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Stationary source emissions — Greenhouse Gas (GHG) emissions in energy-intensive industries

Part 2: Iron and steel industry

National foreword

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European foreword

This document (EN 19694-2:2016) has been prepared by Technical Committee CEN/TC 264 “Air quality”, the secretariat of which is held by DIN.

This European Standard shall be given the status of a national standard, either by publication of an identical text or by endorsement, at the latest by January 2017, and conflicting national standards shall be withdrawn at the latest by January 2017.

Attention is drawn to the possibility that some of the elements of this document may be the subject of patent rights. CEN [and/or CENELEC] shall not be held responsible for identifying any or all such patent rights.

This document has been prepared under a mandate M/478 given to CEN by the European Commission and the European Free Trade Association.

This European Standard deals with sector-specific aspects for the determination of greenhouse gas (GHG) emissions from steel production. This standard can be used to measure, report and compare the GHG emissions of a steel facility. It can also be used to assess the GHG performance of a steel facility or parts of it.

EN 19694, *Stationary source emissions — Determination of greenhouse gas (GHG) emissions in energy-intensive industries* consists of the following parts:

— *Part 1: General aspects*

— *Part 2: Iron and steel industry*

— *Part 3: Cement industry*

— *Part 4: Aluminium industry*

— *Part 5: Lime industry*

— *Part 6: Ferroalloy industry*

According to the CEN/CENELEC Internal Regulations, the national standards organizations of the following countries are bound to implement this European Standard: Austria, Belgium, Bulgaria, Croatia, Cyprus, Czech Republic, Denmark, Estonia, Finland, Former Yugoslav Republic of Macedonia, France, Germany, Greece, Hungary, Iceland, Ireland, Italy, Latvia, Lithuania, Luxembourg, Malta, Netherlands, Norway, Poland, Portugal, Romania, Slovakia, Slovenia, Spain, Sweden, Switzerland, Turkey and the United Kingdom.

Introduction

The steel industry recognizes the urgent need to take action to combat climate change. Slowing and halting global warming will require substantial reductions in greenhouse gas emission on a global scale. To play a part in achieving these reductions, steel production sites, recognized as major emitters of GHG, should as a first step assess their CO_2 emission performance relating to the production of steel products in order to identify and quantify emission reduction opportunities.

Steel production involves complex chemical reactions, successive heating cycles, and the recycling of various by-products. A variety of inputs, including raw materials, reactive agents, fuel and heat sources are transformed into a wide range of steel products, by-products, waste materials and waste energy.

Steel sites manufacture a wide range of products including, among others, sheet products, plate products, long products, pipe and tubes. In addition, some steel sites produce unique high-performance specialty steel products, which are created by employing various sub-processes including micro-alloying and surface treatment, thus requiring additional heat treatments. Therefore, there are no two steel sites in the world which are the same. As a consequence, a sound assessment of performance should be made independent of the production structure.

Regulations related to climate change require steel companies to devise methods to reduce CO_2 emissions from steel sites while continuing to produce steel products from these diverse and complex steelmaking processes. To accomplish this, it is desirable to have universally common indicators for determining the CO_2 emission performance of a site.

It has been the usual practice to determine CO_2 emissions at facility level, from which a CO_2 intensity per unit of reference product, usually “crude steel”, can be derived. ISO TC 17/SC /WG 21 has proposed and issued a standard for the determination of CO_2 intensity derived from the method developed by worldsteel (the world steel association) as ISO 14404-1 and ISO 14404-2.

Although giving a valuable insight on CO_2 emission performance, the “CO_2 intensity” approach suggested by the ISO 14404 standards series has some limitations as it provides only one single CO_2 value for any specific facility, regardless of the complexity of its structure.

With a view to better evaluating the CO_2 performance of a facility along the steel value chain, the European Steel Industry has, since 2005, worked to set up CO_2 accounting rules aimed at carrying out the CO_2 emission performance assessment of steel production facilities while taking into account and properly addressing potential distortions due to differing facility structure. To this end, this standard goes beyond the mere “CO_2 intensity” approach to determine the performance of each process and unit that is part of the facility in order to identify the strengths and weaknesses in the value chain and, at a later stage, consolidate the performance at facility level.

As stressed in Part 1 of this standard series, this standard does not prejudice the content or application of any other standard or legal provision.

1 Scope

This European Standard provides a harmonized methodology for calculating GHG emissions and GHG performance in the steel industry.

This European Standard applies to facilities producing any of the multiple products of the steel value chain. It is supported by a set of worksheets [1].

This European Standard deals with the specific aspects for the determination of GHG emissions from steel production and the assessment of emission performance. This standard is to be used in conjunction with EN 19694-1, which contains overall requirements, definitions and rules applicable to the determination of GHG emissions for energy-intensive sectors, thereby providing a common methodological approach.

EN 19694-1 and EN 19694-2 provide a harmonized method for:

a) measuring, testing and quantifying methods for the determination of greenhouse gas (GHG) emissions;

b) assessing the level of GHG emissions performance of production processes over time, at production sites;

c) the establishment and provision of reliable and accurate information of proper quality for reporting and verification purposes.

In addition, this standard provides a stepwise approach for the determination of CO_2 emissions and the assessment of CO_2 performance of steel facilities, providing a set of methodologies allowing for a fair and reliable assessment of the CO_2 performance of each individual process along the steel production value chain.

It can be seen as a toolbox which enables the determination of CO_2 emissions and the assessment of CO_2 performance of steel production facilities at various levels of disaggregation, establishing a sound system for:

— the evaluation of the global CO_2 performance of a steel production facility taking its production structure into account;

— setting a reliable basis for evaluation of the CO_2 reduction potential in a facility and the contributing processes;

— setting a basis for accurate evaluation of new technologies.

Next to the determination of the direct and indirect CO_2 emissions of a steel facility, this standard has a strong focus on performance assessment which it strives to address through the following aspects:

— assessment of CO_2 impact, including process emissions: this methodology evaluates the total CO_2 emission of a steel facility, with the carbon content of the waste gases burdened as CO_2 to the processes giving rise to them;

— assessment of the actual CO_2 impact: this methodology evaluates the total CO_2 emissions released by a steel facility, but considers waste gases exported or used in a power plant as equal to natural gas in terms of CO_2 emissions;

— carbon input CO_2 performance at facility level: this methodology delivers an indicator comparing the facility performance with best practice, on the basis of the carbon input to the system;

- CO_2 performance assessment at process level: this methodology delivers a set of indicators comparing process performance with best practice at unit level. These indicators are then combined as a consolidated figure for the whole facility. This methodology also provides a theoretical assessment of the CO_2 saving potential up to best practice.

2 Normative references

The following documents, in whole or in part, are normatively referenced in this document and are indispensable for its application. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

EN 19694-1, *Stationary source emissions — Determination of greenhouse gas (GHG) emissions in energy intensive industries — Part 1: General aspects*

ISO/IEC Guide 98-3:2008, *Uncertainty of measurement — Part 3: Guide to the expression of uncertainty in measurement (GUM:1995)*

3 Terms and definitions

For the purposes of this document, the following terms and definitions apply.

3.1
boundaries
organizational or technical limits of a facility or plant

Note 1 to entry: The wording of “battery limits” can also be utilized.

3.2
Electric Arc Furnace facility
steel production facility based entirely or partially on the use of recycled scrap melted in an electric arc furnace

Note 1 to entry: By extension, this type of facility can incorporate a direct reduction production unit.

3.3
integrated facility
steel production facility based on use of virgin iron ores applying the blast furnace route

3.4
net use
net use of a source stream is the amount of fuel, material or energy which is used at the reporting boundaries during the reporting period.

Note 1 to entry: It can be calculated for the total facility from procurements, deliveries and stock variations or at process level from external use and net generation excluding internal recycling.

3.5
processing CO_2 emissions
CO_2 emissions related to the transformation of upstream to downstream products incorporating direct emissions and indirect emissions resulting from procurements

Note 1 to entry: The processing emissions do not include the indirect emissions of upstream products.

3.6

reference CO_2 saving potential

saving potential calculated by taking the difference between the emissions of a plant or facility and the emissions of the corresponding reference plant or facility

Note 1 to entry: This concept is a theoretical one and does not necessarily represent the actual CO_2 saving potential that is technically and economically achievable.

3.7

equipment or unit

technical unit for achieving a specific operation

3.8

total CO_2 emissions

sum of direct and indirect CO_2 emissions

3.9

upstream energy

energy used for the production of one unit of a source stream

4 Abbreviations

ARP	achievable reference performance
ASU	air separation unit
BF	blast furnace
BFG	blast furnace gas
BOF	basic oxygen furnace
BOFG	basic oxygen furnace gas
CDQ	coke dry quenching
COG	coke oven gas
DRI	direct reduced iron
EAF	electric arc furnace
EF	emission factor of a source stream
GHG	greenhouse gases
HBI	hot briquetted iron
HM	hot metal
HP	high pressure

IEeq	indirect emission equivalent factor of a source stream
IPCC	Intergovernmental Panel on Climate Change
LP	low pressure
LPG	liquefied petroleum gas
SRG	smelting reduction gas

5 Scope of reporting for the iron and steel industry

5.1 Plants, processes and boundaries

5.1.1 General

The steel production route involves a number of different processes, which can be operated on site or externalized. Also in each process, some operations can be externalized or may simply not exist so that particular care has to be taken when defining the system boundaries. A list of the processes that can take place in a steel production facility is given hereafter. Their technical boundaries (list of processes or units to be included in the reporting when existing) are given in Annex A.

5.1.2 Integrated steel making

The related plants and processes are:

a) coke plant – coke making;

b) sinter plant – sintering;

c) pellet plant – pelletization;

d) blast furnace plant – blast furnace iron making;

e) BOF plant – BOF steel making including BOF converter, secondary metallurgy and casting.

5.1.3 EAF steel making

EAF steel making is a short production route since in most case, it only implements an EAF plant including the electric arc furnace, secondary metallurgy and casting.

5.1.4 Other primary processes

Beside the blast furnace, some alternative processes have been developed to produce primary iron for use in steel making processes:

a) gas based direct reduction plant – DRI/HBI making;

b) coal based direct reduction plant – DRI/HBI making;

c) smelting reduction plant – iron making.

5.1.5 Rolling mills

A variety of rolling mills are used to transform crude steel into commercial products and the types of rolling mills considered in this standard are:

a) cogging mill for primary rolling of ingots;

b) billet mills;

c) hot strip mill and compact strip mills for production of flat steel;

d) plate mills;

e) bar and rod mills;

f) section mills for production of medium and heavy profiles;

g) wire rod mills;

h) seamless tube mills.

5.1.6 Downstream processes

Downstream treatments apply only to flat rolled products which are transformed into various final products by a succession of operations. Due to the large range of product quality that can be produced by these processes, the operation results vary widely between different sites and, therefore, these processes are excluded from the scope of process performance assessment. Should any operator want to enlarge the scope of assessment, the list of processes to include is given below:

a) pickling;

b) cold rolling;

c) annealing which can be batch or continuous;

d) hot dip metallization;

e) electrolytic metallization including electro-galvanizing, tin plating, tin free plating and other metal coating;

f) organic coating.

5.1.7 Other processes

Additional processes, which can be implemented in a steel production facility, are among others:

a) forging;

b) heat treatment (for plates, sections, tubes, forged pieces);

c) dust treatment;

d) lime production (calcining);

e) steam raising and power generation;

f) air separation;

g) flaring of excess gas;

h) other plants including facility offices, general maintenance shops, on-site transport, central water treatment and water networks.

5.2 Products and by-products

5.2.1 General

A product is the intended output of an activity; it can be a final product delivered to external customers or an input for a downstream plant or process. It is the reference output of a plant or process and can be accompanied by associated by-products or wastes. Only by-products having a noticeable impact on GHG emissions are considered in this standard. Products can be produced on site or procured from other operators. The full list of products and possible by-products is given in Annex B and the classification of products is indicated below.

5.2.2 Upstream products

Upstream products include all products starting from raw materials to hot rolled products which are the first level delivered to customers. They are:

a) coke;

b) sinter;

c) pellets;

d) direct reduced iron (DRI/HBI);

e) hot metal;

f) crude steel;

g) roughing mill semis;

h) hot rolled products.

5.2.3 Downstream products

Downstream products result from the primary transformation of hot rolled steel and are mainly concerning flat products. They are:

a) pickled coils;

b) cold rolled coils;

c) annealed coils;

d) hot dip galvanized coils;

e) electro-galvanized coils;

f) tin plated coils;

g) tin free coils;

h) other metal coated coils;

i) organic coated coils.

5.2.4 Other products

Other products are:

a) forged pieces;

b) heat treated products;

c) treated dust DRI/Pig iron.

5.3 Energy, utilities and other materials

The iron and steel industry uses a large number of energy sources, utilities and other material sources. A number of these streams may have an impact on GHG emissions due to their carbon content and/or the indirect emissions they involve. Based on experience of existing production sites, a list is given in Annex B according to the following classification:

a) solid and liquid fuels and reducing agents: coal, coke, anthracite, heavy oil, light oil, diesel oil, LPG, charcoal, used plastics and tires and others. Annex B gives a detailed list of solid and liquid fuels and reducing agents considered in this standard;

b) gaseous fuels: other than the four gases generated by the steel production processes (COG, BFG, SRG, BOFG) and listed as by-products of the corresponding processes, the steel industry uses natural gas mainly for combustion purpose but also as a reducing agent in direct reduction furnaces or blast furnaces. In specific locations, other gases can be used such as coal mine gas or tail gas from treatment of process gas;

c) utilities: electricity, heat and industrial gases;

d) miscellaneous materials including iron ores, scrap, fluxes, alloys and electrodes;

e) residues which can be by-products or wastes arising from the processes are considered only when they have an impact on GHG emissions.

5.4 Greenhouse gases in the steel industry

As demonstrated by the different field tests carried out to support this standard, CO_2 is the only relevant greenhouse gas in the steel industry.

5.5 Processes and reference products

The assessment of CO_2 emission performance of a process requires, as a first step, the determination of its CO_2 emission intensity (expressed as kg of equivalent CO_2 per tonne of reference product). The reference products of the processes included in the scope of performance analysis are given in Table 1.

Table 1 — Reference products of process

Process	Reference product
Coke making	Total dry wharf coke discharged from coke quenching excluding quenching breeze or CDQ dust
Sintering	Equivalent bell sinter calculated as merchant sinter production x screening ratio at blast furnace
Pelletizing	Equivalent bell pellets calculated as gross pellet production x screening ratio at blast furnace
Gas-based DRI	Total amount of DRI/HBI delivered by the process (including DRI screening fines)
Coal-based DRI	Total amount of DRI after separation of coal char and fluxes (including DRI fines)
Blast furnace iron making Smelting reduction iron making	Total amount of liquid hot metal at tap hole
BOF/EAF steel making & cogging mills[a]	Total amount of continuous casting semis for subsequent use+ amount of ingots not used in cogging mills + amount of cogging mill semis
Hot rolling mills	Total amount of hot rolled products for subsequent use
Other process	Total amount of product
Lime kilns	Total amount of lime + dolime produced

[a] In case of ingot casting, the crude steel product is not ready for hot rolling operation and a first step of rolling (cogging) is necessary to prepare a semi-product similar to crude steel from continuous casting. Including the cogging mill in the crude steel production step clearly highlights the interest of developing continuous casting for reduction of GHG emissions.

5.6 Units

The units used in this standard are as follows:

a) solid materials: metric tonne (t) of dry material;

b) liquid fuels: metric tonne (t) or cubic meter (m^3), depending on local practice;

c) gaseous fuels (or fuel gases): the flow of any gaseous fuel can be expressed either as thousand cubic meters at normal temperature and pressure (1013,25 hPa (1 atm), 273,15 K) on dry basis or as Gigajoule net calorific value (GJ ncv) with reference to H_2O as water vapour;

d) utilities and industrial gas: the units are Megawatt.hour (MWh) for electricity, metric tonne (t) for steam and hot water and thousand cubic meters at normal temperature and pressure (1 013,25 hPa (1 atm), 273,15 K) for industrial gas;

e) CO_2 emissions: metric tonne (t CO_2).

6 Basic principles of CO_2 emission determination

6.1 General

The determination of CO_2 emissions can be done either through calculation (carbon mass balance method) or through stack emission measurement. Given the relatively high number of stacks in a steel plant, the mass balance method is by far the most cost-efficient CO_2 emission determination method. This has been clearly demonstrated during the field tests carried out to support this standard.

It is also the most reliable method as the reconciliation of mass balance data along the value chain enables assessment of the quality of the CO_2 emission data (see Clause 10).

The basic principle of determination of CO_2 emission relies therefore on the application of a global carbon balance at facility or process level. This chapter gives the principle of the carbon balance and provides important information on the origin of data and the determination of emission factors.

6.2 Principle of the carbon mass balance

For any process, the determination of performance starts with the calculation of CO_2 emissions based on a balance of inputs and outputs of the process. Net flow of each source stream is reported and transformed into direct and indirect CO_2 using its direct emission factor and indirect emission equivalent factor. The total emissions of the process are calculated as follows:

Formula (1) – Basic formula for carbon mass balance calculation

$$E_{co_2} = \sum_{i=1}^{n} \left(NU_i \cdot \left(EF_i + IEeq_i \right) \right) \qquad (1)$$

where

i is the index for identification of source stream;

E_{CO2} is total CO_2 emission;

EF_i is the emission factor of source stream i;

$IEeq_i$ is the indirect emission equivalent factor of source stream i;

NU_i is the net use of source stream i (on dry basis, where relevant).

Net use is calculated at process or facility level from the difference between inputs and outputs. It is determined according to Formula (3) at facility level or Formula (17) at process level. Net use is derived from activity data.

Reporting period shall ideally be a calendar year.

6.3 Determination of activity data

Activity data shall come from official site data. The recommended source is the Controlling or Accounting department which uses this data for the monitoring of operating costs and keeps the records.

