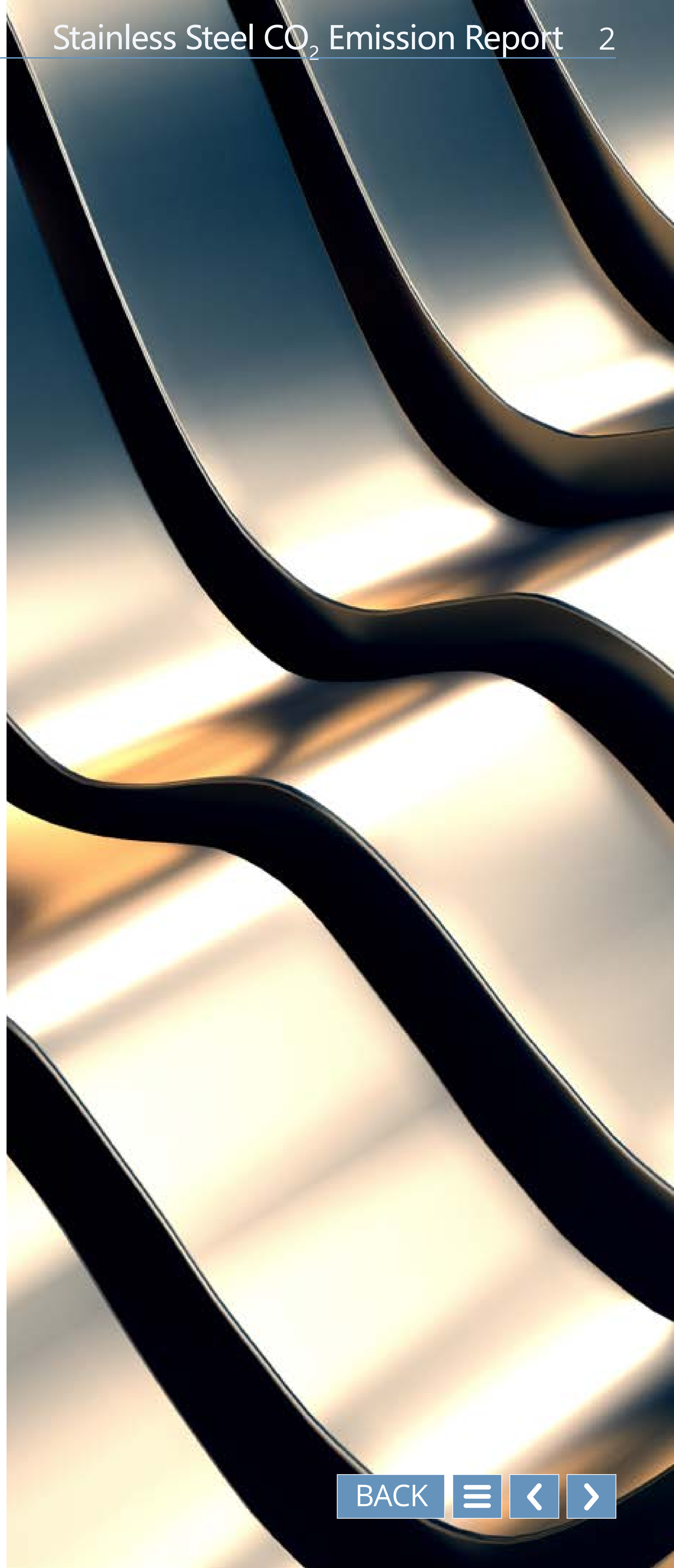
CO_2 Emissions Report

Industry emissions and related data

worldstainless

Contents



Introduction

September 2024

Like any other major industry, the stainless steels industry consistently endeavours to reduce its operational CO_2 emissions year-on-year. Industry direct emissions (known as Scope 1) and indirect emissions (known as Scope 2) have, due to solid industry improvement efforts, progressively reduced over the last decade.

In order to understand emissions associated with the production of stainless steels, it should be noted that within the stainless steels industry there are essentially two active production systems, namely:

- The scrap-based production system in which the bulk of used raw materials are end-of-life stainless steels and/or similar alloy materials that are recycled to produce new stainless steels.

  This production system is aligned to geographical locations where the availability of end-of-life materials and scrap is high.

