under way. The expected effect is medium.
- New smelting reduction process - It is expected that more of pig iron will be produced by this process by 2010. The effect is medium.
- Large-volume consumption of scrap - There is the problem of increase in raw materials cost, but the expected effect is large.

**Reduction in CO₂ Emission from Steel Industry - Trends & Drivers**

The steel industry has responded well to the global need to reduce CO₂ emissions and to this effect it has achieved 20% reduction in past 20 years. Adoption of various processes in very recent past will have an equal impact on CO₂ reduction. These processes are:

- Concentration of steel production at most efficient installations.
- Rebuilding/modernization of plants to improve efficiency.
- Process step elimination.
- Energy optimization in existing processes.
- Use of natural gas instead of coke in Blast Furnaces.
- Ore reduction with natural gas in installed DRI processes.
- Recycling and reuse of steel plant waste.
These measures in short term, will bring further reduction in CO₂ emissions. The industry, however, has to look beyond traditional means of energy saving and should look for long term methods to bring down CO₂ emission drastically. Table 3 presents some of the long term options, with the status of their techno-commercial viability.

**Table 3: Overview of solutions to reduce CO₂ emission.**

<table>
<thead>
<tr>
<th>Time</th>
<th>Core Activities</th>
<th>Supporting Technologies</th>
<th>CO₂ Emission (t CO₂ / tcs)</th>
<th>Techno-logical Aspect</th>
<th>Cost Effect</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td>Reduction &amp; Refining</td>
<td>Scrap Melting</td>
<td></td>
</tr>
<tr>
<td>Past</td>
<td>BF-BOF Efficiency (recycling slag, wastes gases, sensible heat)</td>
<td>Coal Injection</td>
<td>2.119</td>
<td>Known</td>
<td>Known</td>
</tr>
<tr>
<td></td>
<td></td>
<td>NG Injection</td>
<td>1.886</td>
<td>Known</td>
<td>Known</td>
</tr>
<tr>
<td></td>
<td>EAF</td>
<td></td>
<td>0.462</td>
<td>Known</td>
<td>Known</td>
</tr>
<tr>
<td></td>
<td></td>
<td>CCPG (1)</td>
<td>0.380</td>
<td>Known</td>
<td>Known</td>
</tr>
<tr>
<td>Medium</td>
<td>Smelting Reduction</td>
<td>CCPG (1)</td>
<td>2.055</td>
<td>Known</td>
<td>Known</td>
</tr>
<tr>
<td></td>
<td>BF-BOF BF min coke rate TSC (3)</td>
<td>Coal Injection</td>
<td>1.783</td>
<td>Known</td>
<td>Known</td>
</tr>
<tr>
<td></td>
<td></td>
<td>NG Injection</td>
<td>1.599</td>
<td>Known</td>
<td>Known</td>
</tr>
<tr>
<td></td>
<td>EAF + TSC (3)</td>
<td>CCPG (1)</td>
<td>0.275</td>
<td>Known</td>
<td>Known</td>
</tr>
<tr>
<td></td>
<td>DRI NG based + Electricity</td>
<td>CCPG (1)</td>
<td>0.957</td>
<td>Known</td>
<td>Known</td>
</tr>
<tr>
<td>Long</td>
<td>BF + H₂ + Electricity (Plasma) + TSC (3)</td>
<td>CCPG (1)</td>
<td>0.846</td>
<td>To be studied</td>
<td>To be studied</td>
</tr>
<tr>
<td></td>
<td>EAF</td>
<td>NCPG (2)</td>
<td>0.1</td>
<td>Known</td>
<td>Known</td>
</tr>
<tr>
<td></td>
<td>H₂ Reduction</td>
<td>NCPG (2)</td>
<td>0.1</td>
<td>To be studied</td>
<td>To be studied</td>
</tr>
<tr>
<td></td>
<td>Ore Electrolysis</td>
<td>NCPG (2)</td>
<td>0</td>
<td>Known</td>
<td>Known</td>
</tr>
<tr>
<td></td>
<td>CO₂ sequestration</td>
<td>CO₂ sequestration</td>
<td>0</td>
<td>0</td>
<td>Known</td>
</tr>
<tr>
<td></td>
<td>BF, SR, DRI, DAF</td>
<td>Biomass</td>
<td>0</td>
<td>0</td>
<td>Known</td>
</tr>
</tbody>
</table>