6.4 Determination of emission factors

6.4.1 General principles

The determination of the emission factors of materials and energy sources requires careful sampling, analysis and data handling to ensure the lowest possible uncertainty of the calculation results.

Emission factors are calculated from carbon analysis data using the following conversion formula:

Formula (2) – Formula for calculation of emission factors

$$EF_i = f \cdot Total\,C_i \tag{2}$$

where

EF_i is the direct emission factor of source stream i expressed as tonne of CO_2 per unit;

Total C_i is the total carbon content of source stream i expressed as tonnes of carbon per unit (on dry basis, where relevant);

f is the conversion factor of carbon content into respective CO_2 emissions i.e. 3,664 t CO_2/t C.

Where relevant, oxidation and conversion factors shall be used in accordance with EN 19694-1.

Indirect emission equivalent factors shall ideally be determined from actual operational data.

The use of actual results of analysis is strongly recommended for calculation of emission factors. This is especially important for coal and coke which are the major carbon sources for integrated steel making and which can show significant variations in carbon content.

A list of default emission factors is included in Annex C. The default values suggested in Annex C may differ from the ones proposed by the IPCC. They are based on European and global steel industry data and better reflect the characteristics and quality of the raw materials, fuels and gases used by the steel industry.

Alternatively, facility-specific emission factors may be used. They shall be based on analyses carried out in the past and be representative for future batches of the same material.

6.4.2 Sampling of source streams

6.4.2.1 Solid source streams

In an integrated steel making facility solid source streams (in particular coal and coke used either as a fuel or as a reducing agent) represent more than 90 % of the direct emission sources. Therefore particular care has to be taken when sampling these materials. Operators shall implement a comprehensive sampling procedure taking into account the large volumes of material. In many cases, coals are received by ocean carriers with a capacity of up to 150 000 t which can contain several coal qualities. For a medium scale 5 Mt per year facility, this represents an amount of 3,5 Mt of coals and coke or 25 vessels per year with 10 to 20 different origins.

Sampling shall be performed in accordance with the requirements of EN 19694-1.

6.4.2.2 Gaseous and liquid source streams

Liquid source streams (heavy oil, diesel oil, light oil and others) shall also be sampled and analysed in accordance with existing standards. For gaseous fuels (natural gas, by-product gases and others), analysis given by the supplier (external supplier or internal producing process) can be used.

6.4.3 Carbon analysis of materials

Carbon analysis of materials shall be performed in accordance with EN 19694-1. For coals and coke the preferred procedure is to measure in parallel the proximate analysis (fixed carbon, ash and volatile matter) and the net calorific value which can be used to ascertain the quality of data.

6.4.4 Determination of carbon contents for reporting

In most cases, for a given source stream a number of batches from each of several origins are used. As an example, coke making starts from a blend of coking coal made from 5 to10 different coals. All these coals are accumulated as “coking coal”.

Procured materials are generally deposited in primary stockyards from where they are reclaimed to prepare blends for use in the processes. For any generic material, the reported carbon content shall be a weighted average of the carbon contents of individual materials according to their mass flow.

7 Determination of CO_2 emissions at facility level

The straight application of the carbon balance at facility level will lead to the estimation of direct and indirect emissions linked to the activity. In this case, the principle given in Formula (1) is applied and net use is calculated by the formula given in Formula (3). Inventory changes are calculated with Formula (4) or Formula (5) which are equivalent and depend on the preferred data presentation.

Formula (3) – Calculation of net use (NU)

$$NU_i = External\,Purchase_i - External\,Delivery_i - Inventory\,Change_i \tag{3}$$

where

i	is the index of the considered source stream;
NU_i	is the net use of source stream i (on dry basis where relevant);
$External\ Purchase_i$	is the total amount of purchased source stream i (on dry basis where relevant);
$External\ Delivery_i$	is the total amount of sold source stream i (on dry basis where relevant);
$Inventory\ Change_i$	is the total variation of stock inventory (on dry basis). Inventory change is positive if stock increases and negative if stock decreases.

Inventory change can be calculated by one of the following formulae:

Formula 4 – Calculation of inventory change (Method 1)

$$Inventory\,Change_i = Storage_i - Stock\,Reclaimed_i \tag{4}$$

where

$Storage_i$	is the total amount of material sent to stocks for source stream i (on dry basis);
$Stock\ Reclaimed_i$	is the total amount of material reclaimed from stocks for source stream i (on dry basis).

Formula (5) – Calculation of inventory change (Method 2)

$$Inventory\,Change_i = Final\,Stock_i - Initial\,Stock_i \tag{5}$$

where

$Final\ Stock_i$ is the total stock inventory at end of reporting period for stream *i* (on dry basis);

$Initial\ Stock_i$ is the total stock inventory at beginning of reporting period for stream *i* (on dry basis).

For adequate treatment of exported flows of energy or material, deliveries to external power plants are separated from deliveries to other activities. Two subtotals are calculated as presented in the following formulae:

Formula (6)– Calculation of external delivery

$$\text{External Delivery}_{\text{i}} = \text{Delivery to power plant}_{\text{i}} + \text{Delivery to other activities}_{\text{i}} \tag{6}$$

Formula (7) – Determination of total procurement

$$\text{Total Procurement}_{\text{i}} = \text{External purchase}_{\text{i}} + \text{Stock Reclaimed}_{\text{i}} \tag{7}$$

Formula (8) – Determination of total deliveries

$$Total\ Delivery_i = External\ Delivery_i + Storage_i \tag{8}$$

Table 2 gives an example of calculation of net use of materials and energy for a steel production facility. In this example, the net use is calculated by applying the formula given in Formula (4). An example of this net use determination is given in Annex D.

Table 2 — Model for determination of Facility balance – Determination of net use

Source stream	**Procurements**			**Deliveries**				
	External purchase	Stock reclaimed	Total procurement	To power plants	To other activities	Storage	Total deliveries	Net use
Source $stream_1$	P_1	R_1	$Tin_1= P_1+R_1$	PP_1	O_1	S_1	$Tout_1= PP_1+O_1+S_1$	$NU_1= Tin_1-Tout_1$
Source $stream_2$	P_2	R_2	$Tin_2= P_2+R_2$	PP_2	O_2	S_2	$Tout_2= PP_2+O_2+S_2$	$NU_2= Tin_2-Tout_2$
Source $stream_3$	P_3	R_3	$Tin_3= P_3+R_3$	PP_3	O_3	S_3	$Tout_3= PP_3+O_3+S_3$	$NU_3= Tin_3-Tout_3$
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Source $stream_n$	P_n	R_n	$Tin_n= P_n+R_n$	PP_n	O_n	S_n	$Tout_n= PP_n+O_n+S_n$	$NU_n= Tin_n-Tout_n$

where

P_i is the amount of source stream i purchased during the reporting period;

R_i is the amount source stream i recovered from stocks during the reporting period;

Tin_i is the total available amount of source stream i during the reporting period;

PP_i is the amount of source stream i exported to external power plant during the reporting period;

Oi is the amount of source stream i delivered to external activities (customers) during the reporting period;

S_i is the amount of source stream i stored during the reporting period;

$Tout_i$ is the total amount of source stream i not used by processes in the facility during the reporting period;

NU_i is the net amount of source stream i used or delivered by the process during the reporting period.

The net use of each material is converted into direct and indirect CO_2 emissions, as shown in Table 3.

Table 3 — Model for determination of Facility balance – Determination of CO_2 emissions

	Net use	**CO_2 emissions (t)**		
Source stream		Direct	Indirect	Subtotal
Source stream_1	NU_1	$Dir_1=EF_1 \cdot NU_1$	$Ind_1= IEeq_1 \cdot NU_1$	Dir_1+Ind_1
Source stream_2	NU_2	$Dir_2=EF_2 \cdot NU_2$	$Ind_2= IEeq_2 \cdot NU_2$	Dir_2+Ind_2
Source stream_3	NU_3	$Dir_3=EF_3 \cdot NU_3$	$Ind_3= IEeq_3 \cdot NU_3$	Dir_3+Ind_3
Electricity	NU_{elec}		$Ind_{elec}= IEeq_{elec} \cdot NU_{elec}$	Ind_{elec}
Heat	NU_{Heati}		$Ind_{Heati}= IEeq_{Heati} \cdot NU_{Heati}$	Ind_{Heati}
Source stream_n	NU_n	$Dir_n=EF_n \cdot NU_n$	$Ind_n= IEeq_n \cdot NU_n$	Dir_n+Ind_n
Total		ΣDir_i	ΣInd_i	$\Sigma(Dir_i+Ind_i)$

where

Nu_i	is the net use of source stream i as per above;
EF_i	is the emission factor of source stream i;
Dir_i	is the direct CO_2 equivalent of source stream i during the reporting period;
$IEeqi$	is the indirect emission equivalent of source stream i;
$IEeq_{elec}$	is the indirect emission equivalent of electricity;
Eeq_{Heati}	is the indirect emission equivalent of heat i (HP steam, LP steam, Hot water);
Ind_i	is the total indirect CO_2 equivalent of stream i during the reporting period.

In this table, CO_2 emissions are calculated using the following formulae:

Formula (9) – Calculation of direct emissions

$$Direct\,CO_2 = \sum_{i=1}^{n} Dir_i = \sum_{i=1}^{n} \left(EF_i \cdot NU_i \right) \tag{9}$$

Formula (10) – Calculation of indirect emissions

$$Indirect\,CO_2 = \sum_{i=1}^{n} Ind_i = \sum_{i=1}^{n} (IEeq_i \cdot NU_i) \tag{10}$$

Formula (11) – Calculation of total emissions

$$Total\,CO_2 = Direct\,CO_2 + Indirect\,CO_2 \tag{11}$$

The equivalent emission factor for electricity is set at country level or at the level of the relevant regional electricity market (see EN 19694-1). The electricity emission factor retained has to be used to determine the equivalent emission factor of industrial gases (oxygen, nitrogen, argon and compressed air) based on standard equivalents, as given in Annex C.

8 Assessment of CO_2 emission performance

8.1 Assessment of CO_2 impact of a facility, including process emissions

By setting the net use of by-product gases as equal to zero, Formula (11) gives an estimate of the total equivalent CO_2 emissions due to the activity. By burdening CO_2 emissions to the processes giving rise to them, this methodology avoids distortions between on-site or outside use of these gases. An example of this calculation is given in Annex D.

8.2 Assessment of actual CO_2 impact of a facility

Where integrated facilities using the BF/BOF route export by-product gas to external power plants or other users, the straight application of the carbon mass balance methodology to a production facility does not clearly identify the actual impact of the activity on total CO_2 emissions.

As an example, exporting BF gas to a power plant consuming 9,8MJ/kWh (36,7 % efficiency, see Table C.2) results in electricity with an equivalent emission of ca 2,7 kg CO_2/kWh. This value has to be compared with electricity procurements usually showing a much lower national grid emission factor (0,06 to 1,00 kg CO_2/kWh).The methodology used to determine the emissions of the facility without subtracting the emission related to export gas solve this problem only partly since it introduces some double counting by including both the emissions related to power generation from the gas and the CO_2 equivalent of the corresponding electricity.

The same effect exists, at a lower magnitude, when excess gas is exported to other external activities where it replaces fossil fuels with lower emission factors.

The actual CO_2 impact of the facility is determined by taking into consideration these two effects and making the following corrections on indirect emissions:

— gas exports to external power plants are transformed into equivalent electricity on the basis of the reference energy equivalent given in Annex C and the corresponding electricity is subtracted from the facility procurements diminishing the indirect emissions;

— gas exports to other activities are accounted for at the level of natural gas (chosen as reference alternative fuel) and attributed to indirect emissions.

The details of this methodology, which charges the producer of by-product gas with the excess of CO_2 emission resulting from their low quality, rather than the user, are given in Table 4.

Table 4 — Model for assessment of GHG impact of an integrated facility

	Energy	**Equivalent Electricity**	**CO_2 emissions (t)**		
	GJ ncv	MWh	Direct	Indirect	Total
Straight balance			Dir_{CO2}	Ind_{CO2}	$Dir_{CO2}+Ind_{CO2}$
By-product gas exports to:	$PP_{Exp}+Oth_{Exp}$				
power plants	PP_{Exp}	$Eq_{Elec}=PP_{Exp}/9.8$		$-IEeq_{Elec}\cdot Eq_{Elec}$	$-IEeq_{Elec}\cdot Eq_{Elec}$
other activities	Oth_{Exp}			$-EF_{NG}\cdot Oth_{Exp}$	$-EF_{NG}\cdot Oth_{Exp}$
Global GHG impact			Dir_{CO2}	$Ind_{CO2}-IEeq_{Elec}\cdot Eq_{Elec}-EF_{NG}\cdot Oth_{Exp}$	$Dir_{CO2}+Ind_{CO2}-IEeq_{Elec}\cdot Eq_{Elec}-EF_{NG}\cdot Oth_{Exp}$

where

$DirCO_2$ is the total direct CO_2 as given by facility balance (see Formula (9));
$IndCO_2$ is the total indirect CO_2 as given by facility balance (see Formula (10));
PP_{Exp} is the export of by-product gas to power plants;
Eq_{Elec} is the equivalent electricity of gas exported to power plants;
Oth_{Exp} is the export of by-product gas to other activities;
EF_{NG} is the emission factor of natural gas.

An example of application of this impact assessment is given in Annex D. The correction of indirect emissions for gas exports gives a more realistic estimate of the global impact and comparable results for similar plants differing by the ownership of the power plant.

The cumulative value of CO_2 emissions at company or group level sums up the values of calculated net use, direct and indirect emissions for each reported stream for all consolidated facilities. This rule also applies to the determination of CO_2 impact after accounting for gas exports.

8.3 Indicator-based assessment of CO_2 emission performance

8.3.1 Basic principles of performance assessment

The performance assessment of CO_2 emissions goes beyond the determination of an emission inventory. An inventory gives a snapshot of the situation but, owing to the large influence of the production structure on the level of the emissions, falls short of providing reliable and fully comparable information in terms of CO_2 efficiency.

This section of the standard proposes specific methodologies for assessment of performance at process or facility level, ultimately leading to Key Performance Indicators (KPIs) which allow comparison of emission performance between operators and give an estimate of the potential for improvement. KPIs establish a fair comparison between different operators and give reliable information on the actual variation of performance.

8.3.2 Assessment of emission performance at facility level (carbon input performance)

8.3.2.1 General

This section of the standard proposes a methodology to assess the direct CO_2 performance of a facility by looking at the total carbon input to the facility. It enables the comparison between facilities with different production profiles with reference to a reference performance level (Likely CO_2 emissions).

8.3.2.2 Determination of reference emissions for the BF/BOF route

In integrated steel making three sources account for the large majority of the CO_2 emissions:

a) coke making via the final combustion of coke oven gas wherever it occurs and the partial combustion of coke during oven pushing and coke quenching;

b) burden preparation at the sinter plant via the combustion of solid fuels (coke and anthracite) and the decomposition of basic fluxes (limestone). In most cases, the ignition process uses coke oven gas already accounted for at coke plant and not charged to sinter making;

c) hot metal production at the blast furnace via the final combustion of blast furnace gas wherever it occurs, and the final combustion of the BOF gas (recovered or not) resulting from the refining of the carbon contained in the hot metal and the recycling of gas cleaning dust at the sinter plant.

An analysis of the energy balance of an integrated steel production facility shows that sufficient by-product gas is generated, of adequate quality, to secure the energy requirements of all production stages from coke making to hot rolling with significant excess to send to downstream activities or the power plant so that no other fuel is required over and above metallurgical coals (coking coal, anthracite for sintering and BF injection coal), purchased external coke and other blast furnace injections.

If there is no coke plant on site, there is not enough rich process gas for the operation and some external high quality fuel will be necessary for feeding processes such as the hot rolling mills with, as a consequence, an additional carbon input.

As a consequence, Likely CO_2 emissions shall be calculated with Formula (12) for facilities with a coke plant or Formula (13) for facilities without a coke plant.

Formula (12) – Calculation of reference emissions for an integrated facility with a coke plant

$$Likely\,CO_2\,emission = \alpha \bullet Coke + \beta \bullet Sinter + \gamma \bullet Hot\,metal \tag{12}$$

Formula (13) – Calculation of reference emissions for an integrated facility without coke plant

$$Likely\,CO_2\,emission = \beta \bullet Sinter + \gamma \bullet Hot\,metal + \delta \bullet Hot\,rolled \tag{13}$$

In these formulae, α, β, γ and δ represent the CO_2 emission intensity (kg/t product) of the considered processes and coke, sinter, hot metal and hot rolled are the production volumes of these processes. Values for the coefficients (α, β, γ, δ) are suggested in Annex E.

This assessment can be enlarged to include lime kilns.

8.3.2.3 Determination of reference emissions for the EAF route

Steel production sites based on the EAF route are much simpler, usually consisting only of an EAF steel shop and hot rolling mills. A number of facilities also include DRI production which almost exclusively uses natural gas as a CO_2 source. Likely direct emissions of an EAF based facility shall be calculated with Formula (14).

Formula (14) – Calculation of reference emissions for an EAF Facility

$$Likely\,CO_2\,emission = \alpha \cdot DRI + \beta \cdot Crude\,Steel + \gamma \cdot Hot\,rolled \tag{14}$$

In this formula, α, β and γ represent the CO_2 emission intensity (kg/t product) of the considered processes and DRI, Crude Steel and Hot rolled are the production volumes of these processes.

Determining the Likely CO_2 emissions of the EAF route is not as easy as for the integrated route owing to the possible energy switch between electricity and fossil fuels in the EAF. Values for the coefficients (α, β, γ) are suggested in Annex E.

8.3.2.4 Carbon input CO_2 performance indicator

For both categories of facilities, a facility CO_2 performance indicator (carbon input performance indicator) shall be calculated using Formula (15). It evaluates the gap between the operation of the facility and the reference.

