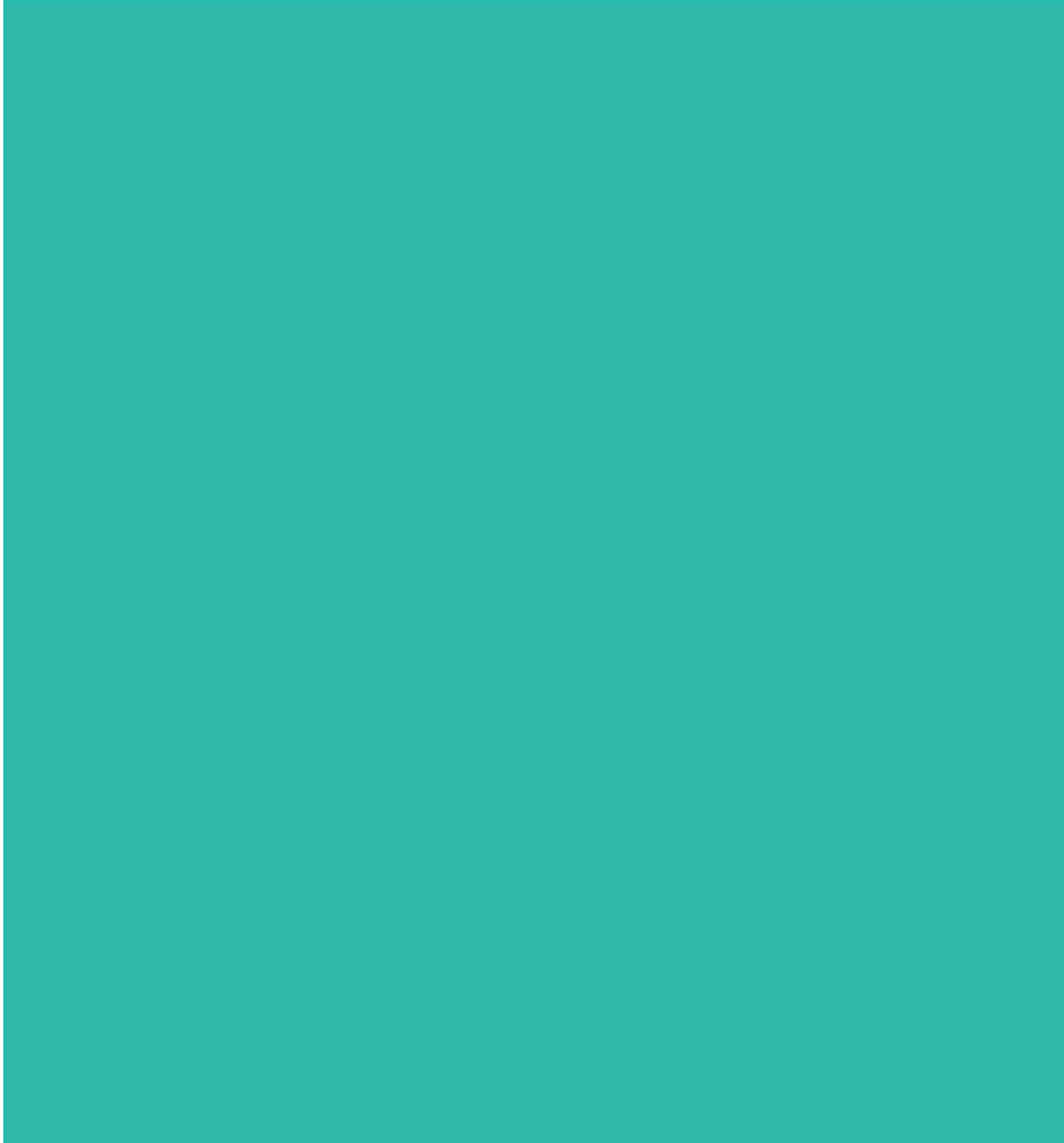


LIFE CYCLE INVENTORY METHODOLOGY REPORT



Life cycle inventory methodology report for steel products

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Director General
World Steel Association (worldsteel)

Avenue de Tervueren 270
1150 Brussels, Belgium
T: +32 (0)2 702 89 00
F: +32 (0)2 702 88 99
E: steel@worldsteel.org

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worldsteel.org

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Acronyms

ADP	Abiotic depletion potential
AP	Acidification potential
BF	Blast furnace
BF Gas	Process gas produced in the blast furnace
BOF	Basic oxygen furnace
BOF Gas	Process gas produced in the basic oxygen furnace
CO Gas	Process gas produced in the coke ovens
CRP	Critical review panel
EAF	Electric arc furnace
ECCS	Electrolytic chrome coated steel (tin-free steel)
EP	Eutrophication potential
EPD	Environmental product declaration
GWP	Global warming potential
HDG	Hot dip galvanised steel
HRC	Hot rolled coil
LCA	Life cycle assessment
LCI	Life cycle inventory
LCIA	Life cycle impact assessment
NCV	Net calorific value
ODP	Ozone depletion potential
POCP	Photochemical ozone creation potential

1. Introduction

1.1 Background

Selecting the most appropriate materials for any application depends on the consideration of a range of technical and economic factors including, for example, functionality, durability and cost. A further and increasingly important factor for material specifiers, in a world where sustainable development is a key issue, is the associated environmental performance of material applications both from a manufacturing and a product performance perspective.

Among the tools available to evaluate environmental performance, life cycle assessment (LCA) provides a holistic approach to evaluate environmental performance by considering the potential impacts from all stages of manufacture, product use and end-of-life stages, which is referred to as the 'cradle-to-grave' approach.

As per ISO 14044: 2006¹, LCA generally comprises four major components:

- Goal and scope definition;
- Life cycle inventory (LCI) - data collection and calculation of an inventory of materials, energy and emissions related to the system being studied;
- Life cycle impact assessment (LCIA) - analysis of data to evaluate contributions to various environmental impact categories; and
- Interpretation - where data are analysed in the context of the methodology, scope and study goals and where the quality of any study conclusions is assessed.

This LCI methodology has been produced by the World Steel Association (worldsteel) to outline a steel specific standard based on ISO 14040: 2006² and ISO 14044: 2006, internationally agreed and universally applicable, to quantify resource use, energy and environmental emissions associated with the manufacture of steel industry products, from the extraction of raw materials in the ground through to the point at which they are ready to be shipped from the steelworks (steel factory gate). The methodology has been developed over many years, and was first published as part of an LCI study report in 1995/6³. It has subsequently been updated in 2000⁴, 2005⁵ and most recently in 2011⁶. Global and regional steel LCI data was published alongside each of these updates and the methodology was critically reviewed by a panel of external LCA experts. This document is intended to collate and clarify the worldsteel methodology in a format that provides clear principles to be applied in steel product LCI studies.

In previous worldsteel LCA updates, a full LCA methodology report, which included both the methodology and the study results, was published. In order to enable third parties to use this methodology and to simplify the publication of future worldsteel updates, the study reports are generated independently of this methodology report. For LCI data generated following this methodology, a separate study report shall be produced. To be conformant with ISO 14044: 2006, this study report shall also undergo a review as described in the standard.

1.2 Target audience and intended application

The intended audience for this methodology report is for:

- Users of the published worldsteel LCI data
- Anyone wishing to develop or use steel product LCIs in line with the worldsteel methodology

This methodology conforms to ISO 14040/44: 2006 and is used when generating the worldsteel LCI datasets. It can also be used by individual companies or organisations when carrying out an LCI of steel products.

The LCI results alone shall not be used for comparisons intended to be used in comparative assertions intended to be disclosed to the public. The LCI data can be used as part of an LCA for comparative studies disclosed to the public if this is stated in the goals and scope of the LCA study, is done based on a proper functional unit and is subject to a study specific critical review by an external panel of experts.

1.3 Basis of methodology

The quality and relevance of LCA/LCI results, and the extent to which they can be applied and interpreted, depends critically upon the methodology used. It is therefore important that the methodology is transparent and well documented.

1.3.1 LCI study scope

This methodology can be applied to studies of the following formats:

- ‘cradle-to-gate’ study,
- ‘cradle-to-gate including end-of-life recycling’ study (sometimes referred to as cradle-to-grave excluding the use phase),
- ‘cradle-to-gate with options’ study, which may include any elements of downstream processing, or
- full ‘cradle-to-grave’ or ‘cradle-to-cradle’ study.

1.3.2 Applicable products

This methodology is applicable to the manufacture of steel products (description⁷ and application⁸ of steel products are available on worldsteel.org) including:

- Cast products such as slab, billet and ingot;
- Flat products such as hot rolled coil, cold rolled coil and plate;
- Long products such as sections, rebar, wire rod and rolled bars;

- Hot rolled products including seamless pipe;
- Extruded products including seamless pipe;
- Metallic coated products such as galvanised or tinplated steel;
- Pre-painted steel products;
- Basic fabricated steel products.

