Embargoed until 00:01 on 19 August 2019

thinkstep ANZ

Under construction

Hidden emissions and untapped potential of buildings for New Zealand's 2050 zero carbon goal

On behalf of NZGBC

Image: Shuttershock

Client:	**New Zealand Green Building Council (NZGBC)**
Title:	**Under construction: Hidden emissions and untapped potential of buildings for New Zealand's 2050 zero carbon goal**
Report version:	v1.3
Report date:	16 August 2019

Document prepared by:

Gayathri Gamage (PhD)	Sustainability Engineer
Jeff Vickers (PhD)	Technical Director
Ben Fisher	Sustainability Engineer
Barbara Nebel (PhD)	CEO

Quality assurance:

Emily Townsend	Sustainability Engineer

Contact

thinkstep Ltd

11 Rawhiti Road
Pukerua Bay
Wellington 5026
New Zealand

Web	www.thinkstep-anz.com
Email	anz@thinkstep.com
Phone	+64 4 889 2520

If you have any suggestions, complaints, or any other feedback, please contact us at anz@thinkstep.com thinkstep

Summary

Background

Buildings contribute to greenhouse gas (GHG) emissions in two key ways:

1. Embodied or upfront carbon emissions (the subject of this report), which are the emissions created through the supply chain when building products are made; and
2. Operational emissions, which are the emissions created by operating or running buildings (heating, cooling, lighting, etc.).

In May 2018, thinkstep published a report calculating that the built environment contributes up to 20% of New Zealand's GHG emissions. This same report showed that approximately half of these emissions were embodied in building materials (buildings and infrastructure), half from operating our building stock, and a small proportion from end-of-life.

Importantly, this 20% figure includes GHG emissions embodied in trade: i.e., it considers only emissions that we can influence by our consumption choices in New Zealand, and not emissions that are embodied in our exports. This figure changes to 13% if a production perspective is applied instead, considering New Zealand's domestic emissions, including those involved in producing our exports.

Purpose

The purpose of this report is to evaluate the potential to decarbonise New Zealand's building and construction sector, with a focus on embodied emissions from now until 2050.

Unlike operational emissions – which are very visible as there is an ongoing cost associated with them (e.g. utility bills) – embodied emissions occur upstream of the building itself, are one-off or irregular, are largely invisible to the architect or builder, and are often locked in early in the building's life cycle and cannot be changed later.

This report focuses on strategies to reduce the GHG emissions from manufacturing building materials; i.e., it takes a supply perspective. Measures which affect the demand for materials, such as sustainable building design, are equally significant but are outside the scope of this report. Importantly, the potential savings multiply if supply-side and demand-side measures are applied together.

Given that many key building products are still manufactured within New Zealand, this report focuses primarily on improvements to local manufacturing that would yield the most significant benefits at the national level. Our intention is to encourage key stakeholders – architects, specifiers, building owners, building occupiers, etc. – to work together with their material suppliers to collectively decarbonise New Zealand's built environment.

Approach

This report first identifies those building materials that contribute the bulk of the embodied GHG emissions in New Zealand's buildings. It then identifies decarbonisation strategies for each material and calculates the potential of these strategies at the national level, both in the short-term (2020 – 2025) and in the long-term (2030 – 2050).

Key findings

At the national level, the carbon footprint of new-build construction and renovation was calculated to emit at least 2,900 kt of CO_2-equivalent (CO_2e) per year – equivalent to more than 1 million passenger cars on New Zealand's roads.

The strategies set out in this report could save approximately 1,200 kt CO_2e per year: equivalent to taking 460,000 passenger cars off the road permanently and 15% of New Zealand's total light vehicle fleet. Most of these savings will occur within New Zealand, though some will occur offshore as they are embodied in imported products. Both the current emissions and the potential savings are an understatement as a result of simplifications made in this study, such as excluding building services and interior fit-out.

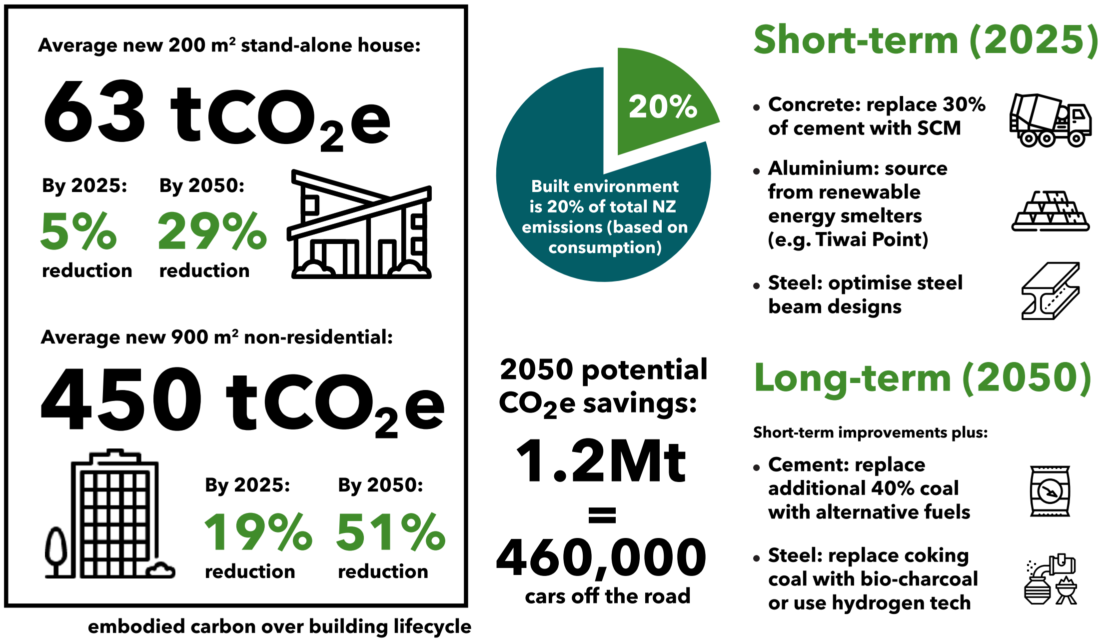
The key materials contributing to embodied GHG emissions in New Zealand were found to be steel and concrete, which together contribute more than 50% of the carbon footprint of both residential and non-residential construction (excluding fit-out and building services). Aluminium was also very significant for non-residential construction. For residential construction, timber framing was the next biggest contributor, followed by paint, aluminium and plasterboard.

At the building level:

- A stand-alone house with a floor area of 200 m^2 currently has embodied carbon of approximately 63 tonnes CO_2e over its 90-year life. In the short-term, these emissions can be reduced by 3 tonnes of CO_2e (5%) by specifying low-carbon concrete. In the long-term, a saving of 18 tonnes CO_2e (29%) could be achieved by improving the ways in which key building materials are manufactured – equivalent to taking seven cars off the road for a year per house.
- A non-residential building with a floor area of 900 m^2 has embodied carbon of approximately 450 tonnes CO_2e. In the short-term, these emissions can be reduced by 85 tonnes of CO_2e (19%) just by specifying low-carbon concrete and aluminium. In the long-term, a saving of 230 tonnes CO_2e (51%) could be achieved by improving the ways in which key building materials are manufactured – equivalent to taking 90 cars off the road for a year per building.

Under construction:

Hidden emissions and untapped potential of buildings for New Zealand's 2050 zero carbon goal



Recommendations

A collaborative effort will enable us to achieve or exceed the 40% decarbonisation potential identified in this report. It is not only material suppliers who need to implement low-carbon manufacturing technologies, but also specifiers and customers who need to consciously choose those materials. This could be encouraged by including embodied carbon considerations in public and private procurement policies, and by ensuring that the New Zealand Emissions Trading Scheme accounts for the emissions embodied in imports. Government could also utilise life cycle assessment – such as that within Green Star – when specifying their building programmes, helping to lead the sector towards low-carbon.

Another prerequisite for specifying low-carbon materials is the availability of data. This has recently been improved through publication of product carbon footprints and Environmental Product Declarations (which include a figure for embodied carbon) for a number of New Zealand-made building products.

Improved public statistics would enable better benchmarking of the embodied carbon in New Zealand's building stock and tracking of improvements over time. This study included a material flow analysis to validate material consumption at a national level, which was made challenging by the lack of detail in publicly available statistics.

In summary, decarbonising the built environment will require:

- Collaboration among all players in the building sector;
- Communication of good information and data;
- Innovation in the manufacturing sector; and
- Policy development encouraging the use of materials with low embodied carbon.

Table of contents

Acknowledgements

This whitepaper was circulated to the industry for feedback before publication. We would like to acknowledge the contributions from the organisations listed below:

- Architectural Profiles Ltd (APL)
- BRANZ
- Concrete New Zealand
- Firth Industries
- Golden Bay Cement
- Heavy Engineering Research Association (HERA)
- HR Cement Ltd
- Inex Metals Ltd
- McKechnie Aluminium
- Metals New Zealand
- New Zealand Green Building Council (NZGBC)
- New Zealand Steel
- Pacific Steel
- VIA Architecture
- Window & Glass Association New Zealand (WGANZ)
- Winstone Wallboards
- Wood Processors & Manufacturers Association of New Zealand (WPMA)

It should be noted that, while these organisations have provided feedback, they do not necessarily endorse the findings of this report.