- The Nickel Pig Iron (NPI) production system in which the bulk of the Nickel units required for stainless steel production is not derived from stainless steel scrap, but from extracted Nickel ores which are then converted into NPI. This production system is primarily but not exclusively aligned to geographical locations where the availability of stainless steel scrap is currently low. NPI is often also known as Iron-Nickel.

There is currently insufficient 'available-to-use' end-of-life stainless steel scrap in all regions of the world to permit only scrap-based production to exist. This situation is likely to remain true for the foreseeable future.

The purpose of this document therefore is to clarify what production emissions exist and where they originate from and in order to achieve these objectives, we have quantified the CO_2 emissions from the following three sources.

- Scope 1 Emissions which covers direct emissions from business-owned or business-controlled emission sources (as described above).
- Scope 2 Emissions which covers indirect emissions from the generation of purchased electricity, steam, heating and cooling consumed by the reporting company (as also described above).
- Scope 3 Emissions which are associated with the extraction, preparation and transport of ores and the subsequent production and transport of ferro-alloys including the energy needed for these processes.

  Special Note; There is no data currently available from stainless steel producers for the emissions associated with the extraction of Nickel ores and the subsequent production of Nickel Pig Iron (NPI). This situation is due to current country-specific legally-imposed disclosure restrictions. However, some of this data is available from industry research groups and as such, this data has been used to provide some 'indicative guidance numbers' later in this report.

These above-described three sources allow us to provide a cradle to gate view of the stainless steel industry's CO_2 emissions.

General Facts

Stainless steel is the term used to describe a remarkable and extremely versatile family of metals that contain a minimum of 10.5 % chromium. Chromium is essential to achieve the metal's "stainless" (or corrosion resistant) properties. Other alloying elements including nickel, molybdenum, titanium and copper provide a wide range of mechanical and physical properties.

Stainless steel has applications that range from household cutlery to reactor tanks for the chemical industry. Stainless steel's resistance to corrosion and staining coupled with highly prized other attributes which deliver low in-service maintenance and 100 % recyclability make it an ideal base material for many applications. Indeed, its mechanical properties permit the easy adoption of stainless steels in buildings and other key applications including railways, subways, tunnels and bridges. Food storage tanks and transport vehicles are often made of stainless steel because it is easy to clean and has excellent hygienic properties. This leads to the use of stainless steel in commercial kitchens and food processing plants, as it can be steam cleaned, sterilised, and does not ever need any additional surface treatment.

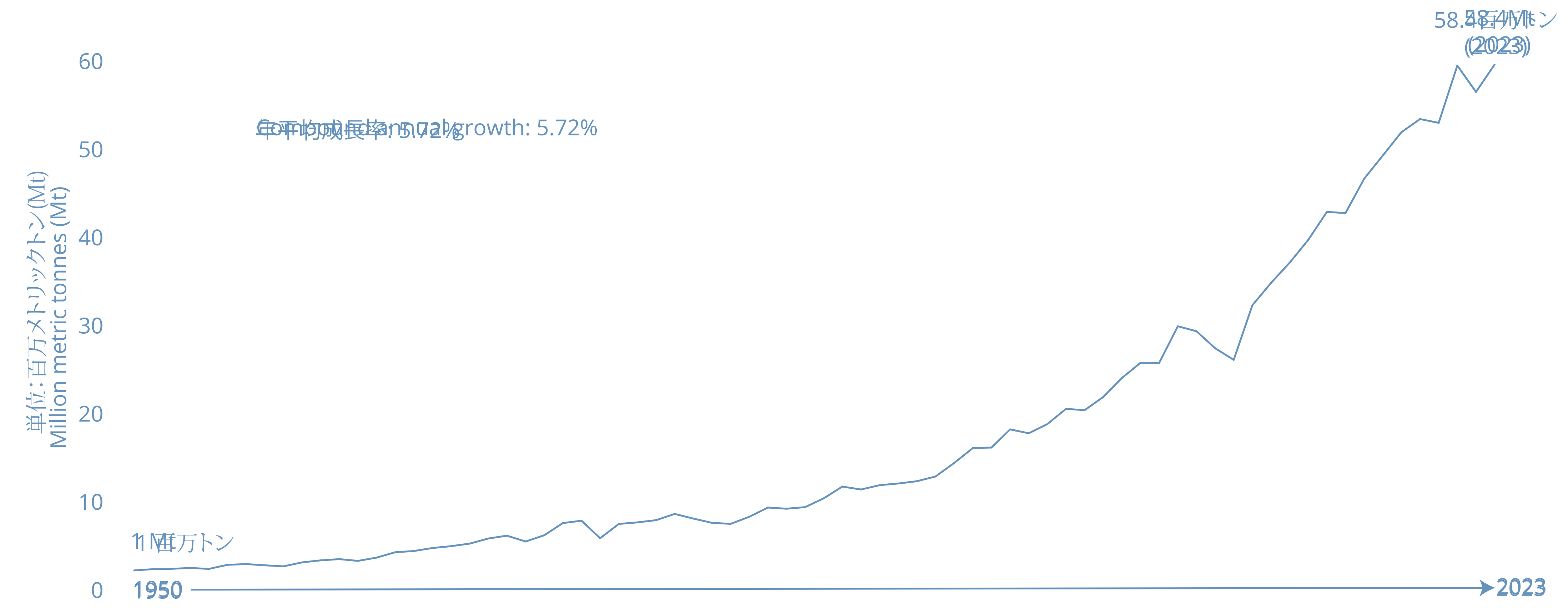
For the stainless steel industry, scrap has a high intrinsic value. The only limitation is the availability of scrap, especially in emerging economies. Furthermore, the durability of stainless steel restricts the availability of scrap. For example, when stainless steel is used in buildings, it remains there for many decades and therefore cannot be reused before the building is demolished or dismantled.