It is anticipated that using this methodology, the boundaries of LCI/LCA studies can be extended past the steel factory gate to include downstream activities, particularly in collaboration with customers who are applying LCAs to their own product systems, and the use phase or end-of-life phase of their product.

The methodology is not applicable to open hearth steelmaking, cast iron production or stainless steel production.

1.3.3 Overarching standards

The primary ISO standards which exist to provide requirements and guidance on methodological choices and to set down rules for transparency and reporting are:

- ISO 14040: 2006 - Environmental management - Life cycle assessment - Principles and framework
- ISO 14044: 2006 - Environmental management - Life cycle assessment - Requirements and guidelines

This worldsteel LCI methodology has been developed in accordance with ISO 14040: 2006 and ISO 14044: 2006. It has undergone three separate critical reviews from independent Critical Review Panels (CRP) of LCA specialists in 1995, 2000 and 2010/2010/11. This latest version of the methodology, which, in technical content, has not significantly changed since the 2011 version, has been reviewed by an external expert. This approach ensures the conformity and integrity of the methodology. The Critical Review Statement is included in Appendix 3. Any study carried out following this methodology should also be reviewed in conformance with the ISO standards.

This methodology does not intend to repeat content of other standards; instead their requirements are an assumed basis for all information contained in this document.

2. Requirements for LCA studies

LCI studies conducted in conformance with this methodology are to conform with the following criteria:

- Conformance with the requirements of ISO 14040: 2006 and ISO 14044: 2006.
- The goal and scope are to conform with section 3.1
- The functional/declared unit to be used is defined in section 3.2
- The system boundaries to be applied are outlined in section 3.3
- Where life cycle impact assessment is to be applied to the data, examples of impact categories that can be applied are listed in section 3.4
- Specific requirements for data collection are detailed in section 3.5
- Specific methodological conditions are followed as detailed in section 3.6
- Interpretation of the LCI and LCIA as detailed in section 3.7

3. Study requirements

3.1 Goal and scope

The goal and scope of this methodology are as follows:

- Conform with ISO 14040: 2006 and ISO 14044: 2006
- To define a methodology for calculating the LCI of steel products

The scope of the methodology is defined in section 1.3.

The goal and scope of LCI studies conducted following this worldsteel methodology should, as a minimum:

- Conform with ISO 14040: 2006 and ISO 14044: 2006
- Conform with this methodology
- Conform with any other standards selected for conformance
- Provide a clear description of the type of steel manufacturing processes, specific products included and the boundaries of the study
- Define the intention to report cradle-to-gate and/or cradle-to-gate-with-recycling LCI data, as well as any other applicable life cycle phases, depending on the type of product and consequent ability to predict downstream impacts
- Define the end-of-life methodology where cradle-to-gate-with-recycling is included.

3.2 Functional unit

In cradle-to-gate studies, the use of a functional unit is not possible due to the lack of knowledge regarding the end use conditions of the product. In this circumstance, a declared unit (which is a term commonly used in EPDs) of 1kg or 1 tonne of a steel product at the factory gate is used. For products that are further processed, an alternative declared unit may be used such as 1m² of a flat steel roofing product, 1m for a length of steel sections.

For the data supplied as cradle-to-gate-with-recycling, the declared unit includes the upstream burdens of the scrap used in the steelmaking process and the credits associated with the end-of-life recycling of the steel product, at a recycling rate specific to the product application and region. The declared unit goes beyond the typical use of a declared unit and would be defined as 1kg or 1 tonne of steel including the net recycling credits associated with the specified application or the amount of steel in the specified application in a specified region.

A full life cycle study may be undertaken with a cradle-to-grave scope where possible. Where this occurs, it is recommended to utilise a functional unit appropriate to the use of the product, where the amount of steel used in a precise application, along with its projected lifespan, maintenance requirements, etc. are all defined.

Further functions relating to the generation of co-products from the steel production system are considered using the allocation procedure recommended in ISO 14040: 2006, as documented in section 3.6.1.

Comparisons and comparative assertions shall only be done based on a proper functional unit and not based on declared units.

3.3 System boundaries

The system boundaries used for the LCI study are to include, as a minimum, all the production steps from raw materials in the earth (i.e. the cradle) to finished products ready to be shipped from the steelworks (i.e. the gate).

A gate-to-gate level model consists of all the steelmaking processes (process chain) as well as any additional on-site ancillary services that are required. This includes all necessary inputs and outputs per process, including materials, energy carriers, emissions, wastes and co-products and ancillary services such as boilers, compressors, waste water treatment etc. The cradle-to-gate level then includes this gate-to-gate level as well as all related upstream processes (raw material inputs) and substitution, waste treatment etc. This is shown in Figure 1.