Any remaining errors or omissions are those of the authors.

1. Introduction

1.1. Background

In May 2018, thinkstep published a report showing that buildings contribute up to 20% of New Zealand's national carbon footprint (Figure 1-1). This figure includes greenhouse gas emissions (GHG emissions) over the full life cycle of buildings (embodied + operational + end-of-life) and was calculated using a consumption-based approach; this means that it includes imports and exports of GHG emissions through international trade. (When considering emissions within New Zealand's borders, the built environment contributed 13% of New Zealand's national carbon footprint.)

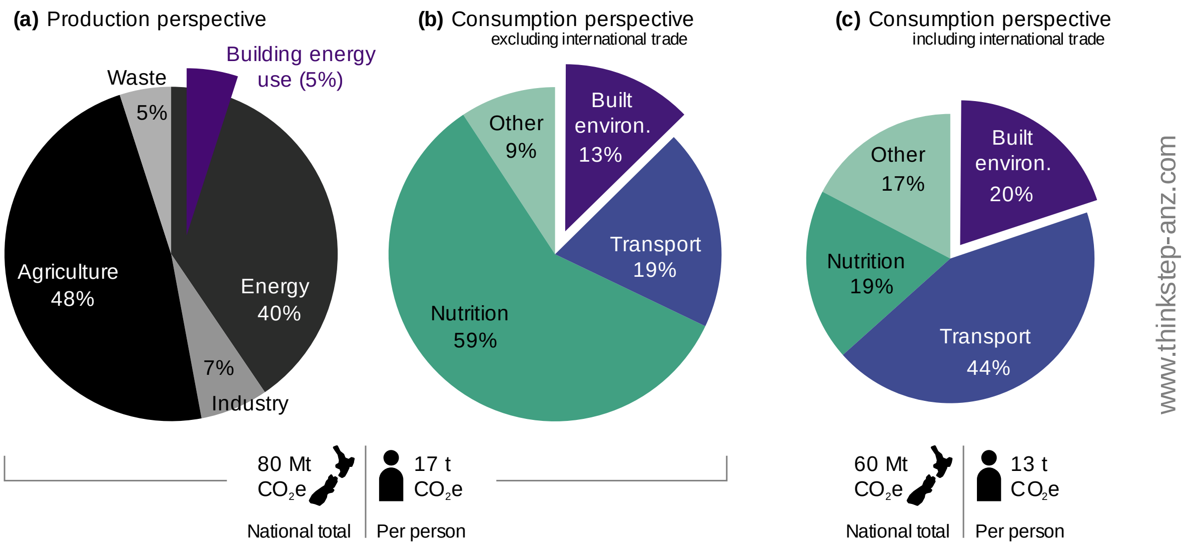


Figure 1-1: A breakdown of New Zealand's carbon footprint in 2015 from: (a) a production perspective; (b) a life cycle consumption perspective excluding international trade; and (c) a life cycle consumption perspective including international trade (Vickers et al. 2018)

The report also showed that approximately **half of all emissions were embodied in building materials** (used for both buildings and infrastructure), **half were from operating our building stock** (i.e., buildings only) and only a small proportion were from end-of-life:

- **Embodied emissions** are the emissions generated during the manufacture of the building products and materials used in new-builds, regular maintenance and renovation. They occur upstream of the building itself, are one-off or irregular, are largely invisible to the architect or builder, and are often locked in before the first occupier even steps into their building for the first time. Given that these emissions cannot be changed later, they gain in importance over time as the energy mix used to operate the building decarbonises (reducing the relevance of the operational phase).

- **Operational emissions** are the emissions produced by running a building, e.g. through heating and cooling. They are very visible as there is an ongoing cost associated with them (utility bills, maintenance bills, etc.), which creates a financial incentive to reduce them. They can be improved through retrofits (e.g. replacing electric radiators with high-efficiency heat pumps) and higher-specification new-builds (e.g. better insulation and air-tightness); however, there are cases where 'lock-in' occurs (e.g. under-slab insulation and building orientation).

1.2. Purpose

This report was commissioned by the New Zealand Green Building Council (NZGBC) to evaluate the potential of decarbonising New Zealand's building stock, with a focus on embodied emissions. It investigates the GHG emissions likely to be generated by New Zealand's building and construction sector from predicted building activities up to 2050.

This report has two primary aims:

1. To quantify the estimated embodied GHG emissions for buildings expected to be constructed in New Zealand by 2050; and
2. To quantify the estimated carbon emissions savings from potential short- and long-term improvement strategies.

This report focuses on improvements in building materials. Its purpose is *not* to make comparisons between materials (e.g. steel versus glulam) or between construction types (e.g. concrete slab versus suspended timber floor). While improvements can also be made through material substitutions and changes to building construction (e.g. changes in structural materials, floor system, cladding materials and roofing materials), these are outside the scope of the present report. Importantly, improvements in building construction types have the potential to decarbonise the built environment even further.

The estimated carbon emission savings within this report consider only supply-side decarbonisation strategies, i.e. those strategies that can be implemented up to and including the final manufacturer's gate. Supply-side strategies include energy-efficiency measures, switching to renewable energy sources, the use of recycled (secondary) input materials, among others.

Demand-side strategies are also likely to have significant benefits but are outside the scope of this study. Examples of demand-side strategies include alterations to building designs to use less materials, substitution of high-impact materials/products for lower-impact materials/products and best-practice construction techniques that reduce waste.

It is important to note that supply-side and demand-side strategies are complementary, with the potential savings being multiplicative.

1.3. What is a carbon footprint?

A carbon footprint is the "sum of greenhouse gas emissions and greenhouse gas removals in a product system, expressed as CO_2-equivalent (CO_2e) and based on a life cycle assessment using the single impact category of climate change" (ISO, 2018, sec. 3.1.1.1).

Embodied carbon is the same except the main life cycle stage considered is material production, involving the GHG emissions and removals from raw material supply, transport of raw materials to the manufacturer, and the actual manufacturing process.

Embodied carbon data for various materials is readily available in Environmental Product Declarations (EPDs), the BRANZ CO_2NSTRUCT database (BRANZ, 2019) and life cycle inventory databases such as thinkstep AG's GaBi Database (thinkstep, 2019).

This study considers potential reductions in GHG emissions from product manufacture (including offcuts and scrap), replacement of building materials (including offcuts and scrap), and end-of-life (landfill or recycling). The carbon footprint embodied in the original build is sometimes known as the 'upfront carbon', while the carbon footprint embodied across the full life cycle is the 'embodied carbon' (see, e.g., WorldGBC, forthcoming). Depending on the definition of 'embodied carbon', it may not always include treatment of building and demolition waste; however, waste treatment is included within this report as it is intrinsically linked to the materials chosen and is distinct from building operation.

Table 1-1 shows the life cycle stages included in this report. This report groups the impact of material wasted during installation with the new-build (product stage) and maintenance/ renovation (use stage) results. Transport from manufacturer to site for the construction stage has been excluded as it is generally not significant, even for imported products (Ghose et al., 2019). While this study is specifically for commercial building types, we have assumed that this is true for transport for all construction types in New Zealand.

Table 1-1: Life cycle stages included in this study (following EN 15804:2012+A1:2013)
(✓ = Included in scope; X = Excluded from scope)

Product stage			Construction process stage		Use stage							End-of-life stage				Recovery stage
Raw material supply	Transport	Manufacturing	Transport	Installation	Use	Maintenance*	Repair	Replacement*	Refurbishment	Operational energy use	Operational water use	Deconstruction/Demolition	Transport	Waste processing	Disposal	Future reuse, recycling or energy recovery potential
A1	A2	A3	A4	A5	B1	B2	B3	B4	B5	B6	B7	C1	C2	C3	C4	D
✓	✓	✓	X	X	X	✓	X	✓	X	X	X	X	X	✓	✓	✓

*For this study, maintenance and replacement of materials are considered equivalent to renovation, and generally referred to as maintenance/renovation for the rest of the report.

This report applies three different ways of viewing New Zealand's national emissions:

- **Consumption GHG emissions excluding biogenic CO_2:** These are the gross GHG emissions associated with what New Zealanders consume, not with what we produce (Figure 1-1c). The consumption-based approach considers GHG emissions embodied in trade, i.e. domestic production + emissions in imports – emissions in exports. It does not account for carbon sequestered in bio-based materials such as wood.

- **Production GHG emissions excluding biogenic CO_2:** These are the gross figures reported in *New Zealand's Greenhouse Gas Inventory* produced by the Ministry for the Environment (e.g. MfE, 2019b). The production-based approach includes everything that New Zealand produces, including products for export (Figure 1-1a and Figure 1-1b). It does not account for carbon sequestered by trees or for GHG emissions embodied in trade.
- **Production GHG emissions excluding biogenic CO_2 and CH_4:** These are the same as the production GHG emissions above, except that biogenic methane has been excluded following the draft Climate Change Response (Zero Carbon) Amendment Bill (MfE, 2019a). This adjustment is to account for the fact that New Zealand has significant emissions from agriculture, yet these emissions are relatively short-lived and should perhaps be addressed separately to long-lived GHGs like carbon dioxide.

