

SHORT-TERM OPPORTUNITIES FOR DECREASING CO₂ EMISSIONS FROM THE STEEL INDUSTRY

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Abstract

There is a strong political will to decrease CO₂ emissions. Although the steel industry only accounts for some 5% of worldwide CO₂ emissions (which totalled 1,200 million tonnes per annum in the late 1990s), it will be strongly affected by this. The EU, for example, is putting up strong economic incentives for reductions. This is taking place at a time when demand for steel products is greater than ever. To radically change existing processes and production routes to decrease the CO₂ emissions would be extremely expensive, even if it were possible. Nevertheless, many of the solutions which have been discussed seem to go in this direction. The other alternative discussed seems to be the creation of process solutions and alterations that lead to a focusing of CO₂ streams, i.e. much higher CO₂ concentrations in flue gases than today, for entrapment of the CO₂ so that it is not discharged into the atmosphere. These solutions are feasible but expensive.

However, there exist today a number of solutions and technologies which, if fully implemented, could substantially decrease CO₂ emissions without seriously altering current methods of operation and are therefore short-term viable solutions. The present paper reviews and discusses such technologies, throughout the steel production paths. If these solutions are fully implemented, the combined impact on CO₂ emissions from the steel industry worldwide is estimated to be a reduction of 100-150 million tonnes of CO₂ per annum, i.e. current emissions can be reduced by some 8-10% within a relatively short time span.

Keywords: CO₂ emissions, iron, steel, heating, oxyfuel

Introduction

Worldwide CO₂ emissions at the end of the 1990s are estimated at 24 million tonnes annually. Of this total, the transport sector accounted for 36% and the steel industry for approximately 5%. Thus it can be concluded that CO₂ emissions are enormous and that the steel industry is far from being a big contributor. However, there is a strong political will – based on the conclusion that CO₂ is an important factor in influencing the greenhouse effect and thus global warming – to reduce CO₂ emissions and this is also manifested for the steel industry. This is taking place at a time when demand for steel products is greater than ever.

In discussions concerning any industry's potential for reducing its CO₂ emissions, it is frequently put forward that:

- So much has already been done that it would be extremely expensive or difficult to do more (a kind of 80/20 rule reasoning).
- To make further decreases, completely new production processes would need to be developed. Such decreases could therefore not be realized until these processes are in place and that may take some 10-20 years.

It is undoubtedly true that any radical change to existing processes and production paths to decrease CO₂ emissions would be extremely expensive, even if it were possible. Notwithstanding this, many of the solutions that have been discussed seem to go in this direction and this also applies within the steel industry. The basis for this paper, however, is an assumption that the statements above are not completely true. On the contrary, what is emphasized here is that solutions already exist – frequently proven ones, which if fully implemented throughout the steel industry at practically every site where they are considered to be viable, would significantly reduce CO₂ emissions.

CO₂ emissions from the steel industry have two main sources: reduction processes and heating processes (the latter also including melting). It is well known that reduction processes are the dominant source. However, the contribution from heating processes is far from negligible. This year, worldwide steel production will probably reach 1 billion tonnes. Two-thirds of this total is produced in integrated steel mills, which last year corresponded to a blast furnace hot metal production of 650 Mt (the additional production of sponge iron (DRI, HBI, etc.) is 36 Mt). However, one should bear in mind that each piece of steel is on average heated twice on its journey through the production chain, and this is far from the only heating process.

The two main paths used for steel production account for quite different impacts on CO₂ emissions. Integrated steel mills, including all upstream processes, average approximately 2 tonnes of CO₂ per tonne of hot rolled plate. For mini-mills, the corresponding figure per tonne of carbon steel long products is 0.5-0.6 tonnes of CO₂. [1]

By using examples, we will elucidate how existing solutions can reduce CO₂ emissions throughout these process paths. There are principally two ways in which to decrease the CO₂ emissions in the short term, i.e. without altering existing production processes to any great degree:

- Improve the overall utilization of the energy within the existing production flow.
- Decrease the need for fossil fuel inputs.

A third option is to re-use the CO₂ produced in other applications. One example of this is found in Sweden, where the gas company AGA provides CO₂ for practically every possible use, from soft drinks and refrigerated transport via clothes washing to dry ice blasting. This CO₂, which is sourced from by-products from the chemical industry, is in most cases replacing other gases that would have had a far worse effect on global warming. However, the CO₂ cleaning technologies currently available, amongst which the PVSA technique seems to be the most suitable in this context, cannot yet make such solutions viable for exhaust gases from iron and steel production. What remains is the use of this (low grade) CO₂ in the oil and natural gas fields (to increase the yield), which might be entirely feasible but beyond the scope of this paper.