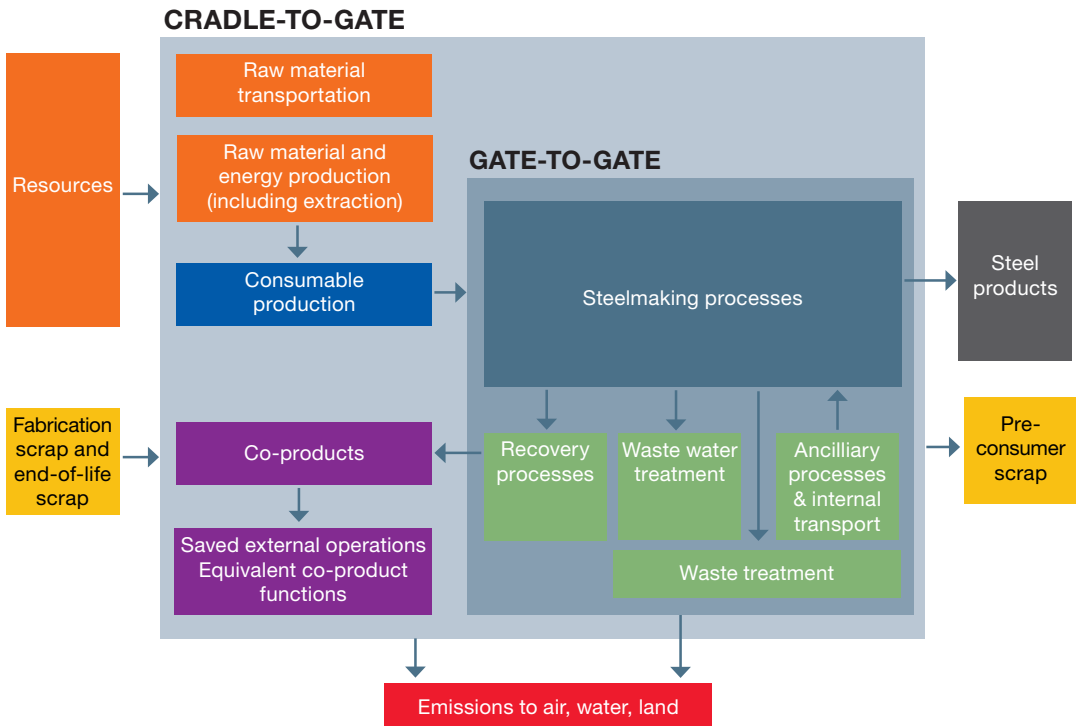


Figure 1: System boundaries overview for cradle-to-gate system

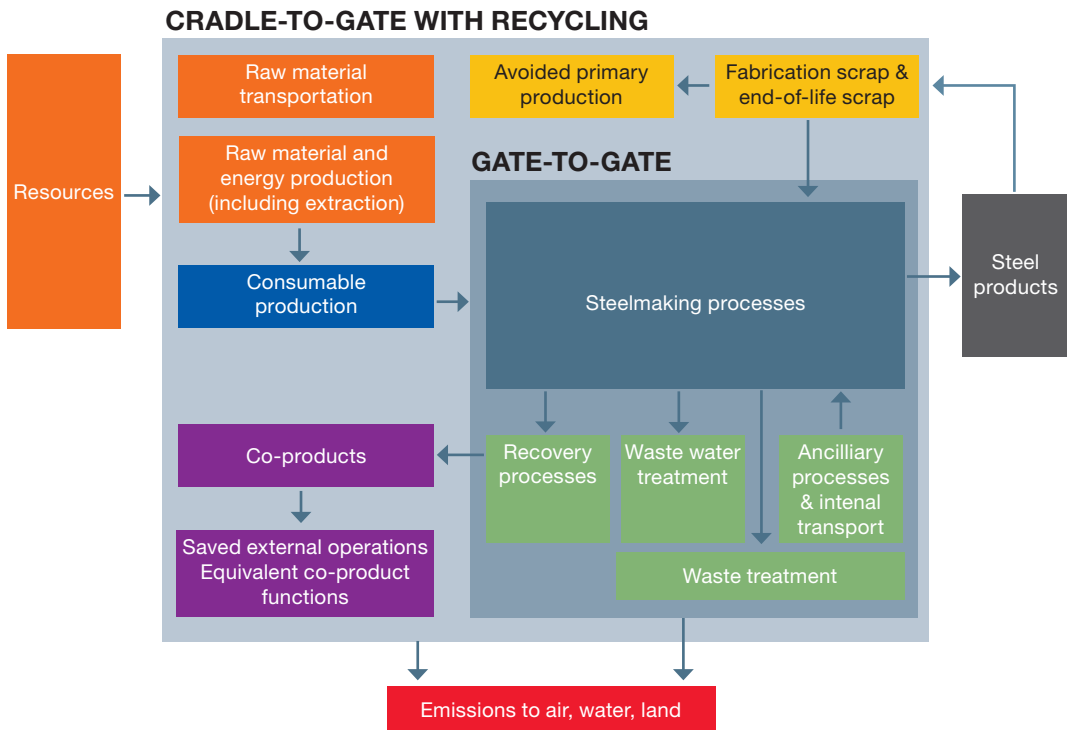


Figure 2: System boundaries overview for cradle-to-gate with recycling system

A cradle-to-gate-with-recycling LCI study considers the cradle-to-gate level as well as the impacts of using steel scrap in the steelmaking process and the credits for the end-of-life recycling of the steel from the final product when it reaches the end of its life (end-of-life scrap), at a specified recycling rate. These impacts and credits can be calculated separately on the input and output side, or as net credits. It does not include the manufacture of the downstream final products or their use. An overview-level example of system boundaries to be used in a cradle-to-gate-with-recycling study is shown in Figure 2.

For studies which utilise datasets obtained from worldsteel, the system boundaries must be checked to ensure that no double-counting occurs when the user models the end-of-life of the downstream product.

Steel LCI data should not include the following, based on materiality: capital goods, R&D, business travel, commissioning and decommissioning, repair and maintenance, cleaning and legal services, marketing, operation of administration offices, etc. The data shall represent normal and abnormal process operation and process maintenance periods, but excluding accidents, spills and similar events.

Typical steel manufacturing flow diagrams via the blast furnace route and the electric arc furnace route are shown in Appendix 1.

As shown in Figure 1 and Figure 2, the system boundaries must encompass the activities of the steel manufacturing sites and the production and transport of raw material inputs, energy sources and other consumables (diesel for internal transportation, oxygen, nitrogen etc.) used within the steelworks. Within the gate-to-gate boundary, the transport refers to transportation of materials within the steelworks boundary. Transportation on the cradle-to-gate level is the transportation of raw materials to the steelworks.

The recovery and use of steel industry co-products outside of the steelworks are taken into account, using the method of system expansion (see section 4.3.4.2 of ISO 14044: 2006) as described in Section 3.6.1.

Externally supplied scrap steel is typically sourced from fabricators, original equipment manufacturers (OEMs), scrap dealers and municipal facilities as manufacturing or fabrication scrap and end-of-life scrap. As indicated in Figure 2 for cradle-to-gate with recycling data, the upstream burdens from using ferrous scrap (scrap LCI) in making new steel are included as well as the credits for recycling steel scrap at the end of the final product's life. The methodology for calculating this burden and credit is included in section 3.6.2.

3.3.1 Technology coverage

Steel is produced predominantly by two process routes; the blast furnace/basic oxygen furnace route and the electric arc furnace route (the BOF and EAF routes respectively). Steelmaking technologies such as the open-hearth process, ingot casting of steel products and stainless steel production are not included.

The relevant steelmaking technology used for the study shall be clearly defined. Where a mix of technologies is used within a dataset, the data should be compiled on a weighted average basis (based on tonnage production), and the calculation rules shall be clearly defined and justified.

3.3.2 Geographic coverage

The primary data used for the study shall be representative of the geographical region of production.

Wherever possible, secondary data used for inputs to the processes shall be representative of the region the materials are sourced from. In particular, electricity generation must be chosen to be the most representative of either a specific supplier (if comparable to the actual composition of electricity used at a given location is known) or the most appropriate regional or national grid mix.

Where a mix of production locations is used within a dataset, the data should be compiled on a weighted average basis (based on tonnage production), and the calculation rules shall be clearly defined and justified.

3.3.3 Time coverage

The data collection is to be related to one year of operation and the time period for the data is to be clearly indicated. The period chosen shall be representative of current steel production.

Where use of a shorter period (minimum 6 months) is unavoidable, its use is to be clearly stated and justified, and any predictable variations due to seasons or operating patterns must be accounted for.

Primary data sets used in LCI studies shall not be more than 5 years old. Any secondary data used should be less than 10 years old unless its ongoing validity is justified.

3.4 Application of LCIA categories

An LCI study should set out to include as many inputs and outputs from the steel production route as reasonably possible so that any future LCA studies can consider a broad range of impact categories. The methodological aspects for key data categories are discussed in section 3.5.

Where an LCA study is being carried out, the impact categories shall be defined. Examples of general category descriptions are shown below. Studies applying the worldsteel methodology shall define and justify specific impact methodologies based on the goal and scope of the study. ISO requests that state-of-the-art methodologies are considered.

- Global warming potential (GWP)
- Acidification potential (AP)
- Eutrophication potential (EP)
- Photochemical oxidant creation potential (POCP) or smog formation potential
- Depletion of abiotic resources (elements) (ADP)
- Depletion of abiotic resources (fossil) (ADP)
- Ozone depletion potential (ODP)

Extra care should be taken when interpreting results or making comparisons with other materials, due to complexities in defining robust characterisation factors that can reflect local environmental conditions, speciation and exposure to emissions.

Normalisation, grouping and weighting are not part of the goal and scope of the worldsteel methodology. Where a study requires the inclusion of normalisation, grouping and/or weighting, this needs to be clearly defined in the goal and scope of the study being conducted. Where a single number is reported, the individual impacts shall also be reported. It should be noted that, according to ISO 14044: 2006, weighting shall not be used for LCA studies intended to support comparative assertions intended to be disclosed to the public.

3.5 Data collection

LCI data shall be collected according to the principles set out in ISO 14040: 2006 and ISO 14044: 2006. This section is intended to clarify the specific application of these principles to the worldsteel methodology.

3.5.1 Transport

The environmental burden of internal transportation is known to be relatively small. A review of a sample of sites in the original study showed an average of 0.001 litres of diesel was consumed (for internal transport) per kg of crude steel produced, corresponding to about

0.03MJ fuel energy per kg of steel product. The combustion of diesel consumed by on-site vehicles should nevertheless be included wherever possible, to ensure that all available data is included and so that assumptions are treated as conservatively as possible. Where it is not measured for individual process units, an aggregated figure should be applied to the LCI of the first crude steel product, or its equivalent.

For external transportation, the means of transportation and distances for the shipment of the main raw materials (in terms of tonnage) to the steelworks shall be recorded as the impacts can be significant. This will include transport by:

- Rail (electricity and diesel powered)
- Road
- Sea
- River

Transportation shall be included for key raw materials such as iron ore, coke, pellet, coal, scrap, limestone, lime and dolomite as well as steel intermediate products being transported between production sites. These raw materials represent more than 95% (w/w) of the total tonnage of inputs (excluding water).

Transportation of the steel product from the steelworks gate shall be included in the LCI for studies which extend beyond the production facility gate.

For studies which only model downstream steel processing, reasonable transportation estimates must be used for the steel used as the ingredient material.

3.5.2 Fuels and energy – upstream data

For all energy inputs (e.g. electricity, heating fuels, diesel for internal transportation), the country/region-specific upstream inventories should be used or any alternative inventory justified.

- The grid electricity production associated with individual sites can have a significant effect on the LCI, particularly regarding CO₂ emissions as well as other environmental issues such as biodiversity and radioactive waste.
- Coal data used should be as representative of the actual coal source as possible. The lower heating value (net calorific value, NCV) shall be used. The coal dataset shall consider the whole supply chain from coal mining to coal processing as well as transportation, and shall include net methane emissions from the coal mine.

3.5.3 Raw and process materials – upstream data

Data for processes outside of the steel industry, e.g. upstream raw material production or scrap processing, should be chosen with care, in order to ensure a high level of data quality. Where possible, primary data for significant upstream processes shall be used, otherwise use of generic data shall be documented.

3.5.3.1 Ferrous scrap recycling

When considering the recyclability of steel at the end of a final product's life, a burden, which describes the value of the scrap (Scrap LCI – see Appendix 2), is applied to the scrap input to the steelmaking process and a credit is applied for the amount of steel that will be recycled when the final product reaches the end of its life. This enables the practitioner to utilise steel product LCI data as 'cradle-to-gate-with-recycling' data, which excludes the final product manufacture and use phase. The allocation procedure for calculating this burden and credit is detailed in section 3.6.2.