Formula (15) – Determination of Facility CO_2 performance indicator

$$Facility\,performance\,indicator = \frac{Accounted\,equivalent\,direct\,CO_2\,input}{Likely\,CO_2\,emission} \qquad (15)$$

In this Formula, the accounted equivalent direct CO_2 input is derived from the sum of energy and materials used for the considered processes, excluding the external fuels used for boilers and power plants and for downstream operations (e.g. annealing furnaces) as calculated by Formula (16).

Formula (16) – Determination of Accounted equivalent direct CO2 input.

$$Accounted\,equivalent\,CO_2\,input = Total\,direct\ CO_2 - \sum_{1}^{n}\left(Excluded\,external\,stream_i \cdot EF_i\right) \qquad (16)$$

where

Total Direct CO_2	is the total emission of the facility as per Formula (11);
Excluded External $Stream_i$	is the amount of external source stream *i* (natural gas, oil, steam coal) going to excluded processes (lime kilns, power plants, downstream processes);
EF_i	is the emission factor for source stream *i*.

For average balance facilities using classical raw materials, this indicator gives a quick insight on important deviations from reference. Examples of application of this methodology are given in Annex E.

8.3.3 Assessment of emission performance at process level

8.3.3.1 Direct and indirect emissions at process level

At process level, the assessment of performance considers not only direct emissions but also indirect emissions which are relevant to get a realistic view of the efficiency of the operation.

In the performance assessment, the carbon contained in intermediate iron bearing materials are not be accounted as carbon output of the process. The corresponding amount is charged to the product in the calculated CO_2 intensity and thus transferred to user.

8.3.3.2 Choice of indirect emission equivalent factors

8.3.3.2.1 General rules

The straight estimation of performance cannot be limited to the calculation of the CO_2 intensity of a process (expressed as kg CO_2 per tonne of reference product), since such a figure does not carry any information about the efficiency of the process:

- it can be influenced by local conditions (e.g. the equivalent emission factor of electricity varies in a 1-20 range and can make any comparison of CO_2 intensity meaningless);
- in multiple process production systems such as steel production, CO_2 emissions of upstream products shall be incorporated in the calculation for a downstream product. In a straight

comparison, performance of upstream processes would impact the result for downstream process in a different way for each site;

— a CO_2 performance reference value has to be provided in order to derive information on the ranking of performance and potential savings.

The performance assessment should as far as possible be independent from local conditions and give a reliable result when applied to any facility worldwide. In order to neutralize the effect of conditions which are not under the control of the operator (e.g. electricity grid emission factor), the proposed methodology assumes that any input to a process will have a unique upstream emission factor:

a) natural raw materials and energy have no upstream value, thus eliminating the potential impact of different mining conditions or transport to user;

b) utilities have identical upstream values, thus eliminating the impact of different CO_2 grid intensity. Electricity is charged at average world level and industrial gases are charged on the basis of their electricity equivalents as indicated in Annex C;

c) external procurements of manufactured products are charged at a level of upstream emission representative of the producing sector;

d) in-house intermediate products used in downstream processes are charged at a reference upstream level in order not to impact the performance of an operator by the performance of the other operators in his Facility. The determination of this reference upstream value for facility products is presented in Clause 9. Owing to the difference between BOF and EAF steel in terms of carbon intensity, it is impossible to determine a single reference value for crude steel used in rolling mills. Hence, the reference value shall be calculated on the basis of the relative amounts of BOF and EAF steel used by each individual facility;

e) ordinary wastes used in the processes have no upstream emission value. They are just charged at the level of their actual carbon content;

f) by-products delivered by the processes carry a direct emission credit based on their actual carbon content. They do not carry indirect emission value in the assessment of the performance with a possible exception for some specific materials.

8.3.3.2.2 Choice of emission factors for steel plant by-product gas

Integrated steel production sites using the BF/BOF route generate large amounts of by-product gas which are used as energy carriers in the process or sent to power plants to generate heat (steam) and power.

Some processes can use a very versatile mix of gases. Notably in coke making the fuel for battery heating may range from 100 % coke oven gas to 100 % blast furnace gas, with similar energy consumptions. Owing to the differences in emission factor between these two gases, namely a factor 1 to 6, the use of BF gas will result in higher emissions and the CO_2 intensity of coke making will primarily measure the heating gas mix, so preventing any meaningful assessment of emission performance. Furthermore, using BF gas at the coke plant will just displace part of the emissions without changing anything at facility level.

To solve this problem, the proposed methodology includes specific ways for treatment of by-product gas ensuring fair assessment of CO_2 impact at facility or process level by considering a unique emission factor for all by-product gases which shall be charged for the user at the level of natural gas which is their most common substitute. The difference from the actual emission factor will remain a charge to the gas production process. Table 5 gives an estimate of the effect for the four by-product gases of the steel industry.

Table 5 — Accounting emission factors for by-product gases

Gas	**Actual emission factor (t/GJ)**	**Harmonized emission factor (t/GJ)**	**Charge to producer (t/GJ)**
Coke oven gas	0,045	0,056	-0,011
Blast furnace gas	0,270	0,056	0,214
Smelting reduction gas	0,195	0,056	0,139
BOF gas	0,180	0,056	0,124

The application of this option to coke oven gas gives a bonus for the coke making process which will offset some of the higher charge for users in all processes.

8.3.3.2.3 Special rules for specific materials

Some specific materials which do not carry upstream CO_2 emissions can play a significant role in terms of CO_2 performance, next to purely technical operating parameters, because they can displaced CO_2 upwards or downwards the value chain. If deemed relevant, provision shall be made to take this aspect into account in order to enable a meaningful assessment of process performance and avoid distortions arising from very specific conditions affecting such materials.

As the purpose of this standard is to assess CO_2 emissions and performance at process and facility level with a view to improving operations, the rules applying for assigning a CO_2 value to by-products or other streams in other standards, are not relevant to this standard.

The methodology chosen to explain their effect or bring the necessary adjustments to the indicators shall be justified, documented and ideally peer-reviewed.

a) Effect of magnetite ore

Three main qualities of iron ore are used by the iron and steel industry. Hematite ores (Fe_2O_3) are largely predominant followed by magnetite ores (Fe_3O_4) and siderite ores ($FeCO_3$).

Owing to oxidation of magnetite during the process of blast furnace burden preparation, the use of magnetite ores reduces the energy requirements and saves CO_2.

On the other hand, the use of siderite ores for burden preparation will decrease the energy consumption owing to oxidation of iron while increasing the CO_2 emissions owing to decomposition of carbonates.

Therefore, the use of magnetite or siderite cannot be chosen for defining reference operations. Such effects shall be taken into account when analysing performance. If data is available, appropriate corrections shall be brought to the performance indicators.

b) Adjustment for iron making slag

Slag generation affects the CO_2 intensity of the iron making process. As the volume of slag often depends on factors which are beyond the responsibility of the operator such as local conditions or company choices regarding raw material procurements, it may be deemed necessary to assign a CO_2 value to iron making that appropriately offsets the impact of slag so as to have a fairer assessment of the CO_2 performance.

Given the wide range of slag production volumes (with a 2012 EU average of 265 kg slag per tonne of hot metal and a standard deviation of 43 kg slag per tonne of hot metal), this aspect should be taken into consideration (EUROFER data, 2012).

c) Adjustment for scrap

Scrap is extensively used in all steel production routes. Because scrap feedstock avoids the high energy requirements of reduction of iron oxides, it significantly reduces the energy and CO_2 intensity of steel production. However, scrap is a limited resource and hot metal production is and will remain unavoidable to secure the steel market demand.

When comparing the performance of production units running at various rates of scrap intake (combined with hot metal and DRI in whichever production route), it may be deemed necessary to assign a CO_2 value to scrap that appropriately offsets its impact so as to have a fairer assessment of the CO_2 performance.

This aspect is irrelevant for EAF performance assessment, unless DRI, hot metal or pig iron are used as a substitute for scrap.

d) Adjustment for DRI, hot metal and pig iron at electric arc furnace

DRI may be used as a scrap substitute in an EAF or BOF for supplementing insufficient availability or quality of scrap. Since DRI contains residual iron oxide, its reduction in EAF or BOF may require extra energy and this effect shall be taken into account when analysing the performance results.

In some case, liquid hot metal can be charged to an EAF thereby substantially reducing the energy requirement. This effect shall also be taken into account in performance analysis.

8.3.3.3 Process performance assessment principle

The graph presented in Figure 1 explains how the reference CO_2 emissions of in-house products are used in the performance assessment:

a) a plant operating better than the reference receives a CO_2 bonus equal to the difference from the reference and its product enters the following steps at reference level;

b) a plant operating worse than the reference receives a CO_2 penalty and the product enters the following steps also at reference level;

c) bonuses and penalties are added up separately over the whole production route;

d) the net difference between total bonus and total penalty gives the offset to reference operation of the facility;

e) the total penalty gives the CO_2 savings potential of the facility from improving operations inferior to the reference (provided that the performance of those areas superior to the reference is maintained).

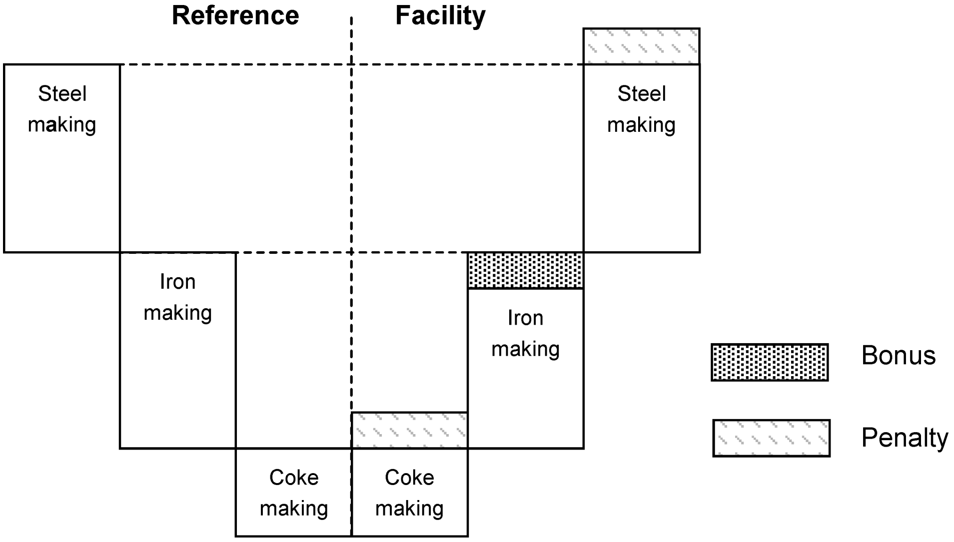


Figure 1 — Principle of performance assessment for multi-step production routes

8.3.3.4 Description of the performance assessment methodology for a process

8.3.3.4.1 Global C balance of the process

The performance assessment at process level applies the carbon balance methodology presented in 6.2 using for each stream the reference indirect emission factors as defined in 8.3.3.2. In this case, the net use of any process is determined according to Formula (17).

Formula (17) – Formula for calculation of net use at process level

$$NU_i = Use_i - Generation_i \tag{17}$$

where

NU_i	is the activity data for stream *i*;
Use_i	is the consumption of stream *i* in the process;
$Generation_i$	is the production of stream *i* by the process.

This results in an estimate of actual direct and indirect emissions of the process. Annex F gives an example for a coke plant.

Accounting of by-product gas

A second step in the assessment of performance is the calculation of the accounted direct emission for the use or generation of by-product gas. The method is shown in Table 6 and an example is given in Annex F.

Table 6 — Accounting of emissions for by-product gas

	Net Use (GJ)	**Actual CO_2 (t)**	**Accounted CO_2 (t)**
CO gas	NU_{COG}	$EF_{COG} \cdot NU_{COG}$	$EF_{NG} \cdot NU_{COG}$
BF gas	NU_{BFG}	$EF_{BFG} \cdot NU_{BFG}$	$EF_{NG} \cdot NU_{BFG}$
SR gas	NU_{SRG}	$EF_{SRG} \cdot NU_{SRG}$	$EF_{NG} \cdot NU_{SRG}$
BOF gas	NU_{BOFG}	$EF_{BOFG} \cdot NU_{BOFG}$	$EF_{NG} \cdot NU_{BOFG}$
Total	ΣNU_i	$\Sigma EF_i \cdot NU_i$	$\Sigma EF_{NG} \cdot NU_i$

8.3.3.4.2 Calculation of accounted emissions

The third step of the assessment methodology is the calculation of accounted emissions for the process using the following formula:

Formula (18) – Calculation of accounted direct emissions

$$Accounted\,direct\,CO_2 = Direct\,CO_2 - Gas\,actual\,CO_2 + Gas\,accounted\,CO_2 \tag{18}$$

where

Direct CO_2 is determined according to Formula (9);

$$Gas\,actual\,CO_2 = \sum_i \left(EF_i \cdot NU_i \right)$$

$$Gas\,accounted\,CO_2 = \sum_i \left(EF_{NG} \cdot NU_i \right)$$

and

I stands for COG, BFG, SRG and BOFG.

The indirect emissions are then incorporated to calculate the accounted total CO_2 using the following Formula:

Formula (19) – Calculation of accounted total emissions

$$Accounted\,total\,CO_2 = Accounted\,direct\,CO_2 + \sum_{i=1}^{n} \left(IEeq_i \cdot NU_i \right) \tag{19}$$

The accounted total CO_2 of a product includes the upstream emissions of the intermediate products (Equivalent CO_2 of upstream products) used by the process charged at the reference level giving an estimate of the CO_2 performance for the product. Excluding these upstream emissions will give an estimate of the accounted processing CO_2 which is another view on process efficiency. The processing CO_2 emission is calculated as follows:

Formula (20) – Calculation of processing CO_2 emissions

$$Accounted\,processing\,CO_2 = Accounted\,total\,CO_2 - Equivalent\,CO_2\,of\,upstream\,products \tag{20}$$

8.3.3.4.3 Calculation of CO_2 emission intensity

The next step is the calculation of CO_2 intensity for the product which is the ratio of accounted CO_2 emissions to reference production.

Formula (21) – Calculation of CO_2 intensity

$$CO_2\ intensity = \frac{Accounted\ total\ CO_2}{Reference\ production} \tag{21}$$

Formula (22) – Calculation of processing CO_2 intensity

$$Processing\ CO_2\ intensity = \frac{Accounted\ processing\ CO_2}{Reference\ production} \tag{22}$$

8.3.3.4.4 Calculation of performance indicators and reference saving potential

Finally, a performance indicator is calculated for each process, dividing its emission intensity by reference intensity values. Indicators higher than 100 % mean that the process emits more than the reference. The definition of reference performance is explained in Chapter 9.

Formula (23) – Definition of CO_2 performance indicator

$$\mathrm{CO_2\ performance\ indicator} = \frac{\mathrm{CO_2\ intensity}}{\mathrm{Reference\ CO_2\ intensity}} \tag{23}$$

Formula (24) – Definition of processing CO_2 performance indicator

$$\mathrm{Processing\ CO_2\ performance\ indicator} = \frac{\mathrm{Processing\ CO_2\ intensity}}{\mathrm{Reference\ CO_2\ intensity}} \tag{24}$$

When the CO_2 emission intensity is higher than the reference a saving potential is calculated by the following Formula:

Formula (25) – Estimation of the reference CO_2 saving potential

$$\mathrm{CO_2\ saving\ potential = Reference\ production * \left(CO_2\ intensity - Reference\ CO_2\ intensity\right)} \tag{25}$$

When the process is operated better than reference, the saving potential is set to zero so that a good process does not balance bad ones in terms of saving potential.

An example of this methodology for determination of emission performance is given in Annex F.

When included in the facility, lime kilns are treated in the same way as other processes but a special treatment is applied for power plants and air separation units.

Boilers and power generators are considered together as a multiple product plant delivering electricity, steam (high and low pressure) and hot water. In this case, the assessment considers the CO_2 emission resulting from fuel combustion and compares it to the likely requirements of net output accounted at their reference equivalent CO_2. The CO_2 performance indicator for boilers and power generation (B&PP) is calculated as follows:

Formula (26) – CO_2 performance indicator for power plants

$$CO_2\ performance\ indicator_{B\&PP} = \frac{\sum_i \left(EF_{fuel,i} \bullet input_{fuel,i}\right)}{\sum_i \left(IEeq_{utility,i} \bullet output_{utility,i}\right)} \tag{26}$$

where

$EF_{fuel,\ i}$ is the emission factor for fuel *i*;

$input_{fuel,\ i}$ is the input of fuel *i*;

$IEeq_{utility,\ i}$ is the indirect emission equivalent of utility *i* (power, steam, hot water – see Annex C);

$output_{utility,\ i}$ is the net delivery of utility *i*.

Air separation units are treated in a similar way since they are also multiple product processes delivering oxygen (high and low pressure), nitrogen and argon. The products are valued at their reference equivalent emission and these total likely requirements are compared with the actual equivalent CO₂ resulting from the consumption of electricity and/or steam. The CO₂ performance indicator for air separation units (ASU) is calculated as follows:

Formula (27) – CO_2 performance indicator for air separation units

$$CO_2\, performance\, indicator_{ASU} = \frac{\sum_i \left(IEeq_{utility,i} \bullet input_{utility,i} \right)}{\sum_i \left(IEeq_{gas,i} \bullet output_{gas,i} \right)} \tag{27}$$

where

$IEeq_{utility,\ i}$ is the indirect emission equivalent of utility *i* (power, steam, hot water – see Annex C);

$input_{fuel,\ i}$ is the input of utility *i*;

$Elec_{gas}$ is the electricity equivalent of gas *i* (O_2, N_2, Ar, compressed air – see Annex C);

$output_{utility,\ I}$ is the net delivery of utility *i*.