There is actually also a fourth option, i.e. alternative fuels, such as gasified waste and hydrogen. Many people see hydrogen as *the* fuel of the future. However, existing hydrogen production facilities require a lot of energy (4-5 kWh/Nm³ or 50-60 kWh/kg) and with rather limited unit sizes. Nevertheless, the transport sector is pushing developments in this field. Linde, for example, is involved in several projects with cars and buses using hydrogen as fuel. Today “hydrogen buses” can be found in 9 major European cities (although they represent a minority of the fleet in each case) and BMW for example has also built a “hydrogen car”. Some “experts” claim that within 20 years, a quarter of the EU car fleet will run on hydrogen. If such a prediction comes true, it would naturally also have an impact on the steel industry’s potential to use hydrogen as a reductant. However, there are in practice today few locations where hydrogen is or could be used as a viable fuel. These are mainly places where a steel mill is located adjacent to a chemical plant from which hydrogen could be obtained as a by-product. There are examples where by-product hydrogen is used as part of the fuel input to re-heat furnaces. Looking at the fuel economics, it is rather easy to draw the conclusion that, in order to be competitive, the price of hydrogen should be no more than 30% of the natural gas price based on a price per Nm³ comparison.

Integrated iron- and steel-making

This covers all production processes from iron ore to final steel product from an integrated steel mill. However, processes related to vessel preheating, scrap preheating, and reheat furnaces and annealing lines are discussed in separate paragraphs below as they are also used in the mini-mill production path.

Pellet production

To produce iron ore pellets for blast furnace and direct reduction processes, the average energy requirement is 540 kWh/t using hematite ore. However, for pellet production from magnetite, the corresponding figure could be as low as 140 kWh/t. The first point to note is the difference, which corresponds to 0.15 t CO₂ per tonne of final steel product. In other words, using magnetite pellets could reduce the overall CO₂ emissions from integrated steel production by 7%. [1]

The energy input in pelletizing processes, e.g. straight grates and grate kilns, is achieved by means of airfuel burners. There is no law of nature which says that airfuel must be used here; the use of oxygen instead of ballast-containing air would result in substantial fuel savings and, thereby, reduce CO₂ emissions. Hitherto, this has not

been fully tested. However, this technology is very well proven and established in many other applications and the time required for successful use in pelletizing processes would therefore also be short. As each tonne of final steel product from an integrated steel mill requires around 1.5 t of pellets, this would have a notable impact on the CO₂ emissions and simultaneously improve the fuel economics of pelletizing.

The blast furnace and BOF processes

To produce iron in solid or liquid form from iron ore we need a reductant. The two most suitable reductants, from a technical and economic perspective, are carbon and hydrogen. The use of pure hydrogen is today frequently not realistic; there are a few exceptions but these are linked to unusual localised conditions.

In practice, the reductants used in today's iron-making are coal and natural gas; the coal being in the form of coke or pulverized coal. Blast furnaces inevitably require coke to a certain extent. It should be noted that the lowest operational limit of coke in a shaft furnace has been estimated at 150-200 kg/t. This is determined by the requirements for the carburization of iron, direct reduction with carbon and, in particular, shaft permeability and burden support. [2]

In the context of iron-making and the decrease of CO₂ emissions, what are known as Full Oxygen Blast Furnace processes are frequently discussed as a possible alternative. The idea of the Full Oxygen Blast Furnace (FOBF) is not new; some researchers discussed it back in the 1930s and 1950s. The modern ideas were presented in the 1980s. They are based on two main principles: using pure oxygen as blast and acquiring a pre-reduction degree of iron (e.g. 90%). However, FOBF processes are hampered by the so-called "hot bottom and cold top problem". Since Fink presented a proposal for an FOBF process in a patent in 1978, the idea of using recirculated top gas for compensating the decreasing amount of shaft gas and adjusting the very high flame temperature has been the basis for most other proposals. [2]

In the discussions on how to reduce CO₂ emissions, FOBF processes – which have not yet been taken into full-scale operation – have experienced a renaissance. However, it should be noted that the FOBF processes themselves do not lead to decreased CO₂ emissions; the fuel rate (normally coke plus injected pulverized coal) is some 20% higher than with a conventional blast furnace. The potential benefit of FOBF processes lies in the possibility of achieving a top gas with low nitrogen content (with a calorific value of 2 kWh/Nm³, more than twice that of conventional blast furnaces) from which the CO₂ can then be removed reasonably effectively. It is then recirculated back into the furnace as part of the fuel input. This entrapped CO₂ can then be disposed of so that it is not discharged into the atmosphere or, for example, used in oil and natural gas fields. Using FOBF processes is a possible solution, but it is not yet a proven alternative.