In the body of this report, we focus on 'gross' GHG emissions; i.e., we exclude removals of carbon dioxide from the atmosphere as a result of the growth of trees and associated emissions of GHGs from biogenic sources. Results including biogenic carbon can be found in Annex B. These results are important for bio-based materials such as timber.

1.4. What is an environmental product declaration (EPD)?

An Environmental Product Declaration (EPD) is like a nutrition label for a product. However, instead of providing data on the energy, fat and sodium in the product, it provides the carbon footprint, water footprint and embodied energy, among other things.

The data in an EPD derives from a Life Cycle Assessment (LCA) – a comprehensive method for calculating the environmental 'footprint' of a product over its full life cycle from cradle to grave (i.e. it includes product stage (cradle to gate), construction process stage, use stage, end-of-life and recovery stage). The advantage of an EPD over a stand-alone LCA is that it requires the study to be conducted and verified following a specific set of rules (known as Product Category Rules or PCR), making it easier to compare different products. Embodied carbon in building materials can be extracted from the EPD results, and this study uses existing New Zealand construction product EPDs for estimating embodied carbon emissions for the expected build-out in New Zealand. Where New Zealand-specific EPDs are unavailable, this study uses Australian EPDs, European EPDs, or data from the GaBi Life Cycle Inventory (LCI) Database (thinkstep, 2019).

1.5. Accounting for recycling

This report applies the cut-off method (also known as the recycled content method or the 100-0 method) for all material recycling. This means that impacts are allocated where they fall and that no credits are awarded for recycling at end-of-life. More specifically, the benefit of using recycled material is awarded to the building that uses that material and no benefit is awarded for recycling at end-of-life to avoid double-counting. For more detail, please see the *Greenhouse Gas Protocol Product Standard* (GHG Protocol, 2011).

2. Analysis

The following approach has been applied in this report:

1. Estimate the annual building rate to 2050 by building type.
2. Choose a representative building and bill of quantities for each building type.
3. Identify carbon footprint data for each building material/product.
4. Estimate replacement cycles for each material over the building's life.
5. Identify end-of-life data for each material.
6. Calculate and validate economy-wide materials flows.
7. Calculate the embodied carbon footprint of the full building stock.
8. Identify improvement strategies for each major hotspot.
9. Calculate the potential for these strategies to reduce embodied emissions in both the short-term and the long-term.

Steps 1–5 are described in further detail below. Steps 6–9 are described in the sections that follow.

2.1. Estimate annual building rate to 2050

BRANZ provided the projected building activity for New Zealand in terms of the estimated floor area per building type per year (Table 2-1) (M. Curtis, pers. comm., 12 August 2019). BRANZ have based their data on building consents (Stats NZ, 2019a) and the *National Construction Pipeline Report* (MBIE, 2018).

Despite population growth and a housing crisis, the building rate has been quite consistent for some time and NZGBC expects it to remain relatively consistent. If this assumption proves untrue and the building rate accelerates, this simply means that the absolute savings calculated in this report are underestimates.

Table 2-1: Annual construction rate for expected construction types in New Zealand

Construction type	Annual build rate (m^2)
Detached houses	3,600,000
Low-rise residential construction (townhouses, units, etc.)	586,500
Medium/high-density residential construction (i.e. apartments)	396,000
Hostels, boarding houses, prisons	45,000
Hotels, motels, and other short-term accommodation	70,000
Hospitals, nursing homes, health	100,000
Education buildings	200,000
Social, cultural, and religious buildings	130,000
Shops, restaurants, and bars	280,000
Offices, administration, public transport	230,000

Construction type	Annual build rate (m^2)
Storage buildings	500,000
Factories	340,000
Farms	800,000

2.2. Choose representative building construction type

Data is not available for all construction types provided in Table 2-1. Therefore, the building types have been grouped into two main categories: residential and non-residential. The non-residential category was further split into multi-storey and warehouse style buildings. Bills of materials from previous New Zealand life cycle assessment (LCA) studies have then been used to represent each type of construction (Table 2-2). No LCA study existed for the warehouse style building, so an estimate was provided by an industry source. Please see Annex A for building-level data.

Table 2-2: Sources of bill of quantities for different construction types

Construction type	Represented by	Reference
Detached houses	Residential: NOW Home	Collins and Blackmore (2010)
Low-rise residential construction (townhouses, units, etc.)		
Medium/High-density residential construction (i.e. apartments)*	Non-residential: multi-storey building study in New Zealand	John et al. (2009)
Hostels, boarding houses, prisons		
Education buildings		
Social, cultural, and religious buildings		
Hotels, motels, and other short-term accommodation		
Hospitals, nursing homes, health		
Shops, restaurants, and bars		
Offices, administration, public transport		
Storage buildings	Non-residential: portal-framed, warehouse-style building	Quantity surveyor's estimate (M. White, 2019, pers. comm.)
Factories		
Farms		

* The category 'Medium/High-density residential construction (i.e. apartments)' was included under non-residential due to their construction type being closer to other non-residential buildings.

The above selection of representative buildings results in new-builds consisting of 58% residential and 42% non-residential per year in New Zealand by floor area. The residential buildings are represented using a timber-framed building. For the non-residential buildings, 47% are modelled using a multi-story reinforced concrete building while 53% are modelled using a single-story steel portal-framed building.

2.2.1. Residential building

For the residential construction type, the NOW Home is a best-practice case for a single storeyed, three-bedroomed home (with garage) with gross floor area of 146 m^2. For carbon footprint calculations, it was assumed that the life of the building is 90 years. From building consents issued in the year 2018 (Stats NZ, 2019b), it was found that the average floor area for stand-alone homes in New Zealand is approximately 200 m^2.

This study developed a weighted average residential building by adjusting the materials used for the foundation, roofing and cladding to reflect their real market share within New Zealand. The methodology applied is described below:

1. **Identify bill of material for alternative material usage:** The study on the NOW Home included three alternative scenarios which provided material quantities required for different types of floor, foundation, external wall, ceiling and roof suitable for the NOW Home design (Table 2-3).
2. **Identify material market share:** Market share was based on volume and area data representing material use for new residential buildings in 2016 from a BRANZ study by MacGregor et al. (2018) (Table 2-4).
3. **Calculate a weighted average bill of quantities** by applying the market shares per material type, incorporating alternative flooring, wall cladding and roofing materials. Given the prevalence of timber framing as per market share (Table 2-4), this study assumed that all framing will be made of timber. ‘Other’ materials were excluded from the market share.
4. **Adjust to reflect open-plan layout:** Based on feedback from industry (K. Golding (Winstone Wallboards) 2019, pers. comm., 12 August 2019), the bill of quantities was adjusted to reflect the difference between the 'NOW' building and a current average new build, with a more open plan layout and therefore less internal walling. The adjustment (reduction to internal plasterboard and timber) was carried out based on the average quantity of plasterboard used for a new build.

The result of this approach is the bill of quantities given in Table 6-5 in Annex A. This is more representative of material use in New Zealand when compared to the use of a single design that excludes alternative options.

Table 2-3: NOW Home and alternative material use

NOW Home	Alternative
Floors/Foundation	
Hardfill	Hardfill (under garage concrete slab only)
Concrete slab and footings	*Suspended timber floor*
Concrete slab insulation	Garage concrete slab
Flooring materials: carpet and ceramic tiles	Underfloor insulation
	Flooring materials: vinyl, carpet and tiles

NOW Home	Alternative
External walls	
Exterior finish: timber weatherboard cladding, paint, etc. Framing Interior finish: internal gypsum board lining, skirting, paint, etc. Insulation	*Exterior finish: brick cladding etc.* Framing Interior finish: internal gypsum board lining, skirting, paint etc. Insulation
Ceiling and roof	
Ceiling: gypsum board lining, steel nail up battens, paint, etc. Insulation Framing *Roofing: concrete tiles, battens etc.* *Eaves: fibre cement soffits, PVC joiners, etc.* Fascia guttering	Ceiling: gypsum board lining, steel nail up battens, paint etc. Insulation Framing *Roofing: steel roofing, battens etc.* *Eaves: HardieSoffit, PVC joiners etc.* Fascia guttering

Table 2-4: Market share of materials for building elements used for the residential design

Material	Framing (m^3)	% share	Foundation (m^3)	% share	Roofing (m^2)	% share	Cladding (m^2)	% share
Concrete	5,000	1%	615,000	96%	266,700	6%	509,400	16%
Timber	358,700	98%	23,900	4%			933,000	29%
Steel	3,500	1%			4,430,900	93%	176,700	6%
Clay (brick)					76,700	2%	1,052,200	33%
Fibre cement							505,400	16%
Other					971,300	N/A	192,500	N/A

2.2.2. Non-residential building

The non-residential construction type is represented by a weighted average of two building types – multi-storey reinforced concrete and a single-story portal-framed warehouse – to reflect two common types of non-residential buildings.

The multi-storeyed building is based on a six-storeyed office building in New Zealand with gross floor area of 4,247 m^2, studied by John et al. (2009). This study considered three different structural options: reinforced concrete, steel and timber. The reinforced concrete building was chosen for this study, as mid/high-rise timber buildings are still an emerging technology type and as a steel-framed building was used for the warehouse (below).

The warehouse-style building was based on a single-story steel portal-framed building. This building assumed a concrete slab, steel cladding and steel roofing. Data for the structure and shell were from an estimate provided by Michael White, a Director at Macrennie Commercial Construction (M. White 2019, pers. comm., 15 August 2019). An allowance was made for 10% of the structure to be fitted out as office space, using data scaled from the multi-storey build above.