(1) Combined Cycle Power Generation: Efficiency improvement of power generation from 0.35 to 0.45.
(2) Non-Carbon based Power Generation: Nuclear, Solar, Hydro, Biomass.
(3) Thin Slab Casting
The advantages/disadvantages of some of these options are briefly presented here below:

- When steel is produced from recycled scrap, the CO₂ emissions are four (4) times lower than for steel production based on ore reduction. Thus production of steel from end of cycle product scrap up to 40% would reduce the CO₂ emissions by 10%. Actual reduction will be higher than 10% as the industry replaces its old inefficient process.

- The development of steel products and consumer goods which have higher strength and lower weight will also impact the scenario favourably in absolute CO₂ emissions to the atmosphere.

- Majority of CO₂ emission from steel plants are contributed due to purchased power (electricity) which is largely coal based. Shift to cleaner fuels like byproduct gases, natural gas will favourably impact CO₂ emissions. Natural gas, however, due to its limited availability cannot be considered as long term solution. Non-CO₂ emitting sources of power like, solar, nuclear, wind and biomass are also being explored to reduce CO₂ burden on the atmosphere. It may be noted that nuclear power is likely to be phased out due to other environmental considerations associated with it. The CO₂ emission potential for different sources for power generation is given below:
  - Nuclear - 4 gm/kWh
  - Gas - 439 gm/kWh
  - Oil - 719 gm/kWh
  - Coal - 856 gm/kWh

- An alternate solution to CO₂ reduction is to remove CO₂ from flue gases and store the same in ocean reservoirs. The cost for such storage is very high (USD 50/t of CO₂) and is a matter of concern. Large afforestation projects could also help in increasing the carbon sink potential of nature. For a 10 MTPA plant, to provide CO₂ sink, a forest area of 95x95 km² is required.

- Hydrogen is seen as alternate to fossil fuels and in conjunction with electricity generated from non-conventional and renewable resources, could offer a long term option for drastic reduction of CO₂ emission. At present and into foreseeable future, the industrial production of H₂ with no accompanying CO₂ emission can only be carried out by electrolysis or via biomass gasification and reforming. Electrolytic H₂ costs are around 0.13-0.25 USD/Nm³ and biomass H₂ costs also may be similar. This higher cost may keep the use of H₂ in steel plants away for some more years i.e. until cheaper sources of power generation are commercialized.

- Electrolysis of iron ore promises large CO₂ reductions, provided power is available at 3 to 4 times lower rates than what is prevailing currently. Nuclear fusion and its commercialization is not expected before 2050.

- Recycling of waste products offer tremendous potential for energy saving and CO₂ reduction. Blast Furnace slag after granulation when used in cement making reduces CO₂ emission from steel works (credit) to the tune of 220 kg/thm. Similar potential exists for LD slag usage in cement making.
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- Biomass provides more flexible solutions as reforestation does not have to take place close to the steel plant and the land required for biomass production, although larger (50% higher) than forest area, could be made available in remote places.
- Recycling of CO\(_2\) and conversion of this gas to various chemicals can further reduce CO\(_2\) emissions. Blast Furnace top gas recycling and synthesis of BF gas are further discussed here as under.

**Blast Furnace Top Gas Recycling**

The BF top gas recycling can further reduce CO\(_2\) emission. Fig. 1 shows various methods for recycling.

![Diagram of BF top gas recycling methods]

(A) No recycling
(B) Simple recycling
(C) Recycling with Oxygen enrichment
(D) Hot Reduction Gas (HRG) recycling with separation of CO\(_2\)

*Fig. 1: BF top gas recycling*
The Case B and C in Figure-1 result in decrease in productivity and increase in fuel rates due to cooling effects of CO\(_2\) in the recycled gas and Case D offers productivity increase by 25% and fuel rate decrease by 20%. In all 13 field tests during the period of 1985 – 1990 producing 250 ton of hot metal with a pilot complex in RPA, Russia were conducted. The process steps followed were, “Compression of dedusted top gas --- removal of CO\(_2\) --- reheating --- injecting into the BF hearth through tuyeres”.

