CARBON FOOTPRINT TS5 POST CAGE

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SUMMARY

The recent 2011 international climate conference in Durban, South Africa, ended with intense discussion about new global climate goals. Nevertheless, companies integrating more and more environmental practices into their business strategies to set their own climate goals and to respond to the rising customer consciousness in eco-friendliness. One of the practices used to achieve this is greenhouse gas (GHG) calculation, also known as Carbon Footprint calculation. The GHG calculation has the goal to calculate the amount of GHG emissions associated with an entire organization or product.

This research has the goal to develop a GHG inventory for a small and medium enterprise (SME) located in New Zealand. First, the motivating factors for starting environmental practices are examined and the barriers for SMEs that keep them from action. This is followed by research in the area of GHG accounting through the review of well known standards of the GHG Protocol, which is a multi-stakeholder partnership of business, governments and non-governmental organizations.

Two possible levels of GHG accounting are described; at either corporate or product level. Corporate level accounting has the aim to calculate all the GHG emissions of a company's operations and facilities within a certain border. This can be applied through either manufacture or fully office-based companies. Product level accounting has the aim to calculate the GHG emissions of a product life cycle and as a result it gives the carbon impact or footprint of the studied product.

The case study explores the proposed method within the case enterprise Master Maintenance Services. During the study the Carbon Footprint of one of their products is calculated, the New Zealand post cage TS5. The study covers the entire life cycle of the post cage, from raw material extraction up to disposal of the cage's components. This is visualized in a process map which acts as guidance through the GHG inventory assessment. Finally, the total product Carbon Footprint is calculated and emissions hotspots are appointed.

Concluding, the lessons learned from preparing the GHG inventory and associated barriers are discussed in relation with a possible SME-friendly GHG calculation tool. This tool may have the ability to motivate SMEs to start GHG accounting as a first environmental practice.

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ABBREVIATIONS

B2B	Business-to-business
B2C	Business-to-consumer
CF	Carbon Footprint
CH_4	Methan
CO_2	Carbon Dioxide
CO_2e	Carbon dioxide equivalent
D&S	Distribution & storage
EMS	Environmental Management Software
EOL	End-of-life
GHG(s)	Greenhouse Gas(es)
GWP	Global Warming Potential
HDPE	High-density polyethylene
HFCs	Hydrofluorocarbons
HGV(s)	Heavy Goods Vehicle(s)
IPCC	Intergovernmental Panel on Climate Change
kW	Kilowatt
kWh	Kilowatt-hour
LCA	Life Cycle Analysis
M&P	Material acquisition & pre-processing
MfE	The Ministry for the Environment
MMS	Master Maintenance Service
N_2O	Nitrous oxide
PFCs	Perfluorocarbons
SF_6	Sulphur hexafluoride
SME(s)	Small and Medium Enterprise(s)
UNFCCC	United Nations Framework Convention on Climate Change
WARM	Waste Reduction Model
WBCSD	World Business Council on Sustainable Development
WRI	World Resource Institute

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1 INTRODUCTION

The energy consumption in New Zealand has increased during the last decade. From the historical data reflected by the Ministry for the Environment – Manatū Mō Te Taiao (MfE) (1), the total energy use in New Zealand increased 20 percent between 1998, a year after the Kyoto protocol adoption, and 2007. This is equivalent to an increase of 8 percent per person over the same time period. The largest growth was found in the commercial sector (24 percent) and in third place the industrial-manufacturing sector with a total growth of 16 percent.

A big issue associated with increasing energy usage is the growing amount of greenhouse gases (GHGs) in the air. These gases absorb and emit radiation in the atmosphere within the thermal infrared range. This process is considered as the fundamental cause of the well known greenhouse effect, which results in global warming.

GHG emissions attributed to the New Zealand's energy sector have increased by 39 percent since 1990 (1). Figure 1 shows the trend of energy related greenhouse gases in New Zealand by sector. The manufacturing industry is responsible for the second largest proportion of GHG emissions, with an amount of 17 percent of the total.

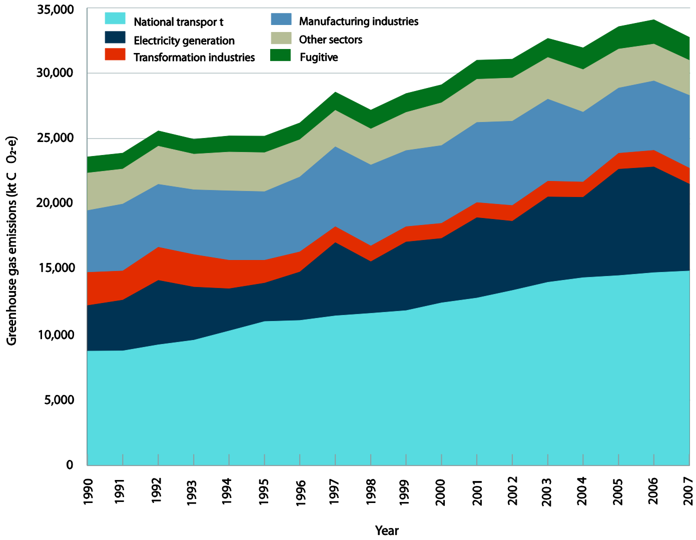


Figure 1: energy-related GHG emissions by sector in New Zealand (1)

Carbon Footprint (CF) calculation, also called GHG calculation, is a possible process to help the manufacturing industry in New Zealand to reduce and manage their GHG emissions. In this way a more sustainable manufacturing environment can be created. Enterprises will also be able to respond to the governments, customers and stakeholders demands and on the other side it helps to improve efficiency, reduce consumed recourses and generate less or no waste (2).

The management of GHG emissions requires an accurate quantification of these emissions. The most successful GHG initiatives undertaken by companies are based on defined standards and guidance. Common resources are; the Greenhouse Gas Protocol of the World Resource Institute (WRI) and World Business Council on Sustainable Development (WBCSD), ISO 14064 part 1 and part 2 and 2006 IPCC guidelines for National Greenhouse Gas inventories (3). These standards must ensure for consistency between GHG initiatives in the world.

The process from understanding to the implementation of these standards can be a large barrier, especially for small to medium enterprises (SMEs). This is either due to missing specific knowledge or a lack of resources and time. That makes a business opportunity feasible to create a web-based GHG calculation tool, which has the potential to be part of a larger Environmental Management Software (EMS) system called ecoPortal®. The ecoPortal® is an environmental, health & safety and quality management system started at The University of Auckland. The calculation tool will help SMEs in the manufacturing industry to account for their GHG emissions and helps to easily manage them, without struggling to understand and implement the standards.

1.1 RESEARCH OBJECTIVES

This research presents an overview of GHG accounting standards and explains how they can be applied by SMEs in the manufacturing industry, followed by a case study that demonstrates the development of a GHG inventory and calculation. The manufacturing company Master Maintenance Service (MMS) will act during the study as the case SME.

The first goal is to describe the practices in establishing a relevant GHG inventory according to defined standards. A distinction is made between preparing an inventory for either an entire firm or just for one product. This creates a supporting framework and design space in GHG accounting for SMEs.

The second goal of the development process is to present the GHG inventory, GHG calculation and results of the case study, product Greenhouse Gas calculation for Master Maintenance Service. The lessons learned from actually preparing the inventory and calculating the results are also presented.

1.2 METHODOLOGY

The theme of this research is GHG accounting within the context of New Zealand's small to medium manufacturing enterprises. The interaction between the theme and the context will be examined by the method, which in this case is the Greenhouse Gas Protocol defined accounting and reporting standards as basis. This is graphically shown in Figure 2. It should be noted that this research is mostly focused on GHG accounting, because of the set objective to develop an inventory instead of a reporting program.

Within this research a distinction is made between three phases, the theory phase, the implementation phase and the modification & reflection phase. The theory phase is focused on gathering and understanding of information about the standards and literature regarding the theme, the context and the existing methods. The acquired knowledge and insight will then be implemented in the case study.

The case study explores the development of a GHG inventory for a SME that is studied holistically by the gained method and theory. The result of the study will be mostly descriptive. It is descriptive in the sense of describing how the subject deals with a SME and how the method should be applied to set up an appropriate GHG inventory.

Finally the theory and implementation phases are reflected upon and extended when necessary.

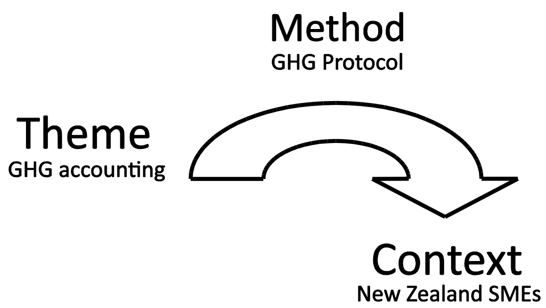


Figure 2: theme, method and context

2 DRIVERS & BUSINESS GOALS

New Zealand is a nation predominated by SMEs. According to the Ministry of Economic Development – Manatū Ōhanga 97.2 percent of the enterprises employe 19 or fewer people (4). The large population of SMEs in New Zealand as well as globally means that this sector has a significant impact on the environment. While worldwide larger companies are aware of their impact and increasingly integrating environmental management into their business strategies, SMEs lag behind in this respect. Although research in New Zealand has shown that in the area of environmental management SMEs showed a positive attitude, that might influence action in engaging of such management activities (5).

Looking closer to the attitude of SMEs regarding to these activities gives a better understanding of the related drivers and associated barriers. A driver is a common term used for the factor that has potential to 'push' or 'pull' enterprises to action or in context with this research to start environmental practices. Push drivers are for example governmental regulations, increasing energy prices and pressure from stakeholders and have the potential to drive SMEs to action. Although, drivers can also have the character of pulling business into action, for example attracting customers or energy efficiency which both result in more profitability and a better competitor position. Research in The United Kingdom listed these push and pull drivers, by questionnaire data obtained from 2500 small enterprises (6). The drivers that are considered to be most important are listed in Table 1.

Push Driver	Pull Driver
Environmental taxes	Cost saving from energy or other resource efficiency
Governmental regulations	Attract new customers
Pressure from existing customers	Good publicity and promotion for your business
Pressure from business stakeholders	Ability to attract and retain staff

Table 1: potential drivers for SMEs

It appears that SMEs partly know and feel that being environmentally responsible is profitable for business, but barriers such as cost, time and a lack of knowledge and resources keep them from action. Assistance from a SME-friendly GHG calculation tool with the potential to overcome these barriers is the outcome. This is in contrast to complicated available Life Cycle Analysis (LCA) software packages with integrated GHG tools such as GaBi or SimaPro. The tool will then serve as a first environmental practice that is able to translate the pull drivers mentioned in Table 1 into action. As a result of this, SMEs will quickly notice benefits. For example saving costs through energy reduction and attracting new customers by good publicity gained out of product carbon footprinting.

The development of such a calculation tool asks for a well defined and accepted accounting standard as its basis. Of the resources mentioned in the introduction, the GHG Protocol seems to be the one that is most suitable. The IPPC standard is designed for national inventories and is for example used in the New Zealand's Greenhouse Gas Inventory 1990-2007 (7) and the ISO 14064 standard describes just GHG quantification and reporting methods without a business perspective. Though, within the context of SMEs this business perspective will be of major importance. A SME's business responsibility will namely exceed environmental responsibility and the same will apply to competitive and environmental advantages achieved by GHG accounting. Therefore a standard is needed with business goals that have both a competitive and environmental perspective.

The GHG Protocol (chapter 3) meets this requirement and defines two levels of GHG accounting with both different business goals. First the corporate level accounting, this level has the aim to account annually for all GHG emissions of the reporting company. Emissions within this level arise from product movement between facilities to all processes of the company. The GHG Protocol lists the following main business goals as reasons to calculate emissions at corporate level:

Business goals
Managing GHG risk and identifying reduction

• Identifying risks associated with GHG constraints in the future
• Identifying cost reduction opportunities
• Setting GHG targets, measuring and reporting progress
Public reporting and participation in voluntary GHG programs
• Voluntary stakeholder reporting of GHG emissions and progress
• Reporting to government programs
• Eco-labeling and GHG certification
Participating in mandatory GHG reporting programs
• Participating in government reporting programs at the national, regional, or local level
Participating in GHG markets
• Supporting internal GHG trading programs
• Participating in external cap and trade allowance trading programs
• Calculating carbon/GHG taxes
Recognition for early voluntary action
• Providing information to credit early GHG emissions action

Table 2: business goals of the Corporate Standard (8)

Secondly product level accounting, has the aim to account for GHG emissions associated with a product. These emissions reflect the impact of production processes, used materials and decisions occurring throughout the life cycle of that specific product. The GHG Protocol lists four business goals as reason to calculate emissions at product level:

Business goals
Climate change management
• Identify new market opportunities
• Identify climate-related physical and regulatory risks in a product's life cycle
• Assess risks from fluctuations in energy costs and material availability
Performance tracking
• Focus efforts on efficiency improvements and cost-saving opportunities through GHG reductions throughout a product's life cycle
• Set product-related GHG reduction targets and develop strategies to achieve goals
• Measure and report GHG performance over time
• Track efficiency improvements throughout a product life cycle over time
Supplier and customer stewardship
• Partner with suppliers to achieve GHG reductions
• Assess supplier performance for GHG aspects of green purchased efforts
• Reduce GHG emissions and energy use, costs, and risks in the supply chain and avoid future costs related to energy and emissions
• Launch a customer education campaign to encourage actions that reduce GHG emissions
Product differentiation
• Achieve competitive advantage by pursuing GHG reduction opportunities and cost savings to create a low-emitting product
• Redesign a product to better respond to customer preferences
• Strengthen brand image regarding GHG performance
• Enhance employee retention and recruitment resulting from pride in product stewardship
• Strengthen corporate reputation and accountability through public disclosure

Table 3: business goals of the Product Standard (9)

The mentioned push and pull drivers are both recognizable in the business goals listed above. Push drivers can be associated with the GHG Protocol's business goals that have in the first place an environmental perspective. For example, participation in mandatory or voluntary GHG reporting programs in order to help the government or stakeholders with the realization of set GHG reduction targets. Pull drivers can be associated with those business goals that lie more in the origin of business strategy and competitiveness. For example, identification of GHG reduction opportunities can be a part of an enterprise's sustainable business strategy. It can be concluded that the GHG Protocol meets the desired requirement and creates a design space through corporate and product level GHG accounting. When this serves as a basis for the SME-friendly GHG calculation tool, the mentioned push and pull driver can be translated into action. With the result that SMEs don't have to struggle with complicated LCA software packages and are able to understand and implement the GHG standards more easily. It gives the ability to perform first environmental practices which can be a step towards environmental management.

