Report on
Annual Worldwide Carbon Dioxide Emissions from Blast Furnace Iron Ore Smelting and Coke-making

Abstract

The 2015 worldwide CO_2 emissions from blast furnace iron smelting, and associated coke-making and ancillary activities came to 2.0 billion tonnes of CO_2 emitted. These blast furnace and coke-making CO_2 emissions made up 5.5% of the world’s total CO_2 emissions from all fossil fuel burning.

Author: Rif Miles Olsen, Two Planet Steel, rmo@twoplanetsteel.com

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Introduction

Two Planet Steel wanted to look up how much carbon dioxide (CO_2) is emitted into Earth's atmosphere by steel-making activities every year. To our surprise these emissions figures are not published in the annual report called the Global Carbon Budget (Le Quere *et al.*), that is published by the large group of scientists (67 of them in 2016) who are concerned to point out the world’s large CO_2 emissions. While the authors of that important annual report are very concerned to calculate and publish total annual CO_2 emissions globally, the methods they use to calculate these emissions do not take into account specific CO_2 emitting activities carried on in the steel-making chain from iron ore mining and enrichment, through iron ore smelting(reduction), to steel-making and finishing activities.

Other sources of information relevant to CO_2 emissions from steel-making include industry groups such as the American Iron and Steel Institute (AISI), the American Coke and Coal Chemicals Institute (ACCCI), and the World Steel Association. The industry institutes and associations also do not publish figures at all on CO_2 emitting activities carried on in the steel-making chain. However, there is enough information from these institutes/associations that, combined with papers, data and statistics from other coal and steel industry sources, is enough to make a reasonably accurate calculation of global CO_2 emissions from iron ore smelting/reduction done in blast furnaces and the processing of coal into coke (coke is a key input into a blast furnace). Fortunately the information and data needed for this calculation is quite small and easy to understand. Also, the CO_2 emissions from blast furnace iron ore smelting/reduction and coke-making done for the blast furnaces constitute a very significant part of the total CO_2 emissions from the whole chain from ore mining to steel-finishing, so that the emissions figures calculated here roughly indicate the size of the total emissions from the whole chain of activity.

The remainder of this technical report comes in two parts (a) presentation of the calculations and (b) a short discussion about the calculation data, also that the calculations given here end up being a conservative, small underestimate of CO_2 emissions from blast furnace iron ore smelting/reduction and coke-making in 2015.

Calculations

	Amount	Data & Information Source(s)
Typical amount of coke consumed for a tonne of iron produced	0.45 (tonne coke)/(tonne iron)	World Steel Association, A
Typical amount of blended coking coal consumed for a tonne of coke produced	1.4(3) (tonne coking coal)/(tonne coke)	Schobert & Schobert
Typical mass of carbon in a tonne of blended coking coal	0.78 (tonne carbon)/(tonne coking coal)	Schobert & Schobert
Fraction of carbon in coking coal converted to CO_2	0.94 or 1.00	ACCCI; Grainger & Gibson; Towsey, Cameron & Gordon; Reeves *et al.*
Mass of a CO_2 molecule divided by mass of a carbon atom	44/12 = 3.67	This mass ratio comes from basic chemistry data.
2015 global blast furnace iron production	1,154,434,000 (tonne iron)	World Steel Association, B

Table 1. Data and a Statistic Relevant to CO_2 Emissions from Blast Furnace Activities.