The results of these tests are reflected below:

- Reduction of coke rate to 280-300 kg/thm (Carbon input decreased by 28-30%).
- Increasing BF efficiency by 25-30% while reducing GHG emissions
- Cut down on the separation cost of CO\(_2\) by raising its content in the BFG (100% recycling means nitrogen free process).
- Stable operation of the furnace was possible.

The technical problems associated with these tests were:

- Engineering problem due to high temperature Hot Reducing Gas (HRG) injection with O\(_2\).
- Economic problem due to large scale oxygen preparation and CO\(_2\) separation.

**Blast Furnace Iron Making System Integrated with Methanol Synthesis.**

The process principle adopted for synthesizing CO\(_2\) to methanol are given in Fig. 2.

Conventionally Methanol is produced from natural gas which mainly contains CO, CO\(_2\) and H\(_2\). In the Blast Furnace process CO\(_2\) can be separated from the top gas and used for methanol synthesis. The methanol thus produced can be used as a fuel for vehicles, feed stock for chemical industries etc. In this process there is a reduction of 20% CO\(_2\) emission in Blast Furnace. It may be noted, the worldwide consumption of methanol is only 2 million tons per annum. It is too small compared to the projected yield from BF gas conversion.

**Recycling of Coke Oven & Blast Furnace Gas in Iron Making.**

- Possible combination (partially not proved technically) is given in Fig.-3.
- Process description:
  - BFG recycling with or without CO\(_2\) separation.
  - Process control O\(_2\) enrichment.
  - COG recycling.
  - Reformed gas recycling of BFG + COG

\[
\text{CO}_2 (\text{BFG}) + \text{CH}_4 (\text{COG}) \rightarrow 2\text{CO} + 2\text{H}_2
\]

- Problems:
  - Impurities of BFG and COG : dust, tar, etc.
  - Fouling effect of catalyst.
Fig. 2: Manufacture of methanol from CO₂
Discussion

- The combination of BF top gas recycling and methanol synthesis can reduce technically total emission of CO$_2$ and energy consumption.
- It is also economically feasible, but further investigation on variable reaction paths, catalyst and separation process are necessary.
- Marketing of chemical feedstock (methanol) is not easy because of surplus availability of methanol globally.

Special Blast Furnace Process

In BF-BOF route of steel making, nearly 65-70% of total energy required in steel making is consumed up to iron making. Steel plants world over had been concentrating on Blast Furnaces to reduce coke rate by increasing hot blast temperature, pulverized coal injection, oxygen enrichment, automation etc. These conventional
changes have brought down energy consumption by more than 20% during past one or two decades. In order to reduce energy consumption and resultant CO₂ reduction, a few long term options are being studied. These are:

**The PIROGAS Process**

The PIROGAS process\(^5\) consists of replacing, in part or in total, the hot blast blown through the blast furnace(s) tuyeres by reducing gas heated to a temperature of about 2000°C. The heating or overheating and, eventually, the production of reducing gas, can be achieved directly in the plasma heater. Up to 80% of the coke required for a conventional blast furnace can be replaced by substitute reducers. The PIROGAS process makes it possible to optimize the ratio between fossil fuels and electric power consumption to achieve optimum economic operation.

Trials carried out on a full size commercial Blast Furnace have confirmed that the plasma heater does not affect the operation of the furnace adversely and, reciprocally, the unavoidable fluctuations in blast furnace operation do not perturb the functioning of the plasma heater. Plasma heaters have a high thermal efficiency (80%) and their electrical behaviour is excellent (power factor >0.9 and no harmonics).

Model simulations show that H₂ overheated by plasma torches and injected through the main tuyeres instead of hot blast, following the PIROGAS process as described above, will decrease the coke rate drastically to 143 kg/thm. However, such an operation has never been demonstrated on a modern Blast Furnace. By assuming that such an operation is feasible, the CO₂ emissions will fall to 0.846 t CO₂/tcs.

It may be concluded from above discussion that for iron ore based steel making using all technically proven processes for production and energy conservation, the limiting CO₂ reduction could be achieved at a level of 1200-1300 kg/t of steel as shown in Fig.-4\(^4\).

![CO₂ Emissions from iron ore based steel making](image-url)
Further reduction is possible only by adopting plasma heating and hydrogen based technologies.