A weighted average of the two building types was calculated based on the annual construction rate for each group to create an ‘average’ non-residential building. It was assumed that the life of this building is 60 years.

The bill of quantities for both buildings are given in Table 6-5 in Annex A.

2.3. Identify carbon footprint data to manufacture each material

Product level carbon is calculated using the bill of quantities extracted from the studies referenced in Table 2-2 and background data used for calculating embodied carbon comprising:

- Data from a published EPD, sourced from New Zealand manufacturers where possible (Table 6-6 in Annex A); or
- Data from thinkstep AG’s GaBi Database (Table 6-7 in Annex A).

In cases where multiple types of material are used in a building, publicly available market share data are used to create weighted impact for this report. This method has been applied for materials such as steel roofing and plasterboard.

2.4. Estimate maintenance/replacement cycles

Average building lifetimes for residential and non-residential buildings are assumed to be 90 years and 60 years respectively. These lifetimes align with BRANZ’s whole-building whole-of-life framework for commercial buildings (Berg et al., 2016) and with soon-to-be-published research for residential buildings (D. Dowdell, pers. comm. 9 August 2019).

During a building’s life, numerous building elements and materials are replaced. In practice, structural components of a building are not generally replaced unless the building is to undergo major renovations or to be demolished and re-built. Areas of damage may also be repaired as opposed to replacing the material in the building completely (e.g. parts of the cladding may be replaced rather than recladding the entire building). The replacement assumptions from Table 6-8 (Annex A) have been applied, largely based on Dowdell et al. (2016).

In addition to the building material inputs given from the bill of quantities, it is assumed that an additional 5% of each material is wasted during construction. (A higher rate of 15% is assumed for plasterboard, following WWB, 2018.) As such, the impact for building construction includes the impact of raw material required for the building, the raw material that is wasted and the impact of waste management of these waste materials. Similarly, it is assumed that the waste rate of input materials for replacement and maintenance/ renovation during the operational phase of the building is also 5% (or 15% for plasterboard).

While not included within the scope of this study, any improvements to reduce waste and spoilage on-site will have significant benefits. Based on the assumptions made in this study, best-practice waste-reduction methods could reduce the impacts in both new-build construction and maintenance/renovation by up to 5% (or 15% for plasterboard).

2.5. Quantify end-of-life impacts

Materials with low economic value at end-of-life (e.g. glass, plasterboard and lower-value wood products) are assumed to be sent to landfill, while materials with high economic value at end-of-life (e.g. steel, aluminium and glulam) are assumed to be recovered with a proportion reused/recycled and a proportion sent to landfill (or incineration in the case of glulam).

The key assumptions made were:

- Metals: 89% recycling + 11% landfill, applying Australian averages from Hyder Consulting (2011 & 2012). This excludes metals encased in concrete.
- Concrete: 20% recycling + 80% landfill/cleanfill. The same assumptions apply to metals encased in concrete (i.e. reinforcing steel) (Dowdell et al., 2016).
- Glulam: 25% incineration + 75% repurposed and reused because of its bulk.
- All other materials: 100% landfill.

In this report, a cut-off approach has been applied for recycling. This approach has been chosen as it captures environmental impacts where they fall; i.e., the use of recycled content reflects the (generally lower impact) recycling process during manufacture and the benefits from recycling material at end-of-life are cut off. This means that any benefit from recycling is not included in total impact (i.e. recycling provides zero impact, with no credit awarded) and left to benefit the life cycle of the next building.

3. Material and carbon flows

3.1. Overview

Total material flows at the national level were calculated by multiplying the material quantities per square metre of average residential and non-residential building by the total square metres of new floor area estimated to be built every year. Table 3-1 and Table 3-2 present this data per building, while Table 3-3 presents nation-wide materials flows.

Given that this bottom-up approach is very sensitive to the buildings that are scaled up and the renovation assumptions that are made for those buildings, a top-down Material Flow Analysis (MFA) was also conducted for the New Zealand Economy (Table 3-3). This MFA focused on apparent consumption of the key building materials contributing to emission hotspots (chapter 4), namely concrete, steel, timber, aluminium, paint and plasterboard. Apparent consumption is calculated as local production plus imports minus exports. However, this analysis was made challenging by the lack of publicly available production statistics for New Zealand building materials and categorisation challenges for certain building products in national import/export statistics (e.g. for curtain walls).

The top-down MFA reveals that the bottom-up calculations of building material consumption are in the same order of magnitude as the available national consumption figures, but on the low side. This is likely due to the limitations of scaling up material quantities for an 'average' building across multiple building types, and conservative assumptions being made with regards to renovation and replacement cycles. In particular, the total consumption of aluminium was over 40% lower than expected, concrete was nearly 30% lower, reinforcing steel over 10% lower. Timber consumption was significantly lower than the available data; however, the share used for framing was unknown.

Material quantities estimated from the bottom-up calculations have not been altered based on the top-down MFA due to the limitations of that data. This means that the calculation of embodied emissions will very likely be an underestimate, and that actual emissions and potential savings would be higher than stated.

3.2. Material use at the building level

Table 3-1: Materials used in an average 200 m² residential building over an assumed 90-year life*

Material	Material (kg)		GWP (kg CO_2e)		Use in building
	New build	Maintenance /renovation	New build	Maintenance /renovation	
Aluminium	263	263	1,460	1,460	Windows – aluminium frame
Brick	3,830	767	914	183	External walls – external finish
Building paper	78.1	78.1	15.0	15.0	External walls – external finish; Roof
Carpet	119	593	278	1,390	Floors – covering
Ceramic	199	993	51.8	259	Internal walls – finish (kitchen tiles); Floors – covering (bathroom tiles)
Clay	183	183	43.5	43.5	Roof – roofing
Concrete	70,500	1,010	11,300	161	Foundation – concrete slab and footings; External walls – external finish; Roof – roofing
Copper	32.9	15.1	122	55.9	Doors – Interior doors (copper flashing); Integrated Water Systems (copper tubing)
Fibre cement	773	200	445	115	Foundation – slab insulation; External walls – external finish
Glass	816	816	898	898	Windows
Glulam	111	0	30.7	0	Pergola
Gravel	34,900	0	75.3	0	Foundation – hardfill
Insulation	605	605	926	926	Insulation – external walls, floors, roof
Paint	226	2,260	537	5,370	External walls – external and internal finish; Roof – ceiling and fascia guttering, Doors – interior doors and garage door
Particleboard	62.3	125	55.4	111	Floors – flooring; External walls – interior finish; Internal walls – finish; Ceiling
Plasterboard	5,000	5,000	869	869	External walls – interior finish; Internal walls – finish; Ceiling

Material	Material (kg)		GWP (kg CO_2e)		Use in building
	New build	Maintenance /renovation	New build	Maintenance /renovation	
Polycarbonate	9.59	9.59	39.6	39.6	Doors – pergola
Polyethylene	386	342	639	566	Foundation – hardfill damp proof course (DPC); Integrated Water Systems (rain water tank)
Polypropylene	11.0	11.0	19.6	19.6	Integrated Water Systems
Polystyrene	29.0	0	63.9	0	Foundation – slab insulation
PVC	2.74	2.74	5.92	5.92	Roof – eaves
Sand	10,500	0	289	0	Foundation – hardfill
Steel (galvanised)	225	66.6	864	256	Framing – external walls, external finish, internal walls, floors, roof; Ceiling; Doors – pergola
Steel cladding	14.6	14.6	57.8	57.8	External walls - external finish
Steel roofing	1,730	1,730	6,860	6,860	Roof – roofing, fascia guttering; Doors – garage door
Steel wire	750	0	2,920	0	Foundation – reinforcing
Timber	7,740	1,820	813	191	Foundation – timber piles; External walls – framing, internal finish; Internal walls – framing, finish; Floors – framing, flooring; Roof – eaves, framing, roofing, fascia guttering; Doors – interior doors, garage door, pergola
Vinyl	0.564	2.82	4.10	20.5	Floors – covering
Weatherboard	1,050	1,050	2,520	2,520	External walls – external finish; Roof – eaves
Other	59.4	0	0	0	External walls – framing; Finish, floor covering, roof – fascia guttering
Total	**140,206**	**17,958**	**33,100**	**22,400**	

* Note: The building shown in this table is hypothetical. It is based on a timer-framed building with several cladding and roofing systems (weighted by market share). It has also been re-scaled from 146 m^2 to the average floor area of a stand-alone house in 2018. For the specific quantities underlying these calculations, please see Annex A. This table also excludes waste during construction and maintenance/renovation. All values have been rounded to 3 significant figures.