It should be noted that this report is not directly focused on the design of the calculation tool itself, but it gives first a review of the GHG Protocol accounting principles, corporate level accounting and product level accounting and finishes with a case study to assess the proposed method. The result and lessons learned from this case study can then be used as input for the actual design of the SME-friendly GHG calculation tool. Which has finally the potential to be part of the EMS system ecoPortal®.

3 THE GREENHOUSE GAS PROTOCOL

The GHG Protocol is a multi-stakeholder partnership of businesses, non-governmental organizations, governments, and others convened by the WRI and WBCSD. The GHG Protocol produced already eight separate but complementary standards, protocols and guidelines. They serve as a basis for most other GHG accounting guidelines including the ISO 14064 (parts 1 and 2) (3).

The proposed methods and tools within this research are based on two of their standards: *A Corporate Accounting and Reporting Standard* (Corporate Standard) (8) and *Product Life Cycle Accounting and Reporting Standard* (Product Standard) (9). Both standards cover the accounting of the six GHG emissions appointed by the Kyoto Protocol: carbon dioxide (CO_2), methan (CH_4), nitrous oxide (N_2O), hydrofluorocarbons (HFCs), perfluorocarbons (PFCs), and sulphur hexafluoride (SF_6). In addtion, the *Product Life Cycle Accounting and Reporting Standard* also accounts for waste associated with the studied product.

The GHG Protocol introduced five accepted accounting and reporting principles, which form the basis of the two standards. These principles must ensure that reported information of a firm's emissions is the best and most true full reflection of reality. When there are ambiguous issues or situations regarding the methods reported in this research, refer back to those five principles.

Corporate Standard

i. *Relevance*: Ensure the GHG inventory appropriately reflects the GHG emissions of the company and serves the decision-making need of users-both internal and external to the company.

ii. *Completeness*: Account for and report on all GHG emissions sources and activities within the chosen inventory boundary. Disclose and justify any specific exclusion.

iii. *Consistency*: Use consistent methodologies to allow for meaningful comparisons of emissions over time. Transparently document any changes to the data, inventory boundary, methods, or any other relevant factors in the time series.

iv. *Transparency*: Address all relevant issues in a factual and coherent manner, based on a clear audit trail. Disclose any relevant assumptions and make appropriate references to the accounting and calculation methodologies and data sources used.

v. *Accuracy*: Ensure that the quantification of GHG emissions is systematically neither over nor under actual emissions, as far as can be judged, and that uncertainties are reduced as far as practicable. Achieve sufficient accuracy to enable users to make decisions with reasonable assurance as to the integrity of the reported information.

Product Standard

i. *Relevance*: Ensure that the product GHG inventory accounting methodologies and report serves the decision-making needs of the intended user. Present information in the report in a way that is readily understandable by the intended users.

ii. *Completeness*: Ensure that the inventory report covers all product life cycle GHG emissions and removals within the specified boundaries; disclose and justify any significant GHG emissions and removals that have been excluded.

iii. *Consistency*: Choose methodologies, data, and assumptions that allow for meaningful comparisons of a GHG inventory over time.

iv. *Transparency*: Address and document all relevant issues in a factual and coherent manner, based on a clear audit trail. Disclose any relevant assumptions and make appropriate references to the methodologies and data sources used in the inventory report. Clearly explain any estimates and avoid bias so that the report faithfully represents what it purports to represent.

v. *Accuracy*: Ensure that reported GHG emissions and removals are not systematically greater than or less than actual emissions and removals and that uncertainties are reduced as far as practicable. Achieve sufficient accuracy to enable intended users to make decisions with reasonable assurance as to the reliability of the reported information.

4 THE CORPORATE STANDARD

The process of establishing a relevant GHG inventory at corporate level will be described in this chapter. Accounting and quantification are the two main steps in this process. During the accounting step the border of the inventory is defined by an organizational and operational boundary. These two boundaries indicate which facilities or operations and associated GHG sources are adopted. Subsequently the quantification process will start to quantify the actual sources and their emissions. During the quantification step the sources are identified, the right quantification method is applied and finally the GHG emissions of the reporting company are calculated.

4.1 ORGANIZATIONAL BOUNDARY

The organizational boundary determines which facilities or operations of the company are included in the inventory. The geographic range of the boundary can vary from sub-national level up to global level, depending on the share of equity or control of a company's facilities and operations. For SMEs this range will typically vary between sub-national and national level. The organizational boundary can be set up by two approaches, the so called equity share approach or control approach.

Following the equity share approach a company accounts for their GHG emissions by the amount of equity they have in a facility or operation. This is most often determined by the percentage of ownership. For example, if a company owned 40 percent of an operation, it should include 40 percent of that operation's emissions in its inventory. The equity approach provides in general a more accurate allocation of GHG emissions than the control approach and aligns with the well accepted financial accounting principles (10).

Following the control approach the operations of which a company has control of will contribute for 100 percent to the emissions of that company. It does not account for the emissions from operations in which it owns an interest but has no control. This is in contrary to equity share approach. The control approach can be divided in either operational or financial control.

- Operational control means that a company has the authority to introduce and implement its own operating policies at the operation.

- Financial control means that a company has the ability to gain economic benefits from facility's operations or processes.

Table 4 gives an overview of the equity and control approach with their associated definitions.

Approach	Typical definition	Accounting of emissions
Equity Share	Percent ownership	By equity share (0% to 100%)
Financial Control	Group company or subsidiary consolidated in financial accounts	100% of emissions if financial control 0% of emissions if no financial control By equity share if joint financial control
Operational Control	Operator, holder of operating license	100% of emissions if an operator 0% of emissions if not an operator

Table 4: the equity share and control approach (8)

The company may define its organizational boundary according to one of these two approaches. Which approach is recommended depends on the structure of that company. Suppose for example an upstream and downstream supply chain which represents a significant portion of a sector's GHG emissions. A company that is a major shareholder in this sector but not in control of the operations may prefer the equity share approach. On the other hand companies or SMEs that operate GHG-intensive facilities prefer the control approach. In the end a company shall document and explain transparently which approach has been chosen according to the principles stated in chapter 3.

4.2 OPERATIONAL BOUNDARY

In addition to defining the organizational boundary, a company needs to address the question of which types of GHG sources are included in the inventory and how they will be classified. This process is known as setting the operational boundaries. Based on the Corporate Standard the GHG sources can be classified by the nature of their emissions, as direct emissions or indirect emissions. Three different scopes provide support in dividing the sources into distinguishable groups.

- Scope 1 emissions, are *direct* GHG emissions from sources that the company owns or controls, such as stationary combustion sources and vehicle fleets.

- Scope 2 emissions, are *indirect* GHG emissions associated with the generation of electricity, heat or steam which are purchased for own consumption. In general *indirect* GHG emissions are a consequence of the operations of the reporting company. The indirect emissions occur at sources owned or controlled by another company.

- Scope 3 emissions, are *indirect* GHG emissions as well only not covered in Scope 2, like outsourced activities or waste disposal.

Figure 3 may give more insight in how to interpret these three different scopes.

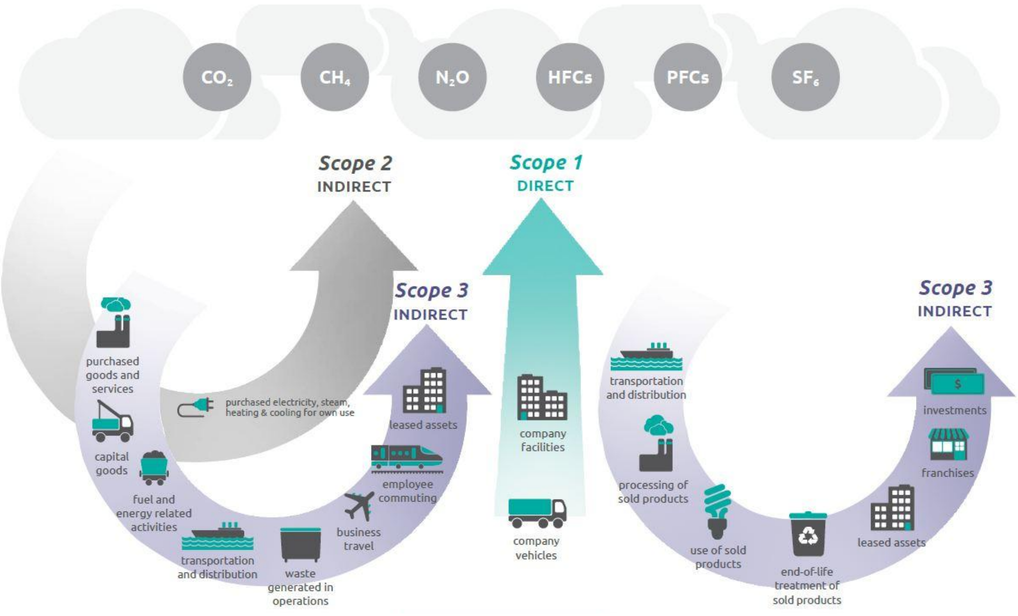


Figure 3: sources and emissions

In general companies are strongly advised to quantify Scope 1 and Scope 2 sources. Because of the wide range of possible Scope 3 sources and the difficulty to account for their emissions this scope is optional. An additional possibility is that GHG programs only require Scope 1 sources. These programs are suited to reduce emissions from a set of direct sources but are inconsistent with the Corporate Standard.

There are also GHG programs that incorporate Scope 3 sources into their requirements. A relevant example is the New Zealand program The CarboNZero Program. It's an initiative managed by Landscape Research Ltd. New Zealand in order to measure, manage, and mitigates carbon dioxide emissions from organizations, products, services and events in New Zealand. Measuring Scope 3 emissions has become an important aspect of the program to be able to understand their impact and additionally it gives the possibility of mitigating or offsetting them. For example, a large amount of Scope 3 emissions due to maritime freight could be of importance when offsetting them to overseas stakeholders (8).

4.3 EMISSION SOURCES

Quantification is the next step in the inventory development. During this step the actual emissions from the various sources are depicted. This step starts with the identification of the sources through an accurate overview of the facilities and operations with their relevant GHG sources. The sources should be classified as Scope 1 or Scope 2 emitters following the definitions set in section 4.2. Depending on the GHG calculation's goal Scope 3 sources may be included as well. Generally the sources are divided into the following five types:

Source type	Example source
Stationary combustion	Boilers Furnaces
Mobile combustion	Automobiles Airplanes
Process combustion	CO_2 from catalytic cracking in petrochemical processing
Fugitive emissions	Cooling towers Equipments leaks from joints
Waste emissions	Incineration CH_4 generated by landfill

Table 5: types of GHG sources

A redefining process should be established for future changes of the organizational or operational boundary. This process identifies new facilities or facilities that have been divested and adds them to the inventory. The same applies to operational changes. In addition, the base year needs to be recalculated. The base year is a reference point against which a company's GHG emissions are measured over time. In general a single year is chosen but the average of multiple years can also be identified as the reference point. Setting a base year serves a number of different purposes, such as tracking emissions over time, tracking progress in emission reduction and it serves as a starting point against which adjustments can be made as the company's organizational or operational boundaries changes. Therefore a base year emissions recalculation policy should be added to this process as well.

4.4 GHG CALCULATION METHODS

GHG emissions can be quantified by either direct measurement or calculation. Direct measurements by measuring a gas's concentration or emission rate are not common and mostly expensive. It happens when measurement equipment is available, for example by chemical processes or stationary combustion where the monitoring equipment already tracks the out coming substance. Emissions are more often quantified by a calculation based approach, using the mass balance approach or emission factor-based approach.

THE MASS BALANCE APPROACH

The mass balance approach, also called the material balance approach, is based on the conservation of mass. According to the conservation of mass the input of a reaction is equal to the output plus emissions.

$$Input = Output + Emissions$$

Consider for example the combustion reaction of wood. Wood is build out of organic elements (C,H and O) and will burn if oxygen is present. This reaction will result in the reaction products carbon dioxide and water (H_2O), with H_2O as output substance and CO_2 as emission. When the actual carbon content of the wood or in general fuel is known, the mass balance approach is relatively accurate to calculate the CO_2 emissions of stationary combustion (11).

The mass balance approach is therefore often used in the area of stationary combustion sources and for certain emissions from alloy production processes. When it is applied it should be over a long period of time so that errors and uncertainties are leveled out.

THE FACTOR-BASED APPROACH

The factor-based approach uses so called emission factors to calculate the emissions. An emissions factor is a coefficient that quantifies the emissions of a GHG per unit activity, such as fuel consumed or material input. These factors are mostly based on a set of measurement data, derived as a representative rate of emissions for a given activity under a particular set of conditions (11). It can be assumed that the factors are of long term data and of acceptable quality when they are developed by industrial associations, governments or research institutes. Although, it should be noted that emission factors are often representative for a specific area or country. To ensure the accuracy of the inventory companies should use these factors belonging to the GHG program's geographic region.

The factor-based approach is accurate for stationary combustion sources and less for process combustion, fugitive emissions and waste sources (11). However, this also depends on the amount of emission factors available for a specific emission source. Some factors tend to be more accurate than others, because of the large variety in process conditions and equipment used to determine them. Ideally, a company should develop their own specific factors by gathering test data of the source. However, not all sources can use this process and such a procedure is too expensive for SMEs.

