Decarbonization Priorities for Electric Furnace Steelmaking

Petrus Christiaan Pistorius

Carnegie Mellon University
Center for Iron and Steelmaking Research, MSE Department,
5000 Forbes Avenue, Pittsburgh, PA, U.S.A, 15213
Phone: +1-412-268-7248
Email: pistorius@cmu.edu

Keywords: Carbon intensity, Electric Arc Furnace Steelmaking, Greenhouse Gas Reporting Program, Furnaces

INTRODUCTION

A recent analysis indicated that the typical CO₂ emissions from electric arc furnace (EAF) steelmaking in the U.S. are 300-400 kg CO₂ per tonne of crude steel,\(^1\) half of this from electricity use, and half from combustion within the furnace. The value for electricity use is based on the U.S. average carbon intensity of approximately 0.4 kg CO₂ per kWh; some EAF producers intentionally purchase renewable electricity.

An emissions total of 300-400 kg CO₂ per tonne of crude steel would be the case for a 100% scrap-based operation. If additional carbon units in the form of pig iron or direct-reduced iron were included in the furnace charge, their associated emissions should be added: around 1,600 kg CO₂ per tonne of pig iron (if produced with coke instead of renewable charcoal), and 600 kg CO₂ per tonne per tonne of DRI.\(^1\) Clearly, maximizing scrap use – within the limits possible while producing steel of acceptable quality – is an important strategy for minimizing the CO₂ intensity of EAF steelmaking.

Emissions of CO₂ from combustion within the EAF are a direct result of the use of relatively large amounts of injected oxygen – a median of around 40 Nm\(^3\) oxygen per tonne of steel\(^1\) – that mostly combusts carbon. Optimizing oxygen use in the furnace – with a view to potentially decreasing the amount used – is another potential strategy to partially decarbonize EAF steelmaking.

Combustion in process units downstream of the EAF is expected to be another significant source of CO₂. These units include tunnel furnaces (to maintain the slab temperature between the continuous caster and rolling mill\(^2\)), and annealing furnaces (following hot and cold rolling).

In this work, the contribution of these non-EAF sources of CO₂ has been evaluated with data reported to the Greenhouse Gas Reporting Program\(^3\). In the United States, stationary sources of more than 25,000 metric tons of carbon dioxide equivalent annually are mandated to report emissions (under EPA rule 98).\(^4\) The reported data are available online, through the "Facility Level Information on GreenHouse gases Tool" (FLIGHT).\(^3\) The data are available at the level of the individual facilities; iron and steel production is one of the many sectors for which emissions are listed; Figure 1 shows data examples.

As Figure 1c) shows, data are listed at the level of the individual sources (such as tunnel furnaces or rolling mills). This allows analysis of the relative contributions of different process units; an example is given in Figure 2.

DATA ANALYSIS APPROACH

Emissions data from FLIGHT were combined with the annual capacity of EAF facilities, from the AIST Electric Arc Furnace Roundup.\(^5\) Note that data on the tonnage produced was not available, so the emissions are expressed relative to plant capacity, rather than actual tons of crude steel. Emissions data for 2020 (the most recent available) and 2018 were used. One of the challenges in combining the EPA and AIST data is differences in plant names. This resulted in exclusion of a few plants from the analysis. However, the total annual capacity of the plants considered in this analysis is approximately 49 million tonnes, which is close to the total EAF crude steel tonnage in 2020, which was 51 million tonnes.\(^6\)
EAF Steelmaking CO₂ Emissions From “Stationary Combustion”

The results are summarized in Figure 3. In drawing this figure, the cumulative steelmaking capacity was plotted after sorting the plants from the smallest to the largest annual capacity. The figures show similar values for the two years considered (2018) and (2020). The plot of EAF emissions vs. capacity is approximately linear, indicating similar emissions from the EAF for plants of different sizes. The EAF emissions amount to approximately 100 kg CO₂e per tonne of crude steel, which is similar to (but a little lower than) the analysis based on oxygen use in EAFs.¹

The line for stationary sources (in Figure 3) has a lower slope for larger plants than smaller plants: downstream furnaces contribute a larger proportion of the total CO₂ emissions for smaller facilities than larger ones. The average contribution is around 85 kg CO₂ per tonne steel; for plants with annual capacities smaller than 1.25 million tonnes the average value is 120 kg CO₂ per tonne steel, whereas for the larger plants the average is 60 kg CO₂ per tonne steel.

¹ For the analysis based on oxygen use in EAFs.
Figure 1. Examples of data available from the EPA Greenhouse Gas Reporting Program (reproduced with permission)

- a) Map showing all iron and steel production facilities; b) information on one facility;
- c) details of emissions reported for one facility.

Figure 2. Example of relative contribution of emissions from stationary sources for one facility (Nucor Steel Decatur; 2020 data). (Total emissions from these sources for 2020: 0.133 million tonnes CO$_2$e.)
Electrification will be an essential part of decreasing the carbon intensity of steelmaking. Induction heating is currently applied in heating of rod and bar stock, and to increase the temperature of strip edges;\textsuperscript{7,8} the principle is that an alternating magnetic field is applied to and induces current in the steel workpiece. Heating occurs to a depth (skin depth) that depends on applied frequency, and the permeability and electrical resistivity of the workpiece.\textsuperscript{9} Because of the large change in the magnetic properties of steel above its Curie temperature (increasing the skin depth, and so decreasing the effective workpiece resistance), the efficiency of induction heating is somewhat lower for heating steel to higher temperatures.\textsuperscript{10}

While non-uniform heating at the corners of rectangular sections is a potential concern,\textsuperscript{7} recent modeling demonstrated induction heating of slab and strip in continuous strip\textsuperscript{9} and endless-rolling plants.\textsuperscript{11} As expected, the temperature difference between surface and center is larger for thicker material (and for faster heating).

There are current examples of the industrial use of induction heating in steel plants: In micromills (for the production of rebar) and induction heater is used to equalize the steel billet temperature after the continuous caster, before the steel enters the first rolling strand.\textsuperscript{12} As mentioned above, induction heating is used in the endless-strip process (ESP).\textsuperscript{13} In that case, the induction heater is placed before the finishing mill (after the roughing mill), to heat the strip before final rolling.

Based on these descriptions in the literature, induction heating of slab and strip is a feasible way to avoid emissions from stationary combustion in steel production.

**CONCLUSION**

Plant emissions data confirm that tunnel and heat-treatment furnaces are significant sources of CO\textsubscript{2} emissions (60 – 120 kg CO\textsubscript{2}e per tonne of crude steel). Induction heating appears to be a feasible method to electrify these heating operations, and avoid the associated carbon dioxide emissions.

**REFERENCES**