Table 3-2: Materials used in an average 900 m^2 non-residential building over an assumed 60-year life*

Material	Material (kg)		GWP (kg CO_2e)		Use in building
	New build	Maintenance /renovation	New build	Maintenance /renovation	
Aluminium	3,530	0	64,200	0	Windows; Doors; Louvres
Concrete	852,000	0	136,000	0	Foundations – beam foundations, raft foundations; Ground floor slabs; Suspended floors – suspended floor slabs, Dycore units; Structure – columns, beams, walls; Stairs
Fibre cement	3,620	3,620	2,090	2,090	Exterior walls – fibre cement soffits
Glass	5,760	0	6,340	0	Windows; Doors; Stairs – balustrading
Insulation	382	382	584	584	Exterior walls; Ceilings exposed to the outside
MDF	199	199	3.30	3.30	Interior linings and ceilings
Paint	86.5	519	205	1,230	Exterior walls, exterior soffits; Doors; Interior walls
Plasterboard	4,570	4,570	795	795	Exterior walls; Interior walls
Plywood	407	0	339	0	Plywood roofs
Polystyrene	230	230	506	506	Insulation
Steel (galvanised)	1,910	381	7,320	1,460	Portal framing; Interior wall framing; Exterior wall framing; Exterior cavity battens
Steel roofing	7,160	3,580	28,300	14,200	Roofing; Spouting; Cladding; Downpipes
Steel wire	15,200	0	59,300	0	Foundations – beam foundations, raft foundations; Ground floor slabs; Suspended floor slabs; Structure – columns, beams, walls; Stairs
Steel reinforcing bar	20,200	0	80,300	0	Structural steel portals
Timber	1,260	315	132	33.1	Roof framing; Plywood roofs; Soffit framing; Window reveals; Doors
Total	**916,000**	**13,800**	**386,000**	**20,900**	

* Note: The building shown in this table is hypothetical. It is based on quantities from two different building types (reinforced concrete and steel portal-framed) and has been re-scaled to the average floor-area for the non-residential sector. For the specific quantities underlying these calculations, please see Annex A. This table also excludes waste during construction and maintenance/renovation. All values have been rounded to 3 significant figures.

3.3. Material flows at the national level

Table 3-3: Material flow analysis: comparing bottom-up and top-down approaches

Material	Residential (t) Bottom-up	Non-residential (t) Bottom-up	Total (t) Bottom-up	Residential (t) Top-down	Non-residential (t) Top-down	Total (t) Top-down
Aluminium[1]	11,600	12,800	24,400	15,000	30,000	45,000
Brick	101,000	0	101,000	-	-	-
Building paper	3,440	0	3,440	-	-	-
Carpet	15,700	0	15,700	-	-	-
Ceramic	26,300	0	26,300	-	-	-
Clay	8,050	0	8,050	-	-	-
Concrete[2]	1,580,000	3,080,000	4,650,000	-	-	6,580,000
Copper	1,060	0	1,060	-	-	-
Fibre cement	21,400	26,200	47,600	-	-	-
Glass	36,000	20,800	56,800	-	-	-
Glulam	2,440	0	2,440	-	-	-
Gravel	769,000	0	769,000	-	-	-
Insulation	26,700	2,760	29,400	-	-	-
MDF	0	1,440	1,440	-	-	-
Paint	54,800	2,190	57,000	-	-	Unknown
Particleboard	4,120	0	4,120	-	-	-
Plasterboard[3]	246,000	36,900	283,000	196,000	65,000	261,000
Plywood	0	1,470	1,470	-	-	-
Polycarbonate	423	0	423	-	-	-

Material	Residential (t)	Non-residential (t)	Total (t)	Residential (t)	Non-residential (t)	Total (t)
	Bottom-up	Bottom-up	Bottom-up	Top-down	Top-down	Top-down
Polyethylene	16,100	0	16,100	-	-	-
Polypropylene	483	0	483	-	-	-
Polystrene	639	1,660	2,300	-	-	-
PVC	121	0	121	-	-	-
Sand	230,000	0	230,000	-	-	-
Steel roofing & cladding	77,000	38,800	116,000	-	-	Unknown
Steel (galvanised)	6,430	8,270	14,700	-	-	-
Steel reinforcing[4]	16,500	128,000	145,000	-	-	167,000
Timber[5]	211,000	5,690	216,000	-	-	<1,290,000
Vinyl	74.5	0	74.5	-	-	-
Weatherboard	46,400	0	46,400	-	-	-
Other	1,310	0	1,310	-	-	-
Total	**3,510,000**	**3,370,000**	**6,880,000**	**-**	**-**	**-**

[1] Aluminium: Top-down figures are industry estimates. Stats NZ import/export statistics show considerably less aluminium entering the country. Most of the non-residential aluminium is estimated to be contained in curtain walling for high-rise buildings and curtain walls contains multiple materials, including aluminium, glass, concrete and steel, making them harder to classify.

[2] Concrete: Calculated as 4,102,273 m^3 of ready-mixed concrete × 2.4 t/m^3 × 67%. Concrete volume is from Stats NZ "Ready mixed concrete by region (AST)" for January – December 2018. Concrete NZ indicate that these figures will include most of the precast industry. The 67% is an economic split between total national spend on buildings in 2018 ($22.8b from Stats NZ Building Activity Survey) and on infrastructure in that same year ($11.3b from http://www.infometrics.co.nz/new-zealand-invest-129b-infrastructure-next-decade/).

[3] Plasterboard: We could find no public data on the size of the New Zealand plasterboard market. However, the company previously indicated that its market share at the start of 2014 was 94%, and that sales were split 75% residential – 25% non-residential (https://www.nzherald.co.nz/business/news/article.cfm?c_id=3&objectid=11189400). Taking a 10-year weighted average of plasterboard imports (tariff codes 6809.11.00.10 and 6809.19.00.10 from Stats NZ) up to 2014 shows imports of approximately 1,700,000 m^2/year. This suggests a total market of approximately 30,000,000 m^2 per year, though this figure is highly uncertain and may lie anywhere between 15,000,000 m^2 and 60,000,000 m^2 as imports vary significantly year-on-year. The area density of plasterboard varies from 7 to 16 kg/m2 (WWB, 2018). A value of 8.7 kg/m2 was assumed for this analysis based on the maximum area density of GIB Standard 13mm (WWB, 2018).

[4] Steel reinforcing: According to its website, "Pacific Steel is New Zealand's only manufacturer of wire rod, reinforcing bar and coil products. Our Auckland based manufacturing facility produces around 250,000 tonnes of manufactured steel per year." They also supply other reinforcing makers locally. The total market is estimated at 250,000 × 67% to account for infrastructure (as above).

5 Sawn timber: 4,461,000 m^3 produced in 2018 with exports of 1,826,000 m^3 in 2017 (MPI, 2018). Imports are minimal. Density assumed to be 488 kg/m^3 (WPMA). Share for buildings unknown.

4. Hotspot assessment

Calculating the embodied carbon footprint for the building sector towards 2050 required calculation of carbon footprints for:

- Building construction;
- Building material waste during construction;
- Replacement of building materials during maintenance and renovation;
- Building material waste during maintenance and renovation; and
- End-of-life treatment of building materials.

The total carbon footprint of residential builds is 1,300 kt CO_2e per year, while the total carbon footprint of non-residential builds is 1,500 kt CO_2e per year – close to a 50:50 split. The material breakdowns for the carbon footprints and material masses of the current scenarios for residential and non-residential builds are given in Figure 4-1 and Figure 4-2. In these figures, some materials are presented together, for example, reinforcing steel, steel cladding and steel roofing are all included under the steel section.

As can be seen, the carbon footprint of residential builds is dominated by steel, concrete, timber and paint, with other significant impacts from aluminium and plasterboard. The relatively high impact of paint is largely the result of the number of times it is replaced during the lifetime of the building (assumed to be every 8 years). The use of materials within the building is provided in Table 3-1.

The carbon footprint for non-residential buildings is dominated by the impact of concrete, steel and aluminium. The use of materials within the building is provided in Table 3-2.

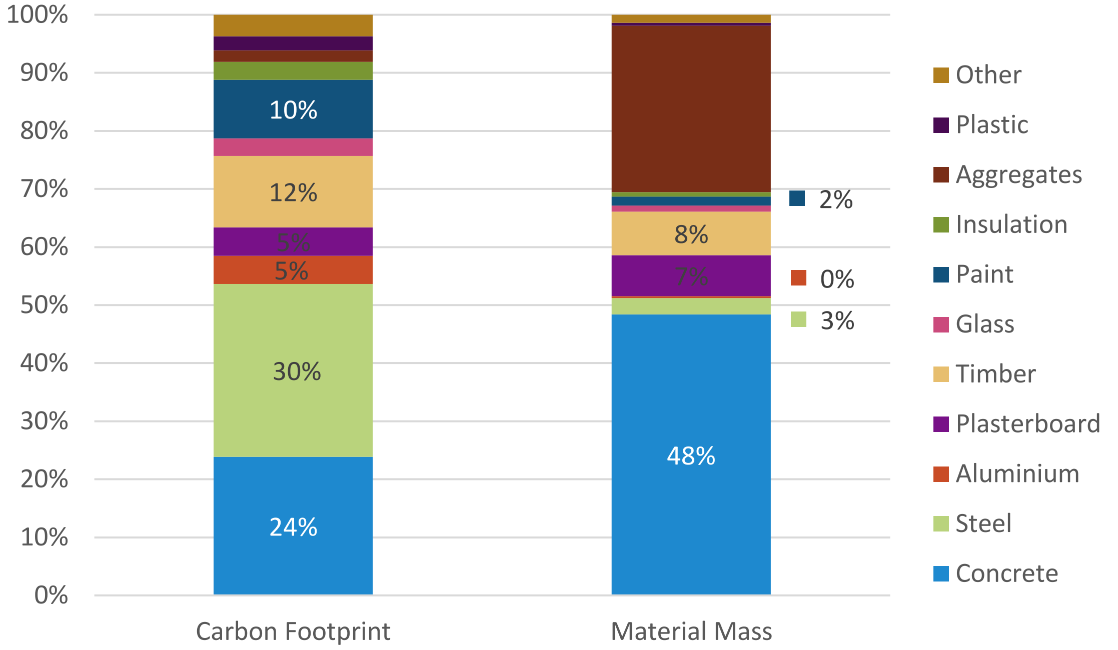


Figure 4-1: Carbon footprint and material mass breakdown for residential buildings over their full life (excl. biogenic CO_2)