4.5 GHG EMISSION CALCULATION

Once for each source the quantification method is determined and data gathering process is completed companies need to calculate their emissions and report them annually. During the data gathering process a company has collected direct emissions from measurements and calculated emissions from mass balances or by activity data and emissions factors. Together they represent the total amount of GHG emissions within the company's boundary. For consistency and comparability all emissions results need to be reported in the unit of carbon dioxide equivalent (CO_2e), which is the cumulative radiative forcing impact of multiple specific GHGs and can be calculated with use of the global warming potential (GWP) factor.

The following rule of thumb is valid for SMEs. Scope 1 emissions are calculated based on the used quantities of commercials fuels, such as natural gas and heating oil. New Zealand's SMEs would do well to use the emissions factor established by the MfE which are a result of New Zealand's Greenhouse Gas Inventory 1990-2007 (7). Scope 2 emissions are primarily calculated with metered electricity usage and associated supplier emission factor. If Scope 3 is taken into account, the emissions will mainly result out of activity data such as fuel use or travelled passenger miles.

There are complete GHG calculation tools available on the GHG Protocol Initiative website (12). These tools have been peer reviewed by both experts and industry leaders and are regularly updated, but are optional. Companies may develop their own sector specific tools, provided that they are more accurate than or at least consistent with the GHG Protocol standards. Available GHG Protocol tools that are appropriate for SMEs are listed in Table 6 and can help with the design of the actual SME-friendly GHG calculation tool.

Calculation tool	Description
Stationary Combustion	Calculates direct and indirect CO_2 emissions from fuel combustion in stationary equipment
Mobile Combustion	Calculates direct and indirect CO_2 emissions from fuel combustion in mobile sources
HFC from Air Conditioning and Refrigeration Use	Calculates direct HFC emissions during manufacture, use and disposal of refrigeration and air-conditioning equipment

Table 6: available tools appropriate for SMEs

The calculation tools mentioned in Table 6 are the so called cross-sector specific tools which can be applied within different sectors. In addition there are sector-specific tools available for the Iron and Steel, Cement and Small Office-Based branches.

5 THE PRODUCT STANDARD

The product level GHG inventory follows the life cycle and attributional approaches and is therefore a subset of the life cycle analysis (LCA). The ISO LCA standard defines four phases of a LCA study: the goal and scope definition, inventory analysis, impact assessment and interpretation. The relationship between the ISO phases and Product Standard is given in Figure 4 (9).

Figure 4: ISO LCA & Product Standard

The main steps conformant with the Product Standard are described in the following sections. First a company has to define the studied product. The studied product is the product on which the GHG life cycle inventory is performed. Next the boundary of the inventory is defined, followed by the collection of data and calculation of emissions.

5.1 SCOPE OF THE PRODUCT INVENTORY

To establish the scope of a product level GHG inventory companies shall first identify the studied product and then define the functional unit. Normally a short review or screening exercise of all the products a company produces, distributes, buys or sells is the first step in the identification process. The product that is the most GHG intensive during its life cycle as well as important in the business strategy should be picked. Emissions occurring along this life cycle have namely the most potential to be reduced. If a company already has completed a Corporate Standard inventory the results of this can help to point out the product with the largest impact. If such an inventory is not available companies may look to environmental extended input-output tables to estimate products their emissions based on economic value. When the main business goal is not pointed at emission reduction but for instance on performance tracking, the studied product is obviously to identify namely the one of interest. In general this also applies to SMEs, because their business is often focused on a single product or service. After all companies should keep in mind that the product level inventory and associated studied product meet their business goals.

For service – orientated companies, the method for choosing the studied service may depend on the company structure. For example, a SME that delivers one service can focus their inventory on that particular one. If a company delivers multiple services the service with the highest financial revenue can be chosen. Naturally, the inventory and associated studied service should meet the stated business goals.

Once the studied product is chosen, the next step is to specify the functional unit. The functional unit reflects in which way the studied product fulfills its function and consists normally out of three parameters: the magnitude of the function or service, the duration of that function or service and the expected level of quality (9). When choosing a functional unit there may be no unique answer, however it should be a unit that can be easily understood and used. Sometimes product rules or sector specific guidance can be a helpful source of the functional unit definition. An example of a functional unit is given in Table 7 and gives more clearance to its definition.

Functional unit	:	lighting 10 square meters with 300 1x for 50000 hours with daylight spectrum at 5600 K
The magnitude	:	lighting 10 square meters
The duration	:	50000 hours
The quality	:	with 300 luminance 1x and a daylight spectrum at 5600 K

Table 7: example of a functional unit light bulb

The functional unit is important because it provides the basis for comparison and communication of results. For services the functional unit includes the same parameters, but without defining the function because it's already the same as the selected service.

5.2 BOUNDARY SETTING

The next step is to define the boundary of the product inventory. The company has to identify all attributable processes along the life cycle of the studied product. These are the materials, energy flows and services that become the product, make the product and carry the product. This also includes the upstream and downstream process emissions, which are known from the Corporate Standard as Scope 3 emissions. Materials, energy flows and services that are not directly connected to the studied product can be excluded. Examples are capital goods, facility lighting and transport of employees.

The boundary for final products should include the complete life cycle. This means from raw materials extraction through the end-of-life stage (i.e. cradle-to-grave). These products are appointed as Business-to-consumer (B2C) goods, companies can also assess the life cycle of Business-to-Business (B2B) goods which can be used as inputs for different final products with other use and disposal characteristics. Commonly, a cradle-to-gate assessment is then performed including acquisition of raw materials and excluding the use and end-of-life stages. Companies should disclose and justify when a cradle-to-gate boundary is used following the fundamental accounting principles (chapter 3).

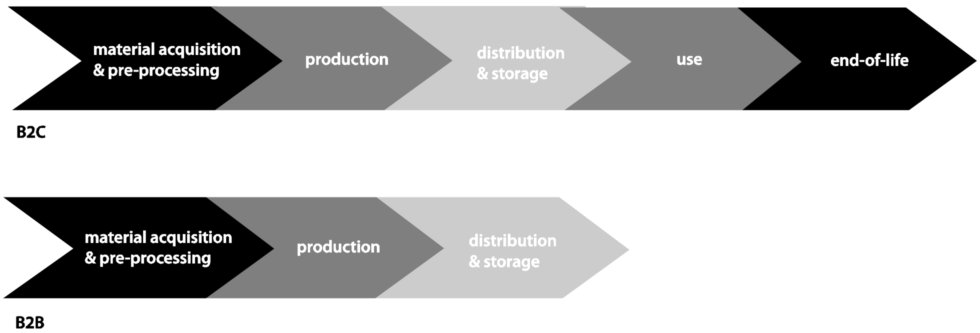


Figure 5: five stages of the product life cycle

Figure 5 illustrates the five life cycle stages that make up the product's life: the material acquisition & pre-processing (M&P) stage, the production stage, the distribution & storage (D&S) stage, the use stage and finally the end-of-life (EOL) stage.

- The M&P stage starts with raw material extraction and ends when product components enter the gate of the studied product's production facility. Examples of attributable processes are mining and extraction of materials, preprocessing of material inputs for product components and transportation.

- The production stage starts when the product components enter the production facility of the studied product and ends when the finished studied product leaves the production gate. Examples of attributable processes are manufacturing, assembly of product parts and packaging.

- The D&S stage starts when the studied product leaves the gate of the production facility and ends when the consumer receives it. Examples of attributable processes are refrigeration of the product and transportation.

- The use stage starts when the consumer takes possession of the product and ends when the product is transported for disposal. Examples of attributable processes are power consumption to fulfill the product its function and maintenance or repair.

- The EOL stage begins when the product is rejected through the consumer for disposal and ends when the product's material is returned to nature or allocated to another product. Examples of attributable process are operations during recycling or land filling and incineration.

The process map visualizes the life cycle stages and attributable processes of the studied product and is required in the product level inventory. It serves as a useful tool throughout the boundary setting procedure as well as a guidance during the complete inventory assessment. The following steps may be used to develop the process map:

Guidance	
1.	Identify the interconnecting life cycle stages
2.	Identify the company's gate by pointing out where the studied product is finished
3.	Identify the component inputs and upstream processing steps, according the appropriate stages
4.	Identify the energy and material flows associated with each upstream process, to appoint any waste or co products
5.	Identify the downstream processing steps and energy and material flows needed to distribute, store and use the studied product
6.	Identify the energy and material inputs needed for the EOL stage

Table 8: steps for establishing the process map (9)

For cradle-to-gate inventory assessments the process maps ends when the studied product is finished, i.e. when the product leaves the gate of the production facility.

Process maps for services are less consistent than for products and will vary depending on the service chosen. It shall be derived from the combined activities that provide the service. These activities may or may not result in a physical output. Therefore the life cycle involves more than just inputs and outputs, it will include all potential emission sources from the activity that contribute to the delivery or use of the service (13).

The last step in the boundary setting procedure is to define the time period of the studied product's life cycle. In general, the time period will depends on the use and EOL stage. The use-stage time period is based on the duration of the product's function. For example, if the function of a computer is to provide 6,000 computing hours, eight hours a day, five days a week, the use stage time period would be 2.9 year. The EOL-stage time period depends on the type of waste treatment and how long it takes for the product's carbon returns to nature. For example, a product's waste that is incinerated has a short time boundary compared to when it's in landfill. The time period of the three other stages M&P, production and D&S can be quantified by the company's processing data. When a company performs a cradle-to-gate inventory they should report the amount of stored carbon in the product as it leaves the gate. This is for transparency reasons and gives other companies an input for their product level GHG inventory.

5.3 DATA COLLECTION

Now the boundary of the studied product's life cycle is defined the data collections starts. This is usually the most time and resource intensive step and it determines more or less the quality of the inventory. For all processes specified in the process map data needs to be collected. This includes direct emission data, activity data and emission factors and financial activity data. Finally, the data needs to be well documented and assessed on quality.

Two different data types are specified by the GHG Protocol: primary data sources and secondary data sources. Primary data is required to be collected for all processes under financial control or operational control, as defined in section 4.1, within the boundary of the inventory. This data is measured or modeled from the specific processes in the product's life cycle. It can be either process activity data or direct emissions data, as long as the result is specific to that attributable process in the life cycle. Examples of primary data are, kilowatt-hours consumed by a process and kilograms material added to a process in the product's life cycle. It should be mentioned that the source of emission factor has no effect on the classification to meet the primary data requirement and emission factor do not need to be classified as primary or secondary.

When primary data is not available or is of poor quality, it's necessary to use secondary data. Secondary data is data that is not from specific processes in the product's life cycle. It's derived from other processes or activities of the reporting company or comes from external sources such as lifecycle databases or industrial associations. Financial activity data is always classified as secondary data and direct emissions and process activity data that do not meet the definition of primary data are classified as secondary data. Examples of secondary data are, kilowatt-hours consumed by another similar process used in the studied product's life cycle and industry-average kilograms of material input into a process.

The reporting company should mention which percentage of the GHG inventory emissions is calculated with primary data, secondary process or financial data. At the same time, companies need to assess their data quality by how representative the data is in time, technology and geography and the quality of the data measurement itself by data completeness and precision. This will improve the final inventory quality and it can be used to provide or demonstrate reliable data quality to stakeholders.

5.4 Allocation

A product's life cycle contains often one common process that has multiple valuable products as inputs or outputs and for which it is not possible to collect data at the individual level. When this is the case, the total emissions or removals from the common process need to be partitioned among the multiple inputs and outputs (9). This is known as allocation and is an important and challenging part of the inventory assessment.

A common process can produce besides waste two types of products; the studied product or a co-product that has value as an input for another process. Inputs may be services, energy flows, materials or intermediate products. Figure 6 illustrates a random common process.

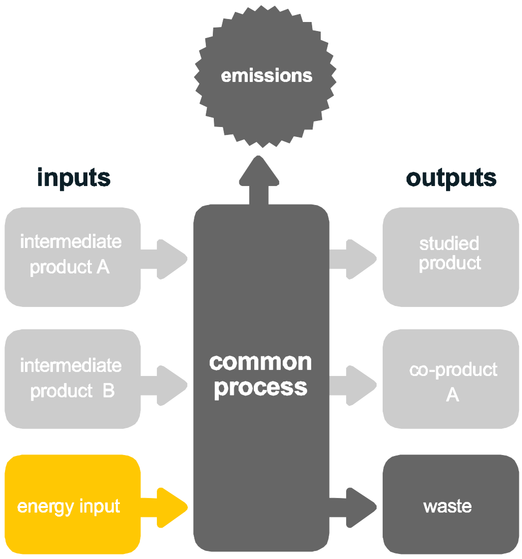


Figure 6: common process

There are different strategies to avoid allocation such as dividing the common process in sub-processes or redefining the functional unit. When allocation is unavoidable companies can perform allocation of emissions and removals by three methods. These methods are based on physical relation, economic relation or 'other relationships' between the studied product and co-product(s). When performing physical allocation, the most accurate factor of underlying physical relationship between studied product, co-products, emissions and removals shall be chosen. For example, if the mass of the process outputs determine the amount of emissions and removals a mass factor gives the most accurate allocation. When physical allocation cannot be applied economic allocation or another relationship method shall be used. Economic allocation divides the emissions from the studied product and co-product(s) according to the economic value of the product when leaving the common process. Other allocation methods use sector, company, academic or other sources for allocating emissions. They should only be used where the two above mentioned methods are not applicable. Companies shall always apply the same allocation methods to similar inputs and outputs within the product's life cycle.

The GHG Protocol describes also two methods for allocation due to recycling, namely the closed loop approximation method and recycled content method. The closed loop approximation method assumes that the material being recycled and associated emissions are used to displace the virgin material and associated emissions. This results in a ratio between virgin and recycled material input and is called the end-of-life recycling rate. In contrast with the previous method, the recycled content method allocates the recycling process emissions to the life cycle that uses the recycled material and is modeled as an open loop situation.

5.5 CALCULATING EMISSIONS

Once the data collection process is completed companies shall calculate and report the total GHG emissions per functional unit. During the data gathering process companies have collected direct emissions from measurements and operational and financial activity with belonging emissions factors. For consistency and comparability all results are reported as a GHG impact in the form of CO_2 equivalents (CO_2e). Companies can then calculate the GHG inventory results as CO_2e per unit of analysis (i.e. functional unit).