8.3.3.5 Combining process steps

The determination of the operating performance of a facility including process steps or of a group of processes requires the combining of the data for these processes.

1) Combining processing CO_2 emissions

Combining processing CO_2 emissions or savings potentials is performed by accumulating the values for the different processes, including the addition of values for any gas flares accounted at the reference emission factors. This additive procedure applies the formulas given in Formula (28).

Formula (28) – Combining processing emissions

$$\text{Cumulative}\, \mathit{accounted}\, \text{processing}\, \text{CO}_2 = \sum_{i=1}^{\text{m}} \left(\text{Processing}\, \text{CO}_{2,\text{j}} + \text{EF}_{\text{NG}} \cdot \text{Gas flare}_{\text{j}} \right) \tag{28}$$

where

j stands for the different processes included in the roll-up.

Formula (29) – Combining savings potentials

$$\mathit{Cumulative}\, \text{CO}_2 \mathit{saving\, potential} = \sum_{1}^{\text{m}} \left(\text{CO}_2\, \mathit{saving\, potential}_j + \text{EF}_{\text{NG}} \cdot \text{Gas flare}_{\text{j}} \right) \tag{29}$$

Partial combining can be performed at intermediate levels of the production route (primary metal, crude steel, hot rolled steel). In this case, the flares are not included in the total. The flares are included only at facility level.

A performance indicator for Processing CO_2 can be calculated by comparing the total combined Processing CO_2 emissions of the scope to the likely emissions calculated on the basis of plant production and reference value for processing emission as indicated in Formula (30).

Formula (30) – Definition of cumulative performance for processing CO_2

$$\text{Processing}\,\text{CO}_2\,\text{performance} = \frac{\text{Cumulative}\,\text{processing}\,CO_2}{\sum_{i=1}^{m}\left(\text{Production}_{\text{j}} \bullet \text{Reference}\,\text{processing}\,\text{CO}_{2,\text{j}}\right)} \tag{30}$$

2) Combining total CO_2 emissions

For total CO_2 emissions, another method of accumulation is required since the simple accumulation of individual process emissions leads to double counting of upstream emissions linked to the in-house use of intermediate products. This issue is solved by calculating the net use of every stream as stated in Formula (31).

Formula (31) – Calculation of net use for a group of processes

$$NU_i = \sum_{j=1}^{m}\left(Use_{i,j} - Generation_{i,j}\right) + Flare_i \tag{31}$$

where

i stands for the different streams;

j is for the processes included in the combination.

Flares are considered as a specific process and therefore added in the combination at facility level only.

The net use of a stream is transformed into CO_2 using its emission factor and reference indirect emission equivalent using the formula given in Formula (32) for every stream except the by-product gases which are charged at natural gas reference and the intermediate products which are treated in a special way.

Formula (32) – Calculation of accounted CO_2 in Facility combination

$$Accounted\,CO_{2,i} = \left(EF_i + IEeq_i\right) \bullet NU_i \tag{32}$$

In case of intermediate products, the formula of Formula (32) applies for positive values of net use. When an intermediate product is delivered over the boundary, it results in a CO_2 attribution based on its reference CO_2 intensity, as shown in Formula (33).

Formula (33) – Calculation of CO_2 attribution in Facility combination

$$\text{Attributed}\,\text{CO}_{2,\text{i}} = -\text{NU}_{\text{i}} \bullet \text{Reference}\,\text{CO}_2\,\text{intensity}_{\text{i}} \tag{33}$$

Hence, in the cumulative process, all the CO_2 equivalents are summed to determine an amount of accounted CO_2 except for net delivered products which have CO_2 attributions based on their reference CO_2 intensity.

Special treatment is prescribed for three specific materials:

a) in-house coke which is considered as accounted CO_2 for the part relating to its emission factor and attributed CO_2 for the part related to its production CO_2;

b) iron making slag which is considered as a product if a CO_2 value is given to it. In this case, it carries an attribution of CO_2 which is added to those of products. A possible option is to limit the attribution to granulated slag which has a real CO_2 saving potential when used as a clinker substitute; this option helps to promote an environmentally friendly operation;

c) scrap: when a value is given to scrap, this value is subtracted from the product attribution. Doing so, the accounted CO_2 is not impacted by scrap value and remains consistent with total facility emissions and the total attribution is also consistent with process requirements.

This is summarized in Table 7.

Table 7 — Cumulative procedure for CO_2 emissions

Stream	Net use	Accounted CO_2	Attributed CO_2
Home coke Coke breeze	$NU_{HC}>0$	$NU_{HC}\cdot(EF_{HC}+IEeq_{HC})$	0
	$NU_{HC}<0$	$NU_{HC}\cdot EF_{HC}$	$-NU_{HC}\cdot IEeq_{HC}$
Product i	$NU_{Pi}>0$	$NU_{PI}\cdot IEeq_{Pi}$	0
	$NU_{Pi}<0$	0	$-NU_{PI}\cdot IEeq_{PI}$
Scrap	NU_{scrap}	$NU_{scrap}\cdot EF_{scrap}$	$-NU_{scrap}\cdot IEeq_{scrap}$
Iron making slag	NU_{IMslag}	0	$-NU_{IMslag}\cdot IE_{eqslag}$
By-product gas	$NU_{gas,i}$	$NU_{gas,i}\cdot EF_{NG}$	
Other streams		$NU_i\cdot (EF_i+IEeq_i)$	0

The CO_2 emission performance of the selected scope can then be calculated as indicated in Formula (34).

Formula 34 – Determination of the total CO_2 performance for a group of processes

$$Cumulative\,CO_2\,performance\,indicator = \frac{\sum_{i=1}^{n} Accounted\,CO_{2,i}}{\sum_{i=1}^{n} Attributed\,CO_{2,i}} \qquad (34)$$

An example of a combination of processes for an integrated steel production facility is given in Annex F, Table F.4. The calculation of the performance indicators at facility level is presented in Annex F, Table F.5.

Combining is necessary for assessment of the global performance of the facility but it can also be performed at different levels of the structure such as primary metals (from coke making to hot metal and DRI production), steel making (primary metals + steel making processes) or hot rolling.

3) Combining at company or group level

At company or group level, the combining of processing and total GHG emissions operates in a similar way to the combining of facility emissions. For partial or total combination, it sums the calculated net uses, accounted and attributed emissions as presented in Table 7 with the specific accounting of products. Processing emissions and savings potentials are summed directly since there is no need for elimination with these parameters.

Performance indicators at group or company level are calculated in the same way as at facility level.

9 Determination of CO_2 reference values

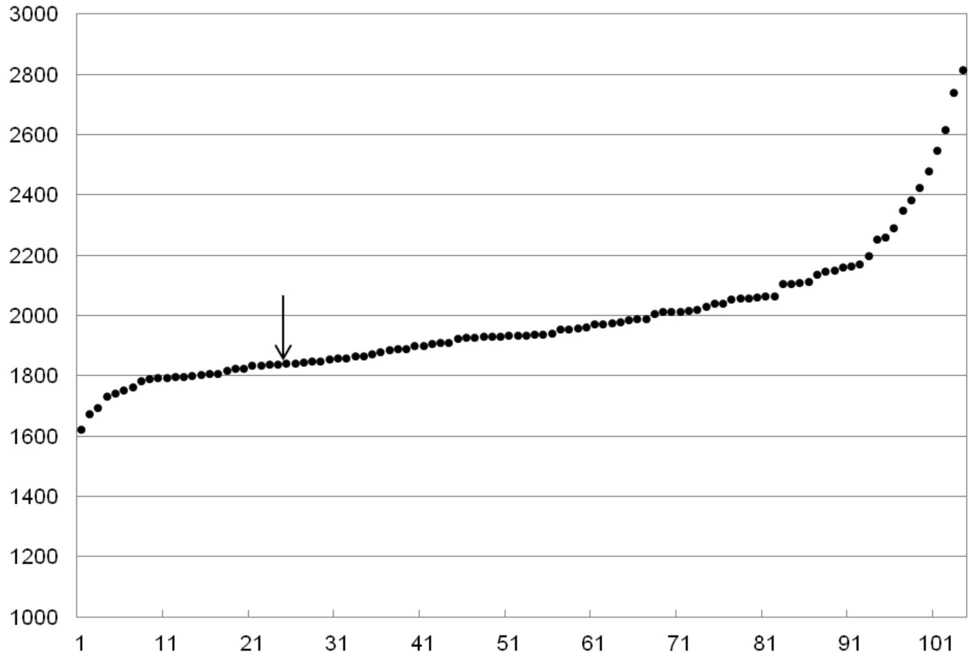
CO_2 reference values used for the assessment of CO_2 process performance shall be derived from the analysis of operating results of existing plants. On this basis, a CO_2 distribution curve (with increasing CO_2 intensities) for a given product can be established. This curve has usually an S shape as shown in Figure 2. Particularly good performance levels are often due to specific local conditions or special operating practices not accessible to everyone. This is the case, for example, for installations enjoying a privileged access to high quality raw materials in limited quantities or installations with a limited product range (one grade, one size).

Conventionally, the CO_2 reference value of a process is set at 25 % from the left of the curve since this level of performance should in principle be accessible to any operator working under normal conditions. This level of CO2 performance is named the “Achievable Reference Performance” or “ARP”.

Key Performance Indicators (KPI) are then constructed on the basis of ARP values so as to enable the comparison of facilities or monitoring of CO_2 performance progress or degradation over time. In the latter case, the exact value of the KPI is less important than its variation.

The ARP values shall ideally be fixed for a sufficient time to allow operators to assess the quality of their process control without influence of external conditions. After a certain period of time, if the analysis of operations shows improvement due to process control improvement or emergence of new technologies, the ARP values shall be reviewed.

Since ARP values of upstream products are necessary at every step of the processing route, the definition of ARP values is a step-wise process carried out along the steel production value chain.



Key

X axis	is number of plants included in analysis
Y axis	is CO_2 intensity of iron making (kg $CO_{2e/t}$ hot metal)
Arrow	is position of Achievable Reference Performance (ARP)

Figure 2 — Distribution curve for CO_2 intensity of iron making (kg CO_2 per tonne of product)

10 Assessment of data quality

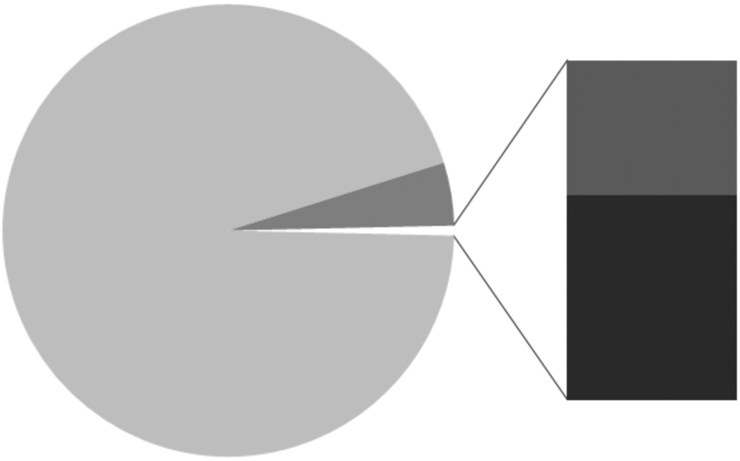
10.1 Preliminery checks to detect unrealistic data

10.1.1 General

Owing to the complexity of the steel production route the GHG performance assessment methodology relies on a large number of data, up to over 300 for the most complex facilities, and before any uncertainty assessment, it is important to implement some preliminary checks to detect unrealistic data.

10.1.2 Material characteristics

In integrated steel production facilities, solid fuels (coal and coke used as reducing agents), account for a predominant part of the direct emissions, followed by the slag forming elements. Figure 3 gives the typical sources of direct emissions for integrated steel production facilities. Solid fuels account for almost 95 % after subtracting the coke plant by-products (tar, benzole). The limestone used at the sinter plant represents almost 4,5 %. Natural gas is used in small amounts and all other sources have a minor impact.



░	▒	▓	█
Coke+Coals-tar	Limestone	Natural gas	Others
94,79 %	4,51 %	0,28 %	0,43 %

Figure 3 — Sources of direct emissions in a typical integrated steel production facility

At other production facilities, the proportion of emissions from natural gas or liquid fuels could be higher but the importance of solid fuels would remain, emphasising the importance of the quality of data relating to the characteristics of these materials.

For coal and coke, accurate reporting of carbon content is important. Cross checking of total carbon and proximate analysis may help to detect doubtful data. Two estimates may be used:

— An estimate of the total carbon content of coals can be made using Formula 35). Here, in terms of mass fraction, carbon is the total minus the non-carbon components, taken as ash and part of the volatile matter. The volatile matter is considered to have the same carbon content as coke oven gas (53 % by weight). For coke containing only small amounts of volatile matter, the formula can be simplified as shown in Formula (36). A difference of more than 1,5 % between the measured and estimated values shall lead to a further data check.

Formula 35 – Estimate of total carbon content for coals

$$Total\,C_{\mathrm{est}} = 1 - ash - 0.47 \cdot VM \qquad (35)$$

Formula 36 – Estimate of total carbon content for coke

$$Total\,C_{\mathrm{est}} = 0.9775 - ash \qquad (36)$$

- Calculating an emission factor expressed as t CO_2/GJ on the basis of total carbon and net calorific value using the formula given in Formula (37) should give values close to 0,095 for coals and 0,105 for cokes. In this case to a deviation of more than 0,005 shall lead to further checks.

Formula 37 – Calculation of emission factor based on energy

$$EF_{en} = f \cdot \frac{Total\,C}{ncv} \qquad (37)$$

where

f is the conversion factor of carbon content into respective CO_2 emissions, i.e. 3,664 t CO_2/t C

Where relevant, oxidation and conversion factors shall be used in accordance with EN 19694-1.

10.1.3 Consistency of mass-flows

10.1.3.1 Check of facility balance

The methodology requires mass-flows to be reported at various levels, typically Facility inputs and deliveries, plant use and generation. This enables a first check on consistency of the mass-flow data to be made by calculating a balance gap for any stream included in the reporting. Formula (38).

Formula 38 – Calculation of balance gap for a stream

$$\text{Balance Gap} = \left(\text{Procurement} + \text{Stock reclaimed} + \sum_{i=1}^{m}\text{Generation}_{\mathrm{j}}\right) - \left(\text{Delivery} + \text{Storage} + \sum_{i=1}^{m}\text{Use}_{\mathrm{j}}\right) \qquad (38)$$

where

j stands for the different processes.

Any significant balance gap observed requires verification of reported data and validation of the final figure which accounts for losses and inventory gaps. A residual balance gap can give an idea of the uncertainty on mass-flow data as it will be shown in Annex H.

10.1.3.2 Check of process data

The determination of process GHG performance is very sensitive to the quality of data as can be seen from the example of a coke plant given in Annex F, Table F.3. The CO_2 emission indicator is calculated at 270 kg/t coke when the carbon input as coking coal is equivalent to 3810 kg CO_2/t coke, meaning that a 1 % error on coking coal rate would result in a 14 % error on the indicator. Even if the coke plant represents only 3 % of the total accounted CO_2 at facility level, it is important to check some important parameters which have a strong influence on the result. These potential checks are shown in Annex G and they mainly look at some potential issues with mass or energy balances.

11 Uncertainty assessment

11.1 General

The operator shall identify sources of uncertainty and their associated levels of uncertainty in accordance with the ISO Guide to the Expression of Uncertainty in Measurement (ISO/IEC Guide 98-3:2008), or another equivalent internationally accepted standard. This requires making separate estimations for activity data and emission factors.

11.2 Uncertainty of activity data

The uncertainty of activity data is calculated by one of the following methods:

a) Repetitive measurement by a fixed measuring device (correlated uncertainties): the resulting uncertainty is calculated by the formula given in Formula (39) which evaluates the overall uncertainty by summation of the uncertainties due to operational drift and calibration. Formula (39) – Calculation of uncertainty on a correlated sum

$$u_{total} = \frac{\sqrt{\sum_{i=1}^{n} (u_i \times X_i)}}{\sum_{i=1}^{n} X_i} \tag{39}$$

where

u_{total} is relative uncertainty on the sum;

u_i is relative uncertainty on each measurement (uncertainty of the sensor);

X_i is value of individual measurements.

Measurements made by different sensors such as weighing hoppers working alternatively: the combined uncertainty is calculated by the formula given in Formula 40). In this case, if flows measured by the different sensors are similar, the relative uncertainty on the total amount is √n less than the sensor uncertainty.

Formula 40 – Calculation of uncertainty of an uncorrelated sum

$$u_{total} = \frac{\sqrt{\sum_{i=1}^{n} (u_i \cdot X_i)}}{\sum_{n=1}^{n} X_i} \tag{40}$$

11.3 Uncertainty of carbon content

The operator shall assess the level of uncertainty on the carbon content of materials.

NOTE The uncertainty depends on the number of analyses performed. The European Commission has published a tool to determine sampling frequency. Examples of the use of this tool are given in Annex H.

11.4 Determination of uncertainty of CO2 emissions for individual sources

In normal practice, sampling and weighing of materials are done in a natural (wet) state and the effective CO_2 calculation for one source is done according to the formula given in Formula 41).

Formula 41 – Calculation of emission associated with a source

$$CO_{2\,source} = f \cdot \left(1 - moisture_{source}\right) \cdot Total\,C_{source} \cdot Flow_{wet\,source} \tag{41}$$

where

$CO_{2\,source}$ is the emission resulting from the source;

$moisture_{source}$ is the moisture of the source on a wet basis;

Total C_{source} is total carbon content of the source on a dry basis;

$Flow_{wet\,source}$ is the yearly flow of the source on a wet basis;

f conversion factor of carbon content into respective CO_2 emissions, i.e. 3,664 t CO_2/t C.

In this case, the uncertainty of the conversion factor for moisture is calculated by the formula given in Formula (39) which transposes to the formula of Formula (42).