Stainless steel is 100 % recyclable and has one of the highest recycling rates of any material. It has been determined that at least 95 % of stainless steels are recycled at the end of their life (see Table 1).

Depending on the type, location and availability of stainless steel scrap, production via the EAF route can be economically advantageous. In addition, the recycling system for stainless steel is very efficient and requires no subsidies.

Over the past 20 years the world has produced approximately 800 million metric tons of stainless steel (worldstainless, 2024). World annual production increased from 25 million tonnes to over 58 million tonnes over the same time period. (see Figure 1) The growth in the use of stainless steel has been the highest of any bulk formable material in the world (worldstainless, 2023). Stainless steel's properties, such as its 100 % recyclability,

Figure 1 Global stainless steel production 1950 - 2023
Data source: worldstainless, 2024



reusability, durability, corrosion resistance, extremely low maintenance needs and product safety partly explain this amazing consumption growth.

Figure 2 shows that the flow of stainless steels are connected by the generation and use of scrap. According to the recently completed KIT Stocks and Flows study, 95% of end-of-life stainless steels are collected for recycling. Of that annual collected end-of-life stainless steels, 74% is directly reused to make new stainless steels and 21 % is reused to make new Carbon and Low Alloy steels.

At a global level almost 50 % of the materials to produce stainless steel are scrap materials (stainless steels and carbon steel scrap) and other raw materials make up around 50 % of the material used to produce stainless steel. The research carried by KIT (2022) also provides key estimates of the life cycle of stainless steel products in six main application sectors (see Table 1).