According to the Product Standard companies should follow the steps listed in Table 9 when calculating the GHG impact of the studied product. During the calculation procedure companies should apply a 100 year GWP to calculate the impact in unit CO_2e.

Calculate the GHG impact using the collected data

Based on activity data:

$$GHG\ impact\ [kg\ CO_2e] = activity\ data\ [unit] \cdot emission\ factor\ \left[kg\frac{GHG}{unit}\right] \cdot GWP\ \left[\frac{kg\ CO_2e}{kg\ GHG}\right]$$

Based on direct emissions

$$GHG\ impact\ [kg\ CO_2e] = direct\ emission\ data\ [kg\ GHG] \cdot GWP\ \left[\frac{kg\ CO_2e}{kg\ GHG}\right]$$

Calculate total CO_2e / functional unit

$$\frac{Total\ CO_2e}{functional\ unit} = \frac{CO_2e\ emissions}{functional\ unit} - \frac{CO_2e\ removals}{functional\ unit}$$

Table 9: calculation steps

Based on the collected activity data, emissions factors, direct emissions and GWP data the GHG impact is calculated. Then all CO_2e values are summed together to calculate the total CO_2e per unit of analysis.

Companies should report different inventory results to be consistent with the Product Standard. This includes:

- Percentage of impact per life cycle stage
- Percentage of primary process, secondary process and secondary financial data
- Biogenic and non-biogenic removals and emissions (when applicable)
- Land use impact (when applicable)

In addition to reporting the inventory results per the life cycle stages, it may be interesting to report the inventory results of the cradle-to-grave and gate-to-gate. This gives insight into the amount of emissions and removals disposed under control of the reporting company.

5.6 Assessing uncertainty

The term uncertainty refers to a systematic procedure to quantify or qualify the uncertainty in a product inventory. It helps companies to understand how they can improve the quality of their inventory. Various types of uncertainty may affect this quality. The GHG Protocol divided these uncertainty types into three categories: parameter uncertainty scenario uncertainty and model uncertainty:

- **Parameter uncertainty:** is the uncertainty regarding whether a value used in the inventory accurately represents the process or activity in the product's life cycle. Corresponding sources are direct emissions data, activity data, emission factor data and GWP.
- **Scenario uncertainty:** is the uncertainty that refers to variation in results due to methodological choices. Corresponding sources are methodological choices.
- **Model uncertainty:** is the uncertainty that arises from limitations in the ability of the modeling approaches used to reflect the real world. Corresponding sources are the limitations in a used model.

Using these three types in a quantitative approach can assist a company with making quality improvements to high uncertain data sources. However, a quantitative approach is not required but can add clarity and transparency to an inventory report. Companies should report a qualitative description of the uncertainty sources and methodological choices made in their inventory. These include the use and end-of-life profiles, allocation methods including recycling, the sources of GWP and any calculation model used to quantify emissions as shown in Table 10.

Source of uncertainty	Qualitative description
Scenario uncertainty	
• Use profile	Describe the use profile of the product. If more than one use profile was used, disclose which one and justify the choice.
• EOL profile	Describe the EOL profile of the product. If more than one OEL profile was used, disclose which one and justify the choice.
• Allocation method(s)	Describe any allocation problems in the inventory and which allocation method was used. If more than one allocation method was used, disclose which one and justify the choice.
• Recycling allocation method(s)	Disclose and reference which method was used.
Parameter uncertainty	
• GWP factors	List the source of GWP factors used.
Model uncertainty	
• Model sources not included in the scenario or parameter uncertainty	Describe the model, identify their source and areas where they deviate from the real world.

Table 10: qualitative description of uncertainty sources GHG Protocol

6 CASE STUDY

In order to get a better understanding of the GHG calculation within SMEs a case study is performed. This study explores the establishment of the inventory and its emissions by a small manufacturing enterprise MMS. MMS assembles and maintains a wide range of products made from steel wire and tubes. Driven by ambition the firm looks for new opportunities to distinguish them self from competitors. Environmental management might be an innovative strategy within their branch. However this is too complicated to start with for a proprietorship like MMS. GHG product calculation is the outcome and results in quick and noticeable benefits. Consider benefits as reducing energy consumption or product carbon footprinting that were previously mentioned in chapter 2. The following is a discussion of the motivating factors and business goals that MMS has appointed before starting the product level GHG calculation.

6.1 DRIVERS & BUSINESS GOALS

MMS delivers new products and maintenance & repair services. The nature of these services is therefore environmental friendly; it's a way of extending a product's life. In order to support more in this friendliness ecoPortal® is already used to manage sustainability and health & safety. The awareness on climate change and the ensuing business market is seen and gives MMS several motivating factors to start a product level GHG inventory. Establishing an inventory at corporate level is currently not seen as added value to their business strategy and is therefore not performed.

MMS is pushed as well as pulled to product carbon footprinting by the pressure and the demand of stakeholders. According to MMS the New Zealand government shall introduce in the nearer future carbon taxes or other environmental regulations. In addition, their biggest customer is the government-owned enterprise New Zealand Post. If taxes or regulations are introduced New Zealand Post will exert pressure on their suppliers including MMS. Gaining knowledge by and showing early voluntary action in GHG accounting gives MMS the opportunity to respond to pressure like this. Also the demand of customers in an enterprise's environmental consciousness is rising. Therefore drivers such as good publicity, good promotion and attracting new customers through carbon footprinting pull MMS into action. Advantages are for example seen during tenders. When different enterprises deliver a product or service with equal quality and price, but MMS environmental knowledge of that product or service lie ahead will make the difference.

The business goals stated by MMS to start a product GHG inventory conform with the Product Standard (chapter 2) are listed in Table 11. Four of the five goals are good from a business perspective and will result in competitive advantages. It shows that the environmental perspective of GHG accounting is in the second place. This is conforms to the drivers that move SMEs to action as mentioned in chapter 2.

Business goals MMS
Competitive advantage
Strengthen corporate reputation
Product carbon footprinting for good publicity
Showing early voluntary action by GHG accounting
Focus efforts on efficiency improvements and cost-saving opportunities

Table 11: business goals MMS

6.2 THE SCOPE OF THE INVENTORY

The studied product is the New Zealand Post cage. Different cages are in use by New Zealand Post, but are all based on the same design series. The studied cage is the largest version (TS5) of the series and is shown in Figure 7. Identification of the studied product was straightforward due to the fact that MMS's business is currently for 80 percent focused on the maintenance & repair services of those cages. The post cage provides thus in the highest financial revenue for MMS.

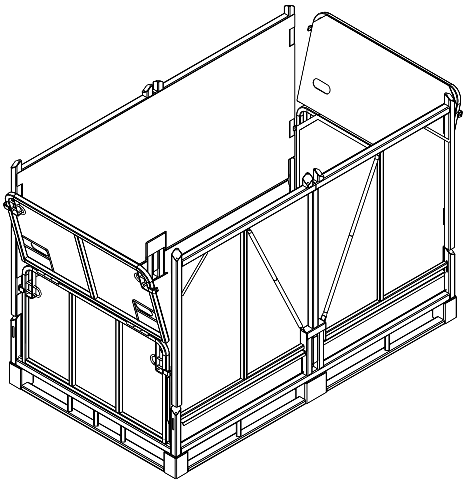


Figure 7: the TS5 post cage

As stated in section 5.1 the functional unit consists out of three parameters: the magnitude of the function or service, the duration of that function or service and the expected level of quality. The function of the TS5 post case is providing storage space to post parcels. The magnitude of the storage space is 2.5 m^3 and the average life time of the cage is 3 year and including maintenance & repair 6 year. The functional unit is therefore 2.5 m^3 storage space during 6 years. The quality of the function providing storage space to post parcels is hard to describe and is therefore disregarded.

Functional unit	:	2.5 m^3 storage space during 3 years
The magnitude	:	2.5 m^3 storage space
The duration	:	6 years
The quality	:	-

Table 12: functional unit of the TS5 post cage

6.3 BOUNDARY SETTING

Before the inventory boundary is determined, it should be clear how MMS is involved in the different life cycle stages of the post cage. MMS stores and distributes the cage to New Zealand Post, provide maintenance & repair services during the use stage and decommission the cage in the beginning of the EOL stage. The actual production of the cage is outsourced to a partner-manufacturer situated in the same building and in the nearer future MMS will take over the assembly phase. However, the life cycle production-stage includes the outsourced manufacturing and assembly of the post cage.

The boundary will reach from cradle to grave and the associated process map is set up with help of the guidance provided in Table 8. The result of this procedure is displayed in Figure 8. It illustrates the materials, energy flows and services needed to create the cage. The following gives a description of each life cycle stage and attributable processes that lie within the boundary:

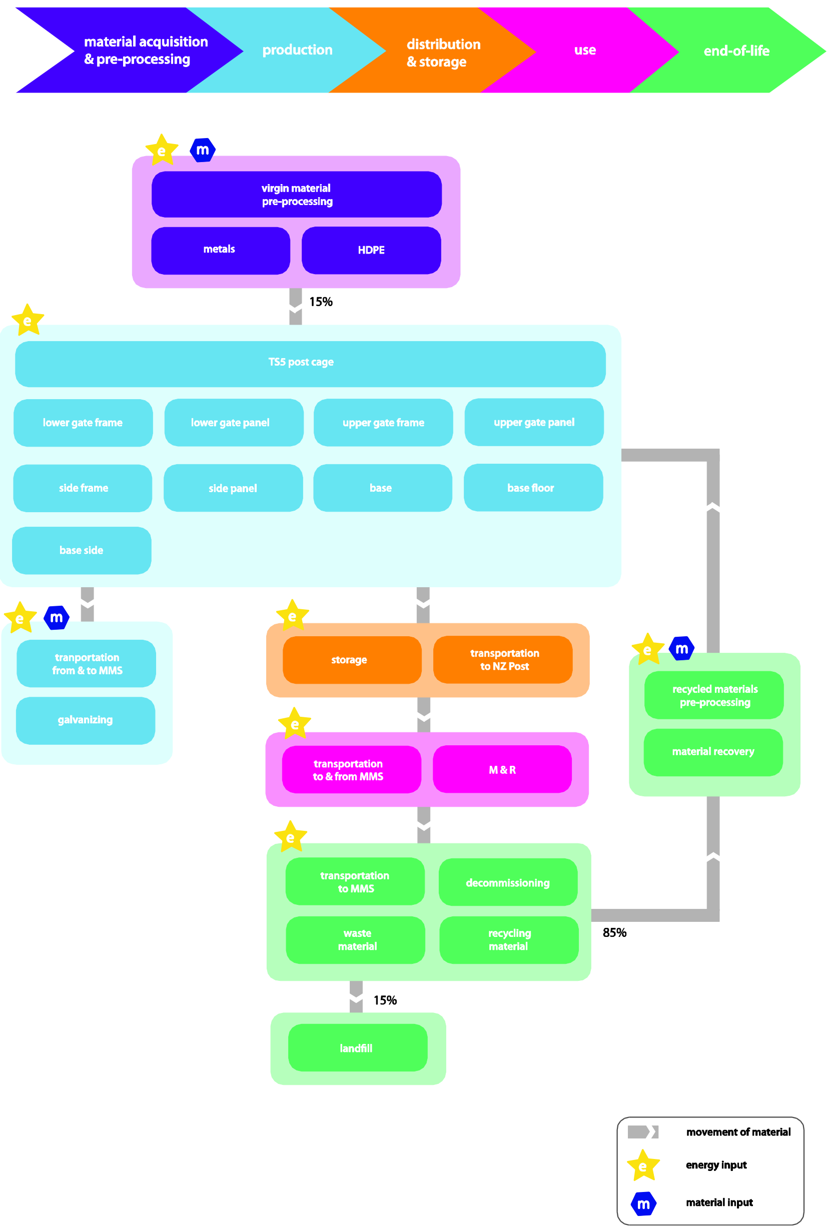
- The M&P stage starts with the extraction of resources for the materials steel and high-density polyethylene (HDPE). Subsequently the pre-processing starts and the raw materials are processed into the cage's base components, which are finally transported to the production facility in Auckland. Due to the complexity of this upstream stage and a lack in time and resources, it's simplified with an already existing cradle-to-gate model for metal and HDPE products. The attributable processes that are taken into account will be described in section 6.4.1.

- The production stage covers the manufacturing processes, galvanizing process and assembly of the cage's components. Appendix A gives a detailed overview of all the production steps, used machines and machining time. Transportation of semi-finished products between the manufacturing processes takes place in the production facility. However, the galvanizing process is outsourced and causes transport emissions.

- The D&S stage starts after the cage is assembled. It includes storage of the cage in MMS's warehouse and transportation to New Zealand Post.

- The use stage includes the maintenance & repair services and the transportation to MMS and back to New Zealand Post.

- The EOL stage includes decommissioning (disassembly of the cage) performed by MMS and recycling and land filling processes. Due to the complexity of this downstream stage and a lack in time and resources it's simplified with a model. The attributable processes that are taken into account will be described in section 6.4.5. Further, it should be noted that for steel an 85 percent EOL recycling rate is used based on Worldsteel information (14). The same recycling rate is assumed to be valid for HDPE. This means that 85 percent of the cage's material is recycled following the closed loop approach which replaces the input of virgin material. The other 15 percent is treated as waste in the form of landfill.



Note: the transportation processes from the M&P stage, land filling stage and recycling stage are not displayed because they are included in WARM (*section 6.4.1).*

Figure 8: process map of the TS5 post cage

6.4 Data collection

For every life cycle stage a descriptive statement is given about the data source, data quality and efforts that can be taken to improve this quality. All the emissions are calculated with the factor based approach and the emission factors sources are accessible without software licence and are provide by governmental initiatives or industry associations. This shows that SMEs are able to start a GHG initiative, without investing in expensive software licenses necessary for LCA programs.

6.4.1 Material acquisition & pre-processing data

The GHG emissions resulting from the upstream M&P stage are calculated by the amount of material used (Appendix A) and the emission factors of the Waste Reduction Model (WARM) from the United States Environmental Protection Agency (EPA) (15). It's based on average United States production data and not specific to the cage's components. Therefore the source is classified as a secondary data source.