Scrap input to the steelmaking process is defined in one of 3 ways in ISO 14021: 2016⁹:

- Internal scrap: steel scrap from the BOF or EAF steelmaking processes up to casting that is put back into the same EAF or BOF process.
- Pre-consumer scrap: material diverted from the waste stream during a manufacturing process. Excluded is reutilisation of materials such as rework, regrind or scrap generated in a process capable of being reclaimed with the same process that generated it (for the worldsteel methodology we refer to this as internal scrap, see above). Pre-consumer scrap includes:
 - o Home scrap: steel scrap from a downstream steelworks process (after BOF or EAF steel casting) that is put back into the BOF or EAF process.
 - o Fabrication scrap or manufacturing scrap from outside the boundary of the steelworks.
- Post-consumer scrap: material generated by households or by commercial, industrial and institutional facilities in their role as end-users of the product which can no longer be used for its intended purpose. This includes:
 - o End-of-life scrap from a product that reaches the end of its life

Contrary to ISO 14021: 2016, this **excludes** returns of material from the distribution chain.

3.5.3.2 Intermediate products from external supply

Semi-finished products (continuously cast products at the steelmaking stage) are sometimes purchased from an external supplier prior to further processing. Efforts should be made to link primary data from the supplier site with data from the customer site so that a representative LCI can be created. Where the source of semi-finished products is not known, a conservative assumption should be taken, in line with accepted LCA practice, to choose a regional or global available average LCI.

3.5.4 Emissions to air, water and soil

All known emissions to air, water and soil are to be accounted for when collecting site based foreground data. While the specific emissions measured will vary from site to site, the table below indicates those 'accounted emissions' which must be accounted for, or suitable substitutes reported.

	Accounted emissions	Flows
Air	Greenhouse gases	Carbon dioxide
	Acidification gases	Nitrogen oxides, sulphur oxides as sulphur dioxide
	Organic emissions	Volatile Organic Compounds (excluding methane)
	Metals	Chromium, manganese, lead, zinc
	Others	Carbon monoxide, particulates (total)
Water	Metals	Chromium, iron, lead, nickel, zinc
	Others	Phosphorus, Chemical Oxygen Demand, oil and suspended matter.

Table 3-1: Example accounted air and water emissions

The list in Table 3-1 includes the significant emissions which arise in different steelmaking processes and contribute to the main environmental impact categories such as global warming potential, acidification potential and eutrophication potential. The emissions relate to the steel production process as a whole, but should be dealt with on a process by process basis (not all flows are relevant for all processes). An updated list shall be generated based on the reporting companies for the study, together with the most up-to-date European Best Available Techniques (BAT) Reference Document for Iron and Steel production¹⁰ or relevant regional emissions references. Emissions shall be included where at least 50% of the sites have reported those emissions as this demonstrates technological consistency. The sites that do not report those emissions shall be provided with an average value from the sites that reported the data.

Regarding water emissions specifically, if the intake water is known to be polluted, the pollutant amounts in the intake should be subtracted from the pollutant amounts in the water released after waste water treatment because they are not attributable to the steelmaking processes.

Where data are not available for specific steelmaking processes, aggregated data are to be collected for the site's waste water treatment and these environmental burdens allocated directly to the first cast steel product or the equivalent base product for sites which only involve downstream processing.

3.5.5 Waste for disposal

Material disposed of in landfills, both internal and external to the steel works, and incinerated materials are classified as waste. All waste flows which are not modelled with specific fates shall be modelled as going to a generic conservative waste landfill process. In the previous worldsteel methodology, impacts from such wastes for disposal were not fully accounted for⁶.

3.5.6 Material for recovery

Materials which are recovered within the site shall be specified as an output from the process in which it is produced and as an input for the process where it is then re-used. The net balance of each material is then calculated in the model for each steel product. Apart from scrap and process gases, the net balance of these internally recycled materials should be generally small.

Materials exported from the site for external applications are classified as co-products (or material for recovery).

Some materials are partly waste and partly co-products. In such cases, the figures shall be included separately for each category. For material recovered, the application of the recovered material should also be included. Allocation procedures shall be applied only to the co-products which have market demand.

All material for recovery flows that do not have a reported use shall be modelled as a waste to landfill as per section 3.5.5 above. This is a conservative approach as it applies a landfill burden to the materials which are in fact recovered and which should therefore receive a credit. However, the quantities are small and the information on their final destination is often not known.

In the previous worldsteel methodology, impacts from material for recovery (which had not already been assigned to a recovery process) were not accounted for.

3.5.7 Data quality requirements

The quality of the data used in the models needs to be as high as practically achievable. Primary data is to be used for gate-to-gate production processes, and primary data should be utilised for upstream and downstream processes if possible, or otherwise sourced from reputable external databases and well documented.

As per ISO 14044: 2006 section 4.2.3.6., the following additional criteria should be addressed:

- Data should be collected over the period of 1 year and should be representative of the technology at the time of the study and at the most 5 years old. Any deviation from this should be justified and well documented.
- Data should be representative for the geographical area and technology mix defined in the goal and scope of the study and should be documented.
- The precision of the data collected should be regarded as +/- 5% unless otherwise indicated, based on the typical accuracy of industrial weighing equipment. Strong preference is given for measured data, followed by calculated and estimated data. Completeness of the primary gate-to-gate data should be in line with the cut-off criteria defined in section 3.5.8.
- The methodology should be applied uniformly to all processes and sites included in the study and data should be reproducible (by someone with access to the site data). Any uncertainty of the information (data, models, assumptions) should be documented where necessary.

Steps should be taken throughout data collection to verify that data sets are robust, reliable, representative and as free from error as is reasonably practicable.

3.5.8 Cut-off criteria

Cut-off criteria to be applied are as follows, to avoid the need to pursue trivial inputs and outputs in the system:

- All energetic inputs to the process stages are to be recorded, including fuels, electricity, steam and compressed air.
- Each excluded material flow must not exceed 1% of mass, energy or environmental relevance, for each unit process.
- The sum of the excluded material flows in the system must not exceed 5% of mass, energy or environmental relevance.

3.5.9 Flares

Process gases are sometimes sent to flare stacks and combusted rather than being used elsewhere due to variations in gas supply and demand and to the availability and practicality of gas collection facilities. As the combusted gases disperse without containment, measurement of these emissions is difficult. Estimates of these emissions are to be included in the LCI.

No manufacturing or economic benefits are realised from flaring, and the associated emissions are allocated entirely to the functional unit of the respective gas source module (e.g. coke oven gas, blast furnace gas and basic oxygen furnace gas).

3.5.10 Data validation

Data within the model shall be checked for completeness and accuracy by performing iron, carbon and mass balances as a minimum. The results are to be checked for consistency with known steelmaking practice, and differences should be explained. Other checks include unit checks, checking outliers of 2 standard deviations, clarification from data collectors etc. More detail is provided in the worldsteel data verification report.

3.6 Methodological details

3.6.1 Co-products

The main co-products for the coke ovens, blast furnace, BOF and EAF are listed in Table 3-2, together with the allocation method chosen. System expansion has been chosen by the steel industry as the approach used to incorporate co-products within the methodology and is described in further detail below. The processes being credited by the use of system expansion should be included in the study report.

Production process	Main co-products	Allocation method
Coke oven	Coke oven gas	System expansion
	Coke Benzene Tar Toluene Xylene Sulphur	System expansion
Blast Furnace	Blast Furnace gas Hot metal Slag	System expansion
Basic Oxygen Furnace (BOF)	BOF gas Crude steel Slag	System expansion
EAF	Crude steel Slag	System expansion

Table 3-2: Steelmaking co-products

3.6.1.1 System expansion method

System expansion is cited in section 4.3.4 of ISO 14044: 2006 as one of the preferred methods to use since it 'avoids' allocation. It is therefore the preferred method of the steel industry as it provides the most consistent solution to avoiding many of the problems of other approaches. It closely represents the real interactions of steel production routes with the environment and avoids unsound theoretical scenarios. Allocation rules are avoided by attributing all system inputs and outputs to the main system function (to produce hot metal) but credits are given for the production (net output) of process gases and slags (that are used outside the product boundary) because their production replaces the alternative production of similar functional products.

The challenge for the usage of system expansion, however, is in the choice and functional equivalence of the alternative systems selected. Great care shall be taken to understand how the co-products are used, and to ensure that alternative systems selected are consistent with actual practice, and where possible, based on average primary production that is offset through the use of the steel co-products. Sensitivity analyses should be conducted where system expansion has a significant impact on the results of the study.

3.6.1.2 Partitioning

Energy partitioning is used for allocation to the various products (electricity, hot water, steam, compressed air and blast air) at power plants and energy distribution systems within the steel production sites.

3.6.1.3 Alternative allocation choices

Some standards governing some LCI or LCA studies, for example for use in EPD (Environmental Product Declaration) programmes, exclude the use of system expansion so

that the LCI of co-products can be quantified, as an input into other product systems. Where this is the case, it is permissible to use the next best alternative, with appropriate documented justification, following the recommendations outlined in section 4.3.4.2 of ISO 14044: 2006. Examples of physical relationships that can be used for partitioning flows in steelmaking processes include energy (calorific value, sensible heat, chemical reaction energy), gangue content, iron content, etc. It is desirable that studies done in this manner would also include sensitivity assessment on the impact of the use of alternate allocation methods instead of system expansion.