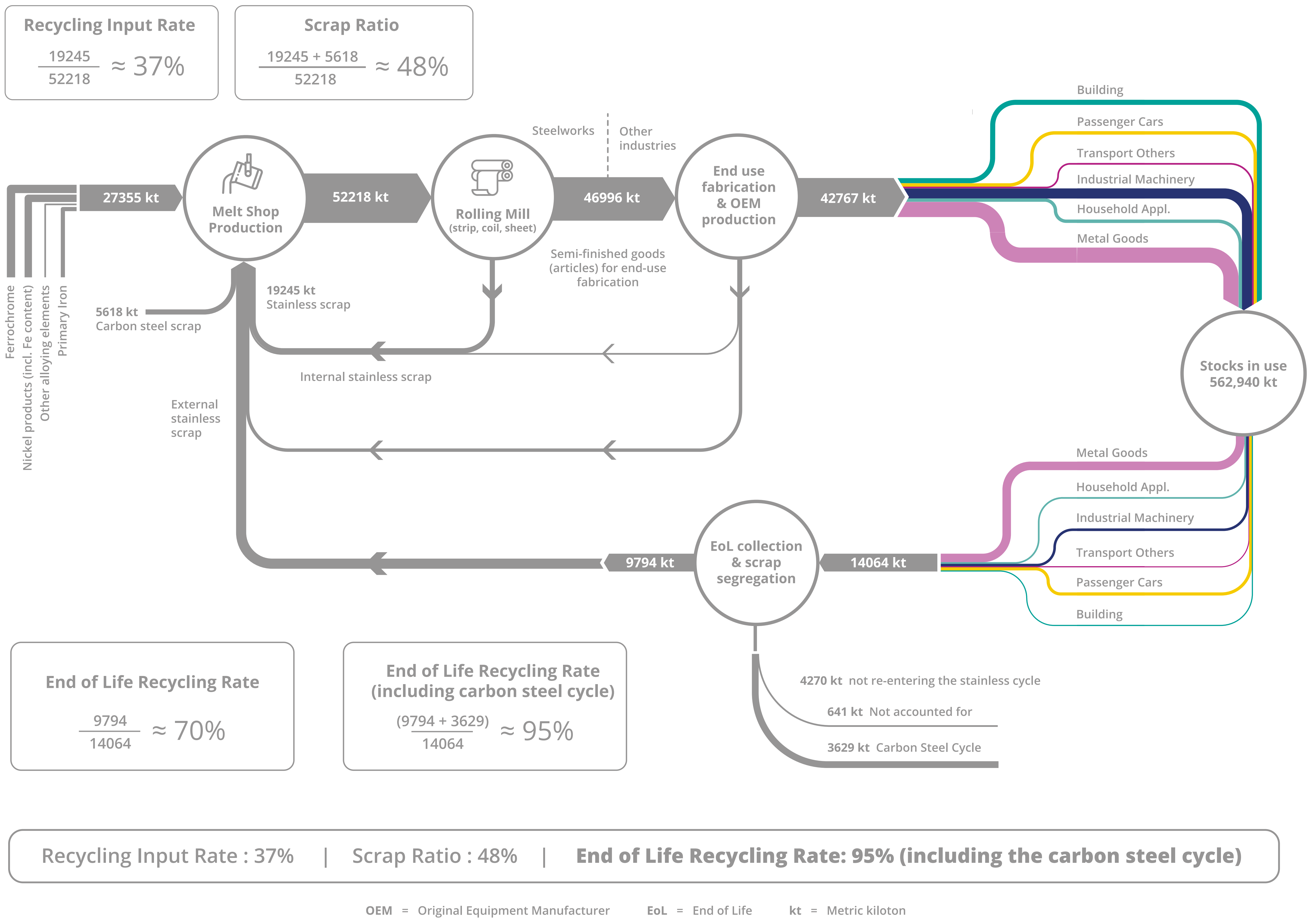
Table 1 Average service life of stainless steels
Data source: KIT and Team Stainless, 2022

Usage sector	Average service life (in years)	Primary replacement drivers
Building & infrastructure	50	Degradation of co-materials
Passenger cars	14	Modernisation trends and marketing
Other transportation	30	Degradation of co-materials
Industrial machinery	25	Degradation of co-materials
Household appliances	15	Fashion and marketing
Metal goods	15	Modernisation trends

Figure 2 Life cycle of stainless steel for the year 2019.

The diagram shows the life cycle of stainless steel from input of raw materials, through steelmaking to fabrication of items in various end-use sectors. It also shows the flow of stainless steel scrap to make new stainless steel or carbon steel. Data is based on calendar year 2019 before the COVID pandemic distorted global manufacturing

Source: KIT and Team Stainless 2022



CO_2 Emissions

Over the last few decades, carbon dioxide emissions have been recognized as a major concern in our society. As a direct consequence, new environmental policies have been established to control and measure CO_2 emissions. The stainless steels industry, just like any other industry, quantifies and communicates its CO_2 production emissions performance.

Recent sustainability studies conducted by worldstainless (between 2007 and 2024) show that emissions from the production and use of stainless steels are generally low. However, and in order to clearly quantify the CO_2 emissions during the production of stainless steel, we will identify the CO_2 emissions from the categories previously defined as Scope 1, Scope 2 and Scope 3.

It is important to remind our readers that the presented emissions data is highly representative of the scrap-based (recycled content) producers. The calculated data for Nickel Pig Iron (NPI) based producers is for indicative guidance only.

Scope 1 Emissions

The current scrap-based producer average is 0.41 tonnes of CO_2 per tonne of stainless steel produced. 85 % of the producer results sit (normally distributed) in the range 0.20 to 0.50 tonnes of CO_2 per tonne of stainless steel produced. In 2012 the average figure was 0.43 tonnes of CO_2 per tonne of stainless steel produced.