**ENERGY CONSUMPTION AND CO₂ EMISSION SCENARIO AT TATA STEEL**

Energy consumption scenario at Tata Steel along with a comparison with IISI average is furnished below in Table 4.

<table>
<thead>
<tr>
<th>Production Process</th>
<th>Hoogoven GCal/tcs</th>
<th>Kimitsu GCal/tcs</th>
<th>Consumption at Tata Steel GCal/tcs</th>
<th>IISI Average GCal/tcs</th>
<th>Gap with respect to IISI</th>
</tr>
</thead>
<tbody>
<tr>
<td>Coke Making</td>
<td>0.565</td>
<td>0.458</td>
<td>1.044</td>
<td>0.516</td>
<td>0.528</td>
</tr>
<tr>
<td>Sinter Plants</td>
<td>0.524</td>
<td>0.671</td>
<td>0.562</td>
<td>0.433</td>
<td>0.129</td>
</tr>
<tr>
<td>Iron Making</td>
<td>2.85</td>
<td>3.387</td>
<td>3.785</td>
<td>2.544</td>
<td>1.241</td>
</tr>
<tr>
<td>Steel Making</td>
<td>0.054</td>
<td>0.115</td>
<td>0.314</td>
<td>0.040</td>
<td>0.274</td>
</tr>
<tr>
<td>Wire Rod Mill</td>
<td>0.66</td>
<td>0.423</td>
<td>0.052</td>
<td>0.049</td>
<td>0.003</td>
</tr>
<tr>
<td>Section Mill</td>
<td></td>
<td></td>
<td>0.058</td>
<td>0.078</td>
<td>(-) 0.020</td>
</tr>
<tr>
<td>Hot Strip Mill</td>
<td></td>
<td></td>
<td>0.410</td>
<td>0.223</td>
<td>0.187</td>
</tr>
<tr>
<td>Boilers/Utilities</td>
<td>Nil</td>
<td>Nil</td>
<td>0.667</td>
<td>0.026</td>
<td>0.641</td>
</tr>
<tr>
<td>Auxiliaries</td>
<td>0.05</td>
<td>0.143</td>
<td>0.543</td>
<td>0.191</td>
<td>0.352</td>
</tr>
<tr>
<td>TOTAL</td>
<td>4.703</td>
<td>5.197</td>
<td>7.435</td>
<td>4.100</td>
<td>3.335</td>
</tr>
</tbody>
</table>

Energy consumption in steel industry has direct impact on CO₂ emission and in most of the Steel Plants world wide, energy is derived from fossil fuel. At Tata Steel, the overall CO₂ emission trend is furnished in Fig. 5. A comparison of over all CO₂ emission from various steel plants in the world is also presented below in Table 5.

![Fig. 5: CO₂ emission at Tata Steel](image-url)
The table shows wide variation in CO$_2$ emission from various plants. This is mainly due to variations in technology adopted, power mix and difference in auxiliary facility and power generation practices. There are many steel plants which are outsourcing the facilities like, Refractory and Lime Production, Coal based Power Plants and Foundries etc.

**Table 5: CO$_2$ Emission from various plants.**

<table>
<thead>
<tr>
<th>Steel Plant</th>
<th>CO$_2$ Emission (kg/t of steel)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hoogovens Steel, Holland</td>
<td>1200 (FY 1998)</td>
</tr>
<tr>
<td>Dofasco, Canada</td>
<td>1300 (FY 2000)</td>
</tr>
<tr>
<td>Kimitsu Works, NSC, Japan</td>
<td>1845 (1999-2000)</td>
</tr>
<tr>
<td>Raahe Steel Works, RAUTARUKKI Steel, Finland</td>
<td>1900 (FY 1998)</td>
</tr>
<tr>
<td>Tata Steel, India</td>
<td>2650 (2000-2001)</td>
</tr>
<tr>
<td>SAIL, India</td>
<td>2900 (1999-2000)</td>
</tr>
</tbody>
</table>

**Gap Analysis**

Following factors are responsible for the gaps in CO$_2$ emission and energy consumption at Tata Steel:

- **Coke Making**: Lower coke, gas and tar yield; higher steam consumption, higher fuel rates are largely responsible for the gaps.
- **Sinter Making**: Higher coke breeze consumption, absence of sensible heat recovery.
- **Iron Making**: Higher coke rate; lower hot blast temperature; higher steam consumption, poor solid waste recycling, lower top gas pressure (No TRT).
- **Steel Making**: Lower gas recovery, large slag volumes, more O$_2$ consumption.
- **Mill**: Lack of hot charging. Low furnace efficiency, high power consumption.
- **Boilers & Power**: Inefficient boilers, low pressure steam generation, poor power generation efficiency and large auxiliary power consumption.
- **Auxiliaries**: Large bleeding losses, steam/compressed air leakages, large fleet of smaller carriers consuming more diesel and several auxiliary facilities like Refractories and Lime Production, Foundries, Engineering Shops etc. (which are outsourced in modern plants).
Actions Planned to Reduce Gaps

- Reduction in ash percentage in BF coke to 17.5% by using low ash coal from Australia.
- Reduction in alumina content in blended fines by 0.20% through improvement in crushing and screening facilities.
- Up-gradation of “F” Blast Furnace and closure of “B” Blast Furnace.
- Closure of Top Charge Battery#3.
- Use of 100% by-product gases for steam and power generation by installation of two numbers of Boilers of 150 TPH capacity. This will have one back pressure turbine and all the old six Boilers at Boiler House#1 shall be shut down.
- Waste heat recovery from ammonia incinerator by installing a waste heat boiler in new incinerator of 10 TPH capacity.
- Improvement of condenser vacuum at Power House#4.
- Increase of CO gas yield to 330 Nm$^3$ / tdc by renovating Primary Cum Deep Coolers and reducing leakages.
- Waste oil injection into Blast Furnaces along with tar (10 barrels per day).
- Recovery of flash steam from Boiler blow down at PH#4.
- Reduction of steam consumption in Canteens through provision of Pressure Reducing Station (PRS) in all canteens.
- Reduction of steam consumption in Blast Furnaces.
- Reduction of steam leakages by changing old steam lines.
- Optimization of pump operation at PH#2.
- Recovery of additional LD gas (10,000 Nm$^3$ / hr) by installing additional gas booster and modifying distribution network.
- Enhanced supply of CO gas to PH#4 by modification of Booster suction and by installing additional Booster.
- Energy saving items at Oxygen Plant (replacement of electrical heater by steam heater, replacement of heat exchanger by direct cooler).
- Replacement of Air Separation Units (ASU1 and ASU2) columns with new columns having structured packing.
- Coke rate reduction in A-G Blast Furnaces by 30 kg per ton of hot metal.
- Coal tar injection in “C” Blast Furnace.
- Sensible heat recovery from “G” Blast Furnace stove waste gases.

These measures are planned to be implemented by December 2003 and the projected energy consumption will be reduced to 6.60 GCal/tcs from a level of 7.435 GCal/tcs in 2000-2001. The corresponding CO$_2$ emission shall be of the order of 2.1 ton per ton of crude steel. Tata Steel is also planning to get its plant audited for energy by M/s. Nippon Steel Corporation, Japan, to reduce the energy consumption at its plant to less than 6.0 GCal/tcs.
Other options under study for implementation in the long run at Tata Steel are presented below. These options when implemented will further reduce the energy consumption to a level of 5.50 GCal/tcs and with corresponding CO₂ emission around 1900 kgs/tcs.

- TRT for “G” Blast Furnace.
- Coke Dry Quenching.
- Waste Heat Recovery from sinter coolers.
- Second LD Gas Holder.
- Waste heat recovery from A-F Blast Furnaces.
- Sensible heat recovery from LD Gas.
- Automatic heat input control in Coke Oven Batteries#5, 6 & 7.
- 100% BF slag granulation (potential reduction 8-10%).
- Phasing out of PH#3 (potential 30% less for equivalent power, if purchased from Tata Power).
- Coke oven gas injection in Blast Furnace.

FLEXIBLE MECHANISM FOR CO₂ REDUCTION—GLOBAL RESPONSE

Only a few countries have introduced energy taxes related to CO₂ emissions. Table 6 gives the details of energy taxes introduced [7] in some of the countries. With regard to CO₂ emission, these taxes would lead to more energy efficient industry.

