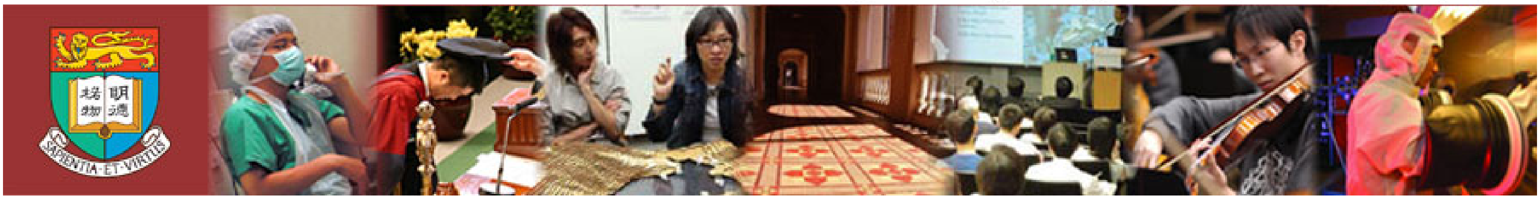


Process Map of Carbon Emission Sources for Stainless Steel Construction Products

KATE Y. CHEN and S. THOMAS NG
Department of Civil Engineering
The University of Hong Kong, Pokfulam Road
HONG KONG
tstng@hku.hk

Abstract: - The building sector plays an indispensable role in the mitigation of greenhouse gas (GHG) emissions as buildings are emission-intensive to construct and operate. The GHG or carbon embodied in building materials share as much as 30% of a building's life cycle emissions. A careful selection of building materials with low environmental impact would thus substantially lower the GHG emissions of buildings. In pursuit of low-carbon buildings, the emission figures of building materials used should be disclosed to relevant stakeholders. Until now there are many GHG emissions gauging tools available, which include the building environment assessment tools, product carbon inventories, life cycle analysis tools, etc. Nonetheless, uncertain assessment results, costly database and tedious training to master those emission assessment tools lower their popularity amongst the material manufacturer and supplier communities. The problem is aggravated when the emissions sources and principle of calculations behind these tools are not clearly revealed to users. The aim of this study is to develop a process map of the embodied carbon emissions sources for an emission-intensive building material, i.e. stainless steel, by revealing its manufacturing processes and supply chain. The process map developed in this study not only allows users to gain a clear insight of the embodied emission sources of stainless steel products but should also serve to identify potential opportunities for emission reduction.

Key-Words: - Greenhouse gas emissions; low-carbon materials; embodied carbon

1 Introduction

Excessive greenhouse gas (GHG) emissions are recognised as the key contributor to climate change. Modern buildings consume an enormous amount of energy, which inevitably produce substantial amount of carbon dioxide (CO_2) – the largest single source of GHGs [1]. The construction sector, therefore, has an indispensable role to play in emission reduction as building facilities are energyand emission-intensive to construct and operate. The GHG emitted during the extraction of raw materials, manufacturing processes, transportation of raw and finished materials and other associated activities are all counted towards the embodied GHG emissions of construction materials, and they share a considerable proportion of the life cycle emissions of buildings. Fieldson et al. [2] demonstrated that the embodied GHG emissions of a typical office building could account for 30% of its life cycle emissions. Providentially, up to 30% of CO_2 emission could be directly reduced in the initial phase through a careful selection of low-carbon materials [3]. Therefore, the embodied GHG of building materials' has attracted much attention in the society and the building sector [4,5].

At present, a number of tools are available to gauge the emissions performance of building materials. However, few of them address the issue of the emissions embodied in building materials [6]. Kenny and Gray [7] compared six prevalent carbon auditing tools, namely: Carbon Footprint (UK), Resurgence (UK), Carbon Fund (USA), Safe Climate (USA), Combat Climate Change (Ireland), and Grian (Ireland), and found that the carbon auditing results of the six tools varied by 55.7%. It is difficult for users to realise the accurate carbon footprint and identify the processes which have the greatest opportunities for emissions reduction. This study aims to develop a process map of the embodied carbon emissions sources for emission-intensive materials.

Given the raw materials and manufacturing processes of each building material are multifarious, it is unrealistic to apply a universal carbon auditing framework to various construction materials. As a result, the proposed carbon auditing model in this study is applicable to a selected building material, i.e. steel, as it is widely adopted for structural sections, cladding, door / window handles, glass facade "spiders" / beams, tie rods, reinforced bars, guardrail / handrail, lintels, etc. in modern buildings [8]. More importantly, steel products are recognised as one of the most emissions-intensive building materials [9,10,11]. Among various types of steel products, stainless steel has even higher embodied GHG emission than ordinary steel products [12,13].