What then are the proven alternatives today? For blast furnaces, the prime ones are related to the injection of reductants and fuel containing hydrogen or other gases generated on site that are not fully utilized. The use of natural gas injection, if available, is definitely a very suitable way to decrease CO₂ emissions. This approach has been applied at many blast furnaces worldwide for many years.

To radically change the prime iron source, e.g. by replacing a blast furnace with a natural gas-based direct reduction process, is theoretically an alternative, but in practice it would be an enormous task and, therefore, beyond the scope of the present paper.

voestalpine Stahl, VAI and Linde are jointly carrying out a project called RedJet at the integrated steel mill in Linz, Austria. Its aim is the improved utilization of gases from other facilities on site, i.e. coke oven gas from the coke-making and BOF gas from the steel-making converter (Basic Oxygen Furnaces – BOF). The idea is to use them for injection in the blast furnace, where they replace part of the top-charged coke and oil-injection. The first step, using solely coke oven gas injection (50 kg/t) by conventional lancing, has demonstrated that overall CO₂ emissions from the blast furnace can be decreased by 75 kg/t, which corresponds to up to 5% reduction in CO₂ emissions. In the second step, which will be initiated later this year, both coke oven and BOF gases (100 kg/t) will be injected using the new RedJet technology. The expected effect from of this is a reduction of 150 kg/t in CO₂ emissions, i.e. a possible 10% reduction.

Another interesting example of a different type can be found at Corus at IJmuiden in the Netherlands. Here, the CO₂ emissions from a BOF shop have been decreased by 2.5% whilst at the same time energy recovery has been improved by 4%. This is achieved by optimizing the flue gas system, particularly the pressure under the hood, in order to lower the air ingress. [3]

Heating processes

Throughout the process chain, heating is carried out in many places. Heating is achieved in a number of different vessel pre-heating stations, e.g. ladle pre-heating. However, the majority of the heating takes place downstream in reheat furnaces of various kinds and annealing lines. A special case is the scrap melting performed in an Electric Arc Furnace (EAF), and it is also worth mentioning scrap preheating carried out prior to the scrap being charged into an EAF or a steel-making converter.

Scrap preheating

Scrap preheating could be a perfect tool to reduce CO₂ emissions, both at mini-mills and integrated steel mills. At mini-mills, the overall impact on CO₂ emissions is frequently dependent on the electricity generation; if all electricity used in a particular EAF is generated by hydro or nuclear power, there would be no benefit in this respect, but if at least part of it comes from coal-fired power plants, a reduction in overall CO₂ emissions could be achieved.

Scrap preheating at integrated steel mills will always lead to reduced CO₂ emissions. This is linked to the fact that scrap “carries” no CO₂. By preheating the scrap prior to charging it into a BOF, the amount of scrap that can be put in whilst maintaining the heat balance could be increased by 4-5%. The scrap would then replace part of the hot metal input, which “carries” a substantial amount of CO₂. At many sites, surplus BOF gas is available, which could be used as fuel in the scrap preheating process. The overall impact on CO₂ emissions from using scrap preheating at integrated steel mills could average 0.1 tonne of CO₂ per tonne of final steel product.

Avoiding the ballast

It is a well-known fact that only three things are needed to start and maintain combustion: oxygen, fuel, and sufficient energy for ignition. The combustion process itself would be most efficient if fuel and oxygen can meet without any restrictions. However, in practical heating applications it is not simply a question of efficient combustion, the heat transfer efficiency is also extremely important. Nevertheless, it has been clearly demonstrated in practice that if oxygen (and not air) is used to combust a fuel, all the heat transfer mechanisms (convection, conduction and radiation) can be promoted at the same time. [4]

Why then is air used for combustion? We all know that air contains 21% oxygen and 79% ballast. In a combustion process, this ballast, practically all nitrogen, has to be heated, for which a lot of fuel is needed. Flue gas volumes are also much greater than with using only oxygen – which also has a negative impact on the capital requirements and, moreover, will substantially increase the production of NO_x . Figure 1 shows a comparison of the impact on CO_2 emissions of using oxyfuel instead of air-fuel.