Scope 2 Emissions

The current scrap-based producer average is 0.39 tonnes of CO_2 per tonne of stainless steel produced. The figure has dropped from the average figure reported in 2023 which was 0.45. Changes in the regional energy grid mixes have positively impacted on Scope 2 emissions and thereby the figure has started to become lower than it historically was.

Scope 3 Emissions

Scope 3 emissions cannot be defined in the same manner. We know that there is a linear relationship between the amount of recycled content (scrap stainless steel and scrap low alloy steels) charged and the magnitude of Scope 3 emissions. The higher the recycled content the lower the Scope 3 emissions.

Furthermore, the available data only covers recycled content (also known as the scrap mix) between 40 % scrap and 97 % scrap, which yields the following Scope 3 emission levels.

- 50 % scrap; 2.90 tonnes of CO_2 per tonne of stainless steel produced

- 75 % scrap; 1.65 tonnes of CO_2 per tonne of stainless steel produced
- 85 % scrap; 1.15 tonnes of CO_2 per tonne of stainless steel produced

Using a 75 % recycled content as a reasonable scrap-based production reference point it becomes apparent that the Scope 3 emissions represent 67 % of the total cradle to gate production emissions for stainless steels.

Using a 50 % recycled content, the Scope 3 emissions represent 78% of the total production emissions.

Using a 30 % recycled content, then, the Scope 3 emissions represent 88 % of the total production emissions.

We can hereby see how the Scope 3 emissions impact the total CO_2 production emissions.

Please note that the graph contains estimated figures below 40% of scrap proportion.

NPI production currently produces emissions in the average range (designated by geographical source) of 60 to 85 tonnes of CO_2 per tonne of Nickel produced. This means that if NPI is used to make an 8 % Nickel containing stainless steel, the increase in Scope 3 emissions (when compared to a 40 % scrap mix) associated with this route will typically be between 4.0 and 6.0 tonnes of CO_2 per tonne of stainless steel produced.

NB; For comparative purposes, a 40 % scrap mix with zero NPI delivers a Scope 3 emissions level of 2.80 tonnes of CO_2 per tonne of stainless steel produced.

The summary table of emissions is shown in Table 2.

We will continue to monitor the evolving technological, grid mix and raw materials developments that we expect to progressively reduce the cradle to gate emissions associated with the production of stainless steels.

Figure 3 Actual CO_2 Emissions for Scrap-Based Production and Calculated CO_2 Emissions for NPI-Based Production
Data source: worldstainless, 2024