WARM assesses the GHGs implications of a range of products and materials, including metals and HDPE. The metals category comprises copper wire and aluminum and steel cans. These three categories were selected because they have been identified as having a large GHG impact across their life cycle and have good data availability. The last category steel cans can be used as a surrogate material for ferrous metals and should then be considered as an approximation only.

The M&P stage of the surrogate for metal involves mining of iron ore, limestone, coal and lime. These inputs are then used to produce pig iron and manufacture steel sheet which is made in a blast furnace and basic oxygen furnace (virgin metal) or electric arc furnace (recycled metal). Finally the steel cans are manufactured. The GHG emissions associated with these steps are divided into process energy emissions, transportation energy emissions and process non-energy emissions resulting from the manufacturing processes. Table 13 gives an overview of the emission factors and the net emission factor of the M&P stage for virgin metal.

GHG emission factor	kg CO_2e / kg metal
Process energy	2.72
Transportation energy	0.37
Process non-energy	0.96
Virgin Metal	**4.05**

Table 13: emission factor for virgin metal

The WARM HDPE category can be used for a large variety of products, from household goods to industrial pallets. The M&P stage of HDPE involves the acquisition of derivatives from refined petroleum or natural gas. This results in process energy and non-energy GHG emissions from the extraction and refining of these inputs. Transportation energy comes from the transport of petroleum or natural gas to the manufacturer. The input material is then modified or undergoes a cracking process which results finally in HDPE. Table 14 gives an overview of the emission factors and the net emission factor of the M&P stage for virgin HDPE products. It should be noted that the transportation energy for HDPE as well for metals includes transportation emissions from the manufacturer to the retail location.

GHG emission factor	kg CO_2e / kg HDPE
Process energy	1.90
Transportation energy	0.04
Process non-energy	0.21
Virgin HDPE	**2.15**

Table 14: emission factor for virgin HDPE

The data quality is classified as poor mainly for two reasons. Firstly the emission factor for metals represents a surrogate metal resulting in approximate GHG emissions and secondly the geographic validity of WARM is unrepresentative for New Zealand. Improvements can be made by setting up an upstream cradle-to-gate inventory for the cage's materials supported by data of the involved companies. As an alternative, life cycle inventory results for steel products such as cold rolled sheet, rectangular beam section or rod can be requested from well known industry associations as Worldsteel or Steelconstruction. Only this data is again based on an industrial average and the depth of information might be low compared to an own designed cradle-to-gate upstream inventory.

6.4.2 PRODUCTION DATA

The GHG emissions resulting from the production stage are determined by the specific machine time and average power of the used production machines. The activity data is then multiplied by the right emissions factor, established by the MfE in 2007 (7), resulting in GHG emissions. This data can be classified as primary data, because the data is specific to the cage's production process.

GHG emission factor	kg CO_2e / kWh
Electrical consumption	0.165

Table 15: emission factor for electrical consumption

Appendix A shows all the production steps, used machines and machine time needed to manufacture the cage. This information comes from routing data of the manufacturer. Ideally, the electrical consumption is measured during each separate production step. This is because of most machines will not draw a constant amount of power over time. For example the actual power that an electro motor demands, found in most production machines, and the energy it consumes are related to the amount of mechanical power that the motor delivers through a specific task. Most off the time this is less than the maximum motor capacity.

Limited time and a lack of resources made it impossible to perform electrical consumption measurements during machine time. The average power consumption in kilowatt (kW) of each machine was therefore requested by the machine manufacturer or when not available calculated with known motor data (Appendix D). These calculations are made under a set of assumptions such as motor efficiency and amount of real power used. This affects finally the high quality machine time data, when calculating the electrical consumption in kilowatt-hour (kWh). Improvements can therefore be made by setting up and performing an electrical consumption measurement for each production step.

Also, other GHG sources should be taken into account such as the released gases during welding or the outsourced galvanizing process. Only it turn out that the availability of proper emission factors for processes like this are rare. They might be available in expensive LCA software packages, but are not accessible without licence. Though, an emission factor for galvanizing was found on the website footprinted.org which is a collaboration of the Swedish KTH Royal Institute of Technology, United States MIT Media Lab and the company Sourcemap Inc. (16).

GHG emission factor	kg CO_2 / kg metal
Galvanizing	0.05

Table 16: emission factor for galvanizing

The data quality can be improved by setting up a specific downstream gata-to-gate inventory for the galvanizing process.

6.4.3 DISTRIBUTION & STORAGE DATA

The GHG emissions resulting from the distribution and storage stage are determined through the distance travelled by a heavy good vehicle (HGVs) (i.e. truck). Storage off the cages is not significantly long enough and its emissions are therefore not included in the distribution & storage stage. The emission factor comes from the United Kingdom Department for Environment Food and Rural Affairs and is based on average kilometres per gallon provided by a large set of heavy good vehicles.

GHG emission factor	kg CO_2 / tkm
HGV	0.336

Table 17: emission factor for HGV

The factor is appropriate for vehicles with a gross vehicle weight ranging from 7.5 tonnes to 17 tonnes and converts tonne km (tkm) to CO_2 emissions. A tkm is the distance travelled multiplied by the weight of freight carried by the vehicle. For example, a truck carrying 5 tonnes freight over 100 km has a tkm value of 500 tkm. This data can be classified as primary data, because the distance travelled is specific to the distribution process.

The data quality can be improved by measuring fuel consumption of the vehicle during the distribution process. This in combination with an appropriate emission factor (kg CO_2 per gallon fuel) provided by the vehicle manufacturer will result in higher data quality.

6.4.4 USE DATA

The GHG emissions resulting from the use stage are determined through the distance travelled by a HGV and the machine time of the machines used during the maintenance & repair procedure. For both data types there is an emission factor available. The HVG emission factor (Table 17) is used to calculate the emissions caused by the transportation process to and from MMS and maintenance & repair emissions are calculated using the electrical consumption emission factor (Table 15). The data quality of both data types can be improved as mentioned in section 6.4.2 and section 6.4.3.

6.4.5 END-OF-LIFE DATA

The GHG emissions resulting from the downstream end-of-life stage are determined by disassembling, recycling and land filling of the cage. Disassembling includes emissions caused by HGV transport (Table 17) of the cage to MMS. The recycling and land filling process emissions are calculated with the amount of material processed and emission factors of WARM. Most materials in WARM are modeled as being recycled in a closed loop, including steel cans and HDPE. This is in consensus with the first allocation method for recycling suggested by the GHG Protocol.

The production of steel cans made out of recycled material, in this case a surrogate for ferrous recycled metals, involves metal recovery and melting of the recovered metal to cast ingots. Metal product manufacturing from fully recycled products involves limestone mining and lime use to produce steel in an electric arc furnace. WARM assumes that one ton steel produced from recovered steel in an electric arc furnace displaces one ton steel produced from virgin inputs in a basic oxygen furnace. Besides this the fabrication values of an oxygen furnace are used within the recycling model. The emission factor is again build up by emissions from process energy, transportation energy and process non-energy. Figure 19 gives the metal product manufacture GHG emissions using fully recycled inputs.

GHG emission factor	kg CO_2e / kg metal
Process energy	0,75
Transportation energy	0,35
Process non-energy	0,96
Recycled metal	**2,06**

Table 18: emission factor for metal product manufacture using 100 % recycled inputs

Industry association Worldsteel provided on request life cycle inventory information (gradle-to-gate including EOL recycling) of two steel products, containing both an 85 percent recycled input. The average GHG emission factor in kg CO_2e per kg steel product is calculated to verify the net recycling emission factor of WARM. With 10 percent difference between the emission factors and a recycling rate of respectively 100 and 85 percent is assumed that WARM approximates the GHG emissions for recycled metal well. Appendix E gives more detail on the calculation.

Recycling of HDPE is also modelled in a close loop, but details of the recycling and attributable processes are not described in the WARM documentation. Table 19 gives the HDPE product manufacture GHG emissions using recycled inputs. Again, it should be noted that the transportation energy for HDPE as well for metals includes transportation that occurs during the recycling process.

GHG emission factor	kg CO_2e / kg HDPE
Process energy	0,14
Transportation energy	0,06
Process non-energy	0
Recycled HDPE	**0,20**

Table 19: emission factor for HDPE product manufacture using 100 % recycled inputs

To ensure consistency the WARM emission factors for land filling are used. WARM considers the CH_4 emissions from anaerobic decomposition of biogenic carbon compounds, transportation-related CO_2 emissions and biogenic carbon stored in the landfill. Because metals and HDPE do not contain biodegradable carbon, they do not generate CH_4 and are not considered to store any biogenic carbon when land filled. The only emissions associated with land filling metals and HDPE are from transportation to the landfill and moving waste into the landfill. Table 20 gives the WARM emission factor for land filling of metals and HDPE.

GHG emission factor	kg CO_2e / kg HDPE
Transportation	0,04
Landfill CH_4	-
Carbon sequestration	-
Recycled HDPE	**0,04**

Table 20: emission factor for land filling metals and HDPE

Improvements in data quality can be made by setting up a downstream gate-to-gate inventory of the EOL stage supported by data of the involved recycling and land filling company.

6.5 Inventory results

This chapter gives the GHG inventory results of the TS5 post cage. First the source and data of the used GWP factors are given, followed by the CF of the cage in carbon dioxide equivalent. This involves all the emissions included in the inventory boundary. Per life cycle stage the percentage with respect to the total CF is given and additional the CF is separated into the gate-to-gate and cradle-to-gate results.

6.5.1 Global Warming Potential

The 100 year GWP factors out of the Second Assessment Report (1995) (17) of the Intergovernmental Panel on Climate Change (IPCC) are used within the calculation. This is in accordance with the Climate Change Convention reporting requirements (2006) used in the New Zealand's GHG Inventory 1990 – 2007 (7) and WARM model (15). In this way there is consistency between all the emissions used in the report. The most current IPCC GWP factors at the time of this report are the factors published in the Fourth Assessment Report (2007) and might be used for future calculations.

GWP (100-Year Time Horizon) Used in This Report

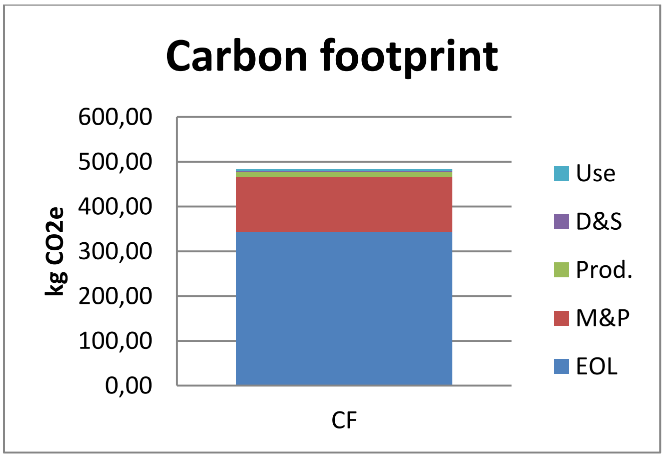
Gas	GWP
CO_2	1
CH_4	21
N_2O	310
SF_6	23,900
HFCs*	-
PFCs*	-

*depends on the type of HFC or PFC gas. More specific GWP information can found in Appendix G

Table 21: GWP 100-year

6.5.2 Carbon Footprint

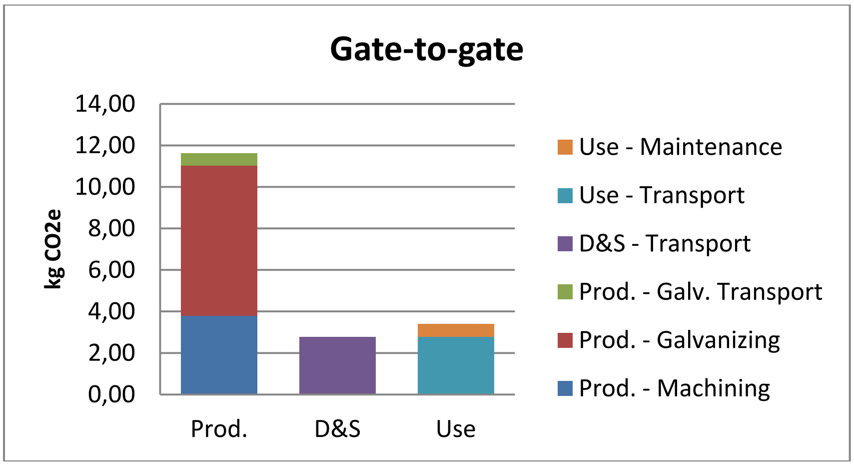
The total product CF is 483.39 kg CO_2e per 2.5 m^3 storage space during 6 years (TS5 post cage including maintenance & repair) and is graphical shown in Figure 9. The majority of carbon dioxide equivalent is attributable to the EOL stage which represents 71.20 percent of the total. Main reason for this is the 85 percent recycling rate for metals and HDPE. This causes a shift in GHG emissions from the virgin M&P stage to the recycled material pre-processing stage. The virgin M&P stage stands for 25.12 percent of the total GHG emissions and the remaining or gate-to-gate emissions stand for 3.68 percent.