Formula 42 – Calculation of uncertainty linked to moisture

$$u_{dry} = \frac{u_{moisture} \cdot moisture}{1 - moisture} \tag{42}$$

where

u_{dry} is the relative uncertainty of the conversion factor;

$u_{moisture}$ is the relative uncertainty of moisture measurement;

.moisture is the measured moisture on a wet basis.

Thus a moisture of 10 % measured with an uncertainty of 10 % will result in an uncertainty of 1,11 % on the calculated dry amount.

Finally, the uncertainty of the total amount of CO_2 due to the source can be calculated from Formula (43).

Formula 43 – Calculation of uncertainty for a product

$$u_{CO2} = \sqrt{\left(u_{flow\,wet}^2 + u_{dry}^2 + u_{Total\,C}^2 + u_{sampling}^2\right)} \tag{43}$$

where

u_{CO2} is the relative uncertainty of the calculated CO_2 amount;

$u_{flow\,net}$ is the relative uncertainty of measured wet flow;

u_{dry} is the relative uncertainty of the dry conversion factor;

$u_{Total\ C}$ is the relative uncertainty on carbon content;

$u_{sampling}$ is the relative uncertainty due to sampling.

11.5 Uncertainty of total direct emissions for a facility

Estimation of the uncertainty of yearly flow data can be problematic for various reasons:

- the very large number of measurements: over 50 000 charges for 1,5 Mt per year coke plant and a similar number of burden lots for a 3,5 Mt per year blast furnace;
- the multiplicity of sensors used for these determinations involving both multiple measurements by single sensors (correlated measurements) and measurements by different weighing sensors (non-correlated measurements).

A reverse estimate of uncertainty can be performed by analyzing the global yearly data of different materials and looking at the global uncertainty, which could explain the balance gap defined in Formula (38). Assuming that all data (procurements, deliveries, generation, use and stock variations) are coming from different sources, they can be considered as not correlated and an estimate of the global uncertainty can be calculated by dividing the absolute balance gap by the quadratic average of reported flows as explained in Annex H.

The emissions of the various sources can be calculated as indicated in Formula (40) since the different sources are not correlated. An example of this calculation is given in Annex H.

Annex A
(informative)

Definition of the technical boundaries of processes

NOTE This list of processes is not exhaustive.

A.1 Integrated steel making

A.1.1 Coke plant – Coke making

The coke plant starts from the primary stock yard, ends at the coke wharf and incorporates the following processes and equipment:

- coal preparation: crushing, screening, and blending;
- coke oven batteries: charging, ovens, pushing, coke transfer, quenching system (wet or dry);
- gas treatment: tar, naphthalene, benzole and sulphur removal. Further treatment of tar is excluded;
- boilers: in-plant generation of steam for process requirements or for heat recovery;
- pollution abatement equipment: dust catching on conveyors, pushing of coke, desulphurization of ammonia mist;
- dedicated water treatment: settling, bio treatment, nitrification and de-nitrification;
- coke screening: separation of large size coke for blast furnace and coke for sinter plant.

A.1.2 Sinter plant – Sintering

The sinter plant starts from the primary stockyard, ends after gross sinter screening and requires the following:

- bedding: preparation of the sinter mix by blending and homogenization of a mixture of ores, fluxes and revert materials;
- sinter burden preparation: dosing of the constituents of the sinter burden (sinter mix, fluxes and solid fuels), mixing and micro-pelletizing;
- sinter baking: production of sinter by in-situ combustion of solid fuels on a travelling grate with downstream suction of air;
- sinter cooling: either on-strand or in external coolers;
- sinter preparation: crushing and screening to a desired mesh size;
- pollution abatement equipment: sinter strand flue gas treatment, dust catching on conveyors and in-building;
- merchant sinter production;

- heat recovery equipment: if existing.

A.1.3 Pellet plant – Pelletization

The pellet plant starts from the primary stock yard, ends after pellet screening and requires the following processes and equipment:

- grinding: preparation of pellet feed unless using already ground iron ore concentrate;
- balling: preparation of green balls;
- pellet baking: hardening of pellets by high temperature treatment on travelling grate, grate kiln or shaft furnace units including cooling;
- pellet preparation: screening (gross pellet production);
- pollution abatement equipment: dust catching on conveyors and at pellet discharge;
- heat recovery equipment: if existing.

A.1.4 Blast furnace plant – Blast furnace iron making

The blast furnace plant starts from reception of burden materials; it ends at filled hot metal ladle and slag delivery and includes:

- BF burden preparation: BF bunkers, dosing and screening;
- blast furnace;
- hot blast stoves: stove battery and heat recovery systems;
- blast blowers: electric, gas engine or steam turbine drive. When managed by the energy departments, the energy consumption of blowers (electricity, gas or steam) is allocated to the blast furnace;
- injection preparation: gas or oil handling and dosing, coal preparation and injection;
- boilers: for blast conditioning when dedicated;
- top gas recovery and cleaning: primary dust catching and filtering or scrubbing;
- slag handling system: slag pits for air cooling or slag granulation;
- energy recovery equipment: heat recovery and top gas recovery turbine (TRT);
- pollution abatement equipment: dust catching on conveyors, handling systems and cast house;
- dedicated water treatment: settling.

A.1.5 BOF plant – BOF steel making

The BOF plant starts from reception of liquid hot metal; it ends at delivery of crude steel and includes:

- hot metal pretreatment: desulfurization, desiliconization and dephosphorization;
- hot metal transfer: pouring to charging ladle and deslagging;

- cold iron casting;
- BOF converter: converter and gas recovery & cleaning;
- secondary metallurgy: all types of raw steel treatment, bubbling, vacuum, ladle furnace;
- ladle repair shop: masonry, preheating;
- casting shop: ingot casting and/or continuous casting;
- scrap yard: cutting and basket preparation;
- slag yard: treatment and evacuation;
- pollution abatement equipment: dust catching on conveyors, handling systems and building dedusting;
- dedicated water treatment: settling.

A.2 EAF steel making

The EAF plant starts with reception of raw materials; it ends at delivery of crude steel and includes:

- hot metal pretreatment: desulfurization, desiliconization and dephosphorization;
- hot metal transfer: pouring to charging ladle and deslagging;
- electric arc furnace: furnace, power supply and gas recovery and cleaning;
- secondary metallurgy: all types of raw steel treatment, bubbling, vacuum, ladle furnace;
- ladle repair shop: masonry, preheating;
- casting shop: ingot casting or continuous casting;
- scrap yard: cutting and basket preparation;
- slag yard: treatment and evacuation;
- pollution abatement equipment: dust catching on material lines, conveyors and building dedusting;
- cooling system;
- dedicated water treatment: settling.

A.3 Other primary processes

A.3.1 Gas based direct reduction

The direct reduction plant starts from raw material stock yard and includes:

- burden preparation: reclaiming from stocks, screening;
- reducing gas preparation: reformer or gas recycling and pre-heating;

- reduction furnace: shaft furnace or fluid bed reactors;
- top gas treatment: cooling, washing, compression and eventual CO_2 removal;
- product handling: DRI cooling or hot briquetting, screening and delivery;
- pollution abatement equipment: dust catching on conveyors and handling systems;
- dedicated water treatment: settling.

A.3.2 Coal based direct reduction

The direct reduction plant starts from raw material stock yard and includes:

- burden preparation: reclaiming from stocks, screening;
- reduction furnace: reduction kiln and cooler;
- energy recovery equipment: boilers and power generator if existing;
- product handling: screening and delivery;
- pollution abatement equipments: dust catching on conveyors and handling systems;
- dedicated water treatment: settling.

A.3.3 Smelting reduction plant – Iron making

The smelting reduction plant starts from reception of burden materials; it ends at filled hot metal ladle and slag delivery and includes:

- burden preparation: bunkers, dosing and screening;
- smelting reactor;
- coal preparation: drying, crushing and sizing;
- top gas recovery and cleaning: primary dust catching and filtering or scrubbing;
- slag handling system: slag pits for air cooling or slag granulation;
- energy recovery equipment: heat recovery and top gas recovery turbine (TRT);
- pollution abatement equipments: dust catching on conveyors, handling systems and cast house;
- dedicated water treatment: settling.

A.4 Rolling mills

A.4.1 Roughing mills

Primary rolling of ingots is performed by roughing mills, slabbing, blooming or billet mill which require the following:

- ingot stripping: including mold preparation;

- soaking pits;
- rolling stands;
- roll shop;
- dedicated water treatment;
- by-product handling.

A.4.2 Hot rolling mills

Hot rolling of different steel products requires similar equipment:

- preparation of semis: applying mainly to flat products, processes include scarfing and slitting;
- heating furnaces: including heat recovery system;
- rolling mill: including all auxiliary equipment and cooling system to delivery of reference product;
- roll shop;
- dedicated water treatment;
- by-product handling;
- for heavy plate and tube mills, heat treatment of product is excluded from the boundaries.

A.5 Downstream processes

A.5.1 Pickling plant

Pickling eliminates the layer of oxide created on the surface of hot rolled products. A pickling plant includes:

- pickling line: decoiler, welding machine, shot blasting and scale breakers, pickling and rinsing baths, coiler;
- boilers: for generation of steam or hot water used for bath heating;
- acid regeneration unit: incineration of waste acid bath delivering hydrochloric acid and iron oxides;
- dedicated water treatment.

A.5.2 Cold rolling mill

Cold rolling delivers thin steel sheet using reversing or continuous tandem mills. A cold rolling plant includes:

- rolling mill: decoiler, welding machine, rolling stands, coiler;
- roll shop;
- dedicated water treatment.

A.5.3 Annealing plants

Annealing modifies the structure of cold rolled steel sheet. Two technologies are possible, batch annealing in which a coil is placed in an oven which realizes all the cycle and continuous annealing which includes:

- annealing line: decoiler, welding machine, degreasing system, annealing furnace and coiler;
- dedicated water treatment.

A.5.4 Hot dip metallization plants

Hot dip metallization consists in covering the surface of steel sheet with a protective layer by passing it through a bath of molten metal (Al, Pb, Zn). A hot dip metallization plant includes:

- hot dip line: decoiler, welding machine, degreasing system, annealing furnace, metal bath, final surface treatment and coiler;
- dedicated water treatment.

A.5.5 Electrolytic metallization plants

Electrolytic metallization involves covering the surface of steel sheet with a protective layer by passing it through a bath of electrolyte containing the metal (Cu, Cr, Sn, Zn). An electrolytic metallization plant includes:

- metallization line: decoiler, welding machine, degreasing system, electrolytic bath, final surface treatment and coiler;
- waste bath treatment;
- dedicated water treatment.

A.5.6 Organic coating plants

Organic coating involves covering the surface of steel sheet with a protective layer by application of paint or varnish. An organic coating plant includes:

- painting line: decoiler, welding machine, degreasing system, painting, baking furnace and coiler;
- gaseous effluent incineration;
- dedicated water treatment.

A.6 Other processes

A.6.1 Forge plant

Processing of steel for production of forged pieces for various use in automotive industry, mechanical industry. Such plant incorporates:

- reheating furnace for steel input;
- forging press;
- pollution abatement equipment: dust catching on material lines, handling systems and cast house;

- dedicated water treatment.

A.6.2 Heat treatment plant

The final process for the production of specific products like heavy plates, sections, tubes or forging pieces usually involves a heat treatment furnace only.

A.6.3 Dust treatment

There are developed technologies for treatment of dust and sludge delivering a metalized iron or a pig iron. Such a plant incorporates:

- dust and sludge preparation: mixing, balling, coal or coke addition, flux addition;
- treatment reactor: including flue gas treatment;
- product handling: screening or casting;
- pollution abatement equipment: dust catching on conveyors, handling systems and cast house;
- dedicated water treatment.

A.6.4 Lime plant

Lime and dolime are produced by calcination of limestone or dolomite. The lime plant includes:

- raw material preparation: crushing and screening;
- calcination kiln: shaft furnace or rotary kiln;
- product handling: screening;
- pollution abatement equipment: dust catching on conveyors, handling systems and cast house.

A.6.5 Boilers and power plant

Waste gas boilers and power generation are differentiated in the analysis owing to the possibility of export of steam to processes or use of recovered steam.

A.6.6 Air separation units

Air separation units deliver the industrial gases, oxygen, nitrogen and argon used by the various steel making processes. These productions are often outsourced.

A.6.7 Flares

Flares are necessary to control the pressure in the gas network and release excess gas when storage is full or process plant is idled.

Annex B
(informative)

Products and by-products of the iron and steel Industry

B.1 Introduction

B.1.1 General

The iron and steel industry generates a large number of by-products but a limited number of them have noticeable effect on the GHG emissions. This annex gives a list of products and relevant by-products.

B.1.2 Upstream processes

Upstream products include all products starting from raw materials to hot rolled products which are the first level delivered to customers. The list of products that can be produced by iron and steel processes, and their related by-products is given below.

B.1.3 Coke

Coke is the result of carbonization of coking coal in airtight ovens. Coke is a mixture of carbon (80 % to 90 %), ash with minor amounts of sulphur and residual volatiles. The reference unit is the metric tonne of dry wharf coke i.e. total coke discharged from quenching system. Coke can be accompanied by the following by-products:

- coke oven gas: a mixture of H_2 (~60 %), CH_4 (~25 %), CO (~6 %) and minor amounts of other hydrocarbons, nitrogen and CO_2 resulting from release of volatile matter of coking coal;
- coke quenching breeze: fine coke recovered from the quenching system;
- tar: a mixture of hydrocarbons recovered from coke oven gas primary cleaning;
- benzole: a mixture of hydrocarbons, mainly benzene, recovered from eventual post-processing of coke oven gas;
- naphthalenic oil: light domestic oil charged with naphthalene as a result of cleaning coke oven gas.

B.1.4 Sinter

Sinter is the result of a pyro-metallurgical treatment of fine iron ores with addition of carbonated fluxes, solid fuels and revert materials. Starting from ores finer than 6 mm to 8 mm, the sintering process delivers lumpy agglomerates generally limited to 40 mm. The sinter plant does not deliver by-products but a distinction has to be made between:

- gross sinter: sometimes known as “merchant sinter” which is the product delivered by the sinter plant either to the using process or to stock.
- bell sinter: this is the sinter actually used for further processing after final screening before charging to the processing reactor. The screening fines (0 % to 20 %) are returned to the sinter plant.

B.1.5 Pellets

Pellets are the result of the conversion of high grade iron ore to spherical agglomerates 10 mm to 16 mm in diameter. Pelletization uses very fine size ores (- 100 µm) mixed with binders and fluxes before balling and baking.

B.1.6 Direct reduced iron (DRI)

DRI results from the treatment of iron ores or pellets by a reducing medium. The product keeps the shape of the raw materials unless hot briquetted and contains up to 88 % metallic iron, 5 % residual iron oxide, 0,2 % to 2,5 % carbon and the initial gangue of iron ore. Depending on the technology, a distinction is made between:

- gas-based direct reduction: reduction is performed in shaft furnaces or fluid bed reactors using a reducing gas sourced from reforming of natural gas, partial oxidation or recovery of by-product gas from other processes;
- coal-based direct reduction: reduction is performed by in situ gasification of coal in a rotary kiln with energy generated by combustion of the gas issuing from the solid charge in the freeboard.

In some plants, the direct reduced iron is discharged hot from the reduction furnace and briquetted to give a safer material for transportation. It is then called Hot Briquetted Iron (HBI).

B.1.7 Hot metal

Hot metal is a liquid alloy of iron, carbon, silicon, manganese and phosphorus as major components. Hot metal can be the product of either the blast furnace (BF) process which use prepared ores (sinter, pellets and lump ore), coke and injections (coal, oil, natural gas…) or a smelting reduction (SR) process aimed at maximal use of natural ores (fines or lumps) and coal. Hot metal is also called “Pig Iron” a name preferably used for solid iron cast into small ingots known as “pigs”. The important by-products of hot metal production are:

- top gas: gas recovered at exit from a BF or SR reactor. It contains significant amounts of CO and H_2 and can be used as a fuel in the different processes of the facility or for power generation;
- slag: formed from the gangue materials of the burden and the ash of coke and injections, the slag resulting from hot metal production can be used in cement as a substitute for clinker if it has been granulated when tapped;
- gas cleaning dust: a mixture of mineral burden materials and coke/coal fines recovered at primary dust catchers, gas cleaning dusts can be and usually are recycled to the sinter plant;
- gas cleaning sludge: composed of the fine fractions of dust carried out by the top gas, the sludge is recovered at secondary gas cleaning. Only a part of this sludge can be recycled to the sinter plant because the presence of some elements like zinc or alkalis is detrimental to operation.

B.1.8 Crude steel

Product of the steel making process, crude steel is defined as first cast product suitable for sale or further processing. It can be in the form of ingots or continuously cast products (slabs, thin slabs, blooms and billets). Crude steel represents the reference product of a steel plant contrary to its intermediate products which are:

- primary liquid steel: product of the refining or melting process resp. BOF liquid steel and EAF liquid steel;

- refined liquid steel: product of the secondary metallurgy process (vacuum treatment, alloying and temperature tuning) and delivered to the casting shop.

The by-products of steel plants having an impact on greenhouse gas emissions are:

- BOF gas;
- scrap either produced or consumed in the process;
- Melting slag of electric arc furnaces.

B.1.9 Roughing mill semis

The roughing mill semis are produced by primary rolling of ingots and further processed by hot rolling mills. They can be slabs, blooms or billets.

B.1.10 Hot rolled products

A large variety of hot rolled products are delivered by dedicated rolling mills. The products considered are:

- hot rolled coils: flat product delivered by hot strip mill or compact strip mill;
- heavy plates: thick flat product delivered by plate mill starting from slabs or ingots. The reference unit is the metric tonne of saleable plate after cutting to customer size requirements;
- bars and rods: long products issuing from billet rolling with different shaped bars, rebar, light profiles (L, U, I, T);
- sections: medium or heavy beams resulting from bloom or billet rolling;
- wire rod: long product with diameter less than 6 mm delivered as coils and resulting from billet rolling;
- seamless tubes: tubular products issuing from piercing and rolling of round billets or blooms.