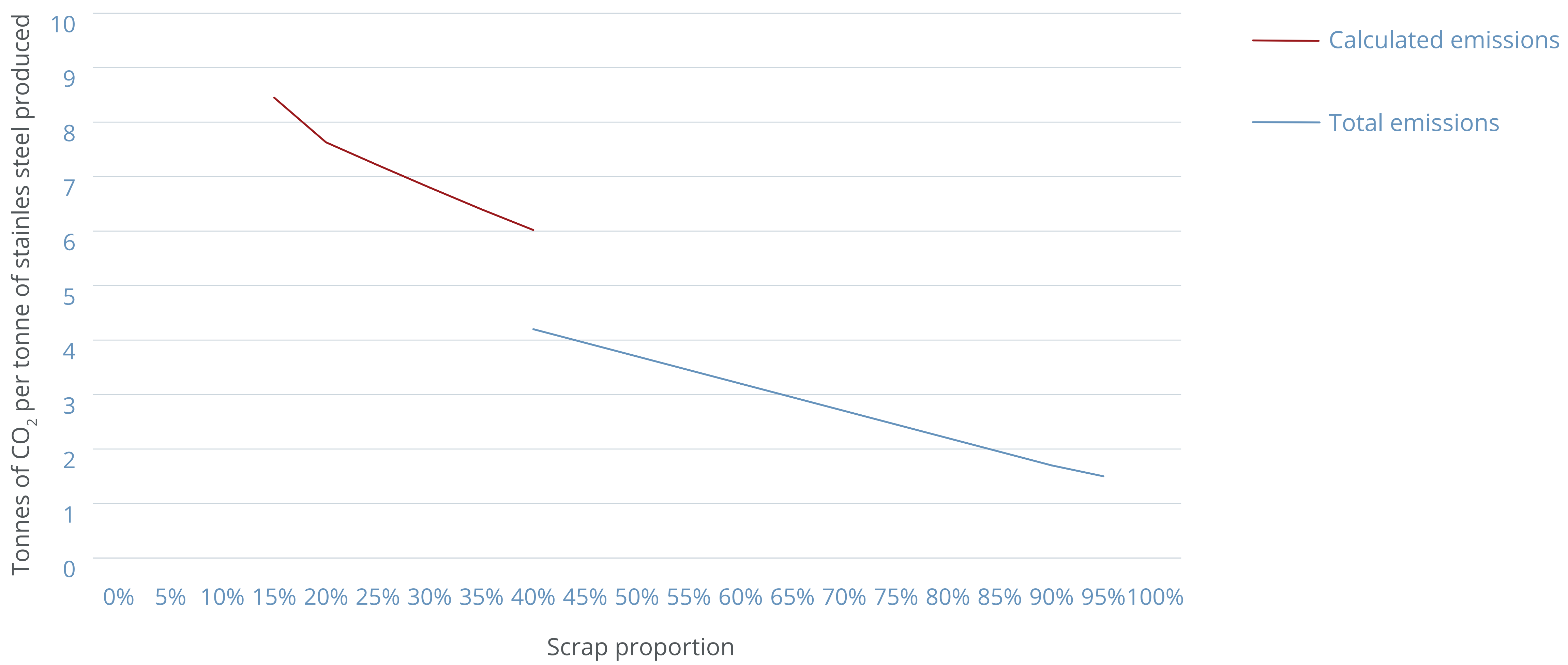


Table 2 CO_2 Intensity data; Production year 2022
Sources: world stainless association 2024; World Steel Association

Legend:
Scope 1 = Direct emissions, eg; natural gas, heavy oil and light oil
Scope 2 = Electricity and steam emissions
Scope 3 = Upstream emissions from the production of raw materials, eg; FeCr, FeNi and FeMo

	Scrap proportions	tonnes of CO_2/ton of stainless steel	Scope 3 proportions
Scope 1 emissions		0.41	
Scope 2 emissions		0.39	
Scope 3 emissions	85% scrap	1.15	59 %
	75% scrap	1.65	67 %
	50% scrap	2.90	78 %
	30% scrap	6.00	88 %
Total CO_2 emissions (ton CO_2) / ton stainless steel	85% scrap	1.95	
	75% scrap	2.45	
	50% scrap	3.70	
	30% scrap	6.80	
Carbon steel CO_2 emissions		1.91	

CO_2 production emissions for alloys in structures over 110 years of operational life

Figure 4 CO_2 production emissions for alloys in structures over 110 years of operational life
The data was calculated from material and processing emissions data available from the world stainless association, the World Steel Association and the Organisation for Economic Co-operation and Development (OECD).