Stage	kg CO_2e	%
M&P	121.44	25.12
Prod.	11.63	2.41
D&S	2.77	0.57
Use	3.40	0.70
End-of-life	344.16	71.20
Total	483.39	-

Figure 9: CF of the TS5 post cage

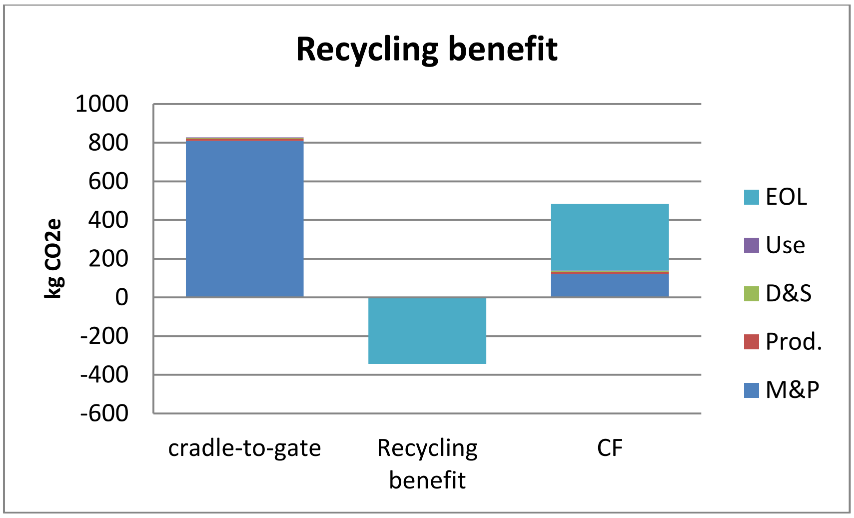
The gate-to-gate inventory results are shown in Figure 10. It includes the outsourced production stage, D&S stage and the use stage and is based on primary data. The use stage is consists of maintenance & repair provided by MMS and lies therefore within the gate. Together the gate-to-gate impact is 17.80 kg CO_2e. The production stage has the largest impact with a major contribution from the galvanizing process. When MMS doesn't provided maintenance & repair services, the total product CF will reduce with 3.40 kg CO_2e, but the life time of the cage will decrease from six years to three years. Therefore two post cages are needed to replace one post cage that is under maintenance by MMS. This means that MMS's services result in a carbon saving of 476.6 kg CO_2e per post cage.



gate-to-gate CF	
17.80	kg CO_2e

Figure 10: gate to gate CF of the TS5 post cage

Figure 11 shows the benefit of the EOL recycling stage. First the cradle-to-gate CF based on virgin material manufacturing is calculated, which is equal to 827.39 kg CO_2e. Secondly, the recycling benefit (85 percent recycling rate) is calculated which is equal to 344 kg CO_2e. Because recycling is modeled as a closed loop process, the emission reductions are calculated by taking the difference between GHG emissions from manufacturing a material from virgin inputs and an equivalent amount of recycled inputs. In fact the recycled material avoids or offsets the upstream emissions associated with virgin material manufacturing. Therefore the recycling benefit is shown as a negative number. The net result of the cradle-to-gate virgin CF plus the recycling benefit results then in the total product CF that is shown in Figure 9. The benefit of recycling is 44.5 percent.



Recycling benefit	
41.60	%

Figure 11: recycling benefit

Figure 13Figure 12 and Figure 13 give insight in the proportion of emissions per product part associated with the material manufacturing (i.e. M&P and recycling stage) and machining phase. The parts with a high percentage of carbon dioxide equivalent, have the most potential to reduce the total product CF. Both figures show that the base, which consists out of the base frame, base floor and base side panel, has the largest impact. 65 percent of the manufacturing GHG emissions are associated with the base, which can be explained by the fact that it represents 57 percent of the total amount of metal used. This fact and the design and function of the post cage indicate that it's probably over weighted, which gives GHG reduction opportunities by redesigning it using less material.

Figure 12: product manufacturing emissions per part

Also, more than half of the emissions due to machining belong to the base. A large proportion of these emissions belong to the welding operations. All the base frame pieces are welded together and finally the base floor and base side panel are welded to the frame. A smarter and lighter design for the base as well as for the other parts can reduce the machining and material manufacturing emissions and at the same time it can reduce emission caused by transport.

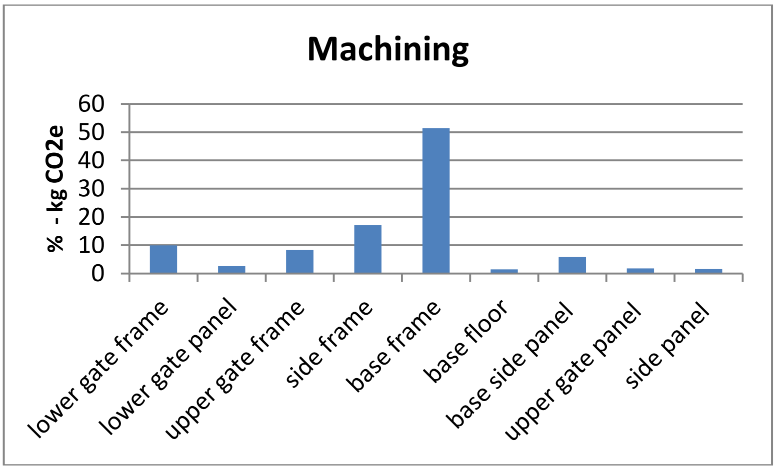


Figure 13: machining emissions per part

6.6 ASSESSING UNCERTAINTY

The following is a qualitative description of the required uncertainty sources according to section 5.6. This includes scenario uncertainty of the use profile, EOL profile and recycling allocation method, parameter uncertainty of the global warming potential (GWP) factors and model uncertainty of WARM.

Use profile

The use profile of the cage includes two attributable processes: transportation from New Zealand Post to MMS and back and in between maintenance & repair services. Further the cage uses no other attributable processes as for example energy to fulfill its function.

End-of-life profile

The EOL profile of the cage includes recycling and disposal in landfill. First, MMS starts with the decommissioning of the post cage. Metal and HDPE parts are separated and MMS offers them to a recycling agent. Therefore recycling is one method used in the EOL profile. In general not all the metal and HDPE collected can be recycled and a recycling rate of 100 percent is rarely, so a fraction of the cage's material is treated as waste. According to the Solid Waste Composition Report of the MfE (18) New Zealand disposed 3,156 million tonnes of municipal waste (including industrial waste) to landfill in 2006, whereof three quarters is potential reusable material including metal and plastic. In addition, there is no incineration of this type of waste in New Zealand. The only incineration is for small specific waste streams, including medical, quarantine and hazardous wastes (7). Therefore the second method used in the EOL profile is land filling.

Recycling allocation method

The recycling process for metal and HDPE is based on the closed loop approximation method. This method is defined as a method to allocate recycled material that maintains the same inherent properties as its virgin material input. The emissions factor for recycled metal is based on the following recycling process. Recycled metal is processed, re-melted and cast into metal ingots. It is known that the ingots have the same inherent properties as virgin metal (14). Because of this it can be assumed that the recycled metal displaces the production of virgin metal. This kind of process information is missing for HDPE. Although, research shows that when suitable reprocessing conditions are adopted the recycled material properties are near to those of virgin HDPE (19).

Global Warming Potential

The 100 year GWP factors out of the Second Assessment Report (1995) of the Intergovernmental Panel on Climate Change are used and are listed in Table 21. According to the IPCC, the GWPs typically have an uncertainty of ±35 percent (17).

WARM

The waste reduction model (WARM) is used to estimate the GHG emission associated with virgin and recycled material production. As already stated in section 6.4.1 WARM is based on United States data and is therefore geographical unrepresentative for New Zealand. The other limitation is the 'metal can' model that is used as a surrogate model for the cage's metal components.

The model itself is also based on assumptions (15) which deviates it from the real world:

- The manufacturing GHG analysis is based on industry averages for energy usage and in some cases these averages are based on limited data.
- The GHG emission factors for recycling incorporate assumptions on loss of material through collection, sorting and manufacturing. There is uncertainty in the loss rates: some recovery facilities and manufacturing processes may recover or use recycled material more or less efficient than as estimated.
- It is assumed that increased recycling does not change overall demand for products.

7 CONCLUSIONS & RECOMMENDATIONS

The previous chapters showed motivation factors for SMEs to start GHG accounting, the background theory of GHG accounting at corporate and product level and the implementation of this in a case study. The background theory sets a framework for accounting and the case study shows how this can be implemented within a SME. During the study several lessons were learned about limitations and opportunities of the method. This concerns for example emerging bottlenecks due to consistency with the GHG Protocol and making advantage by two levels of GHG accounting. With this knowledge the theory is reflected and extended upon the context SMEs. This will be described in the following chapter.

The background theory investigated the different steps for preparing a GHG inventory and calculation emissions. This can be done at corporate level or product level, which gives the opportunity to implement the method in different sectors of industry. Besides applying the method to manufacturing SMEs, corporate level accounting can be applied to office-based SMEs and takes typically energy related emissions of facilities and operations they own into account. Regarding to the development of an SME-friendly GHG calculation tool, covering a larger set of sectors increases the chances of success. Although, there are many barriers to overcome and the case study gave more insight in these.

The case study explores the implementation of the Product Standard method within the enterprise MMS. The Corporate Standard wasn't applied due to set business goals and acting drivers. This study resulted finally in a product CF and is most valuable for MMS itself. It acts as a starting point in environmental practices and shows stakeholders MMS's awareness in global warming. From a research point of view, the actual path to the product CF is much more valuable. During the implementation phase it appeared that the data availability of appropriate and free emission factors is scarce and that the needed activity data is an issue of concern within the context of SMEs. To overcome these bottlenecks two possible solutions are described.

New Zealand is a country that is aware of its contribution to global warming. This is showed through numbers of energy consumption and energy-related GHG emissions and used sector results of the New Zealand's Greenhouse Gas Inventory 1990-2007, which are all composed by the New Zealand's MfE. Without the support of specific emission data of larger companies this wasn't possible. This fact confirms that larger companies are integrating environmental management into their business; otherwise the MfE would not be able to establish such a comprehensive inventory. When data from this level is used to provide New Zealand's SMEs information about their upstream and downstream attributable processes, the shortage of emission factors takes back and the inventory quality improves. Unfortunately, the translation of emission data to usable emission factors cannot be realized by SMEs their selves. A solution for this problem requires collaboration with New Zealand's industrial associations such as the New Zealand Sustainable Steel Council. The result is sector specific emission data which can be used as a starting point to start a calculation tool for that specific sector and can be extended later on to a SME-friendly GHG calculation tool.

Opportunities are also seen in using both levels of accounting in one enterprise. When starting a GHG initiative at corporate level to determine Scope 1 and Scope 2 emissions, these results can be used as a data source when calculating a product's CF. At the same time these corporate data help to identify the most emission intensive product categories and can result in major cost benefits through energy reduction. Here is assumed that the Scope 1 and Scope 2 emissions are basic emissions and energy related. Although, the upstream and downstream emissions know as the Scope 3 emissions are again hard to evaluate as already mentioned above. Therefore the SME-friendly GHG calculation tool has to support SMEs by providing specific cradle-to-gate information about input products and different EOL scenarios. This together gives SMEs the opportunity to become acquainted with GHG accounting and to take advantage of the drivers that pulled them into action.

Another bottleneck arises when designing a SME-friendly GHG calculation tool that is fully consistent with the GHG Protocol accounting principles. Due to the variety of emission sources and attributable processes between SMEs per industrial sector as well as per specific sector, the boundary of each GHG inventory will vary. This asks for a large data base of emission factors and EOL scenarios, which takes years to develop. In addition, the purpose of the calculation tool will then shift towards the side of already existing LCA software packages. Besides this, the possible tool has the purpose to act as a first environmental practice to overcome the mentioned barriers. Later on SMEs can use the gained experience to set up their own GHG accounting and reporting program conforming to the protocol.

Concluding, the insights and lessons learned provide a starting point for further research and design of a SME-friendly GHG calculation tool. It is recommended to start a co-operation with New Zealand's industrial associations and government to gather high quality downstream (M&P stage) and upstream data (D&S and EOL stage), as displayed in Figure 14. This can be used to start a sector specific tool design which can be expanded later on. At the same time interested SMEs need to be assisted with accounting for Scope 1 and Scope 2 emissions. Together, these data stream will support the tool design and in return the involved companies can take advantage of the results.

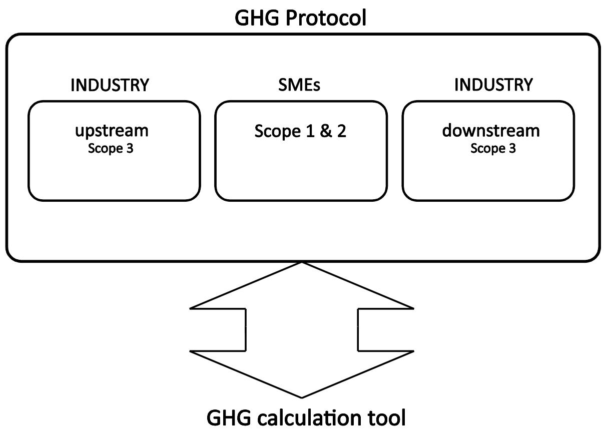


Figure 14: tool design

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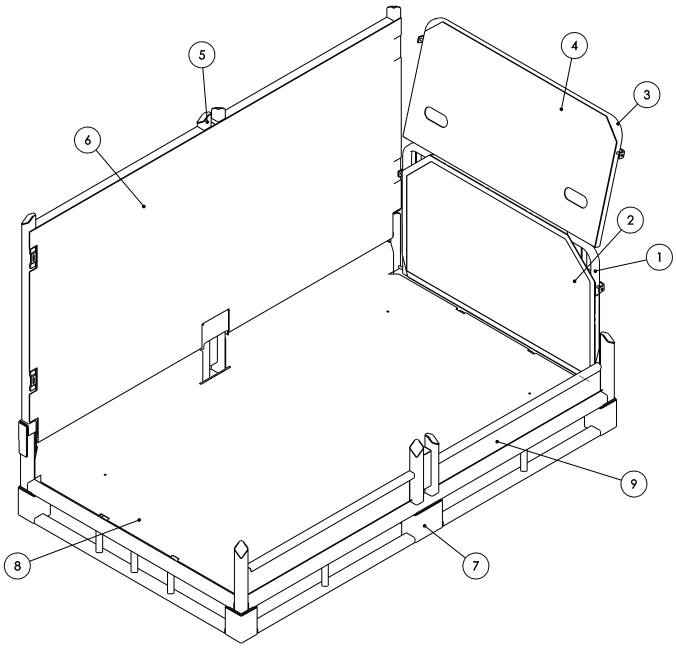
APPENDIX

APPENDIX A – PRODUCTION DETAILS

This Appendix contains the machining details of the post cage's parts. Together with the machinery details (Appendix D) it results in the activity data for the cage's production process.