B.2 Downstream processes

Downstream products are the result of post-processing of hot rolled products. In this standard, only the products issuing from certain metallurgical operations are considered. They are:

- pickled coils: output of surface oxide elimination treatment in a hot acid bath;
- cold rolled coils: thin sheet coils resulting from rolling of pickled coil on reversing or tandem mills;
- annealed coils: heat treated cold rolled coils issuing from a batch or continuous process;
- hot dip galvanized coils: Zinc covered coils resulting from passage through a hot bath of liquid zinc;
- electro-galvanized coils: Zinc covered coils resulting from electro deposition from an electrolyte bath of zinc;
- tin plated coils: packaging steel resulting from electro deposition from an electrolyte bath of tin;
- tin free coils: packaging steel resulting from electro deposition from an electrolyte bath of chromium;

- other metal coated coils: coils coated with other metals like Al or Cu for specific uses;
- organic coated coils: painted or varnished coils.

B.3 Other products

Other products include:

- forged pieces;
- heat treated products;
- lime and dolime;
- DRI or hot metal from dust treatment.

B.4 Energy, utilities and other materials

B.4.1 Introduction

The iron and steel industry uses a large number of energy, utilities and other material sources. A number of these streams may have an impact on GHG emissions owing to their carbon content or/and the indirect emissions they represent. Based on experience of existing production sites, the following list is proposed.

B.4.2 Solid and liquid fuels and reducing agents

Solid and liquid fuels and reducing agents mainly comprise the following items:

- purchased coke: coke purchased from external coke plants for use as a complement to in-house coke. This coke has a similar size to in-house coke and will be screened on site for use in various processes;
- purchased nut coke: small size coke (-30 mm) for use in blast furnace;
- coking coal: used in coke making, this quality of coal has generally a low ash content and volatile matters in the range 21 % to 30 %;
- anthracite: low volatile coal mainly used at sinter plants. Some amount can be used in BOF and EAF plants;
- DRI coal: coal used in direct reduction processes such as rotary kilns or rotary hearth furnaces. Low volatile contents are usually preferred;
- BF injection coal: coal used as alternative reduction agent in blast furnaces also known as PCI (Pulverized coal injection). Low ash contents are preferred but the range of volatile content is large (10 % to 40 %);
- smelting reduction coal: coal used as the main energy source in smelting reduction processes. This brand of coal is quite similar to BF injection coal;
- EAF coal: carbonized coal used as an energy vector or slag foaming agent in the electric arc furnace;
- steam coal: coal with high ash content for use in boilers and power plants;

- petroleum coke: also named pet coke, residue of the oil industry that can be used for sintering or in EAF;
- heavy oil: low sulphur heavy oil for injection to blast furnaces or combustion in reheating furnaces and boilers;
- light domestic oil: mainly used for preparation of the coal blend and naphthalene removal at coke plants and in boilers for building heating;
- Diesel oil: used for handling equipment;
- LPG: liquefied petroleum gas, used as an alternative to light oil;
- charcoal: charcoal is mainly used for iron making in small size blast furnaces. It can also be used as a solid fuel for sintering. Made from biomass, charcoal requires specific accounting rules;
- used plastics: used plastics are used in some coke plants and blast furnaces;
- used tires: used tires are used in some electric arc furnaces where they can replace other carbonaceous fuels like anthracite or EAF coal.

Some other fuels can be used in specific locations which are not listed here.

B.4.3 Gaseous fuels and gaseous reducing agents

Apart from the four gases generated by steel production processes and listed as by-products of the corresponding processes, the iron and steel industry uses natural gas mainly for combustion purpose but also as a reducing agent in direct reduction furnaces or for injection into blast furnaces. In specific locations, other gases can be used such as coal mine gas or tail gas from treatment of process gas.

B.4.4 Utilities

The utilities used in steel production sites are listed and presented below:

- electricity: electricity can be produced on site by a power plant or by energy recovery equipment such as the top gas recovery turbines of blast furnaces or turbo-generators fed by the steam of a coke dry quenching system;
- heat: includes:
  - high pressure steam: high pressure steam produced by boilers or energy recovery system in used in steam turbines acting as generators or blast furnace boilers;
  - low pressure steam: low pressure steam is used for process purposes and can be produced by dedicated boilers or a facility network;
  - hot water: hot water is mainly used in downstream processes for heating or pickling and degreasing baths.
- high pressure/purity oxygen: high pressure/purity oxygen is mainly used for refining in basic oxygen furnaces (BOF) which requires high pressure to generate a high momentum oxygen jet at the lance and high oxygen content (+99,9 %). This is also true of decarburisation lances and oxy-fuel burners used on EAFs. High purity oxygen can also be used for blast enrichment at blast furnace but pressure is lower in this case;

- low pressure/purity oxygen: low pressure/purity oxygen has a developing use for blast enrichment at blast furnace or blowing of smelting reduction furnaces;
- nitrogen: nitrogen can be used to generate neutral atmosphere in several processes like pulverized coal transportation;
- argon: argon is principally used in steel making shops for stirring during the refining of steel and for shrouding liquid steel streams during continuous casting;
- compressed air: compressed air can be generated at the boundaries of a process or by a central compressing plant feeding a network;
- hydrogen: hydrogen is used for creating controlled atmosphere in annealing furnaces.

B.4.5 Other materials

The main other materials used by the iron and steel industry are as follows:

- EAF electrodes: produced from almost pure carbon, the electrodes are used in electric arc furnaces, ladle furnaces (baked electrodes) and some special smelting furnaces (self-baking electrodes);
- ferro-alloys: ferro-alloys are used in very small quantities in the production of most carbon steel and the most important in terms of carbon content are ferro-chromium and ferro-manganese. They are used in larger amounts for production of specialty and stainless steel;
- scrap: scrap is the major component of the EAF burden. Although the classification of scrap includes a large number of categories, it is interesting to separate four main categories;
    - Own-arising scrap produced on site by the various steel production and processing levels. They include the so-called internal scraps produced in the steel shop itself;
    - Pre-consumer scrap resulting from losses during manufacturing of consumer goods. They are high quality scrap equivalent to own-arising scrap;
    - Post-consumer scrap coming from recycling of end of life goods. They are usually of variable quality and can be polluted by tramp elements and inert materials;
    - Iron scrap containing residues of pig iron rather than steel.
- slag forming materials: these materials have a significant impact on GHG emissions owing to their CO_2 content or the indirect emissions linked to their production. They are used to adjust the basicity of process slag and include:
    - limestone: this calcium carbonate is mainly used in iron making charged either in sinter plants or at blast furnaces. Minor amounts can be used in steel shops. The other major use is for lime production in sites equipped with lime kilns;
    - burnt lime (often referred to simply as lime): the result of the calcination of limestone, the burnt lime is mainly use in steel making furnaces (BOF and EAF), but sometimes forms part of the charge in sintering;
    - dolomite: double carbonate of calcium and magnesium, dolomite is used in steel making processes and lime kilns;
    - burnt dolomite: also called dolime, it is principally used in steel making processes.

- refractories.
- iron ores: some iron ores contain noticeable amounts of carbonates. Three categories can be used:
  - iron ore fines: natural ore with mesh size below 6 mm to 8 mm. This ore is often known as sinter feed but can also be used for pelletizing (after grinding) or fluid bed reduction;
  - pellet feed: this ore usually results from beneficiation of raw iron ore and is already ground to below 100 µm, ready for pelletizing.
  - lump ore: usually crushed to 35/40 mm and screened to separate fines, this ore can be used in primary metal production processes but also as a coolant in BOF converters.

For iron ore, a distinction can be made between hematite and magnetite ores owing to their energy impact in burden preparation processes.

Annex C
(informative)

Default values for emission factors and upstream data

The default values suggested in this annex may differ from the ones proposed by the IPCC. They are based on European and global steel industry data and better reflect the characteristics and quality of the raw materials, fuels and gases used by the industry. Emission factors are derived from carbon content analysis.

Table C.1 — Default values proposed for characteristics of materials and energy

Source stream	**Unit**	**EF (tCO_2/unit)**	**Net calorific value (GJ/unit)**	**IEeq CO_2 (tCO_2/unit)**	**Upstream energy (GJ/unit)**	**Reference**
Products						
Gas based DRI	t	0,0733				IPCC[a]
Coal based DRI	t	0,0733				IPCC[a]
Blast furnace hot metal	t	0,1722				Expert knowledge[b]
Smelting reduction hot metal	t	0,1722				Expert knowledge[b]
Condensed Fuels and Reducing Agents						
Coke	t	3,257	30,100	0,224	4,000	worldsteel[c]
Coke breeze	t	3,115	29,925	0,270	5,719	Expert knowledge[b]
Coking coal	t	3,059	32,200			worldsteel[c]
Anthracite	t	2,8947	29,300			Expert knowledge[b]
DRI coal	t	2,955	31,100			worldsteel[c]
BF injection coal	t	2,955	31,100			worldsteel[c]
Smelting reduction coal	t	2,955	31,100			worldsteel[c]
EAF coal	t	3,257	30,100	0,270	5,719	worldsteel[c]
Steam coal	t	2,461	25,900			worldsteel[c]
Petroleum coke	t	3,1145	31,935			Expert knowledge[b]
Heavy oil	m^3	2,907	37,000			worldsteel[c]
Light domestic oil/Diesel oil	m^3	2,601	35,100			worldsteel[c]
Propane	t	2,9941	46,350			Expert knowledge[b]
Butane	t	3,0288	45,750			Expert knowledge[b]
Charcoal	t	2,6382	18,800			Expert

Source stream	Unit	EF (tCO_2/unit)	Net calorific value (GJ/unit)	IEeq CO_2 (tCO_2/unit)	Upstream energy (GJ/unit)	Reference
						knowledge[b]
Used plastics	t	2,4158	46,000			voestalpine data
Used tires	t	2,1985	35,000			Expert knowledge[b]
Gaseous Fuels						
Coke oven gas	k. m^3N	0,836	19,000	0.044		worldsteel[c]
Blast furnace gas	k. m^3N	0,891	3,300	0.275		worldsteel[c]
Smelting reduction gas	k. m^3N	1,571	7,660	0.205		Expert knowledge[b]
BOF gas	k. m^3N	1,512	8,400	0.186		worldsteel[c]
Natural gas	k. m^3N	2,014	35,900	0.056		worldsteel[c]
Materials						
EAF/BOF electrodes	t	3,663				worldsteel[c]
Ferro chromium	t	0,275				worldsteel[c]
Ferro manganese	t	0,2748				Expert knowledge[b]
Post consumer scrap	t	0,0066				EUROFER[d]
Limestone	t	0,440				IPCC[a]
Burnt lime	t	0,0238		0,950	4,500	worldsteel[c]
Crude dolomite	t	0,471				worldsteel[c]
Dolime	t	0,0238		1,100	4,500	Expert knowledge[b]
Fine iron ore	t	0,0018				Expert knowledge[b]
Ground pellet feed	t	0,0018		0,023	0,392	Expert knowledge[b]
Lump ore	t	0,0055				Expert knowledge[b]
Residues						
Tar	t	3,389	37,000			worldsteel[c]
Benzole	t	3,382	40,570			worldsteel[c]
Naphtalenic oil	t	3,0962	42,000			Expert knowledge[b]
CDQ Dust	t	3,2244	30,135			Expert knowledge[b]

Source stream	Unit	EF (tCO_2/unit)	Net calorific value (GJ/unit)	IEeq CO_2 (tCO_2/unit)	Upstream energy (GJ/unit)	Reference
DRI screening fines	t	0,0733				Expert knowledge[b]
BF gas dust	t	1,4657	13,700			Expert knowledge[b]
BF gas sludge	t	1,4657	13,700			Expert knowledge[b]
SR gas dust	t	1,4657	13,700			Expert knowledge[b]
SR gas sludge	t	1,4657	13,700			Expert knowledge[b]
Pig iron scrap	t	0,172				worldsteel[c]

[a] 2006 IPCC Guidelines for National Greenhouse Gas Inventories, Chapter 4 'Metal Industry Emissions', Table 4.3.

[b] Expert knowledge: emission factors based on EU industry data and accepted as representative by CEN/TC 264/WG 33/SG 2 during the development of the standard.

[c] World Steel Association, CO_2 Emissions Data Collection, User Guide, version 6, Appendix 4.

[d] CO_2 emission factor for scrap derived from a carbon content in carbon steel scrap of 0,18% (EUROFER, Rule book for the data collection and CO_2 benchmarks construction for the European Iron and Steel Industry, July 2012). Given the high heterogeneity of steel scrap and the absence of reliable official statistics for carbon content in steel scrap, this methodology sets the carbon content of steel scrap as equal to the carbon content of carbon steel put on the market. The emissions factor derived therefrom (0,0066 $tonne_{CO2}/tonne_{scrap}$) can be used, unless a better proxy is available.

Table C.2 — Reference values for indirect equivalent CO_2 and equivalent energy of utilities

Utilities	Unit	kWh/m^{3}N	IEeq CO_2 t/unit	Upstream energy[c] GJ/unit
Electricity	MWh		[a]	9,800
High pressure steam	t		0,213[b]	3,800[b]
Low pressure steam	t		0,194[b]	3,460[b]
Hot water	t		0,048[b]	0,850[b]
High pressure oxygen	10^3.m^{3}N	0,710	[c]	6,958
Low pressure oxygen	10^3.m^{3}N	0,500	[c]	4,900
Nitrogen	10^3.m^{3}N	0,200	[c]	1,960
Argon	10^3.m^{3}N	0,200	[c]	1,960
Compressed air	10^3.m^{3}N	0,110	[c]	1,078

[a] These values shall be calculated on the basis of the relevant emission factor for electricity.

[b] The reference values for steam and hot water have been calculated on the basis of boilers using natural gas with 85 % efficiency and producing steam at 500 °C for high pressure steam, 300 °C for low pressure steam and 80 °C for hot water.

[c] Upstream CO_2 values for industrial gas are not reported since they are calculated on the basis of electricity equivalent and upstream CO_2 factor of electricity.

Annex D
(informative)

Examples of application of carbon mass balance methodology

The application of carbon mass balance methodology at facility level considers only the inputs and outputs of the process route. This means that internal exchanges between processes are eliminated and production levels are not being considered, just looking at the net use of the facility. In the following example, if the facility actually produces some 6,3 Mt crude steel, a part is rolled and the steel output is a mix of slabs and hot rolled coils. The total iron input to the processing route comes from iron ores, pellets and purchased scrap with a minor part of sinter recovered from stocks. This input covers the iron contained in delivered slabs and coils and stored pig iron.

The following tables give an example of calculation of CO_2 emissions for a large integrated steel facility.

Table D.1 — Example of facility balance – Determination of net use as per Table 2

	Unit	External Purchase	Stock reclaimed	Total procurement	External power plant	Other delivery	Storage	Total delivery	Net use
Products									
Merchant sinter	t		243 667	243 667					243 667
Pellets	t dry	1 043 458	92 287	1 135 745					1 135 745
Blast furnace hot metal	t						103 671	103 671	-103 671
Continuous casting BOF steel	t					1 891 039		1 891 039	-1 891 039
Hot rolled coils	t					4 307 878		4 307 878	-4 307 878
Condensed fuels									
Home coke	t dry		38 400	38 400					38 400
Purchased coke	t dry	551 081	33 974	585 054					585 054

	Unit	External Purchase	Stock reclaimed	Total procurement	External power plant	Other delivery	Storage	Total delivery	Net use
Coking coal	t dry	1 674 594	70 851	1 745 445					1 745 445
Anthracite	t dry	397 903		397 903			83 138	83 138	314 765
BF injection coal	t dry	1 180 617		1 180 617			9 504	9 504	1 171 113
Light domestic oil	m^3	6 109		6 109					6 109
Gazeous fuels									
Coke oven gas	GJ ncv				1 413 510	1 124 730		2 538 240	-2 538 240
Blast furnace gas	GJ ncv				12 344 934	1 985 748		14 330 682	-14 330 682
BOF gas	GJ ncv				1 679 930	330 549		2 010 479	-2 010 479
Natural gas	GJ ncv	821 061		821 061		193 817		193 817	627 244
Utilities									
Electricity	MWh	1 629 079		1 629 079		106 863		106 863	1 522 216
High pressure steam	t	13 752		13 752					13 752
High pressure oxygen	10^3.m^{3}N	348 372		348 372		2 200		2 200	346 172
Low pressure oxygen	10^3.m^{3}N	260 130		260 130					260 130
Nitrogen	10^3.m^{3}N	203 017		203 017	53	236		289	202 728
Argon	10^3.m^{3}N	2 039		2 039					2 039
Compressed air	10^3.m^{3}N	348 799		348 799					348 799
Miscellaneous materials									
Pre-consumer scrap	t	399 379		399 379					399 379
Post-consumer scrap	t	170 941		170 941					170 941

	Unit	External Purchase	Stock reclaimed	Total procurement	External power plant	Other delivery	Storage	Total delivery	Net use
Limestone	t dry	1 257 819	4 513	1 262 332					1 262 332
Burnt lime	t	303 612	153	303 766		2 682		2 682	301 084
Dolomite	t dry	80 730		80 730					80 730
Fine iron ore	t dry	7 065 101		7 065 101			50 117	50 117	7 014 984
Lump ore	t dry	1 262 007	50 184	1 312 191					1 312 191
Residues									
Tar	t					46 215	1 407	47 622	-47 622
BF gas dust	t dry						2 835	2 835	-2 835
BF gas sludge	t dry		2 440	2 440					2 440
Ironmaking slag	t dry					306 612		306 612	-306 612
Granulated slag	t dry					1 430 812		1 430 812	-1 430 812