2 Research Method

In this paper, relevant documents, e.g. industrial reports, manuals, guidelines and articles were studied to reveal the stainless steel manufacturing processes and associated emission sources. Moreover, to corroborate and enhance the findings of the review, opinions on the manufacturing process and embodied GHG emissions of stainless steel products were sought from industry experts through semi-structured interviews. Based on the desktop study and the perspectives from the professionals in the interview, a process map of the embodied carbon emissions sources for stainless steel is derived.

To identify the manufacturing processes and GHG emissions sources of stainless steel products, the following literatures were reviewed, and they include the:

i) international industrial reports and guidelines, e.g. Worldsteel Association's carbon emission database, GHG Protocol Initiative guideline (The GHG Protocol Initiative, 2008), International Stainless Steel Forum's (ISSF) publications [12], and International Iron and Steel Institute's collected data [14]; and
ii) locally recognised industrial reports and guidelines, e.g. Australian Steel Institute's report on steel's life cycle [15], Natural Resources Canada's industrial report [16], U.S. Environmental Protection Agency's reports [17], etc.

Face-to-face semi-structured interviews which lasted for around 50 minutes were conducted. The target interviewees were required to respond to a set of open-ended questions regarding the manufacturing processes of general steel products, including both carbon-steel and alloy products, and main sources of GHG emissions during the manufacturing process. The perspectives and opinions of interviewees were audibly recorded throughout the interview, and interview reports were then compiled and validated by the interviewees. Useful information was subsequently extracted.

As the information collected requires knowledge and sound experience in the field of steel manufacturing and carbon auditing, only experts and professionals in the steel manufacturing industry or carbon auditing were selected and invited. Local steel manufacturers / suppliers and carbon auditors who have profound knowledge and understanding of steel product manufacturing and carbon auditing were targeted.

Fifteen interview invitations were randomly sent to the target respondents respectively; four experts from the steel manufacturing industry completed the interview, and their background is provided in Table 1.

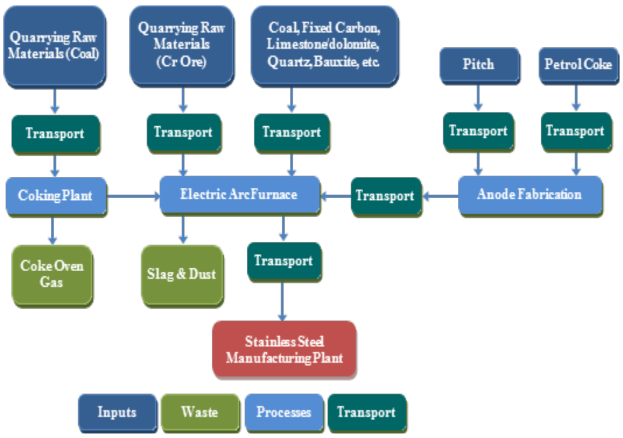
Table 1: Interviewees' profiles

Interviewee ID	*Position*	*Background of Organisation*
M1	Product Manager	Manufacturer
M2	Risk Manager	Manufacturer
S3	Technical Director	Supplier
S4	Sale Manager	Supplier

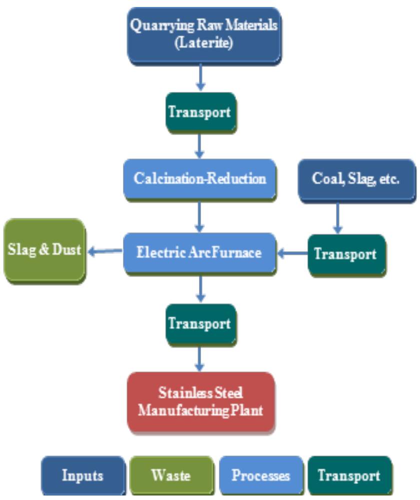
3 Process Map

The chromium is added into the stainless steel in the form of chromium ferroalloys in which the high-carbon ferrochromium is most commonly used [18] instead of pure chromium metal. The production of chromium ferroalloy is an electric-intensive process. Due to a large variety of manufacturing processes, ores, and practices of making high-carbon ferrochromium [18], it is hard to provide a standard list of processes and raw materials for high-carbon ferrochromium production. In this study, the process map and emission sources of high-carbon ferrochromium production (as shown in Figure 1 (a)) were developed based on the most commonly adopted method provided in the reviewed documents.