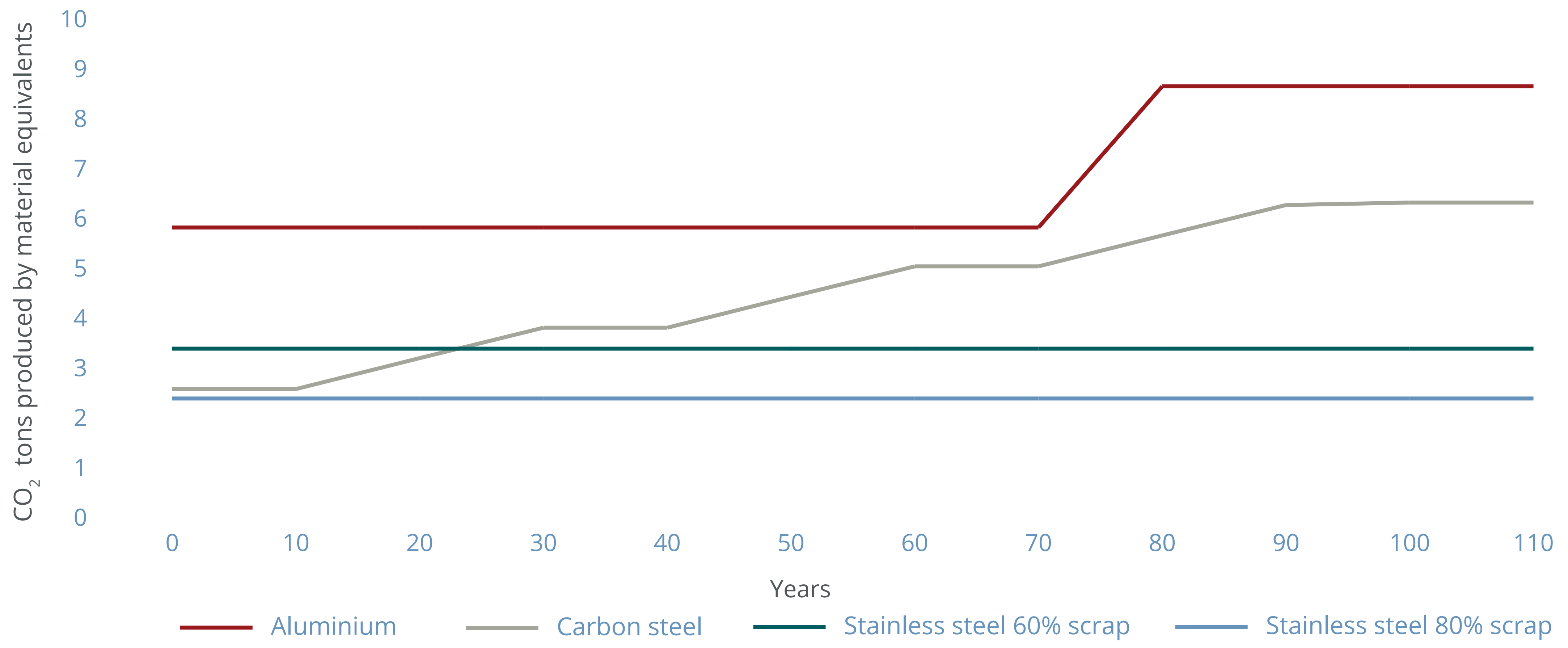


Figure 4 shows the CO_2 production and maintenance emissions for stainless steels, carbon steel and aluminium. Two different types of produced stainless steel have been included, namely Stainless 1 which is produced with an 80% recycle content and Stainless 2 which is produced with a 60% recycled content.

The data comprises CO_2 tons emitted per ton of material produced (Scope 1 + Scope 2 + Scope 3) plus any CO_2 emissions associated with regular maintenance needs. The carbon steel emissions increase every 10 years due to regular maintenance needed to supress corrosion. Stainless steel and Aluminium emissions do not increase as their passive films prevent the need for regular maintenance. The lifetime of stainless steels in-service beyond 110 years are not yet known as the industry is currently 111 years old.

The CO_2 emissions data and associated included recycling credits are industry supplied figures.

The Aluminium data has been adjusted downwards to reflect the fact that the density of Aluminium is about one third that of carbon steel and stainless steels.

Life Cycle Emissions

Some people believe that steel products, including stainless steels, are examples of materials whose CO_2 emissions are at a high level. However, we must question if this is truly the case.

As described so far, it is true that there is a certain amount of CO_2 emissions associated with the stainless steel production process. However, stainless steel is a reusable, durable, and corrosion resistant material that has low maintenance needs and a long service life.