Using oxyfuel instead of airfuel combustion for all kinds of heating operations opens up tremendous opportunities, as it leads to fuel savings, reduces the time required for the heating process and reduces emissions. Numerous results from installations have proven this. There are two main areas worth mentioning in this context: vessel pre-heating, and reheat furnaces and annealing lines.

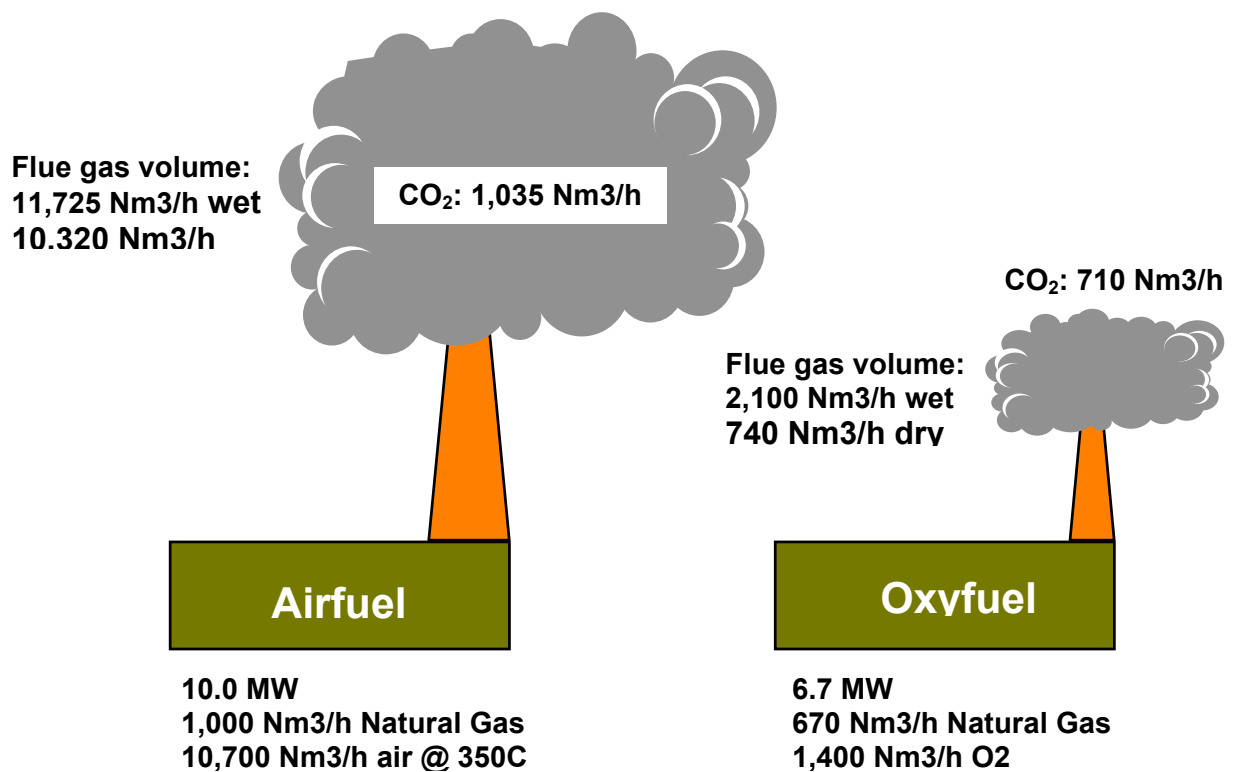


Figure 1. Comparison of the impact on CO_2 emissions of using oxyfuel instead of air-fuel (preheated air) at heating of semis at equivalent conditions.

Vessel preheating

The use of oxyfuel to preheat vessels such as torpedoes, ladles and converters has been around for several decades. However, the number of installations is still surprisingly low given its potential. Using oxyfuel instead of airfuel would reduce the fuel consumption drastically by approximately 50%, which would bring about a proportional decrease in CO₂ emissions. However, it would also have additional benefits such as a shorter heating time and hotter vessels. These would, for example, lead to fewer ladles in circulation and the possibility of reducing tapping temperatures. The latter directly saves energy in the furnace, but it could also decrease the tap-to-tap time of the furnace. The time saving would lead to additional energy savings as the specific (time dependent) heat losses from a furnace, would then be lowered [5].