The alloying element nickel required in stainless-steel manufacturing is in the form of ferronickel. Laterite ores are the main raw material inputs to produce ferronickel [19]. Before the ores are charged into ferronickel EAF, they must be dried and heated in the calcination-reduction process to remove the crystalline water. After reaction with other feed materials (coal, slag, etc.), the ferronickel will be separated under high temperatures inside the EAF. If desired, the ferronickel might be refined into a purer ferronickel product to meet market specifications. The smelting process in the ferronickel EAF consumes a huge amount of electricity, which is the main source of GHG emissions of ferronickel production. In this study, the process map and emission sources of high-carbon ferrochromium production (as shown in Figure 1 (b)) were developed based on the most commonly adopted method provided in the reviewed documents.



(a) Primary high-carbon ferrochromium production



(b) Primary ferronickel production

Figure 1: Process map of stainless steel

The review outcomes show that the stainless steel production process is similar to ordinary steel production, except that higher portions of ferroalloys are added into stainless steel. Chromium is the essential element to make the steel "stainless," while nickel helps to develop the property of withstanding extreme temperatures. Usually the proportion of chromium is no less than 10.5% by weight, while nickel content usually ranges from less than 2% to as much as 25% by weight. Other alloying elements including molybdenum, copper, etc. would provide a wide range of mechanical and physical properties of stainless steel and they have minor contribution to the total embodied GHG emissions.

It is found in the reviewed documents that, similar to non-alloy steels, there are two predominate routes of producing stainless steel, namely the basic oxygen furnace (BOF) and electric arc furnace (EAF). The EAF route is the predominant way of producing stainless steel that more than 80% of all new stainless steel is manufactured through EAF [12]. Therefore, this study will look into the EAF route only.

In the EAF route, steel products are primarily produced by recycling ferrous scrap in an EAF. In many integrated steel plants, the molten steel from BOF, alloy contents and steel scrap are discharged into the EAF directly. The EAF melts the feed materials with a strong electric current for 8 to 12 hours. After that, the molten alloy goes through the processes of casting, rolling, annealing, descaling, cutting, coating, packing, etc. Due to that, the coke-making, iron-making, and steel-making steps are omitted; considerably less GHG emissions are released in the EAF route.

Interviewees M1 and M2 who work for steel manufacturers pointed out that steel is a 100% recyclable material. Nowadays, very little waste steel is sent to landfill. The majority of local construction steel products are produced through the EAF route by bought recycled steel. They stressed that electricity consumption is the most emission-intensive source for steel made through the EAF route. The key processes and emission sources of stainless steel manufacturing are presented in Figure 2.

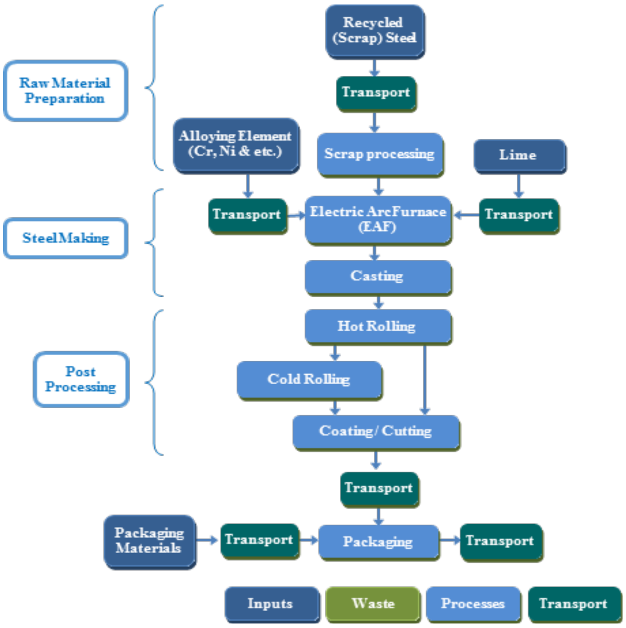


Figure 2: Process map of stainless steel manufacturing

4 Conclusion

The construction materials' embodied carbon share a considerable portion of buildings' life cycle carbon emissions. Therefore, the embodied carbon of building materials' becomes an increasing concern in the building sector as it provides good opportunities to reduce building carbon footprint.

The existing tools gauging the emissions performance of building materials has various limitations such as the emissions sources and the lack of transparency in the principle of calculations behind these tools. This study aims to develop a process map of carbon emission sources for an emission-intensive building materials, i.e. stainless steel. The study discloses the manufacturing processes of stainless steel by reviewing the related international and local industrial reports which is followed by the opinions of local experts in stainless steel production.

With this process map, stainless steel manufacturers and suppliers can easily identify the major carbon emission sources from the manufacturing process, and thereby identify the best emission reduction approaches during the manufacturing process. This study also serves as a solid background for the future research on a carbon auditing framework for stainless steel and other emission-intensive materials.

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