Multiplying together the amounts in the first three lines of Table 1 gives the typical amount of carbon in the coking coal required to produce one tonne of iron from typical blast furnace operations, *i.e.* 0.50(2) (tonne carbon)/(tonne iron). Depending upon whether the method of coke-making used in the steel plant is by-product coke-making or heat-recovery coke-making, either close to 94% or close to 100% of the carbon in the input coking coal is converted into CO_2 at some point in the steel plant's operation (details of how these numbers are arrived at are gone over in the discussion). To be conservative (i.e. to minimize the final CO_2 emitted numbers), it is assumed for this calculation that by-product coke-making is practiced at all steel-plants in the world. With this conservative assumption, multiplying the smaller, 0.94, fraction of the fourth line of Table 1 by the previous calculated amount, gives the typical amount of carbon in the coking coal, that gets converted into CO_2, required to produce one tonne of iron from typical blast furnace operations, *i.e.* 0.47(8) (tonne carbon-to-CO_2)/(tonne iron). This just calculated figure can be multiplied by the carbon-to-CO_2 mass multiple, 44/12 = 3.67 (fifth line in Table 1), to give the typical amount of CO_2 emitted for each tonne iron produced in a typical blast furnace, *i.e.* 1.73 (tonne CO_2 emitted)/(tonne iron produced). So, finally, multiplying together the World Steel Association's 2015 worldwide blast furnace iron production figure (sixth line in Table 1), and this calculated 1.73 (tonne CO_2 emitted)/(tonne iron produced) figure, we have:

The 2015 worldwide CO_2 emissions from
blast furnace iron smelting and associated coke-making = 2.0(0) billion tonnes of CO_2 emitted

The 2015 Global Carbon Budget estimate for worldwide CO_2 emissions from all fossil fuel burning activities is 36.3 billion tonnes of CO_2 emitted [1] (Le Quere *et al.*). So, blast furnace and coke-making CO_2 emissions made up 5.5% of the grand total.

1 The 36.3 billion tonnes of CO_2 emissions figure is calculated from the Le Quere *et al.* 2015 E_{FF} figure of 9.9 billion tonnes carbon emitted in carbon dioxide emissions by multiplying it by 3.67 (tonne CO_{2}/)/(tonne carbon), *i.e.* the carbon-to-CO_2 mass conversion factor.

Discussion of calculation data

Turning to the amount of coke used to smelt one tonne of iron, 0.45 (tonne coke)/(tonne iron), given in first line of Table 1. This coke usage varies between blast furnaces of different ages, and this has been slowing going down with time (Quanci). As such it is difficult to get an average value of the coke usage across all the blast furnaces in the world. However, one organization, The Institute for Industrial Productivity (IIP), which is concerned with industry generally (so it is not strictly a steel, coal or coke organization), gives a higher 0.46–0.48 (tonne coke)/(tonne iron) figure than the one given in Table 1 (IIP, Coke Making). The present calculations used the lower figure because (i) it was lower (so it does not inflate the final computed CO_2 emissions number), and (ii) it came from the World Steel Association (which stated "Typically, it takes 1.5 tonnes of iron ore and around 450 kg of coke to produce a tonne of pig iron") which is expected to know the coke usage of many different blast furnaces and, likely, would tend to low-ball what a typical or average value of the coke usage is.

The given amount, 1.4(3) tonnes of coking coal needed to make 1 tonne of coke, second line of Table 1, from Schobert and Schobert, was chosen for the calculations because (i) it was given in a report sponsored by a coal mining company (and so it had access to a lot of industry information) and the report claims the figure to be the median of nine industry values the coal company knew of and (ii) it was lower than (more conservative than) the IIP number of 1.6 (tonnes coking coal)/(tonne coke), while the Schobert and Schobert figure fell between a number given on the website of another coal mining company, 1.5 (tonnes coking coal)/(tonne coke) (Grand Cache Coal), and a 1.33 (tonnes coking coal)/(tonne coke) figure that can be inferred from the data in the paper by Towsey, Cameron, and Gordon.

The given amount, 0.78 tonnes of carbon in 1 tonne of blended coking coal, third line of Table 1, from Schobert and Schobert, was chosen for the calculations mainly because this was the only online source found that gives specific total carbon content of *blends* of bituminous coal suitable for making coke. The lack of data online for such blends appears to be due to such information being considered insider or proprietary information of individual coke-making companies. The given amount does appear to be a reasonable figure in that (i) it is in-line with several online publications which make partial statements about the bituminous coal ingredients for coke (sometimes numbers were given for "fixed carbon," *i.e.* the carbon that makes it into the coke, while the unfixed or volatile carbon content numbers were omitted from online statements) and (ii) 78% carbon content is well below the percent carbon content of some high carbon content bituminous coals.