Table D.2 — Example of Facility balance – Determination of CO_2 emissions

	Net use		Direct CO_2 (t)	Indirect CO_2 (t)	Total CO_2 (t)
Products	**Value**	**Unit**			
Merchant sinter	243 667	t		66 550	66 550
Pellets	1 135 745	t dry	416	130 611	131 027
Blast furnace hot metal	-103 671	t	-17 854		-17 854
Continuous casting BOF steel	-1 891 039	t	-2 772		-2 772
Hot rolled coils	-4 307 878	t	-6 314		-6 314
Condensed fuels					
Home coke	38 400	t dry	123 820	10 366	134 186
Purchased coke	585 054	t dry	1 829 762	157 925	1 987 687
Coking coal	1 745 445	t dry	5 243 482		5 243 482
Anthracite	314 765	t dry	974 304		974 304
BF injection coal	1 171 113	t dry	3 545 793		3 545 793
Light domestic oil	6 109	m3	16 038		16 038
Gas fuels					
Coke oven gas	-2 538 240	GJ ncv	0		0
Blast furnace gas	-14 330 682	GJ ncv	0		0
BOF gas	-2 010 479	GJ ncv	0		0
Natural gas	627 244	GJ ncv	34 004		34 004
Utilities					
Electricity	1 522 216	MWh		109 643	109 643
High pressure steam	13 752	t		2 929	2 929
High pressure oxygen	346 172	$10^3.m^3N$		17 703	17 703
Low pressure oxygen	260 130	$10^3.m^3N$		9 368	9 368
Nitrogen	202 728	$10^3.m^3N$		2 920	2 920
Argon	2 039	$10^3.m^3N$		29	29
Compressed air	348 799	$10^3.m^3N$		2 764	2 764
Miscellaneous materials					
Pre-consumer scrap	399 379	t	1 463		1 463
Post-consumer scrap	170 941	t	626		626
Limestone	1 262 332	t dry	549 531		549 531
Burnt lime	301 084	t	7 171	316 138	323 309
Dolomite	80 730	t dry	38 455		38 455
Fine iron ore	7 014 984	t dry	12 852		12 852
Lump ore	1 312 191	t dry	2 404		2 404
Residues					
Tar	-47 622	t	-158 964		-158 964
BF gas dust	-2 835	t dry	-4 155		-4 155
BF gas sludge	2 440	t dry	3 576		3 576
Ironmaking slag	-306 612	t dry			
Granulated slag	-1 430 812	t dry			
		Total	12 193 640	826 947	13 020 587

Table D.3 — Example of assessment of GHG impact of an integrated facility

	Energy	Equivalent electricity	CO_2 emissions (t)		
	GJ ncv	MWh	Direct	Indirect	Total
Straight balance			12 193 640	826 947	13 020 587
Gas exports	18 879 401		4 331 668		4 331 668
to power plants	15 438 374	1 575 344		113 470	113 470
to other activities	3 441 027			192 882	192 882
	Global CO_2 impact		12 193 640	520 595	12 714 235

Annex E
(informative)

Assessment of emission performance at facility level (carbon input performance)

E.1 Assessment for integrated steel production facilities

The reference factors for the assessment of input carbon performance in an integrated steel production facility are derived from good practice plant data. They have been chosen based on analysis of available data of European plants. They cannot be considered as a benchmark and are given here for illustration purposes only.

This methodology allows operators to assess and document progress in their operations. It is not fit for comparison of performance between plants due to the impact site layout differences may have on the outcome of the assessment.

Coke making generates coke oven gas at a rate ranging from 7 200 MJ/t coke to 8 200 MJ/t coke. A mean value of 7800 MJ/t has been used and charged at a normal emission factor for coke oven gas (EUROFER data). Carbon losses during pushing and quenching are difficult to estimate owing to the uncertainties on carbon balance but experts agree on a minimum value of 1 % of the carbon input equivalent to a loss of 10 kg C/t coke.

The consumption of solid fuels at sinter plants varies in a large range but a value of 50 kg/t merchant sinter can be considered as acceptable with a 50/50 mix of coke and anthracite. The consumption of basic fluxes depends on the quality of iron ore and a value of 130 kg limestone per tonne of merchant sinter can be considered as representative (EUROFER data).

The carbon input to blast furnaces through reducing agents (coke + nozzle injection) also varies in a significant range. A minimum value is set at 414,1 kg C/t hot metal due to thermodynamic limitations linked with the reduction equilibrium of iron oxides and a value of 420 kg C/t hot metal is achieved by a number of performing blast furnaces [6], [7], [8], [9].

The reference value for hot rolling pertains to a standard plate mill with a heating temperature of 1250 °C.

Based on these assumptions, Table E.1 shows how to calculate CO_2 reference values (rounded at the closest multiple of 5). Table E.2 shows the outcome of the application of the carbon input methodology to an existing facility, based on the CO_2 reference values from Table E.1. In the example, the table shows that accounted equivalent emissions exceed the theoretical ones by 1,6 %.

With this, an assessment of performance can be achieved which does not depend on the structure of the facility since the theoretical carbon input is calculated on the basis of the actual levels of production. A change of the performance indicator really means a change in process efficiency but without the possibility of attributing the decrease in performance to a particular production step.

Table E.1 — CO_2 reference values for the integrated route

	Amount	**Emission factor**	**Reference CO_2**
Coke plant			
Coke oven gas	7 800 MJ/t	0,045 kg/MJ	351 kg/t
Carbon losses (1 %)	10 kg/t	3,664 kg/kg	37 kg/t
Attributed CO_2		α	390 kg/t
Sinter plant			
Solid fuels	50 kg/t	3,151 kg/kg	158 kg/t
Limestone	130 kg/t	0,440 kg/kg	57 kg/t
Attributed CO_2		β	215 kg/t
Blast furnace			
Reducing agents	420 kg C/t	3,664 kg/kg	1 539 kg/t
Attributed CO_2		γ_{BF}	1 540 kg/t
Smelting reduction			
Reducing agents	770 kg C/t	3,664 kg/kg	2 821 kg/t
Fluxes	320 kg/t	0,460 kg/kg	147 kg/t
Attributed CO_2[a]		γ_{SR}	2 970 kg/t
Hot rolling fuels	1 350 MJ/t	0,056 kg/MJ	76 kg/t
Attributed CO2		δ	75 kg/t

[a] Only sites without coke plant. Otherwise, heating fuels for rolling are already accounted in the attribution to the coke plant.

Table E.2 — Example of assessment of integrated facility emission performance

	Net use	Accounted CO_2 input
External coke	623 455 t	1 953 582 t
Coking coal	1 745 445 t	5 243 482 t
Anthracite	314 765 t	974 304 t
PCI coal	1 171 113 t	3 545 793 t
Natural gas	627 244 GJ	34 004 t
Limestone	1 262 332 t	549 531 t
Others [a]		-107 057 t
Process related emissions		12 193 640 t

	Production	Likely CO_2 emissions
Home coke	1 379 008 t	537 813 t
Merchant sinter	7 735 553 t	1 663 144 t
Hot metal	6 277 643 t	9 667 570 t
Total theoretical emissions		11 868 527 t

Facility performance indicator	102,7 %

[a] Tar and miscellaneous.

E.2 Assessment for EAF facilities

Steel production facilities based on the EAF route generally comprise an EAF shop and hot rolling mills. Carbon inputs to EAF shops can vary over a large range due to the possibility of interchanging fossil fuel and electricity. Performance is also strongly dependent on the type of steel grades which are produced. The example given by Table E.3 pertains to an EAF shop with a rolling mill. The CO_2 reference value for the EAF shop illustrates good performance for the production of 100 % scrap-based carbon steel. The value for hot rolling pertains to a standard plate mill with a heating temperature of 1 250 °C.

Table E.3 — CO_2 reference values for EAF based facilities

	Amount	**Emission factor**	**Reference CO_2**
DRI fuels	10 000 MJ/t	0,056 kg/MJ	560 kg/t
Attributed CO_2		**α**	560 kg/t
EAF carbon input	18 kg/t	3,664 kg/kg	66 kg/t
Heating fuels	300 MJ/t	0,056 kg/MJ	17 kg/t
Attributed CO_2		**β**	85 kg/t
Hot rolling fuels	1 350 MJ/t	0,056 kg/MJ	76 kg/t
Attributed CO_2		**γ**	75 kg/t

Table E.3 shows the outcome of the application of the carbon input methodology to an existing facility incorporating direct reduction for about half of its iron sources. In this table, the allocation for crude steel has been diminished by the amount of carbon contained in DRI which replaces part of the existing carbon fed to the EAF since the EAF process is limited in its potential carbon use.

Table E.4 — Example of assessment of EAF facility emission performance

	Net use	Accounted CO_2 input
EAF coal	8 754 t	28 451 t
Natural gas	6 384 000 GJ	358 172 t
EAF electrodes	1 765 t	6 338 t
Ferro-alloys	9 325 t	492 t
Scrap	485 325 t	3 203 t
Direct emissions		396 656 t

	Production	Likely CO_2 emissions
DRI	514 677 t	288 219 t
Crude steel	889 226 t	28 438 t
Hot rolled	717 400 t	53 805 t
Total theoretical emissions		370 462 t

Facility performance indicator	107,1 %

Such a methodology, when applied to the EAF route, is less accurate due to the fact that CO_2 performance is strongly linked to the electricity consumption profile of the facility, which the carbon input performance assessment overlooks.

Annex F
(informative)

Determination of process performance

F.1 Carbon mass balance of the process

Table F.1 shows the outcome of the application of the carbon mass balance to a coke plant.

Table F.1 — Carbon mass balance of a coke plant

		Use	Direct CO_2	Indirect CO_2	Generation	Direct CO_2	Indirect CO_2
	Unit		**(t)**	**(t)**		**(t)**	**(t)**
Condensed fuels							
Own coke	t dry	0	0	0	1 379 008	4 446 534	0
Coking coal	t dry	1 747 885	5 250 813	0	0	0	0
Light domestic oil	m^3	3 518	9 236	867	0	0	0
Gas fuels							
Coke oven gas	GJ ncv	675 104	32 732	0	10 552 431	511 621	0
Blast furnace gas	GJ ncv	3 068 092	822 557	0	0	0	0
BOF gas	GJ ncv	759 422	138 454	0	0	0	0
Utilities							
Electricity	MWh	52 833	0	30 676	0	0	0
Low pressure steam	t	112 617	0	21 842	0	0	0
High pressure oxygen	k.m^3N	1 519	0	626	0	0	0
Nitrogen	k.m^3N	7 479	0	869	0	0	0
Compressed air	k.m^3N	10 090	0	644	0	0	0
Residues							
Tar	t	0	0	0	47 622	158 964	0
Total	t	0	6 253 791	55 524	11 979 061	5 117 119	0

F.2 Accounting of by-product gas

Table F.2 shows the outcome of the application of the rule for accounting for by-product gas to a coke plant. Positive net emissions linked to the gas balance turn into a credit which better reflects the net energy export of the coke plant. The difference is mostly charged to blast furnace and BOF operation which generate gas with a higher emission factor than the reference.

Table F.2 — Accounted CO_2 emissions for by-product gas

	Net use (GJ ncv)	Actual CO_2 (t)	Accounted CO_2 (t)
Coke oven gas	-9 877 327	-478 889	-553 660
Blast furnace gas	3 068 092	822 557	171 978
BOF gas	759 422	138 454	42 568
Total	-6 049 813	482 122	-339 114

Extra credit to coke plant	74 771
Extra charge to blast furnace	650 580
Extra charge to BOF plant	95 885
Total correction	821 236

F.3 Determination of emission performance

The methodology described in 8.3.3 applied to the coke plant used in this example is presented in Table F.3 which summarizes all the steps of calculation following the global plant balance.

In this example, the analysed plant appears a little bit less efficient than the reference in terms of Total CO_2 intensity but better than the reference in terms of Processing CO_2 intensity (ARP values in the example are set at 269 kg/t and 223 kg/t respectively). This means that the analysed process is efficient in terms of energy intensity but is penalized by the actual carbon balance of coke making which shows an excess carbon input in coking coals as compared to the output in coke, coke oven gas and other by-products (tar in this example).

Table F.3 — Determination of performance indicators for a coke plant

CO_2 use		CO_2 gen
Direct (t)	**Indirect (t)**	**Direct (t)**
6 253 791	55 524	5 117 119

Reference production (t)	1 379 008
C Balance	102,8 %

	Net balance	
Gas accounting	**Actual CO_2 (t)**	**Accounted CO_2 (t)**
Coke oven gas	-478 889	-553 660
Blast furnace gas	822 557	171 978
BOF gas	138 454	42 568
Total	482 122	-339 114

Actual direct CO_2 (t)	1 136 672
Accounted direct CO_2 (t)	315 437
Accounted CO_2 (t)	370 960
Processing CO_2 (t)	307 045
CO_2 emission indicator	0,269 t/t
Processing CO_2 indicator	0,223 t/t

Total CO_2	CO_2 performance indicator	107,6 %
	CO_2 bonus (t)	0
	CO_2 saving potential (t)	26 208
Processing CO_2	CO_2 Performance Indicator	96,8 %
	CO_2 bonus (t)	10 127
	CO_2 saving potential (t)	0

Table F.4 — Example of combination at facility level

		Net use	Direct CO_2	Accounted CO_2	Attribution
	Unit		**(t)**	**(t)**	**(t)**
Products					
Merchant sinter	t	-8 188 095			
Bell sinter	t	214 348		61 967	
Pellets	t dry	1 153 319	423	132 632	
Blast furnace hot metal	t	-103 671	-17 854		181 357
BOF crude steel	t	-1 891 039	-2 772		3 684 294
Hot rolled coils	t	-4 307 878	-6 314		9 180 110
Condensed fuels					
Own coke	t dry	7 221	23 284	25 233	
Purchased coke	t dry	571 378	1 786 988	1 941 222	
Coking coal	t dry	1 747 885	5 250 813	5 250 813	
Anthracite	t dry	319 042	987 542	987 542	
BF injection coal	t dry	1 164 265	3 525 059	3 525 059	
Light domestic oil	m^3	3 518	9 236	9 236	
Gas fuels					
Coke oven gas	GJ ncv	-3 395 879	-164 645	-190 351	
Blast furnace gas	GJ ncv	-14 662 346	-3 930 984	-821 877	
BOF gas	GJ ncv	-2 010 479	-366 540	-112 695	
Natural gas	GJ ncv	539 978	29 273	29 273	0
Utilities					
Electricity	MWh	1 438 594	0	835 277	0
High pressure steam	t	366 632	0	78 094	0
High pressure oxygen	k.m^3N	343 452	0	141 585	0
Low pressure oxygen	k.m^3N	260 130	0	75 518	0
Nitrogen	k.m^3N	202 782	0	23 548	0
Argon	k.m^3N	2 037	0	237	0
Compressed air	k.m^3N	347 093	0	22 168	0
Miscellaneous materials					
Pre-consumer scrap	t	399 379	1 463	1 463	-527 180
Post-consumer scrap	t	170 941	626	626	-225 642
Limestone	t dry	1 262 332	549 531	549 531	0
Burnt lime	t	269 678	6 423	289 585	0
Dolomite	t dry	80 730	38 455	38 455	0

		Net use	Direct CO_2	Accounted CO_2	Attribution
	Unit		**(t)**	**(t)**	**(t)**
Fine iron ore	t dry	6 723 946	12 319	12 319	
Lump ore	t dry	1 295 575	2 374	2 374	
Residues					
Tar	t	-47 622	-158 964	-158 964	
BF gas dust	t dry	-11 304	-16 568	-16 568	
BF gas sludge	t dry	8 727	12 791	12 791	
Ironmaking slag	t dry	-1 737 424			
Granulated slag	t dry	-1 430 812			786 947
Home scrap	t				
Total	t		7 571 960	12 746 092	13 079 885

Table F.5 — Example of calculation of facility performance

	Net balance	
Gas accounting	**Actual CO_2**	**Accounted CO_2**
Coke oven gas	-164 645	-190 351
Blast furnace gas	-3 930 984	-821 877
BOF gas	-366 540	-112 695
Total	-4 462 168	-1 124 923

Actual direct CO_2	7 571 960
Accounted direct CO_2	10 909 205
Processing CO_2	11 115 344

Total CO_2	CO_2 Performance indicator	97,4 %
	CO_2 bonus	829 143
	CO_2 saving potential	244 268
Processing CO_2	CO_2 performance indicator	96,1 %
	CO_2 bonus	755 493
	CO_2 saving potential	327 838

Annex G
(informative)

Description of data checks on process data

G.1 Coke plant

Five checks can be performed on coke plant data as shown by the example of Table G.1. They set limits to the values of the calculated parameters:

- coking coal rate expressed as kg of coal per tonne of coke produced;
- coke oven gas production;
- reaction heat calculated as the difference between calorific content of coking coal and outputs of the coke oven (coke, tar, benzole, coke oven gas and quenching breeze or dust);
- carbon gap calculated in the same way as the reaction heat from carbon input and output;
- carbon balance fit calculated as the ratio from carbon input (coking coal) to carbon output (coke, tar, benzole, coke oven gas and quenching breeze or dust).

Table G.1 — Data check for coke plant

Coke plant	Unit	Value	Min	Max
Coking coal	kg/t	1 267	1 220	1 320
Coke oven gas	MJ/t	7 652	7 500	8 500
Reaction heat	MJ/t	1 651	1 000	
Carbon gap	kg/t	26	5	
C balance		102,8 %	100 %	105 %

In the example given, even if all the parameters are in the accepted range, it looks that coal input is at a good level but coke oven gas production could be a little bit low.

G.2 Sinter plant

Two data consistency checks can be performed for a sinter plant:

- the consumption of limestone can be related to the slag volume at the blast furnace and is usually in the range 100 to 180 kg/t merchant sinter depending on the sinter rate at the blast furnace;
- in the global material balance the total of iron ores, solid fuel ash and lime resulting from limestone decomposition should be close to 1 t/t merchant sinter.