3.6.2 Steel scrap

A key feature of the sustainability of steel is its inherent recyclability, without the inevitable consequence of downgrading to lower value products due to the recycling process. Provision of information on the environmental impacts and benefits of recycling is necessary as part of each LCI study. Consideration of the recyclability of steel products within an LCA study allows the final user of steel LCI data to consider all aspects of steel's production, and its contribution to future resource availability as part of a more holistic assessment.

A credit is given for the net scrap that is produced at the end of a final products life. This net scrap is determined as follows:

$$\text{Net scrap} = \text{Amount of steel recycled at end-of-life} - \text{Scrap input}$$

where the end-of-life recycling rate should be expressed as X tonnes of steel recycled per tonne of steel in the final product (this is commonly also expressed as a percentage). Scrap input should also be expressed as X tonnes of steel scrap input per tonne of steel produced. Using this equation, the LCI for future steel scrap being made available for recycling is considered to be the same as the scrap consumed today.

In this case the scrap input generally refers to the net scrap input, i.e. it does not consider the recirculating, internal or home scrap that is generated in the processes that are being studied, i.e. scrap from the hot rolling process that goes back into the BOF or EAF is not included as an external scrap input for hot rolled coil. Thus, the scrap input is often considered to be external or post-consumer scrap, i.e. scrap produced in processes downstream of the production of the steel product in question: on the steel plant, fabrication and manufacturing scrap as well as end-of-life scrap.

A closed loop approach can be applied for the recycling of steel, following ISO 14044: 2006 section 4.3.4.3, which describes the allocation procedures for closed loop material recycling.

As well as being in line with ISO 14044: 2006, this approach is also in line with EN 15804: 2012 + A1: 2013, assuming that the quality of the steel made by the EAF and BOF production routes is equivalent.

The Declaration by the Metals Industry on Recycling Principles¹¹ provides further interpretation of recycling as described in ISO 14044: 2006.

The general life cycle equation for this “closed material loop recycling methodology” is applied as shown by the equation below :

$$\text{LCI for 1 kg of steel product including recycling} = X - (RR - S) Y(X_{pr} - X_{re})$$

Where:

X is the cradle-to-gate LCI of the steel product

$(RR - S)$ is the net amount of scrap produced from the system:

RR is the end-of-life recycling rate of the steel product. This value is dependent on the goal and scope of the product being studied and the value selected should be justified.

S is the scrap input to the steelmaking process – this is the net scrap consumed in the steelmaking process and does not include internally generated scrap. Home scrap is considered when the scrap comes from a process which occurs on the steelmaking site, but does not contribute to any of the production stages of the product.

$Y(X_{pr} - X_{re})$ is the LCI value of steel scrap:

Y is the process yield of the EAF (more than 1kg scrap is required to produce 1kg steel).

X_{pr} is the LCI for 100% primary metal production. This is a theoretical value for steel slab made in the BOF route, assuming 0% scrap input.

X_{re} is the LCI for 100% secondary metal production from scrap in the EAF (assuming 100% scrap input).

Recycling credits should be reported separately to maximise transparency and to allow the assessment of when different impacts or benefits occur in the life cycle of products. In addition, recycling credits may also be reported in an aggregated form together with the cradle-to-gate LCI.

Further detailed explanation is provided in Appendix 2.

3.7 Interpretation

The results of the LCI/LCIA are to be interpreted according to the Goal and Scope, in section 3.1. The interpretation should address the following topics:

- Identification of significant findings such as the main contributors to the overall results or certain impact categories.
- Evaluation of completeness and sensitivity to justify the inclusion or exclusion of data from the system boundary or methodological choices.

- Sensitivity assessment of system expansion (or another justified allocation approach) on key co-products that influence the LCI.
- Conclusions, limitations and recommendations of the appropriateness of the definitions of the system function, functional unit and system boundaries.

3.8 Critical review

In order to ensure that this methodology correctly follows the methodology for life cycle assessments according to ISO 14040: 2006 and ISO 14044: 2006, a critical review by an external expert, Prof. Dr. Matthias Finkbeiner, according to ISO TS 14071: 2014¹² has been conducted. The critical review statement is included in Appendix 3.

Studies performed using this methodology shall also undergo critical review if they are to be used to support public assertions.

4. Appendices

Appendix 1:

Steel product manufacturing flow diagrams via the BOF and EAF routes

Appendix 2:

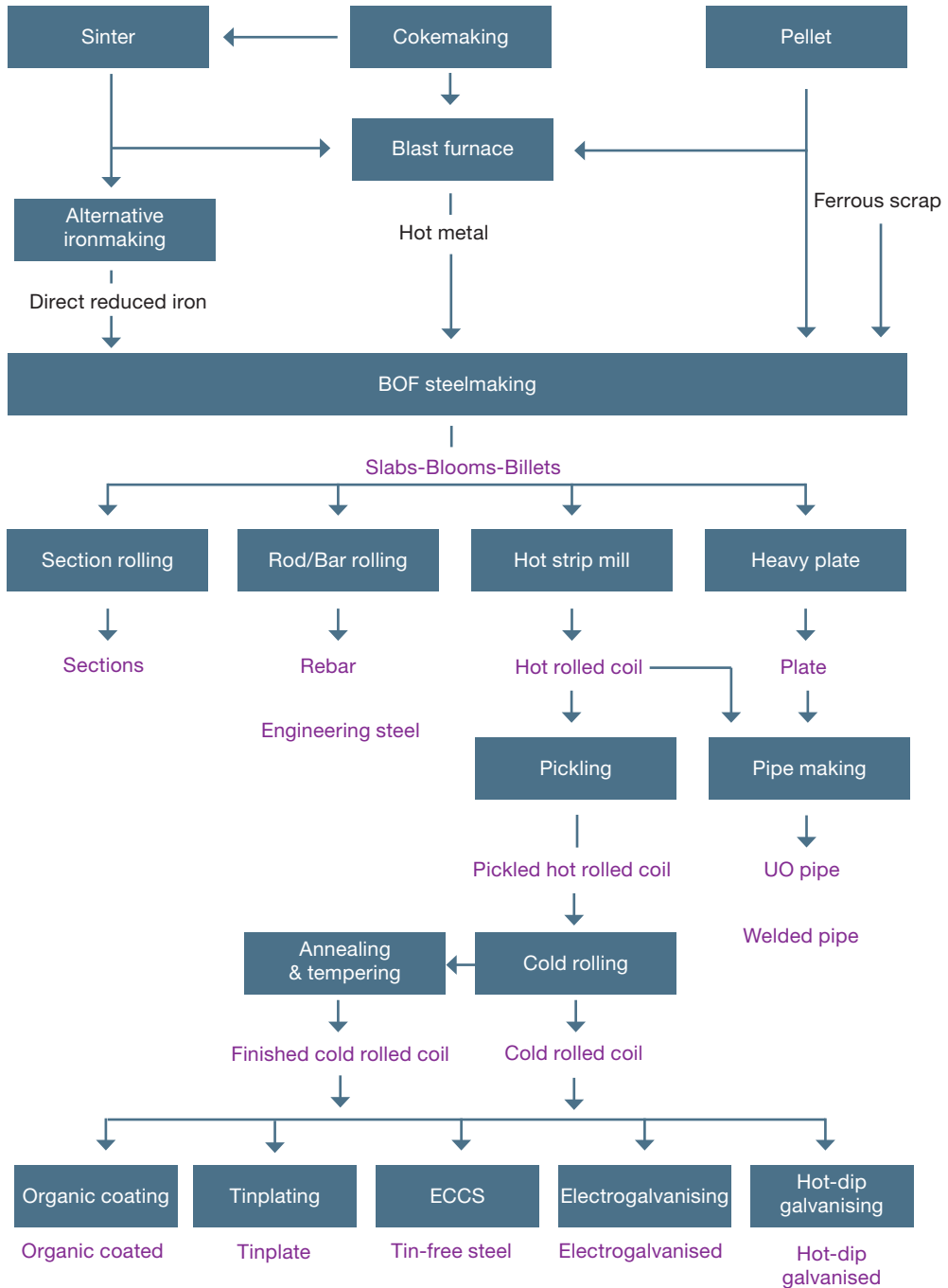
Recycling methodology description

Appendix 3:

Critical review statement

Appendix 1: Steel product manufacturing flow diagrams via the BOF and EAF routes

BLAST FURNACE ROUTE



Typical representation of steelmaking processes. **Process routes can vary; all routes not included.** Steel products highlighted in purple.