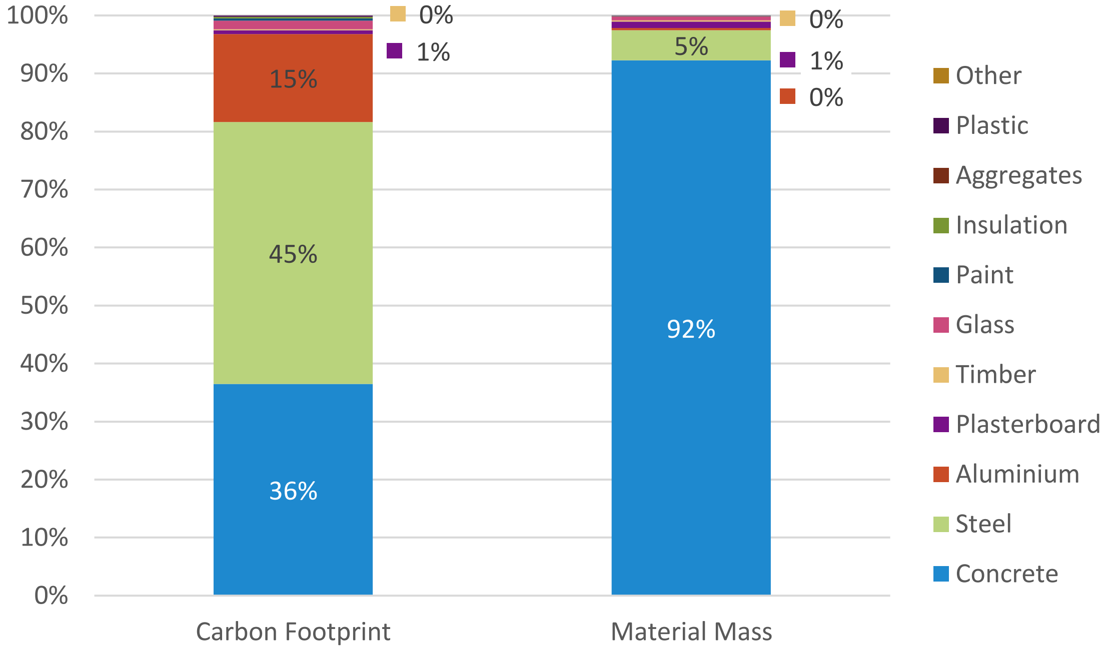


Figure 4-2: Carbon footprint and material mass breakdown for non-residential buildings over their full life (excl. biogenic CO_2)

5. Improvement strategies

As highlighted in the previous section, concrete, steel, aluminium, plasterboard (residential construction only) and timber (residential construction only) are the most significant hotspots in the life cycle of New Zealand's buildings.

This section focuses on potential improvement strategies per material type. The strategies are separated into short-term and long-term:

- **Short-term strategies** include actions that can be taken within the next 1 to 5 years (2020 – 2025), typically by a change in specification from the client and often with some additional investment by the manufacturer (e.g. to upgrade existing plant).
- **Long-term strategies** are likely to require significant capital investment to upgrade manufacturing plants and are expected to be available 10 to 30 years from now (2030 – 2050).

5.1. Cement and concrete

Short-term: Replace 30% of Portland cement with SCMs

While Ordinary Portland Cement (classed as General Purpose Cement in New Zealand) makes up more than one-tenth of the mass of concrete (Allied Concrete 2018), it contributes 70 – 80% of the carbon footprint of virgin concrete (thinkstep, 2019). For this reason, replacement of cement with supplementary cementitious materials (SCMs) is a popular carbon-reduction strategy for concrete throughout the world.

New Zealand currently has very low rates of Portland cement substitution (estimated at 1 – 2%). This presents a considerable opportunity for reducing the carbon footprint of concrete in New Zealand.

The New Zealand Standard NZS 3122:2009 for General Purpose (GP) and General Blended (GB) cements allows for up to 35% substitution with fly-ash or pozzolans, and up to 75% with ground granulated blast furnace slag. Microsilica (which includes silica fume) can be added at a rate of up to 10% in type GP and GB cements. Geopolymer concretes (e.g. Wagners EFC) can achieve 100% Portland cement replacement; however, this often comes with a significant price premium.

The main reasons for the low use of SCMs in the New Zealand context (based on discussions with Golden Bay Cement, HR Cement and Firth Industries) are:

- A lack of local supply of manufactured SCMs, e.g. fly ash;
- The high cost of imported SCMs relative to the cost of Portland cement;
- Reluctance by customers, specifiers and engineers to adopt them; and
- Conformance with the applicable New Zealand concrete standards.

Type GB cements and geopolymer cements have some performance characteristics that meet market resistance: namely, lower early strength development and longer concrete set times (plastic placement of concrete). These issues may be delaying the widespread acceptance of SCMs in the construction industry, as greater use may require changes to standard practice construction techniques.

SCMs, when added to cement (and therefore concrete), offer other benefits that may be required for concrete durability in specialised applications. Within the cement and concrete industry, it is well known that some SCMs increase compressive strengths at 56 days and longer. SCMs also reduce the heat of hydration in concrete, thereby reducing thermal cracking in large concrete pours, and improve concrete resistance to chloride and sulphate ingress, leading to better protection against corrosion of the embodied reinforcing.

Concrete made using type GB cement with an SCM substitution of approximately 30% can exceed the strength development of a similar concrete made using GP cement over longer time periods. However, our concrete industry relies on 28-day compressive strengths for compliance to current New Zealand concrete standards and does not make provision for concrete strength testing at 56 days or longer. Many applications do not require early concrete strength development and the higher levels of SCM substitution in cement would be ideal for such applications.

Looking at each of the alternatives in more detail:

- **Fly ash** from the Huntly Power Station is in irregular supply (as the station often burns gas rather than coal); this means that fly ash is imported from countries such as Indonesia (increasing the price and carbon footprint). The quality of imported fly ash can also be extremely variable.
- **Ground granulated blast furnace slag** is also imported and rarely used because of its high cost. (The slag from the Glenbrook Steel Mill is not suitable as a cement replacement and is used for other purposes instead.) Additionally, there is a global shortage of this by-product from the iron industry with unreliable supply and quality issues related to the slag from many producers.
- **Silica fume**, a by-product of the silica metals industry, is in high demand and expensive to import.
- **Natural pozzolans:** HR Cement in Tauranga is currently commissioning a grinding plant which will substitute approximately 25% of Portland cement with volcanic ash (natural pozzolans) from the North Island Volcanic Plateau. Golden Bay Cement is currently investigating a pozzolan blended cement with at least 20% cement substitution and is undertaking considerable testing to prove its performance. Following that, Golden Bay Cement indicates that new cement milling technology (meaning considerable capital investment) will be required as natural pozzolans present challenges in transitioning the raw material into a usable resource.

Cement substitution of 25 – 100% would reduce the carbon footprint of concrete by between 20% and 80% (factoring in imported SCMs).

A combination of import costs and strong international demand for SCMs has forced their local price up to beyond the price of Portland cement. Annual global production of cement is approximately 5 billion tonnes, whereas approximately 750 million tonnes of fly ash, granulated blast furnace slag and silica fume are produced (Global Slag Conference, Aachen, Germany 26 – 27 March 2019). There is therefore insufficient supply of these materials to meet global demand for SCMs in blended or geopolymer cements.

The advantage of natural pozzolans is that there is a stable local supply not dependent on the coal industry; this means that they have the potential to be cost competitive versus Portland cement over the long term. Therefore, they seem to be the most likely option for New Zealand in the medium to long term.

The short-term strategy considered in this report is to replace 30% of all Ordinary Portland Cement with a combination of fly ash (local or imported) and locally sourced volcanic ash. Given that local supply of fly ash is unreliable and should theoretically reduce to zero over time as New Zealand seeks to decarbonise its electricity mix, SCMs are assumed to be made up of 50% imported fly ash from Indonesia and 50% volcanic ash from the North Island Volcanic Plateau. While higher replacement rates are possible, they are not possible in all cases (because of longer setting times) and would rely on imported materials.

Reduction potential: 21 – 24% per m^3 of concrete, depending on concrete MPa rating

Long-term: Replace a further 40% of all coal alternative fuels in cement manufacture

Since the closure of the Westport cement works in 2016, New Zealand's only remaining integrated cement plant is operated by Golden Bay Cement at Portland, near Whāngarei. All other cement is either imported directly or ground locally from imported clinker.