*Table 6: Energy taxes in the EU (1996) for industrial manufacturing (In Euro Currency)*

<table>
<thead>
<tr>
<th>Country</th>
<th>Heavy Fuel Oil (100 kg)</th>
<th>Coal (1000 kg)</th>
<th>Natural Gas (1000 m³)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Austria</td>
<td>38</td>
<td>-</td>
<td>52</td>
</tr>
<tr>
<td>Belgium</td>
<td>19</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Denmark</td>
<td>16</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>Finland</td>
<td>36</td>
<td>12</td>
<td>12</td>
</tr>
<tr>
<td>France</td>
<td>24</td>
<td>-</td>
<td>13</td>
</tr>
<tr>
<td>Germany</td>
<td>20</td>
<td>-</td>
<td>21</td>
</tr>
<tr>
<td>Greece</td>
<td>42</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Ireland</td>
<td>13</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Italy</td>
<td>43</td>
<td>6-10</td>
<td>-</td>
</tr>
<tr>
<td>Luxembourg</td>
<td>19</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Netherlands</td>
<td>31</td>
<td>11</td>
<td>8</td>
</tr>
<tr>
<td>Portugal</td>
<td>28</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Spain</td>
<td>13</td>
<td>-</td>
<td>1.5%</td>
</tr>
<tr>
<td>Sweden</td>
<td>47</td>
<td>25</td>
<td>20</td>
</tr>
<tr>
<td>United Kingdom</td>
<td>22</td>
<td>-</td>
<td>-</td>
</tr>
</tbody>
</table>
Considering the taxation content of the debates on environmental impacts, Europe appears to be at the leading edge of 'green' taxes. A report from the European Environment Agency (EEA) in Copenhagen claimed that 'green' taxes adopted by individual European countries over the past decade were gaining acceptance. They included revenue-producing fiscal taxes, incentive taxes designed to change environmental attitudes and 'cost-covering charges' intended to charge polluters for the cost of regulating emissions. Moreover, the European Commission has declared its strong interest in green taxes in its Fifth Environmental Action Plan. Newly industrialized countries such as Korea, Taiwan and Singapore are beginning to follow Europe's lead with energy and waste taxes.

Certain observers believe that 'green' taxes are unlikely in the USA, at the federal level, in the immediate future, owing partly to the complexity of, and the 'checks and balances' within, the legislative process. However, some action is occurring at the State level. For example, Louisiana has introduced an 'environmental scoreboard' for companies to measure compliance with environmental laws. Good scores were rewarded with graded exemptions from property taxes.

Notwithstanding the varied legislative and fiscal background, international public policy might seek to impose carbon taxes or similar restrictions on CO₂ emissions, which would impact negatively on the International Iron and Steel Industry. A Carbon/CO₂/Energy Tax would have a damaging impact on the steel industry's costs, its profitability and hence its ability to survive and invest. A tax applied in an unequal way could result in production switching to less efficient steel producers, thereby increasing total global CO₂ emissions.

Reduction of emissions from the international steel industry will be most effectively reduced by maximizing the recycling of scrap, the transfer of technology to producers with higher energy efficiency and the development of more efficient processes.

CONCLUSIONS

The carbon dioxide emission from Steel Plants has been recognized as an important concern globally. In the past two decades steel industry has reduced CO₂ emission by 15-20% by adopting newer technologies and improvement in processes. Further reduction by 15-20% is expected in next decade by implementation of newly developed techniques and controls. Drastic reduction in CO₂ emission is possible only by adoption of technologies like plasma heating, CO₂ recovery, BF and CO gas injection in Blast Furnaces and use of hydrogen on commercial scale in iron ore smelting. Increased use of recycled steel will also play an important role. Life Cycle Assessment for steel products to improve product quality and strength including weight of product will enhance consumer confidence besides reducing the environmental burden. Further reduction of CO₂ in the steel plant globally can come only through adopting flexible mechanisms and CO₂ trading.

At Tata Steel, various measures initiated and to be implemented in next five years will reduce CO₂ emission and energy consumption to world average levels.

There are challenges and opportunity available in steel industry to address this vital issue of CO₂ reduction which is essential for its survival.
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REFERENCES