Appendix 2: Recycling methodology description

A2.1 Introduction

The World Steel Association (worldsteel) has developed an LCI database of steel products, which includes an approach to account for end-of-life recycling, to aid LCA practitioners modelling steel products in full cradle to grave life cycle assessments. This appendix explains how the closed material loop recycling methodology employed by worldsteel has been developed and how it can be used to generate product LCIs, including the end-of-life. The guidance given in this appendix is only advisory; other alternative methods are valid depending upon the goals and scope of the LCA study.

A2.2 Rationale for chosen recycling approach

The worldsteel LCI data collection methodology considers a cradle to gate approach, with the option of taking account of recycling in the following way:

- allocating for scrap inputs to the steelmaking process and
- allocating for steel scrap outputs from the whole product systems (e.g. scrap arising from an end-of-life building or vehicle).

Where systems have both scrap inputs and outputs, it is necessary to apply consistent allocation procedures to each and therefore the above-mentioned inputs and outputs of steel scrap can be treated symmetrically. This is assumed to be the case for the worldsteel methodology.

In formulating this methodology, worldsteel has followed ISO 14044: 2006, which sets out allocation procedures for reuse and recycling. Within this standard a distinction is made between open and closed loop recycling. Open loop recycling is used to describe product systems where material is recycled into a new different product or where inherent material properties change. Closed loop recycling applies to products that are recycled to produce the same product type or where the inherent material properties do not change. Where inherent material properties do not change, this is also known as closed material loop recycling.

The vast majority of steel recycling involves re-melting scrap to produce new steels with no change in the inherent properties of the basic steel material and therefore steel recycling can be regarded as closed loop. In this situation ISO 14044: 2006 states that 'in such cases the need for allocation is avoided since the use of secondary material displaces the use of virgin (primary) materials'. This guidance provides the basis for the 'closed material loop' recycling methodology and is the recommended method when carrying out a full cradle to grave LCA study incorporating the end-of-life.

A2.3 Recycling approaches

There are many ongoing discussions about different ways in which recycling can be considered and there are a few standards or methodologies that consider recycling in different ways. Some examples are:

- World Resources Institute / World Business Council for Sustainable Development standards developed under the GHG Protocol Initiative¹³
- PAS 2050 (Publicly Available Specification 2050: Specification for the assessment of the life cycle greenhouse gas emissions of goods and services), British Standards Institute, Carbon Trust, DEFRA¹⁴
- European Standard EN 15804: 2012: Sustainability of construction works. Environmental product declarations. Core rules for the product category of construction products¹⁵
- ISO/TS 14067: 2013: Greenhouse gases - Carbon footprint of products¹⁶
- The European Commission's Product Environmental Footprint Guidance, 2017¹⁷
- ILCD: The European Commission's International Reference Life Cycle Data System Handbook¹⁸
- ISO 21930: 2017: Sustainability in building construction - Environmental declaration of building products¹⁹

The two main approaches to recycling which form the basis for many discussions are:

- **Cut-off approach (100-0)**

The cut-off approach considers the impacts and/or benefits of recycling that only occur within the product system being studied. There is no crediting or assignment of environmental impacts between different product systems and material scrap at the point of discard is considered to have no upstream environmental impacts beyond re-melting. This is also known as the recycled content method because the benefits of material recycling are only taken into account on the input side (considered as being 'free') and recycling at end-of-life is neglected regardless of recycling rate. From a policy perspective, this method leads to a focus on increasing the percentage of recycled materials in the product. Figure A2-1 shows how the cut-off approach would be applied for each stage of the life cycle; the impacts from the disposal of steel, if any, are negligible.

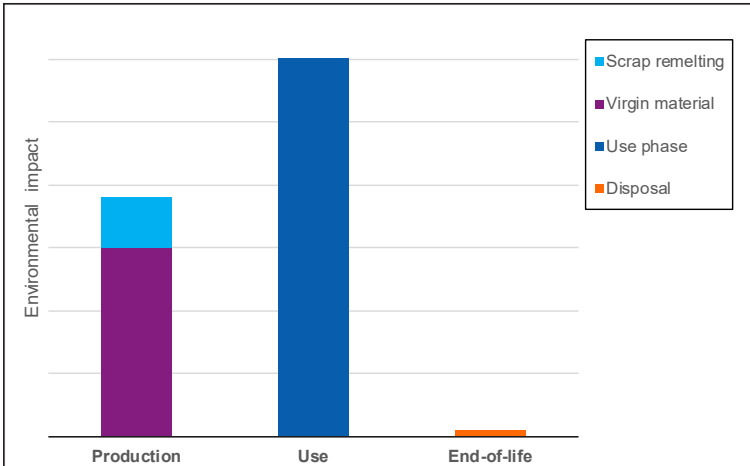


Figure A2-1: Cut-off approach for a product system that uses both virgin metal and recycled metal inputs

- **End-of-life approach (0-100)**

The end-of-life approach takes an overall approach to recycling as it considers the assignment of environmental impacts and credits between different product systems across different life cycles and the environmental impact of the product system is dependent on the recycling rate at end-of-life. Another way of thinking about this method is in terms of system expansion where the boundary of the study is extended to include another product system. Where a material is recycled at end-of-life, the product system is credited with an avoided burden based on the reduced requirement for virgin material production in the next life cycle. Equally, any recycled content adds the same burden to the product system in order to share the burden with the previous life cycle. This method is also known as the closed material loop method because recycling saves the production of virgin material with the same properties. The approach is particularly relevant for metals such as steel (Section A2.5) where recycling rates of end-of-life products are known. From a policy perspective, this method leads to a focus on recycling at end-of-life and promotes the concepts of the circular economy. Figure A2-2 shows how the end-of-life approach would be applied for each stage of the life cycle; the impacts from the disposal of steel, if any, are negligible.

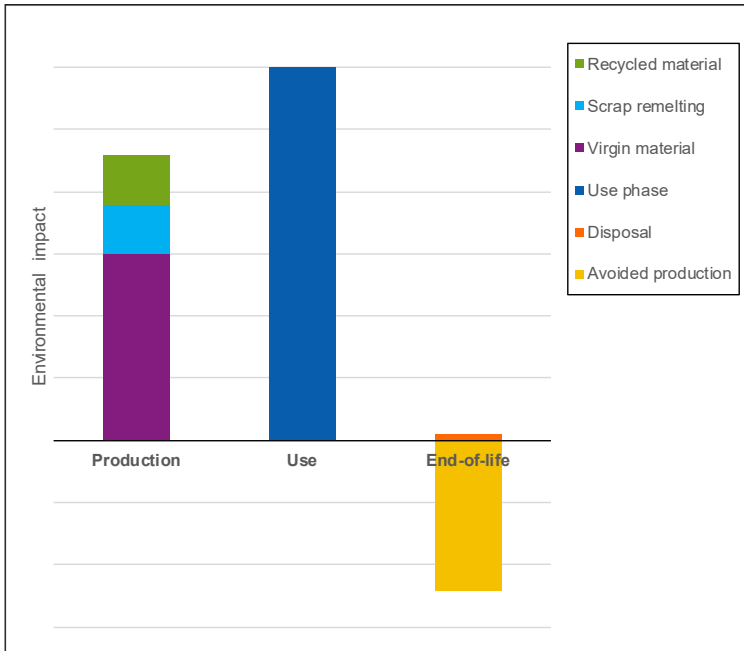


Figure A2-2: End-of-life approach for a product system that uses both primary and recycled steel inputs

A compromise approach is sometimes offered, referred to as the 50-50 method. This position represents the arbitrary half-way point (on a spectrum) of modelled approaches that compromises the two extreme approaches:

The 50:50 method falls half way in between the cut-off approach and end-of-life approach. For this reason, it is seen as a compromise method, which credits both recycled content and end-of-life recycling. This method, although a compromise, can be a solution for systems where it is not clear if it is beneficial to provide incentives for recycled content or recycling at end-of-life.

The Declaration by the Metals Industry on Recycling Principles¹¹ clearly defines the distinction between the recycled content approach and the end-of-life approach and why the latter is supported by the metals industry.

A2.4 Steel recycling practices

To help to understand the rationale behind the closed loop recycling methodology, it is useful to first explore steel recycling practice. In the manufacture of steel the term 'primary production' generally refers to the manufacture of iron (hot metal) from iron ore in a blast furnace (BF), which is subsequently processed in the basic oxygen furnace (BOF) to make steel. 'Secondary production' refers to the 'recycling' route, and is typically the electric arc furnace (EAF) process, which converts scrap into new steel by re-melting old steel. However, primary steel production is not unique to the BOF route and similarly secondary steel production is not unique to the EAF. For example, it is common practice to use 10-30% scrap

as iron input in the BOF route. Primary steel production occurs in the EAF route also, when pre-reduced iron is used as a feedstock to the EAF process.

Figure A2-3 shows that both the EAF and BOF processes produce primary and secondary steel.