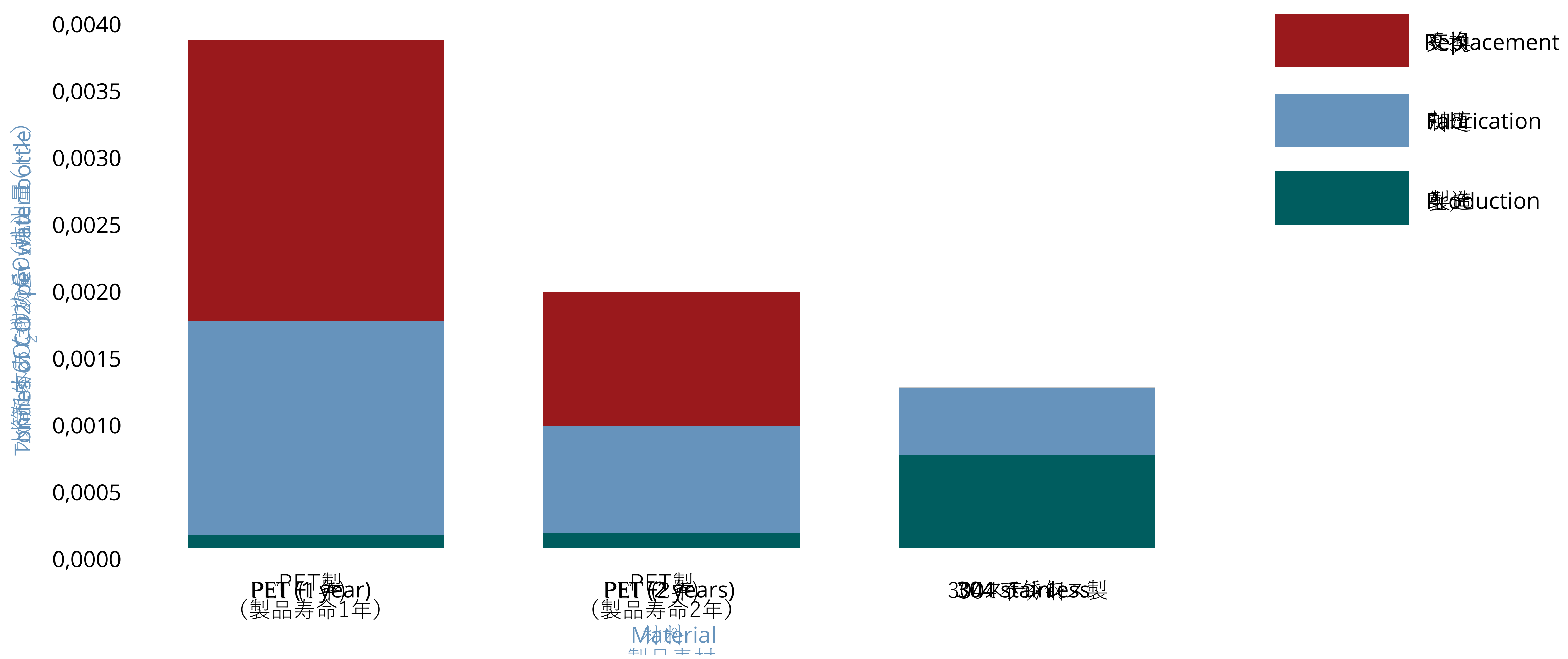
Life cycle emissions consider all the Carbon-equivalent emission output over different phases of a product's life cycle. It is also needed to determine frequency at each stage during its life cycle. The life cycle covers different stages such as material production, material transport, fabrication, fabricated product transport, installation, maintenance, replacement, and recycling.

Example: the life cycle of water bottles

Plastic water bottles have an average operational life of 1 or 2 years. Figure 5 shows the life cycle emissions of water bottles used for over 20 years, depending on different material namely type 304 of stainless steel and polyethylene terephthalate (for 1 and 2 years of service life).

While a 304 stainless steel water bottle has a high amount of CO_2 emissions during material production, the CO_2 emissions in subsequent processes are relatively low, making the total life cycle emissions the lowest. On the other hand, PET water bottles have very low CO_2 emissions during material production, but significantly higher CO_2 emissions during replacement, material disposal and the limited level of recycling which exists today. This is due to their short service life, resulting in a high frequency of replacements.

Figure 5 Life Cycle Emissions of water bottles in a period of 20 years
Data source: worldstainless, 2023



For major products and installations, around 70 % of the life cycle emissions occur in the usage or operational phase. These water bottles are just an example. Selective use of material is therefore important.

Depending on comparative material, it is true that stainless steel covers high emissions during its production process.

If we look at the whole picture, however, it is also true that stainless steel is an excellent material in terms of the life cycle emissions. Furthermore, we can expect further reductions in the production emissions for stainless steels in the future, as the use of scrap or utilization of renewable energy increases.

Summary

It is fair to say that the production emissions for stainless steels whilst being relatively low only are partly informative. There are two high-level production systems at play both of which are necessary to support the global demand for stainless steels. Over the coming years the production emissions associated with Nickel Pig Iron (NPI) will progressively fall as greener technologies in the production of NPI become more widely utilised.

Furthermore, the life cycle emissions associated with using stainless steels offer a different and more compelling perspective for the benefits of using sustainable and resilient materials. Selecting materials that do not degrade and equally do not require significant maintenance and/or partial replacement presents a different and much lower emissions profile.

More information on application-aligned comparative materials sustainability modelling can be found via info@worldstainless.org.

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About worldstainless

worldstainless is a not-for-profit research and development association which was founded in 1996 as the International Stainless Steel Forum.

Its primary roles are to undertake stainless steel industry beneficial tasks that are better coordinated centrally in the fields of

- Promoting industry and material sustainability benefits
- Conserving resources and promoting the circular economy
- Providing economic and industry-leading statistics
- Support industry health & safety needs and developments
- Outlining market development and expansion opportunities
- Maintaining brand reputational positioning
- Materials education

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