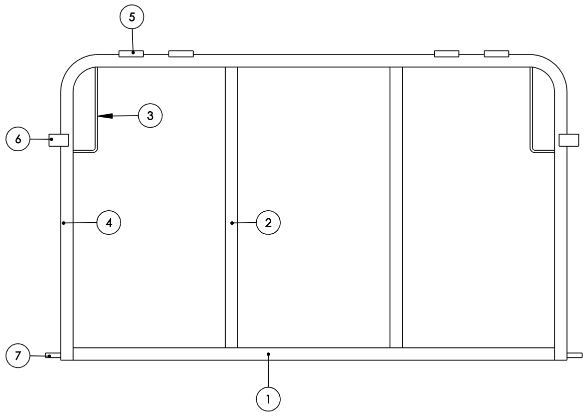


ITEM NO.[1]	QTY. [2]	Part	Weight [kg]
1	2	lower gate frame	5.60
2	2	lower gate panel	10.50
3	2	upper gate frame	4.70
4	2	upper gate panel	1.40
5	2	side frame	20.60
6	2	side panel	5.10
7	1	base frame	68.50
8	1	base floor	27.50
9	4	base side panel	3.60

Figure 15: TS5 post cage

[1] ITEM NO. i.e. ITEM NUMBER
[2] QTY. i.e. QUANTITY

Lower gate frame



ITEM NO.	QTY.	Material
1	1	ERW tube 25.4*25.4 *1.6mm
2	2	ERW tube 25.4*25.4 *1.6mm
3	2	MS flat bar 25*5mm
4	1	ERW tube 25.4*25.4 *1.6mm
5	4	ERW tube 12.7 dia *2mm
6	2	MS flat bar 25*5mm
7	2	B&CW wire 9mm

Figure 16: lower gate frame

Routing

Op. NO.[3]	Op. Details	ITEM NO.	Time [min]
1	cut1	7	0.1
2	cut1	1	4.5
		2	
		4	
		5	
3	notch	1	0.5
		2	
4	drill	4	0.8
5	DYNO bend	4	1
6	ROBOT weld	#ALL	3.5
7	MIG weld	7	2
8	OUT[4] galvanizing	lower gate frame	-

Table 22: routing of the lower gate frame

[3] OP. NO. i.e. OPERATION NUMBER
[4] OUT i.e. out worker

LOWER GATE PANEL

ITEM NO.	QTY.	Material
-	1	ALU sheet 1.6mm

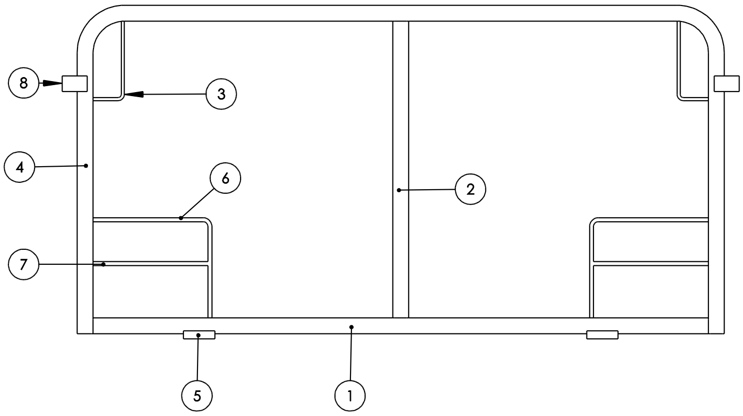
Figure 17: lower gate panel

Routing

Op. NO.	Op. Details	ITEM NO.	Time [min]
1	cut2	-	2
2	crop	-	1.5
3	drill	-	3.5

Table 23: routing of the lower gate panel

UPPER GATE FRAME



ITEM NO.	QTY.	Material
1	1	ERW tube 25.4*25.4 *1.6mm
2	1	ERW tube 25.4*25.4 *1.6mm
3	2	MS flat bar 25*5mm
4	1	ERW tube 25.4*25.4 *1.6mm
5	2	ERW tube 12.7 dia *2.0mm
6	2	B&CW wire 6.3mm
7	2	B&CW wire 6.3mm
8	2	MS flat bar 25*5mm

Figure 18: upper gate frame

Routing

Op. NO.	Op. Details	ITEM NO.	Time [min]
1	str & cut	7	0.35
2	cut & bend	6	0.15
3	cut1	1	3.8
		2	
		4	
		5	
4	notch	1	0.5
		2	
5	drill	4	0.4
6	DYNO bend	4	1
7	ROBOT weld	#ALL	3
8	OUT galvanizing	upper gate frame	-

Table 24: routing of the upper gate frame

UPPER GATE PANEL

ITEM NO.	QTY.	Material
-	1	HDPE sheet 2.75mm

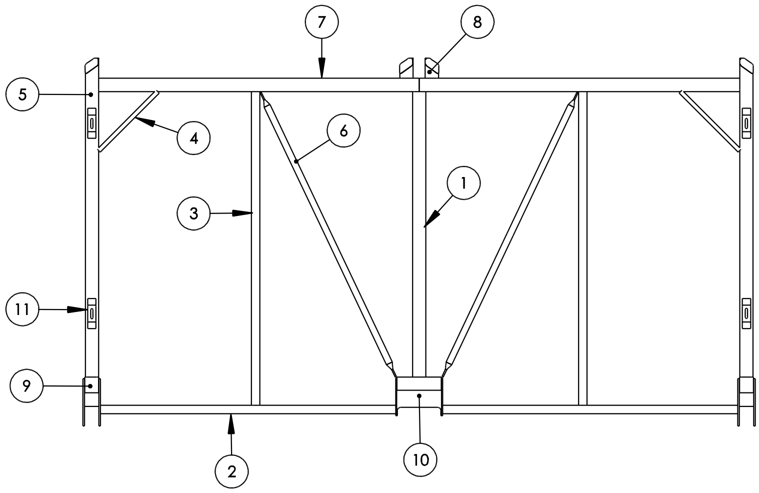
Figure 19: upper gate panel

Routing

Op. NO.	Op. Details	ITEM NO.	Time [min]
1	cut2	-	2
2	punch	-	0.45
3	drill	-	3

Table 25: routing of the upper gate panel

SIDE FRAME



ITEM NO.	QTY.	Material
1	1	RHS 40*40 *2mm
2	2	RHS 25.4*25.4 *1.6mm
3	2	RHS 25.4*25.4 *1.6mm
4	2	B&CW wire 12.5mm
5	2	RHS 40*40 *2mm
6	2	ERW tube 19.1 dia *2mm
7	1	RHS 40*40 *2mm
8	2	RHS 40*40 *2mm
9	2	CR sheet 5mm
10	1	CR sheet 5mm
11	4	MS flat bar 25*5mm

Figure 20: side frame

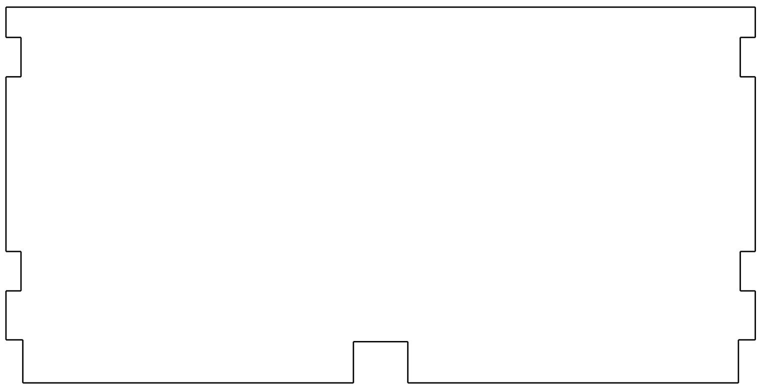
Routing

Op. NO.	Op. Details	ITEM NO.	Time [min]
1	str & cut	4	0.15
2	cut1	11	1
3	punch	11	1
4	press	11	1
5	cut1	1	3
		5	
		7	
		8	
6	cut1	6	0.5
7	flat	6	0.5
8	drill	6	0.8
9	cut1	2	1
		3	
10	cut2	10	1.5
11	fold	10	2
12	press	6	1
13	cut2 & fold	5	4.5

		8	
14	notch	1	1.5
		2	
		3	
		7	
		8	
15	ROBOT weld	#ALL	10
16	OUT galvanizing	side frame	-

Table 26: routing of the side frame

SIDE PANEL



ITEM NO.	QTY.	Material
-	1	HDPE sheet 2.75mm

Figure 21: side panel

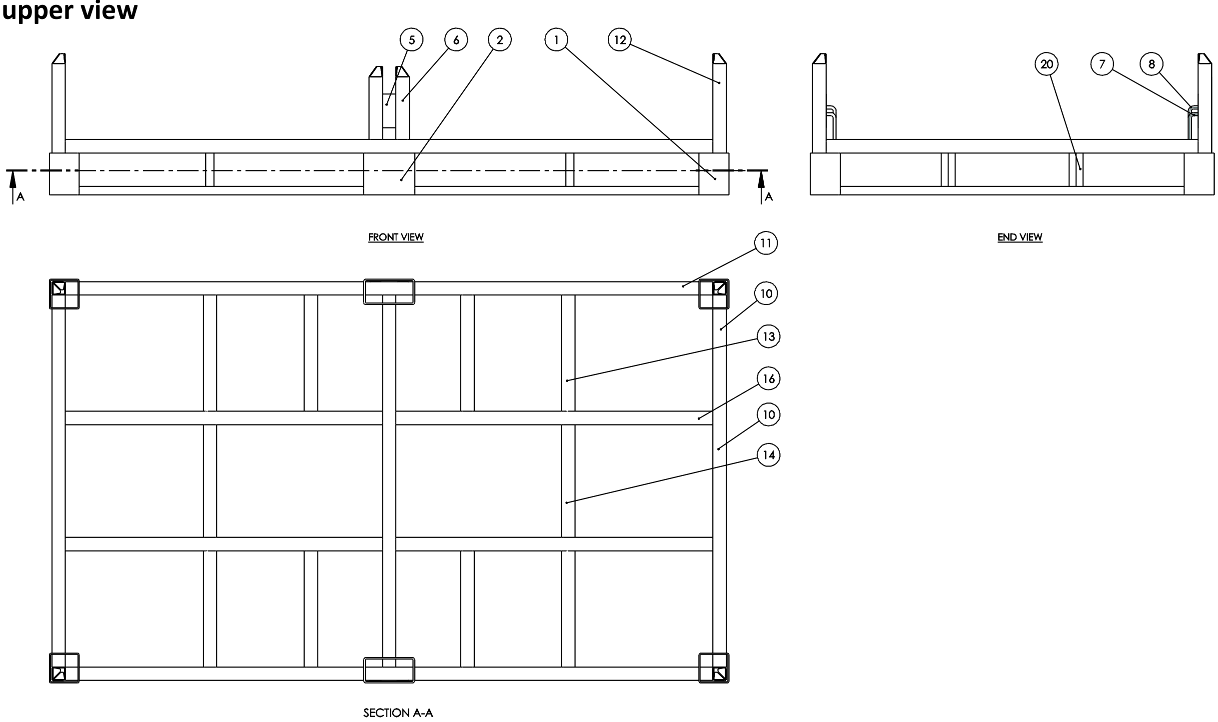
Routing

Op. NO.	Op. Details	ITEM NO.	Time [min]
1	cut2	-	2
2	punch	-	0.45

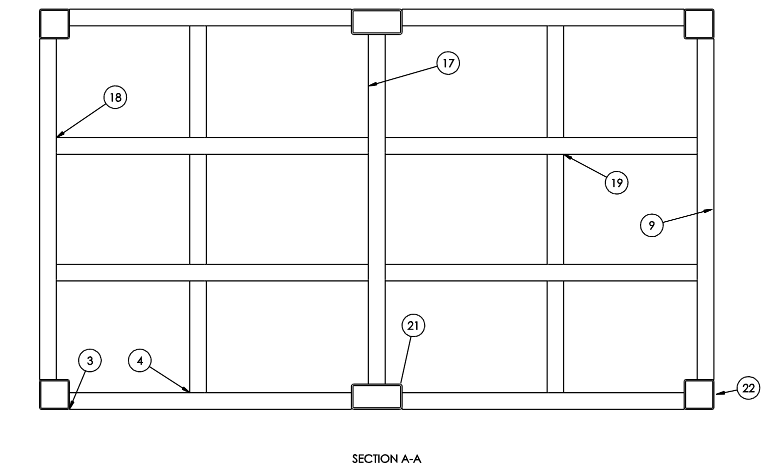
Table 27: routing of the side panel

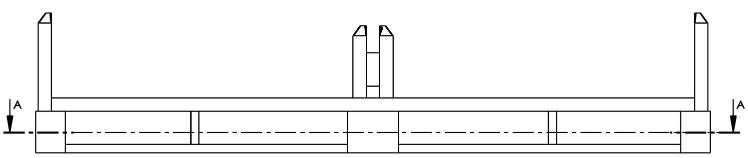
Base frame

upper view



lower view





ITEM NO.	QTY.	Material
1	4	RHS 89*89 *3.5mm
2	2	RHS 152*76 *4.9mm
3	4	RHS 50*25 *2.5mm
4	4	RHS 50*25 *2.5mm
5	2	RHS 40*40 *2mm

6	4	RHS 40*40 *2mm
7	4	B&CW wire 9mm
8	4	B&CW wire 9mm
9	2	RHS 50*25 *2.5mm
10	2	RHS 40*40 *2mm
11	2	RHS 40*40 *2mm
12	4	RHS 40*40 *2mm
13	8	RHS 40*40 *2mm
14	2	RHS 40*40 *2mm
15		
16	4	RHS 40*40 *2mm
17	1	RHS 40*40 *2mm
18	4	RHS 40*40 *2mm
19	2	RHS 40*40 *2mm
20	11	RHS 25*25 *2mm
21	2	CR sheet 2.5mm
22	4	CR sheet 2.5mm