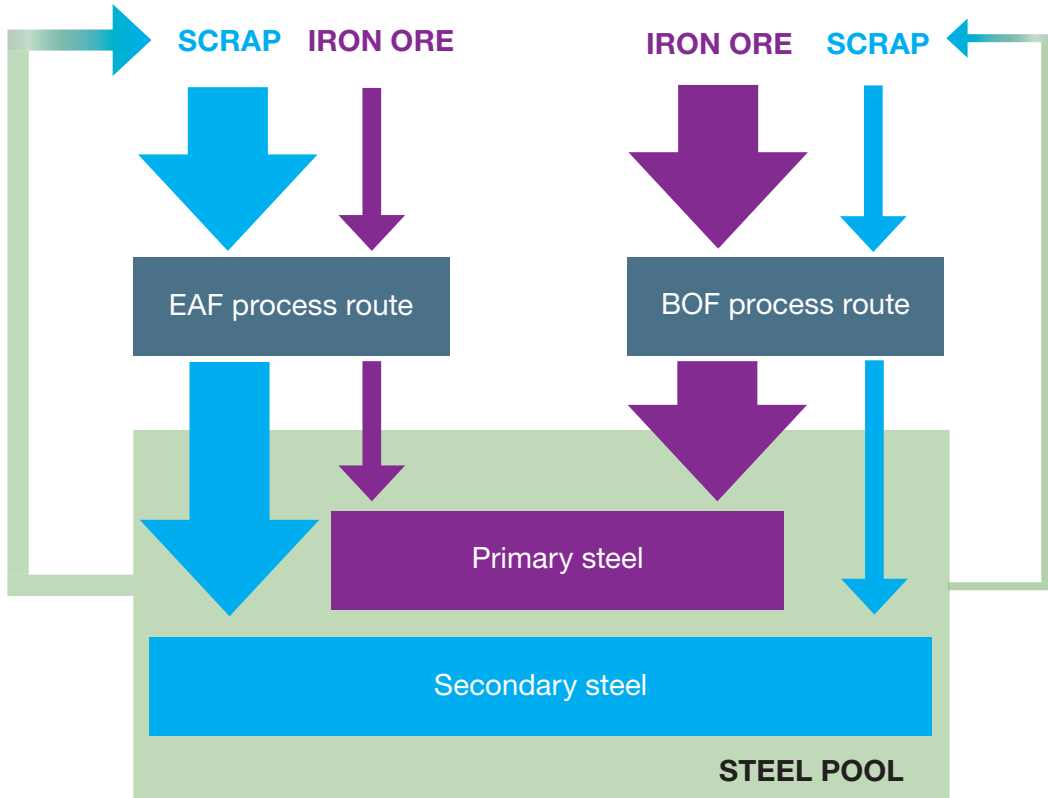


Figure A2-3: Typical connection between primary and secondary steel production

Steel is 100% recyclable and scrap can be converted to the same (or higher or lower) grade steel depending upon the metallurgy and processing of the recycling route. Some recycled products such as rebar require minimal processing whilst the higher value engineering steels require more metallurgical and process controls to meet tighter specifications. The final economic value of the product is not determined by recycled content and there are many examples of high value products that contain large amounts of recycled steel. Some steel products are principally sourced via the primary route mainly because the steel specifications require low residual elements and this can be achieved most cost-effectively using more primary material. In most cases scrap with a low amount of residual elements commands a higher market price owing to the ease of processing through the recycling routes.

The growing world demand for steel means that there is a continuing capacity to absorb steel scrap. History has shown that there has not been enough scrap arising to manufacture all the steel required to satisfy the market. This is not a consequence of deficiencies in collecting scrap as the recovery rates of steel products are high.

A2.5 Closed material loop recycling

The choice of recycling methodology can depend on not only the goal and scope of the study but also the recycling system for the material used in the product life cycle. In the worldsteel methodology, the rationale for applying the closed material loop method as default is:

1. Steel scrap has significant economic value which means that where scrap is recovered it will be used for recycling. This means that there is no requirement to create a demand for recycled material as this market is already well established.
2. Steel is recycled in a closed material loop such that the inherent properties of the primary and secondary product are equivalent. In other words, the production of secondary material displaces primary production.
3. The magnitude of steel recycling is driven by end-of-life recycling rates and an end-of-life approach captures the impact of different recycling rates in different regions and for different end-product categories.
4. The demand for steel scrap exceeds the availability of the scrap. This is magnified partly due to the long lifetime of steel products. Designing products for easier end-of-life disassembly and recycling will enable more steel scrap to be recycled.

Using the closed material loop methodology, recovered steel scrap for recycling is usually allocated a credit (or benefit). When scrap is used in the manufacture of a new product there is an allocation (or debit) associated with the scrap input. In this way, the benefit of net scrap arising or the debit of net scrap input can be accounted for. Based on guidance from ISO 14044: 2006 this scrap is allocated a value associated with avoided impacts such as an alternative source of equivalent (virgin) ferrous metal.

In the case of steel, the best approximation for the virgin product replaced by using scrap is the first recognisable steel product, which is cast steel or steel slab. In this case, it can be argued that secondary steel from scrap (in the EAF route) avoids primary steel from the BOF route. With this approach the allocation for scrap needs to be adjusted to take account of the scrap/steel yield associated with secondary steelmaking.

The worldsteel methodology follows the end-of-life approach because it accounts for the full life cycle of a product, from cradle to grave, the grave being the furnace into which the end-of-life steel scrap is recycled back into.

A2.6 worldsteel methodology

The worldsteel methodology for the use of steel scrap in the steelmaking process and the production of steel scrap at the end-of-life of a product is described in detail in the following sections.

A2.6.1 Terminology required

A number of parameters need to be defined relating to steel and recycling which will be used in the following explanations.

The main terms are as follows:

- i) Recovery rate (RR): the fraction of steel recovered as scrap during the lifetime of a steel product and includes any scrap that is generated after manufacturing the steel product under analysis.
- ii) Metallic yield (Y): the process yield (or efficiency) of the EAF process. It is the ratio of steel output to scrap input (i.e. >1kg scrap is required to produce 1kg steel).
- iii) LCI for primary steel production (X_{pr}): the theoretical LCI for 100% primary metal production, from the BOF route, assuming 0% scrap input.
- iv) LCI for secondary steel production (X_{re}): the LCI for 100% secondary metal production from scrap in the EAF, assuming 100% scrap input.
- v) The letter X in each of these terms refers to any LCI parameter, e.g. natural gas, CO₂, water, limestone etc.
- vi) S is the amount of scrap used in the steelmaking process to make a specific product.

A2.6.2 The LCI of steel scrap

The worldsteel methodology assumes the burdens of scrap input and the credits for recycling the steel at the end of the life of a product are equal, per kg, and that all scrap is treated equally. In reality there are numerous grades of steel products and steel scrap but it is not feasible to calculate an LCI for each grade.

Collecting scrap at the end of the product's life and recycling it through the steelmaking process enables the saving of primary, virgin steel production.

This is commonly referred to as the integrated or BOF steelmaking route, but in reality, some steel scrap is always required in the process. Thus, there is no process using 100% virgin material (with 0% scrap input) and this theoretical value therefore needs to be calculated (see section A2.6.3).

Furthermore, it is not the scrap itself that replaces this primary steel, as the scrap needs to be processed or recycled to make new steel. The EAF process is an example of 100% scrap recycling, though some EAFs also use hot metal or DRI (direct reduced iron) as an input to the process.

And finally, the EAF process is not 100% efficient, i.e. it needs more than 1 kg of scrap to make 1 kg steel.

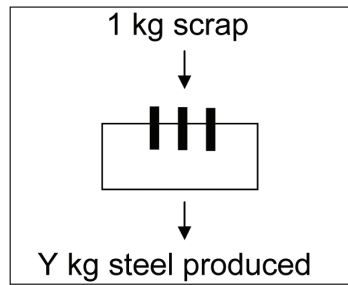


Figure A2-4: The yield of the EAF process

The LCI associated with the scrap is thus equal to the credit associated with the avoided primary production of steel (assuming 0% scrap input), minus the burden associated with the recycling of steel scrap to make new steel, multiplied by the yield of this process to consider losses in the process:

$$ScrapLCI = (X_{pr} - X_{re})Y$$

X_{pr} = the theoretical LCI for 100% primary metal production, from the BOF route, assuming 0% scrap input.

X_{re} = the LCI for 100% secondary metal production from scrap in the EAF, assuming 100% scrap input.

The letter X in each of these terms refers to any LCI parameter, e.g. natural gas, CO_2 , water, limestone etc. To calculate the CO_2 for scrap would therefore be done as follows:

$$CO_2Scrap = (CO_{2pr} - CO_{2re})Y$$

Y is the process yield of the EAF (more than 1kg scrap is required to produce 1kg steel).

The values for X_{re} and Y are known by the industry as these values come from the worldsteel LCI data collection exercise, from the steel producing companies. However, the theoretical value of X_{pr} needs to be calculated.