Turning to the fraction of carbon in coking coal turned into carbon dioxide by coke-making, blast furnace smelting and their ancillary activities (conversion fractions are given in the fourth line of Table 1). There are two basic types of coke-making, by-product coke-making and heat-recovery coke-making (AISI). Of the first type, of all the carbon going into the coke-making ovens about 6% of this leaves the whole industrial plant as either tar or light oil (principally benzene and toluene), while the remaining 94% of the carbon leaves the coke-ovens either as carbon or in methane, carbon monoxide or carbon dioxide (ACCCI; Grainger & Gibson; Towsey, Cameron, and Gordon). The methane, carbon dioxide and carbon monoxide leaves the by-product ovens in a gas mixture, called coke oven gas (COG), that includes hydrogen; COG is used on site as a useful fuel for heating applications, such as heating the coke-ovens themselves (Towsey, Cameron, and Gordon). This combustion of COG turns close to 100% of the carbon contained in the methane and carbon monoxide into carbon dioxide, so that nearly all carbon in the post-combustion COG is only in carbon dioxide. For modern heat-recovery coke-making, all of the carbon-containing, volatile hydrocarbons forced out of the coking coal are so thoroughly combusted in the heat-recovery coke-making plants that the only carbon containing gas emitted from these plants is carbon dioxide (Towsey, Cameron, and Gordon). Turning to the unoxidized carbon leaving both types of coking ovens (by-product and heat recovery), it comes out of the coke-ovens as the main component of coke or coke breeze (*i.e.* pieces of coke too small to be used in a blast furnace). Coke breeze is primarily used in steel plants as fuel to heat and drive the sintering of small grain iron-ore or for iron pelletization (Walker; Towsey, Cameron, and Gordon). While, the combustion of coke breeze in iron ore sintering and pelletization may not be complete, most of the coke breeze carbon is turned into carbon dioxide, and, since the mass of coke breeze is less than 5% of the coke used in blast furnaces (Sweetser), the amount of partially combusted carbon monoxide leaving the sintering plants is small relative to the carbon dioxide leaving the sintering plant, coke-ovens and blast furnaces. The flue gas leaving modern blast furnaces, called blast furnace gas (BFG), contains a mixture of both carbon monoxide and carbon dioxide, as well as hydrogen and nitrogen (Towsey, Cameron, and Gordon); however, the carbon monoxide in BFG is not allowed to leave the plant but is used as heating fuel (primarily for the blast furnaces hot stoves) so that nearly all the carbon in blast furnace coke gets turned into carbon dioxide either in the blast furnace or in the combustion of the BFG (Towsey, Cameron, and Gordon). In addition, although there may be some small amounts of carbon monoxide that get emitted from a steel plant using a blast furnace, this carbon monoxide gets converted into carbon dioxide in normal atmospheric processes (that produce ozone) (Reeves *et al.*). So, except for the tar and light oil made with by-product coke-making, all of the carbon in the input coking coal ends up as carbon dioxide. This consideration of the end fate of the carbon initially in the coking coal shows that close to 94% of this carbon is eventually turned into carbon dioxide when by-product coke-making is used, while close to 100% of this carbon is converted to carbon dioxide when heat-recovery coke-making is used. These conclusions lead to the 0.94 and 1.00 fractions in the fourth line of Table 1.

The remaining two lines in Table 1 cover a well established fact of chemistry and the total of blast furnace iron production numbers summed over very detailed blast furnace iron production numbers the World Steel Association compiles every month from every country with a major or minor iron and steel industry.

The calculation results are the main result of this technical report.

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