Let us look at a proven example of what this could lead to. The operating power with oxyfuel for a 60t ladle is approximately 1.2 MW. The average annual level is 0.8 MW, which at 7,500 h/y means 6 GWh/y. This is around half of what would be required with airfuel; thus the annual saving is 6 GWh. Assuming the fuel is natural gas, the resulting decrease in CO₂ emissions would be 1,200 t/y, and this is only for one (1) preheating station.

We can also estimate the global impact of solely using oxyfuel instead of airfuel for vessel preheating in the steel industry. Let us first make two assumptions: 10% of vessel preheating is currently achieved using oxyfuel and the average oxyfuel energy requirement is 10 kWh/t, i.e. half of that required for airfuel. Thus, the potential global saving in CO₂ emissions is 1.6 Mt/y.

The additional impact from direct and indirect energy savings in the furnace is hard to estimate. However, completely converting all vessel preheating into oxyfuel could reduce CO₂ emissions by some 2 Mt/y.

Reheat furnaces and annealing lines

Using oxyfuel instead of airfuel combustion for all kinds of heating in furnace operations opens up tremendous opportunities, as it leads to:

- Fuel savings of up to 45%.
- Increased throughput (tonnes/hour) by up to 80% in existing furnaces with no additional staff.
- Substantial reductions of NO_x, SO_x and CO₂ emissions even at increased throughput.

Reductions in SO_x and CO₂ are directly proportional to the fuel consumption.

Since 1990, Linde has constructed 80 oxyfuel installations, including practically every type of furnace in rolling mills, forge shops and annealing lines. Thus, the viability of oxyfuel in this context has also been proven – it seems that the successful use in modern steel-making and many branches of industry will also be repeated here. In this context, it should be mentioned that the oxyfuel installations in reheat furnaces and annealing lines in Sweden have led to a combined reduction in CO₂ emissions from this operation of 60,000 t/y [6]. Figure 2 shows a photograph of a walking beam furnace in Sweden that was recently converted to all oxyfuel operation.



Figure 2. The photograph shows a walking beam furnace in Sweden that has been converted to all oxyfuel operation using 26 flameless oxyfuel burners.

Let us now look at the potential impact this could have on CO₂ emissions. The average reduction in fuel consumption from converting these furnaces from airfuel to oxyfuel would be 150-200 kWh/t, and at least 2,000 Mt/y of steel passes through such operations. Accordingly, this would reduce the steel industry's CO₂ emissions by perhaps 80 Mt/y, or some 6-7% of this industry's total CO₂ emissions.

What is also worth noting, although the technology has been installed for more than a decade, are the ongoing developments that could bring down emissions further. In 2003, so-called flameless oxyfuel technology was introduced in full-scale production in a walking beam furnace and a continuous annealing line (also for ladle and converter preheating). These Linde turnkey projects were successful in providing more heating capacity in large furnaces and at the same time achieving ultra low NO_x levels. However, for further fuel (and CO₂) savings, particularly in strip heating, there is Direct Flame Impingement technology. This technology was introduced at Outokumpu Stainless Nyby Works in Sweden in 2002. Figure 3 illustrates the very impressive heating efficiency of this technology and the superiority of oxyfuel.

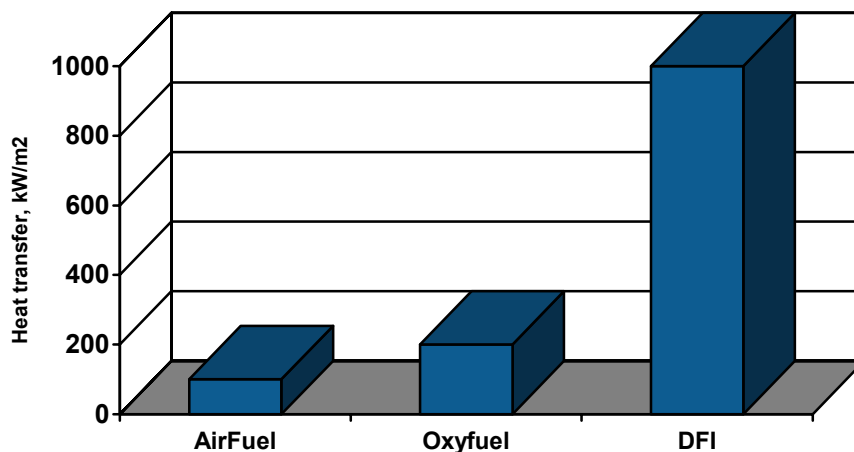


Figure 3. Heat transfer efficiency of airfuel, oxyfuel and Direct Flame Impingement.