A2.6.3 Theoretical value of 100% primary BOF steel, X_{pr}

This can be calculated based on the LCI of steel slab made by the primary, or BOF route, which is calculated by worldsteel based on actual data provided by the steel producing companies. As the steel slab contains a certain amount of scrap, this needs to be 'removed' from the LCI so that only virgin steel is accounted for.

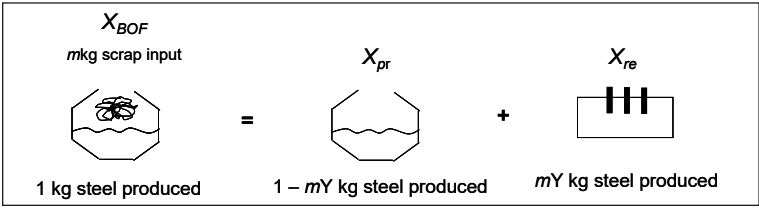


Figure A2-5: Theoretical value of X_{pr}

The scrap input to the BOF process (m kg scrap per 1 kg steel produced) that needs to be 'removed' would be melted in the EAF process producing mY kg steel, Y being the yield of the steelmaking process. Therefore, the theoretical 100% primary route, X_{pr} , needs to produce 1-mY kg steel.

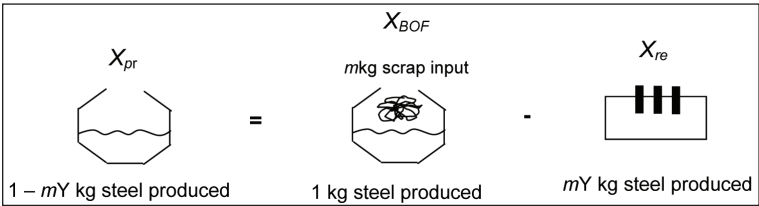


Figure A2-6 Theoretical value of X_{pr}

In effect:

$$X_{BOF} = (1 - mY)(X_{pr}) + mYX_{re}$$

m = scrap input to the BOF route ($Scrap_{BOF}$) and $Y = \frac{1}{Scrap_{re}}$

Therefore, $mY = \frac{Scrap_{BOF}}{Scrap_{re}}$

This would then give the following:

$$X_{BOF} = \left(1 - \frac{Scrap_{BOF}}{Scrap_{re}}\right)(X_{pr}) + \left(\frac{Scrap_{BOF}}{Scrap_{re}}\right)X_{re}$$

Rearranging this equation will enable the theoretical value for 100% primary steel to be calculated:

$$X_{pr} = \frac{X_{BOF} - \left(\frac{Scrap_{BOF}}{Scrap_{re}} X_{re} \right)}{1 - \frac{Scrap_{BOF}}{Scrap_{re}}}$$

This value for X_{pr} can now be included in the scrap LCI equation and will therefore be applied to each of the inputs and outputs of the LCI.

It should be noted that if an extrapolation was carried out to determine the theoretical value for X_{pr} with zero scrap input, based on the values of X_{BOF} and X_{re} , the same value would be reached for X_{pr} .

A2.6.4 Applying the scrap LCI burden and credit

The scrap LCI, defined as $ScrapLCI = (X_{pr} - X_{re})Y$ is applied to the steel product cradle to gate LCIs in order to include the end-of-life phase. A credit is given for the steel scrap that will be recycled at the end-of-life of the product, and this is referred to as RR. However, in doing this, a burden needs to be applied to any scrap that is used in the steelmaking process, referred to as S.

Thus, the LCI of a product, from cradle to gate including end-of-life, can be calculated as:

$$LCI_{includingEoL} = X - (RR - S)(X_{pr} - X_{re})Y$$

Where X is the LCI of the product being studied, and is cradle to gate, i.e. including all upstream as well as steel production.

It is recommended that the recycling credits are reported separately to maximise transparency and to allow the assessment of when different impacts or benefits occur in the life cycle of products. Recycling credits may also be reported in an aggregated form together with the cradle-to-gate LCI.

Appendix 3: Critical review statement

Commissioned by: World Steel Association (worldsteel), Brussels, Belgium

Reviewer: Prof. Dr. Matthias Finkbeiner, Berlin, Germany

References:

- ISO 14040 (2006): Environmental Management - Life Cycle Assessment - Principles and Framework
- ISO 14044 (2006): Environmental Management - Life Cycle Assessment – Requirements and Guidelines
- ISO/TS 14071 (2014): Environmental management -Life cycle assessment - Critical review processes and reviewer competencies: Additional requirements and guidelines to ISO 14044:2006

Scope of the critical review

The requirements and guidelines of the reference standards apply to LCA studies. The document reviewed here is not an LCA study per se, it is a methodology guidance document, that is intended to be used in LCA studies of steel products. As such, the scope of this critical review had to be adapted to this intended application. The reviewer had the task to assess whether:

- the methodology proposed is consistent with the international standards ISO 14040 and ISO 14044,
- the methodology is scientifically and technically valid,
- the methodology is appropriate and reasonable in relation to the intended application,
- the technological coverage is representative of the steel industry,
- the methodology required for interpretations reflects the pertinent limitations, and
- the methodology report is transparent and consistent.

The review was performed according to paragraph 6.2 of ISO 14044, because the methodology as such is not intended to be used for comparative assertions intended to be disclosed to the public. This does not preclude that the methodology may be used in studies where comparative assertions are made, provided a separate panel review of that study is carried out. This review statement is only valid for this specific report in its final version received on 4 September 2017.

Due to the scope described above, an analysis of LCI models or the verification of individual datasets are not applicable to this review.

Review process

The review process was coordinated between worldsteel and the reviewer. The first draft of the methodology report was submitted to the reviewer on 7 June 2017. The reviewer provided 36 comments of general, technical and editorial nature to the commissioner by the end of June 2017. After personal and email communication to clarify some of the comments, worldsteel provided an updated methodology report addressing all comments on 29 August 2017. The feedback provided and the agreements on the treatment of the review comments were properly adopted in this version of the methodology. Just three minor clarifications were requested by the reviewer for the finalisation of the methodology. The final version of the methodology report was provided on 4 September 2017. All critical issues and the majority of recommendations of the reviewer were addressed in a comprehensive manner.

The reviewer acknowledges the unrestricted access to all requested information as well as the open and constructive dialogue during the critical review process.

General evaluation

This methodology report is the result of a cooperative effort of the leading steel producers in the world organised by its global industry association, worldsteel. The current methodology report is the third update of the methodology, while it is published as a separate document for the first time. In the first publication from 1995/6 the methodology was published together with the steel LCIs. Methodology and data were updated in 2000/1 and 2011. As a result, the methodology has reached a high level of maturity.

The decision to publish the methodology independent from the LCIs was motivated by the intention to enable third parties to use this methodology for their studies and to simplify the publication of future worldsteel LCI updates as the study reports can be generated independently of the methodology report. For the updated worldsteel LCI data following this methodology, a separate study report is produced.

The guidance provided in the methodology report is comprehensive and well documented. The methodological choices are deemed to be representative and appropriate for the global production of steel. The defined methodological scope was found to be appropriate for the intended application.

Conclusion

The methodology is suitable for carrying out LCA studies in conformity with ISO 14040 and ISO 14044. The reviewer found the overall quality of the methodology to be mature and of a high standard for the intended application. The methodology is reported in a comprehensive manner including a transparent documentation of its scope and methodological choices.



Matthias Finkbeiner
14 September 2017

References

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- ³ IISI World Steel Life Cycle Inventory Study Report. Brussels 1996
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- ⁷ Product description for steel products available from worldsteel website: <https://www.worldsteel.org/en/dam/jcr:3a47cc15-21c2-4bac-bb3d-876ef332708e/Steel+products+description.pdf>
- ⁸ Product use matrix available from worldsteel website: <https://www.worldsteel.org/en/dam/jcr:efa1f2d6-f1a2-453f-86b7-1e8c804ce6a9/Life+cycle+inventory+for+15+steel+products+classified+by+sector.pdf>
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- ¹⁶ ISO 14067 ISO/TS 14067: 2013: Greenhouse gases - Carbon footprint of products – Requirements and guidelines for quantification and communication
- ¹⁷ European Commission Joint Research Centre: Product Environmental Footprint Guidance Document 6.2, 2017
- ¹⁸ European Commission: Joint Research Centre: International Reference Life Cycle Data System Handbook: 2012
- ¹⁹ ISO 21930: 2017: Sustainability in building construction - Environmental declaration of building products; Geneva

World Steel Association

Avenue de Tervueren 270
1150 Brussels
Belgium

T: +32 2 702 8900
F: +32 2 702 8899
E: steel@worldsteel.org

C413 Office Building
Beijing Lufthansa Center
50 Liangmaqiao Road
Chaoyang District
Beijing 100125
China

T: +86 10 6464 6733
F: +86 10 6464 6744
E: china@worldsteel.org