Figure 22: base frame

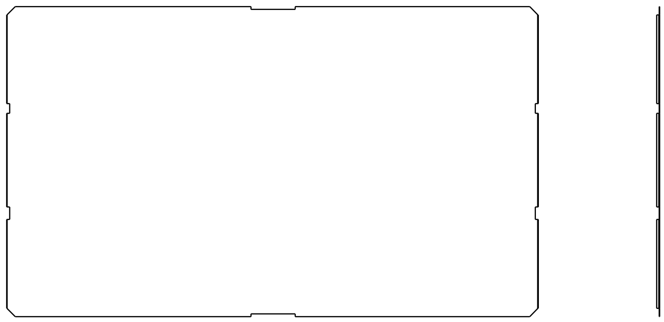
Routing

Op. NO.	Op. Details	ITEM NO.	Time [min]
1	cut1	1	22.9
		2	
		5	
		6	
		10	
		11	
		12	
		13	
		14	
		15	
		16	
2	cut1	3	16.3
		4	
		9	
		17	
		18	
		19	
		20	
3	crop & fold	21	13.5
		22	
4	cut2 & bend	7	20.5
		8	
5	notch	#ALL RHSs	15
6	ROBOT weld	base side[5]	15.4
7	ROBOT weld	base front & back	23.2
8	ROBOT weld	base bottom	20.0
9	ROBOT weld	base	4.5
10	OUT galvanizing	base	-
11	MIG weld	floor to base	5

Table 28: routing of the base frame

[5] Includes base side panels

Base floor



ITEM NO.	QTY.	Material
-	1	CR sheet 1.6mm

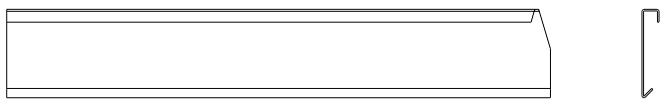
Figure 23: base floor

Routing

Op. NO.	Op. Details	ITEM NO.	Time [min]
1	cut2	-	4.8
2	crop	-	
3	bend	-	

Table 29: routing of the base floor

Base side panel



ITEM NO.	QTY.	Material
-	1	CR sheet 2.5mm

Figure 24: base side panel

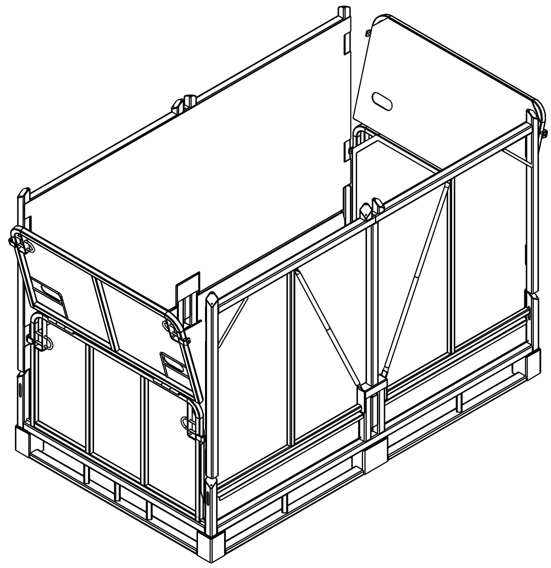
Routing

Op. NO.	Op. Details	ITEM NO.	Time [min]
1	cut2	-	4.8
2	crop	-	
3	bend	-	

Table 30: routing of the base side panel

APPENDIX B – ASSEMBLY DETAILS

The cage's assembly process exists mainly out of man labor and a few machine related operations that are shown in Table 31. Together with the machinery details (Appendix D) it results in the activity data for the cage's assembly process.



ITEM NO.	QTY.	Material
TS5 cage	-	-

Figure 25: TS5 post cage

Routing

Op. NO.	Op. Details	ITEM NO.	Time [min]
1	weld	base floor & base	5
2	drill	base floor	2
3	drill	lower gate panel	6.5
4		upper gate panel	

Table 31: routing of the assembly TS5 post cage

APPENDIX C – MAINTENANCE & REPAIR DETAILS

The work done during maintenance & repair phase consists mostly out of man labor. Two machines are used a welding machine and an angel grinder. Together with the machinery details (Appendix D) it results in the activity data for the cage's maintenance & repair process.

Op. NO.	Op. Details	ITEM NO.	Time [min]
1	MAN weld	-	15
2	grind	-	5
3		-	
4		-	

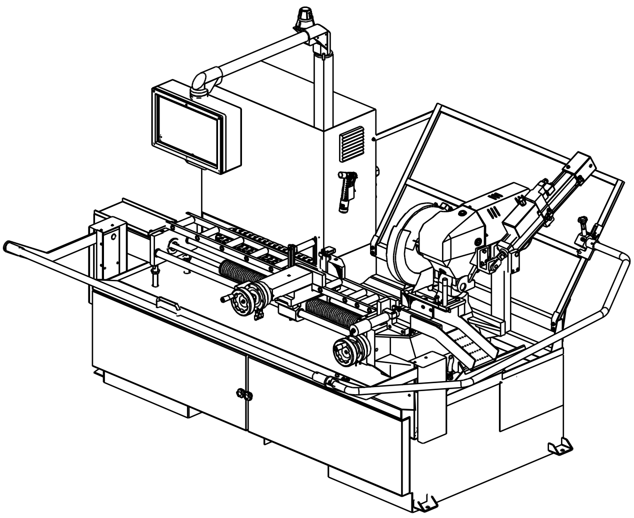
Table 32: maintenance & repair - TS5 post cage

APPENDIX D – MACHINERY DETAILS

This Appendix contains the machinery details of the machines involved in the production, assembly and maintenance & repair process of the post cage.

Task	Machine
Cut1	MEP Condor
DYNO bend	DYNOBEND CB60
ROBOT weld	ALMEGA VX-V6L Welding Robot & Controller
Str. & cut	WAFIOS R33
MAN weld	DYNA AUTO XC350
Fold	DYE
Press	DYE
Bend	DYE
Cut2	CAMMAC
Crop	Bentley Power Press M-series
Punch	Bentley Power Press M-series
Notch	Bentley Power Press M-series
Drill	WIDMEK
Grind	

MEP condor



Motor	Power	
Head spindle motor	2.2	kW
Electric coolant pumper motor	0.1	kW
Feed step motor	0.44	kW
Step servo – valve head descent motor	0.048	kW
Total	**2.778**	**kW**

Source: product manual - rated electrical power consumption

DYNO bend

Average power	5.0	kW

Source: manufacturer information

ALMEGA VX-V6L Welding Robot & Controller

Average power	5.0	kW

Source: manufacturer information

WAFIOS R33

Average power	2.778	kW

Assumption: equal total power as MEP condor

DYNA AUTO XC350

Power	15	kW

Source: manufacturer information

The electric input (P_{out}) is calculated with the equation below. The data needed is found on the motor's name plate. P_{out} is the output power and η is the efficiency of the motor. Assumed is that 60% of the maximum power is used during machinery time.

$$P_{in} = \frac{P_{out} * 0.6}{\eta}$$

All the machines listed below are equipped with one electro motor.

DYE

$\boldsymbol{P_{out}}$	5.5	kW
$\boldsymbol{\eta}$	0.79	-
$\boldsymbol{P_{in}}$	4.2	kW

Source: motor's name plate

CAMMAC

$\boldsymbol{P_{out}}$	5.5	kW
$\boldsymbol{\eta}$	0.79	-
$\boldsymbol{P_{in}}$	4.2	kW

Source: motor's name plate

Bentley Power Press M-series

$\boldsymbol{P_{out}}$	7	kW
$\boldsymbol{\eta}$	0.84	-
$\boldsymbol{P_{in}}$	5	kW

Source: motor's name plate

WIDMEK

$\boldsymbol{P_{out}}$	0.65	kW
$\boldsymbol{\eta}$	0.68	-
$\boldsymbol{P_{in}}$	0.57	kW

Source: motor's name plate

Grind

$\boldsymbol{P_{out}}$	0.65	kW
$\boldsymbol{\eta}$	0.68	-
$\boldsymbol{P_{in}}$	0.57	kW

Source: equal power as WIDMEK drill

APPENDIX E – EMISSION FACTOR WORLDSTEEL

The industry association Worldsteel provided on request life cycle inventory results (cradle-to-gate including EOL recycling) of two steel products: steel sections and wire rod. The related GHG emissions to air are shown in Table 33.

GHG emissions [gram]	Steel section	Steel wire rod
CO_2	1113	1231
CH_4	3.02	2.63
N_2O	2.11	1.93

Table 33: Worldsteel GHG emission data

Using the 100 year IPCC GWP values (Table 21) and the following equation

$$GHG\ impact\ [kg\ CO_2e] = GHG\ emission\ data\ [kg\ GHG] \cdot GWP\ \left[\frac{kg\ CO_2e}{kg\ GHG}\right],$$

results in:

GHG emission factor	kg CO_2e / kg steel
Steel section	1.83
Steel wire rod	1.88
Average ($\boldsymbol{section + wire\ rod\ /\ 2}$)	1.86

Table 34: GHG emission facto for steel based on Worldsteel data

APPENDIX F – TRANSPORTATION DETAILS

Activity data for the HGV transportation processes.

Life cycle stage	Description	Distance [km]
Production	Transportation to the galvanizing company and back to MMS	12
D&S	Transportation to New Zealand Post*	40
Use	Transportation to MMS and back to New Zealand Post	40
EOL	Transportation from New Zealand Post*	40

*includes also the distance travelled back with an empty truck

Table 35: transporation details

APPENDIX G – IPCC GLOBAL WARMING POTENTIAL FACTORS

Gas	GWP
CO_2	1
CH_4	21
N_2O	310
SF_6	23,900
HFC-23	11,700
HFC-32	650
HFC-125	2,800
HFC-134a	1,300
HFC-143a	3,800
HFC-152a	140
PFC-218	7,000
PFC-318	3,200
PFC-3-1-10	2,600
PFC-5-1-14	7,400

Table 36: IPCC 100-year GWP factors

APPENDIX H – GHG CALCULATION EXCEL

Material acquisition & pre-processing stage

Virgin material production	Amount [kg]	Recycling rate [%]	Emissions [kg CO2e]
Metal	193	85	117,25
HDPE	13	85	4,19
Metal	193	0	781,65
HDPE	13	0	27,95

Components [metal]	QTY	Weight [kg]	Total [kg]	Emissions [kg CO2e]
virgin				
lower gate frame	2	5,6	11,2	6,80
lower gate panel	2	10,5	21	12,76
upper gate frame	2	4,6	9,2	5,59
side frame	2	20,6	41,2	25,03
base frame	1	68,5	68,5	41,61
base floor	1	27,5	27,5	16,71
base side panel	4	3,6	14,4	8,75
Total [kg]			193	117,25

Components [HDPE]	QTY	Weight [kg]	Total [kg]	Emissions [kg CO2e]
virgin				
upper gate panel	2	1,4	2,8	0,90
side panel	2	5,1	10,2	3,29
Total [kg]			13	4,19

Production stage

Production process	Energy [kWh]	Amount [kg]	Emissions [kg CO2e]
Machining	23	-	3,80
Galvanizing	-	145	7,25

Components	QTY	Energy [kWh]	Total	[%]
lower gate frame*	2	1,14	2,28	9,91
lower gate panel	2	0,298	0,596	2,59
upper gate frame*	2	0,96	1,92	8,35
side frame*	2	1,964	3,928	17,08
base frame*	1	11,828	11,828	51,43
base floor	1	0,336	0,336	1,46
base side panel*	4	0,336	1,344	5,84
upper gate panel [HDPE]	2	0,206	0,412	1,79
side panel [HDPE]	2	0,178	0,356	1,55
Total			23	100,00

* Galvanizing

Transport	Distance [km]	Weight [kg]	Emissions [kg CO2e]
HGV	12	145	0,58

Distribution & storage stage

Transport	Distance [km]	Weight [kg]	Emissions [kg CO2e]
HGV	40	206	2,77

Use stage

Transport	Distance [km]	Weight [kg]	Emissions [kg CO2e]
HGV	40	206	2,77

Maintenance	Energy [kWh]		Emissions [kg CO2e]
Machining	3,8		0,63

End-of-life stage

Transport	Distance [km]	Weight [kg]	Emissions [kg CO2e]
HGV	40	206	2,77
Air freight			

Recycling	Amount [kg]	Recyling rate [%]	Emissions [kg CO2e]
Metal	193	85	337,94
HDPE	13	85	2,21

Landfill	Amount [kg]	Recyling rate [%]	Emissions [kg CO2e]
Metal	193	85	1,16
HDPE	13	85	0,08

Components [metal] recycling	QTY	Weight [kg]	Total [kg]	Emissions [kg CO2e]
lower gate frame	2	5,6	11,2	19,61
lower gate panel	2	10,5	21	36,77
upper gate frame	2	4,6	9,2	16,11
side frame	2	20,6	41,2	72,14
base frame	1	68,5	68,5	119,94
base floot	1	27,5	27,5	48,15
base side panel	4	3,6	14,4	25,21
Total [kg]			193	337,94

Components [HDPE] virgin	QTY	Weight [kg]	Total [kg]	Emissions [kg CO2e]
upper gate panel	2	1,4	2,8	0,48
side panel	2	5,1	10,2	1,73
Total [kg]			13	2,21

Emission factor data

Stage	Specification	Emission factor	Unit	Source
M&P	Metal production	4,05	kg CO2e / kg metal	WARM
M&P	HDPE production	2,15	kg CO2e / kg HDPE	WARM
Prod/S&T	Electrical consumption	0,165	kg CO2e / kWh	MfE
Prod	Galvanizing	0,05	kg CO2e / kg metal	footprinted.org
D&S/Use	HGV	0,336	kg CO2 / tkm	DEFRA
EOL	Metal recycling	2,06	kg CO2e / kg metal	WARM
EOL	HDPE recycling	0,2	kg CO2e / kg HDPE	WARM
EOL	Metal landfill	0,04	kg CO2e / kg metal	WARM
EOL	HDPE landfill	0,04	kg CO2e / kg HDPE	WARM