Table G.2 — Example of data check for a sinter plant

Sinter plant	Unit	Value	Min	Max
Solid fuels	kg/t	57		
Carbonated fluxes	kg/t	154	100	180
Ores & pellets	kg/t	845		
Dust & sludge	kg/t	14		
Mass balance	kg/t	945	980	1 020

G.3 Iron making

Five data quality checks are possible for blast furnace iron making:

- a check on the carbon balance examining inputs by coke and injections and outputs by carbon in hot metal, top gas, dust and sludge;
- a check on the energy balance of the blast furnace to verify that the reported data are consistent with the 10 GJ typically necessary for hot metal production (decomposition of iron oxides and tramp elements (Si, Mn, P), delivering the carbon needed to saturate the hot metal and heat it to 1 500 °C. This is possible by estimating the energy input from coke and injection net of dust and sludge production and accounting for 10 % input from sensible heat of hot blast. Allowing for 3 % energy loss (heat losses and sensible heat of top gas), the available energy can be calculated by subtracting the top gas production and the sensible heat of slag (~ 2 GJ/t) and should be in a narrow range around 10 GJ;
- a check on the carbon balance comparing total input (except heating gas fuels) to output resulting from hot metal, top gas, dust and sludge;
- a check on iron balance since iron inputs from sinter, pellets, lump ore and scrap eventually should be close to 950 kg/t HM;
- a check on power and steam consumption to be sure that cold blast coming from a utility plant is well attributed to the blast furnace since blast compression represents some 7 % of the energy input to a blast furnace.

An example of such data check is given in Table G.3 which shows a problem with the carbon balance. An excess of carbon in the input impacts the performance indicator unfavourably.

The same data checks can be performed for smelting reduction plants except the check of power and steam consumption since these processes use oxygen in place of blast.

Table G.3 — Example of data check for a blast furnace

Blast Furnace plant	Unit	Value	Min	Max
Coke	MJ/t	8 700		
Injections	MJ/t	5 792		
Blast furnace gas	MJ/t	4 557		
Dust & sludge	MJ/t	278		
Energy balance gap	MJ/t	10 201	9 800	11 000
C balance		104,9 %	98 %	102 %
Bell sinter	kg/t	1 266		
Ores & pellets	kg/t	336		
Scrap	kg/t	0		
Iron input	kg/t	949	940	960
Ironmaking slag	kg/t	277		
Electricity & steam	MJ/t	1 005	940	

G.4 Steel making

The main check to perform for steel plants relates to the iron balance, with the aim of ensuring that inputs coming from hot metal, DRI, ores and net scrap, eliminating the internal steel plant scraps which do not leave the boundaries, are sufficient to cover the output as crude steel and iron contained in slag; i.e. a total of at least 1 015 kg/t steel.

For BOF plants, it is also recommended to check that BOF gas production does not exceed the physical possibility resulting from a carbon input coming mainly from hot metal and a BOF gas recovery of at most 90 % due to poor gas quality at beginning and end of blowing.

An example of this data check is given in Table G.4.

Table G.4 — Example of data check for a BOF plant

BOF shop	Unit	Value	Min	Max
Hot metal (BF & SR)	kg/t	975		
DRI	kg/t	0		
Net scrap use	kg/t	103		
Ores & pellets	kg/t	24		
Iron input	kg/t	1 040	1 015	1 100
Coke	kg/t	0		
BOF gas	MJ/t	707		794

G.5 Hot rolling mills

Owing to the importance of crude steel in the CO_2 intensity of hot rolled products, it is necessary to check that crude steel input is consistent with the reported scrap generation and iron losses resulting from scale formation during heating and rolling. Therefore, the net steel use (crude steel – scrap) should be larger than 1 005 kg/t product as shown in Table G.5.

Table G.5 — Example of data check for hot rolling mills

Hot rolling mills	Unit	Value	Min	Max
Crude steel	kg/t	1 060		
Scrap	kg/t	42		
Net use	kg/t	1 018	1 005	1 030

Performing these checks can help to eliminate of number of biases in the reporting of activity data and improve the performance assessment.

Annex H
(informative)

Elements on sampling, analyses and uncertainty

H.1 General

As mentioned in 10.1, cokes and coals play a prominent role in the GHG emissions of integrated steel production facilities and a good sampling and analysis procedure is necessary to minimize the uncertainties on activity data and carbon content measurements.

H.2 Coal analysis

Owing to the potential impact on the process, operators look for consistency of characteristics of the blend of materials used. This is achieved by mixing different qualities of coals which are procured in large unit amounts and therefore stored prior their utilization. The same desire for consistency results in strict specifications of coal quality to limit the variations in compositional and metallurgical properties.

As an example, Table H.1 gives some information on coals received in an integrated steel production facility over a long period. These coals have been received from overseas in carriers up to 100 000 t. The table has been compiled using the average carbon analysis by lot received and gives the following indications:

- The range of variation increases with the duration of coal utilization which can be a result of heterogeneity of the deposit;
- The standard deviation of carbon content of the coal is always lower than 2 %;
- The uncertainty of the average analysis of all the lots from each coal source, calculated using the Frequency of analysis tool published by the European Commission,[1] often corresponds to the top tier requirements when the number of lots is high enough.

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[1] http://ec.europa.eu/clima/policies/ets/monitoring/docs/tool_frequency_en.xls

Table H.1 — Statistics on coal analysis in an integrated facility

	Coal#1	**Coal#2**	**Coal#3**	**Coal#4**	**Coal#5**	**Coal#6**	**Coal#7**	**Coal#8**
Number of lots	29	42	14	54	72	9	11	122
Years of use	1994-1998	1993-2002	2005-2011	1997-2011	1999-2011	2010-2011	2010-2011	1992-2008
Min (%)	76,69	81,26	83,13	81,06	80,56	81,40	79,80	75,01
Max (%)	79,36	86,41	87,26	85,29	84,92	83,60	83,60	81,95
Average (%)	78,00	84,31	84,89	83,29	83,10	81,92	81,28	78,27
Range	1,71 %	3,06 %	2,43 %	2,54 %	2,62 %	1,34 %	2,34 %	4,43 %
Standard deviation	0,70	1,23	1,27	0,83	0,97	0,72	1,16	1,46
% of average	0,90 %	1,46 %	1,50 %	1,00 %	1,16 %	0,88 %	1,42 %	1,87 %
Uncertainty on average	0,341 %	0,454 %	0,867 %	0,272 %	0.274 %	0,673 %	0,957 %	0,335 %
Requirements	Tier 4	0,50 %	Tier 3	0,83 %	Tier 2	1,67 %	Tier 1	2,50 %
NOTE The tier thresholds are those defined in Table 1 of Annex II of the EU ETS Monitoring and Reporting Regulation (601/2012/EU).								

Another analysis of the problem has been performed using series of data created with the random number generator of Excel. The settings chosen were an average value of 80 % and values of relative standard deviation, in the range 0,25 % to 3 %. The same EU tool has been used, varying the frequency of analysis from once per month to the maximum permitted of 500/year. The results of this simulation are given in Table H.2 where the resulting uncertainty on average carbon content is compared to Tier thresholds set at one third of those imposed for activity data.

When these results are compared with the relative standard deviations observed on the actual coal analysis, it appears that Tier 4 could be reached in almost every case with one analysis per week. For coals used at the level of 1 million tons per year, this corresponds to a frequency of analysis of 1 per 20 kt.

Table H.2 — Simulation of uncertainty analysis on carbon contents

	Relative standard deviation						
	0,25 %	0,50 %	1,00 %	1,50 %	2,00 %	2,50 %	3,00 %
Samples	**Uncertainty on average**						
12	0,200 %	0,348 %	0,380 %	0,662 %	1,641 %	1,985 %	1,685 %
24	0,108 %	0,259 %	0,337 %	0,502 %	0,858 %	1,201 %	1,094 %
36	0,078 %	0,179 %	0,280 %	0,480 %	0,804 %	0,971 %	0,944 %
52	0,072 %	0,140 %	0,244 %	0,406 %	0,601 %	0,737 %	0,756 %
104	0,050 %	0,102 %	0,172 %	0,305 %	0,410 %	0,514 %	0,548 %
183	0,035 %	0,078 %	0,135 %	0,221 %	0,300 %	0,380 %	0,439 %
365	0,027 %	0,052 %	0,103 %	0,152 %	0,214 %	0,267 %	0,296 %
500	0,022 %	0,043 %	0,087 %	0,132 %	0,180 %	0,224 %	0,246 %
Tier 4	0,50 %	Tier 3	0,83 %	Tier 2	1,67 %	Tier 1	2,50 %

H.3 Uncertainty on yearly activity data

Estimation of the uncertainty of yearly activity data is made by assuming that each reported flow has the same uncertainty, u_i, and by applying the formula of Formula 40) for uncorrelated parameters. The resulting global uncertainty is given by Formula (H.2) below.

Formula H.1 – Calculation of uncertainty on activity data

$$u_{total} = u_i \cdot \frac{\sum_1^n X_1^2}{\sum_1^n X_i} \tag{H.1}$$

The value of *u* which can explain the balance gap can then be derived from the following formula:

$$Balance\,gap = u_{total} \cdot \sum_1^n X_i = u_i \cdot \sqrt{\sum_1^n X_i^2} \tag{H.2}$$

The following table gives an example of application of this methodology to the reported solid fuels data of a large integrated facility. It shows that the calculated balance gaps are explained usually by uncertainties of less than 2 % on the individual data.

Table H.3 — Example of estimate of uncertainty on yearly flow data

	Home coke	**External coke**	**Anthracite**	**BF coal**	**Coking coal**	**Total**
	T	t	t	t	t	t
Group purchase	0	305 641	0	0	0	305 641
Other purchase	0	245 439	397 903	1 180 617	1 674 594	3 498 554
Reclaiming from stocks	38 400	33 974	0	0	70 851	143 225
Storage	0	0	83 138	9 504	0	92 643
Production	1 379 008	0				1 379 008
Use at coke plant	0	0	0	0	1 747 885	1 747 885
Use at sinter plant	110 479	34 697	319 042	0	0	464 218
Use at blast furnace	1 275 750	536 681	0	1 164 265	0	2 976 696
Quadratic average	1 882 254	666 364	516 746	1 658 150	2 421 650	3 587 171
Balance gap*	27 905	13 677	-4 277	6 848	-2 440	41 713
Uncertainty	1,48 %	2,05 %	0,83 %	0,41 %	0,10 %	1,16 %
Year 1	0,75 %		1,86 %	1,69 %	0,56 %	1,26 %
Year 2	0,87 %		3,47 %	1,63 %	0,38 %	1,03 %
Year 3	1,84 %	2,05 %	7,38 %	1,34 %	0,45 %	0,61 %
Year 4	2,42 %	1,64 %	3,69 %	0,91 %	0,16 %	0,80 %
Year 5	1,48 %	2,05 %	0,83 %	0,41 %	0,10 %	1,16 %
* Procurements+Reclaiming+Production-Deliveries-Home use						

H.4 Uncertainty on direct CO_2 emissions

An example of estimation of uncertainty of direct CO_2 emissions has been compiled using the data given in the facility example of Annex D. The calculation has been performed with the following steps:

- Estimation of the uncertainty of net use of the intervening materials by application of the formula given in Formula (40) and presented in the preceding Section. For this calculation, values of uncertainties of 1,5 % have been assumed for procurements and deliveries and 3 % for stock variations;

- Estimation of the uncertainty of the conversion factor from wet to dry materials using assumptions of moisture and uncertainty of moisture content from application of Formula (42);

- Calculation of the uncertainty of equivalent CO_2 emission of each source assuming a 1,5 % uncertainty of carbon content and application of Formula (43).

Application of the composition of uncorrelated data (Formula (40)) to the individual energy sources calculating the values of

$$\left(u_{CO2eq,i} \cdot Direct\,CO_{2,i}\right)^2 \tag{H.3}$$

which are summed for the full set of materials. The square root of this sum is then divided by the calculated direct emissions giving the resulting uncertainty of direct emission as presented by the example in Table H.4.

In this table, the uncertainty of net use is calculated by application of Formula (40) to the components of calculation of net use presented in Annex D.

The assumed uncertainties on the parameters for calculation are given at the bottom of the table and result in 1,29 % uncertainty of direct emissions. Coke and coals represent 99,4 % of the total quadratic sum showing the importance of accurate measurement, sampling and analysis of these materials.

Doubling the value of uncertainty of included parameter gives the results in Table H.5 which shows the minor influence of stock variations and moisture as compared to external exchanges and carbon analysis. These results are given only for example, in a real situation, each uncertainty for each material shall be determined in by applying the rules for the number of samples and analysis.

Table H.4 — Calculation of uncertainty on direct emissions

	Net use		Direct CO_2 (t)	Indirect CO_2 (t)	Total CO_2 (t)	Uncertainty on net use	Moisture	u_dry	u_CO_2eq	Quadratic factor
Products	Value	Unit								
Merchant sinter	243 667	t		66 550	66 550	5,00 %	1,00 %	0,10 %	2,35 %	0.000E+00
Pellets	1 135 745	t dry	416	130 611	131 027	1,44 %	2,00 %	0,20 %	2,35 %	9.545E+01
Blast furnace hot metal	-103 671	t	-17 854		-17 854	5,00 %			2,32 %	1.711E+05
Continuous casting BOF steel	-1 891 039	t	-2 772		-2 772	5,00 %			1,80 %	2.497E+03
Hot rolled coils	-4 307 878	t	-6 314		-6 314	1,50 %			2,32 %	2.149E+04
Condensed fuels										0.000E+00
Home coke	38 400	t dry	123 820	10 366	134 186	5,00 %	3,00 %	0,31 %	5,32 %	4.346E+07
Purchased coke	585 054	t dry	1 829 762	157 925	1 987 687	1,44 %	5,00 %	0,53 %	2,40 %	1.934E+09
Coking coal	1 745 445	t dry	5 243 482		5 243 482	1,45 %	8,00 %	0,87 %	2,50 %	1.720E+10
Anthracite	314 765	t dry	974 304		974 304	1,51 %	8,00 %	0,87 %	2,00 %	3.803E+08
BF injection coal	1 171 113	t dry	3 545 793		3 545 793	1,49 %	8,00 %	0,87 %	2,00 %	5.037E+09
Light domestic oil	6 109	m^3	16 038	0	16 038	1,50 %	0,00 %		1,80 %	8.359E+04
Gas fuels										0.000E+00
Coke oven gas	-2 538 240	GJ ncv	0		0	1,07 %				0.000E+00
Blast furnace gas	-14 330 682	GJ ncv	0		0	1,31 %				0.000E+00
BOF gas	-2 010 479	GJ ncv	0		0	1,28 %				0.000E+00
Natural gas	627 244	GJ ncv	34 004		34 004	1,25 %	0,00 %		1,80 %	3.758E+05
Utilities										0.000E+00
Electricity	1 522 216	MWh		109 643	109 643	1,41 %				0.000E+00
High pressure steam	13 752	t		2 929	2 929	1,50 %				0.000E+00
High pressure oxygen	346 172	k.m^3N		17 703	17 703	1,49 %				0.000E+00
Low pressure	260 130	k.m^3N		9 368	9 368	1,50 %				0.000E+00

	Net use		Direct CO$_2$ (t)	Indirect CO$_2$ (t)	Total CO$_2$ (t)	Uncertainty on net use	Moisture	u_dry	u_CO$_2$eq	Quadratic factor
oxygen										
Nitrogen	202 728	k.m^{3}N		2 920	2 920	1,50 %				0.000E+00
Argon	2 039	k.m^{3}N		29	29	1,50 %				0.000E+00
Compressed air	348 799	k.m^{3}N		2 764	2 764	1,50 %				0.000E+00
Miscellaneous materials										0.000E+00
Pre-consumer scrap	399 379	t	1 463		1 463	1.50 %			1,80 %	6.960E+02
Post-consumer scrap	170 941	t	626		626	1.50 %			1,80 %	1.275E+02
Limestone	1 262 332	t dry	549 531		549 531	1.49 %	5,00 %	0,53 %	1,88 %	1.065E+08
Burnt lime	301 084	t	7 171	316 138	323 309	1.49 %			1,80 %	1.671E+04
Dolomite	80 730	t dry	38 455		38 455	1.50 %	5,00 %	0,53 %	1,88 %	5.216E+05
Fine iron ore	7 014 984	t dry	12 852		12 852	1.49 %	10,00 %	1,11 %	2,12 %	7.407E+04
Lump ore	1 312 191	t dry	2 404		2 404	1.46 %	10,00 %	1,11 %	2,12 %	2.592E+03
Residues										0.000E+00
Tar	-47 622	t	-158 964		-158 964	1.46 %			1,80 %	8.213E+06
BF gas dust	-2 835	t dry	-4 155		-4 155	5.00 %	2,00 %		1,80 %	5.611E+03
BF gas sludge	2 440	t dry	3 576		3 576	5.00 %	30,00 %	4,29 %	4,65 %	2.765E+04
Ironmaking slag	-306 612	t dry				1.50 %			1,80 %	0.000E+00
Granulated slag	-1 430 812	t dry			0	1.50 %			1,80 %	0.000E+00
Total			12 193 640	826 947	13 020 587			Total		2.471E+10
Uncertainty on direct emissions			1,29 %					Square root		157 199

Uncertainty levels		Purchase delivery	1,50 %	Stocks	5,00 %	Sampling	1,00 %
		C analysis	1,50 %	Moisture	10,00 %		

Table H.5 — Influence on uncertainty levels on resulting uncertainty on direct emissions

Reference	1,29 %
Purchase-delivery	1,75 %
Stocks	1,29 %
C analysis	1,92 %
Moisture	1,52 %
Sampling	1,60 %

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