The Golden Bay Cement plant has already replaced a significant share of its heating coal with biomass, with current replacement levels of up to 30% (Golden Bay Cement, 2018). There is the potential to increase this further, though this would increase the total thermal energy required as biomass has a higher moisture content and lower calorific value than do conventional fossil fuels (IEA and WBCSD-CSI, 2018). The demand for biomass has created a market where price has increased and supply is scare. Golden Bay Cement is currently implementing a project to use tyre-derived fuel and this will further increase its biomass substitution given the approximate 30% natural rubber component of tyres.

The analysis in this report assumes that 25% of all coal is currently replaced by biomass, that this increases to 35% and that a further 30% of all coal is replaced by tyres, leading to a total coal replacement of 65%. Higher demand for energy due to the lower-grade fuel – estimated as 0.25 GJ/t clinker (IEA and WBCSD-CSI, 2018) – is factored into the analysis.

Reduction potential: 6 – 7% per m^3 of concrete, depending on concrete MPa rating [1]
Combined reduction potential: 28 – 32% per m^3 of concrete

---

[1] This reduction is relatively small when compared to the use of 30% SCMs, despite the large conversion to biomass simply because Portland cement production releases carbon dioxide through the manufacturing process itself: $CaCO_3$ + heat → CaO + CO_2. These process emissions are a significant part of the carbon footprint of cement. The only current way to capture these emissions is through carbon capture and storage, a technology that the authors consider is unlikely without considerable financial incentives.

5.2. Steel

New Zealand's only large-scale domestic steel-maker is New Zealand Steel's Glenbrook Steel Mill near Waiuku, Auckland, which is part of the BlueScope Steel group. Pacific Steel's Electric Arc Furnace (EAF) in Otahuhu, Auckland, was closed in 2016.

Like nearly all primary steel mills currently in operation, Glenbrook uses coal to reduce iron oxide to metallic iron before manufacturing steel. Coal, therefore, is not just for heat production; the carbon it contains is also a necessary part of the chemical process. There is no commercial process for making iron from raw materials that does not produce CO_2. While significant research is under way to address this, many of the most promising solutions are more than a decade away (ETC, 2018a). This makes steel harder to decarbonise than products of sectors that use coal for process heat alone (ETC, 2018a).

Short-term: Optimise steel framing

While use of recycled steel seems like an obvious short-term solution, it will not provide the benefits expected because there is simply not enough steel scrap available on the global market. Recovery and recycling rates of steel are already approaching 75% globally and yet secondary steel makes up only 25% of global steel production (McCarthy and Börkey, 2018). While recycling rates can improve further, overall demand for steel is also projected to grow into 2020 despite a slowing global economy (worldsteel, 2019). As long as demand continues to grow, steel products will need to be manufactured from a mix of virgin (primary) and recycled (secondary) sources.

The best short-term strategy is likely to be precision manufacturing; i.e., thinning structural beams in places where the additional strength is not needed rather than manufacturing beams with uniform dimensions. Steltech (part of the BlueScope Steel group) introduced this practice within the New Zealand market.

Industry estimates suggest that the potential to reduce steel mass through optimised steel design in portal-framed, single-story steel structures is in the order of 20 – 35%, while the potential to reduce steel mass in multi-storey buildings is in the order of 10 – 12%.

This report applies a blanket reduction potential of 10% across all steel framing, given that (1) floor area statistics are split by the end use of the building (e.g. schools) rather than by the number of storeys, and (2) Steltech has been operating since 1987, meaning that a share of all buildings is already being optimised. Our understanding is that steel offcuts lost through the manufacturing process are sent back to the Glenbrook Steel Mill for recycling, as they are uncontaminated, and this creates a local recycling loop. The improvement measure considered here accounts for the energy required to re-melt the steel and reprocess it back into steel plate (meaning that the total saving is lower than 10%).

Reduction potential: 8% for all steel framing.

Long-term: Low-carbon steel-making

There are several potential solutions for reducing the carbon footprint of steel:

- **Electric Arc Furnace:** Given the long distance between New Zealand and other markets, and our renewable electricity mix, reopening an EAF would be one approach. However, it would be effective only if met by a corresponding scaling back of primary steel production locally. While this would help to reduce New Zealand's domestic GHG emissions, it would make only a small difference at a global scale as we would simply be redirecting steel scrap that would otherwise go to another EAF offshore.
- **Hydrogen:** Hydrogen-based direct reduced iron is a promising solution to low-carbon steel (ETC, 2018a). While there are pilot plants already under way, its widespread availability is not expected until the 2040s (ETC, 2018a). As such, it may come too late for the 2050 time-horizon considered in this study.
- **Charcoal:** Given that it is the carbon in coal that is necessary for manufacturing steel, not the coal itself, one solution is to replace coal by charcoal from sustainably sourced wood. This is already considered a mature technology in Brazil (ETC, 2018b). CarbonScape is an example of a company in New Zealand working on this technology. They are developing a solution to produce charcoal from wood using industrial microwaves – a solution that may offer a low carbon footprint in the New Zealand context, given our renewable electricity mix. New Zealand Steel announced a trial with CarbonScape in 2013 (Scoop, 2013); however, we understand that this charcoal is not yet available for commercial use.

Any of these strategies would likely yield significant benefits at the New Zealand level. A 'right-sized' EAF for the New Zealand market could also be used together with charcoal or hydrogen (i.e. producing a blend of virgin and recycled steel) to lower the carbon footprint further within New Zealand.

The charcoal strategy has been applied in this analysis because: (1) the plant upgrades necessary to use charcoal seem likely to be less costly than would installing a new EAF or a hydrogen-based furnace; (2) New Zealand has ample land on which to grow forests for charcoal production; and (3) it draws on local knowledge and local strengths. Charcoal may also be a potential stepping stone towards hydrogen, making greater use of the existing plant until hydrogen is ready for full commercialisation.

In addition to 100% substitution of fossil coal with bio-based charcoal, this analysis assumes that a municipal landfill with gas capture or an anaerobic digestor is co-located near the Glenbrook Steel Mill (allowing up to 20% of all natural gas to be substituted with biogas, while also producing electricity via co-generation) and that New Zealand's electricity mix decarbonises to nearly 100% renewable by the 2030s.

Combining direct substitution of coal with charcoal, substituting 20% natural gas with biogas and using 100% renewable electricity would reduce the carbon of finished steel products by 60% (authors' calculations).

While we apply the charcoal strategy within this report, we are conscious that numerous obstacles would still need to be overcome to make this viable, including scaling up the technology to full commercial scale, sourcing enough biomass, siting of the pyrolysis plant, research and development to convert from sub-bituminous coal to charcoal, etc. If some of these obstacles cannot be overcome, it may be that the hydrogen strategy would become the preferred option and it is expected that this would also lead to significant carbon savings so long as the hydrogen were produced from renewable electricity. Estimates from German steelmaker Salzgitter suggest a reduction of 80% would be possible by 2050 (ETC, 2018b).

Reduction potential: 60% reduction for finished steel products such as Pacific Steel's reinforcing steel and New Zealand Steel's roofing and cladding products. This 60% reduction has also been applied for imported steel as it is difficult to separate local production from imports within the available statistics. The assumption is, therefore, that our major import partners also decarbonise their own production by a similar margin (even though they may not be using bioenergy to achieve this), or that imports are replaced by local production.

5.3. Aluminium

Short-term: Source all aluminium from smelters using renewable electricity

Primary aluminium production is electricity intensive and it is the source of electricity (coal or hydroelectric, for example) that determines its carbon footprint (IAI, 2017). As a result, the biggest improvement that can be made for aluminium is by choosing where you purchase it from.

Figure 5-1 shows the difference that renewable electricity makes. All scenarios below are stylised but are designed to indicate representative supply chains for aluminium worldwide. Chinese production uses 90% coal electricity and 10% hydroelectricity, resulting in a carbon footprint of approximately 20 kg CO_2e/kg (IAI, 2017). Meanwhile, Canada and NZAS use 100% hydroelectric power, resulting in a carbon footprint of 5 kg CO_2e/kg – four times lower (IAI, 2017). The global average is 18 kg CO_2e/kg (IAI, 2017).