Improved use of existing and alternative fuels

Another interesting aspect in the context of oxyfuel should also be noted. Large quantities of fuel with a low calorific value are available at steel mills, e.g. blast furnace top gas and BOF gas. In many places, at least some of these gases are not used; they are just put to flaring. What is frequently hampering their greater use is the flame temperature required in heating applications. However, using oxyfuel instead of air-fuel would in many cases make it possible to even run the heating application solely with blast furnace top gas as the fuel. Where these gases are being flared today, the resultant impact on the site's CO₂ emissions of using them in this way would be very positive and would replace other energy sources.

A relatively simple and practical example of the use of "low grade" fuels can be found in blast furnace hot stoves. There are examples of installations where the use of blast furnace top gas, which would otherwise have been flared, in this process (to heat the air-blast) has increased. This was made possible by applying oxygen-enrichment to maintain the flame temperature. Fuel economy was thus improved and CO₂ emissions were reduced.

Using "bio fuel", i.e. ethanol, would reduce CO₂ emissions. An interesting alternative is using fuel in the form of gasified waste. This could for example be Automotive Shredder Residue (ASR) from the shredding of end-of-life vehicles, currently mainly considered to be waste but with an energy content of 5-6 kWh/kg. The annual generation of ASR is 2-3 Mt in the EU, and with the increasing stringency of legislation the alternative of sending it to a landfill will no longer be feasible in the future. The resulting gas from the gasification of waste can be used as a fuel in practically all heating applications, including scrap preheating. However, it might find a use in blast furnaces too, where it can be injected in the same way as, for example, natural gas.

CO₂ emissions relating to oxygen production

As many of the examples and solutions presented in this paper, all aimed at reducing CO₂ emissions, use oxygen, it is appropriate to comment on the CO₂ emissions relating to oxygen production. The production of 1 Nm³ of gaseous oxygen requires approximately 0.5 kWh of electricity. If this electricity is produced by hydro or nuclear power plants, it "carries" no CO₂. However, if produced using fossil fuel it would correspond to 0.5 kg CO₂ per Nm³ of oxygen. Thus, in the worst case scenario, oxyfuel combustion contributes (from oxygen production) 0.1 kg CO₂ per kWh. Turning that worst case scenario into practice, we know that oxyfuel combustion (compared with airfuel) would reduce the fuel consumption by an average of 40%, and the combined effect on CO₂ emissions would then be a reduction of approximately 35%. It should be noted that all figures presented in this paper concerning the effects of solutions using oxygen on CO₂ emissions have taken into account CO₂ emissions relating to oxygen production.

Conclusions

The examples presented all show the considerable potential for substantially reducing CO₂ emissions in the short-term perspective, including:

- Use of oxygen in pellet production.
- Oxygen-enrichment in hot stoves to enable the increased use of, for example, blast furnace top gas as fuel.
- Injection of natural gas in blast furnaces.
- Injection of coke oven gas and BOF gas in blast furnaces.
- Improved control of flue gas system at BOF steel-making.
- Use of oxyfuel instead of airfuel combustion in all kinds of vessel preheating.
- Scrap preheating in EAF and BOF steel-making.
- Conversion of airfuel combustion into oxyfuel in reheat furnaces and annealing lines.
- Use of low-grade fuel for heating at integrated steel mills.
- Use of fuel from gasification of waste.

Thus, there exist today a number of solutions and technologies which could substantially decrease CO₂ emissions without seriously altering current methods of operation and are therefore short-term viable solutions. Additionally, they would lead to improved fuel economics and reduced processing times. The combined impact of the full implementation of these technologies and solutions throughout the world steel industry would bring about a reduction of CO₂ emissions of 100-150 million tonnes of CO₂ per annum, i.e. current emissions could be reduced by some 8-10%.

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