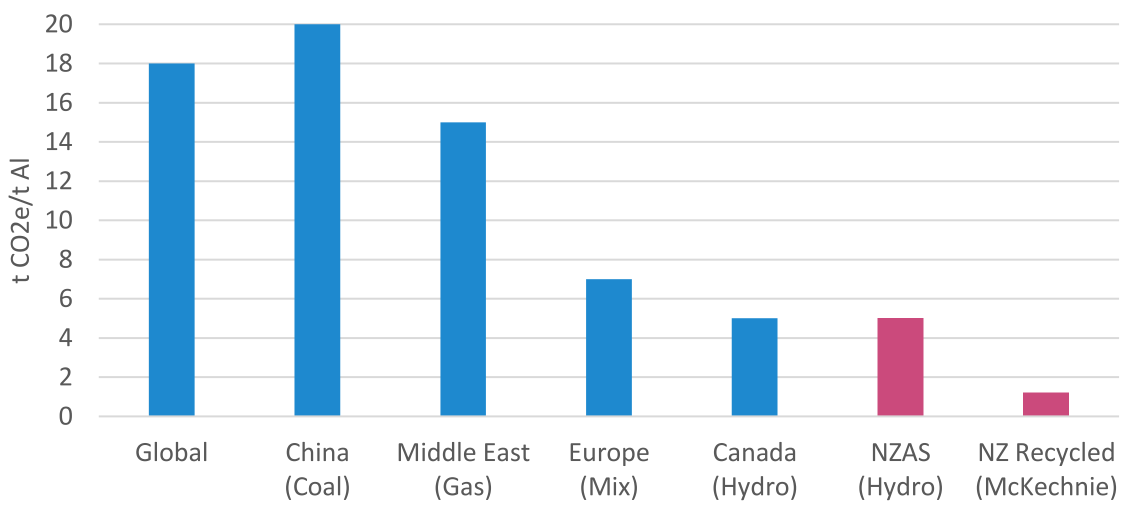


Figure 5-1: Carbon footprint of aluminium – regional scenarios (reproduced from IAI, 2017)

Changes in procurement practices can specify that aluminium comes from smelters which use hydro-power and other renewable sources. This, in turn, creates a financial incentive for other smelters to convert their electricity sources (where feasible). However, it is important to note this emission reduction strategy is global in nature – it will not benefit *New Zealand's Greenhouse Gas Inventory* (i.e. our production footprint) because New Zealand's only aluminium smelter at Tiwai Point is already 100% hydro-powered. Despite this, much of the aluminium used in building and construction in New Zealand is in the form of joinery imported from other countries, particularly China.

Reduction potential: 14% reduction for residential buildings and 74% reduction for non-residential buildings, assuming all aluminium is sourced from hydro-powered smelters. (These reduction potentials assume the current split of domestically-produced versus imported aluminium billet, which industry estimate to be 95% domestic production for residential buildings and 10-15% for non-residential buildings.)

Long-term: Decarbonise aluminium smelting and increase recycled use

There are two key solutions for reducing the carbon footprint of aluminium:

- **Carbon Free Smelting:** The aluminium smelting process uses carbon electrodes to reduce the aluminium oxide, producing CO_2. New technology is in development to replace carbon electrodes with an alternative material, which would produce only O_2. Combined with renewable electricity sources, this would essentially result in zero carbon emissions from the smelting process. The new process is being developed by Elysis, a joint venture between NZAS's majority shareholder Rio Tinto and Alcoa, and has already been earmarked for testing at NZAS.
- **Recycling:** Most aluminium is already recycled and now contributes significantly to the global market with much lower emissions than primary production, e.g. McKechnie in New Zealand produces aluminium extrusions with a carbon footprint of only 1.2 kg CO_2e/kg (McKechnie, 2019). Secondary aluminium is not widely used in extrusion plants, due to difficulties with the technology, but it is being successfully used by McKechnie together with primary aluminium. Industry estimates are that recycled aluminium will make up 30% of the market in future and it is assumed that with enough research this aluminium blend will be able to be used in the extrusion industry.

Reduction potential: 57% reduction for residential buildings and 87% reduction for non-residential buildings, assuming 70% virgin aluminium produced using hydro-power and Carbon Free Smelting and 30% recycled aluminium. (As above, the potential for improvement is higher for non-residential buildings as a much greater share of aluminium comes from smelters who use non-renewable electricity.)

5.4. Plasterboard

Short-term: None considered

There are relatively few options to improve plasterboard in the short term, except through reducing offcuts. New Zealand currently has no facilities for recycling plasterboard back into plasterboard; however, some composting facilities accept plasterboard as it has benefits as a soil improver. No improvement options are considered in this analysis.

Long-term: Decarbonise the energy mix for plasterboard production

New Zealand has two plasterboard manufacturing plants: one in Auckland and one in Christchurch. Both are owned by Winstone Wallboards, part of the Fletcher Building Group. Winstone Wallboards is the largest supplier of plasterboard in New Zealand, though some product is also imported from Australia and Southeast Asia.

Plasterboard production involves three key steps (Smith et al., 2017):

1. Calcination of gypsum at high temperature to form plaster of Paris;
2. Rehydration of plaster of Paris and pressing it between two paper layers; and
3. Drying off excess water in an oven.

Steps (1) and (3) require considerable process heat, which is derived either from natural gas (in Auckland and for imported products) or LPG (in Christchurch).

This analysis assumes that future plants are relocated near sources of geothermal steam (e.g. the industrial geothermal steam field at Kawerau) and that this steam is used in the drying stage (step 3). The calcination stage (step 1) is assumed to remain as one that uses natural gas or LPG since the geothermal steam is not of a sufficiently high temperature for this process. Also, it is assumed that New Zealand's electricity mix is assumed to become nearly 100% renewable by the 2030s.

Note: While this analysis assumes geothermal steam for drying, it would also be possible to decarbonise plasterboard production significantly by using electric heat so long as the electricity comes from renewable sources.

Reduction potential: 74% reduction in manufacturing GHG emissions.

5.5. Wood products

No improvement strategies are considered for timber and other wood products as the local industry already uses a significant share of biomass for thermal energy (e.g. for kiln-drying wood), meaning that there is a smaller potential for improvement. The improvement strategies for wood are largely those that would benefit wider New Zealand, i.e. a low-carbon electricity mix (for sawmilling, etc.) and greater availability of biofuels such as biodiesel (for forestry).

5.6. Paint

Unlike most other products considered in this report, paint manufacture is not energy intensive. Instead, virtually all impacts come from the raw materials that are blended together to form the paint. Past unpublished life cycle assessments conducted by thinkstep show that the carbon footprint of paint is driven by titanium dioxide (particularly for white paints) and the resins/binders in the paint. New Zealand company Avertana is currently pioneering a technology to turn waste steel slag from the Glenbrook Steel Mill into titanium dioxide. This technology seems very promising as a means to decarbonise paint; however, no attempt was made to quantify this as part of the current study due to the early stages of development and lack of available data at commercial scale.

6. Results and conclusions

6.1. How to interpret these results

Scenarios investigated

Three scenarios are investigated within this section:

1. Current scenario with no improvements to building materials.
2. Short-term material improvements, specifically:
   - Concrete: 30% substitution of cement by fly ash and natural pozzolans;
   - Steel: 10% reduction in mass for steel beams through optimised design by the steel fabricator; and
   - Aluminium: sourcing moves from current supply mix to material produced using hydroelectricity (e.g., local sourcing from Tiwai Point).
3. Long-term material improvements (in addition to the short-term improvements noted above), specifically:
   - Concrete: maintain 30% substitution of cement (now using natural pozzolans only) and further substitution of coal for alternative fuels in cement production;
   - Steel: significant decarbonisation through some combination of: replacement of coking coal with renewable charcoal, hydrogen-based direct reduced iron and/or a local Electric Arc Furnace;
   - Aluminium: move to Carbon Free Smelting and increase recycled content of all building products to 30%; and
   - Plasterboard: changes to manufacturing energy mix.

Putting the results into perspective

Numbers of cars taken off the road: These figures are calculated by dividing the total carbon emissions from the passenger fleet by the total size of the passenger fleet (MoT, 2018).

Comparison to New Zealand's national carbon footprint: This report applies three different ways of viewing New Zealand's national emissions:

- *Consumption GHG emissions excluding biogenic CO_2:* These are the gross GHG emissions associated with what New Zealanders consume, not with what we produce (Figure 1-1c on page 9). The consumption-based approach considers GHG emissions embodied in trade, i.e. domestic production + emissions in imports – emissions in exports. It does not account for carbon sequestered in bio-based materials such as wood.
- *Production GHG emissions, excluding biogenic CO_2:* These are the gross figures reported in *New Zealand's Greenhouse Gas Inventory* produced by the Ministry for

the Environment (e.g. MfE, 2019b). The production-based approach includes everything that New Zealand produces, including products for export (Figure 1-1a and Figure 1-1b on page 9). It does not account for carbon sequestered by trees, or for GHG emissions embodied in trade.

- *Production GHG emissions excluding biogenic CO_2 and CH_4:* These are the same as production GHG emissions above, except that biogenic methane has been excluded following the draft Zero Carbon Bill (MfE, 2019a).

6.2. Improvements by life cycle stage

Figure 6-1 and Figure 6-2 illustrate life cycle stage breakdown (construction, construction waste, maintenance/renovation, maintenance/renovation waste and end-of-life) of carbon footprint per 1 m^2 of floor area for residential and non-residential buildings respectively. The non-residential build has slightly greater impact per square meter of floor area, when compared to the residential builds and considering the current, short - and long-term scenarios.

Short-term improvements include improvements to concrete and aluminium and result in a total improvement of 20% (residential and non-residential) when compared to the current embodied carbon. Long-term improvements investigated include improvements to steel and plasterboard manufacturing, and the short-term improvements to aluminium and concrete manufacturing. A 43% improvement to carbon footprint occurs in the long term with all material improvements investigated.

Residential builds

- Current scenario: The impact from residential builds is split between initial construction stage (52%) and maintenance/renovation (35%). Renovation is very significant for the residential building due to its assumed 90-year life, meaning that many of the materials need to be replaced. Waste from construction, maintenance/renovation and building end-of-life makes up the remaining 13%.
- Short-term material improvements result in total savings of 5% when compared to the current scenario, largely thanks to improvements in concrete production.
- Long-term material improvements result in total savings of 29%. These savings come through a combination of improvements to the carbon footprint of steel, concrete and aluminium.

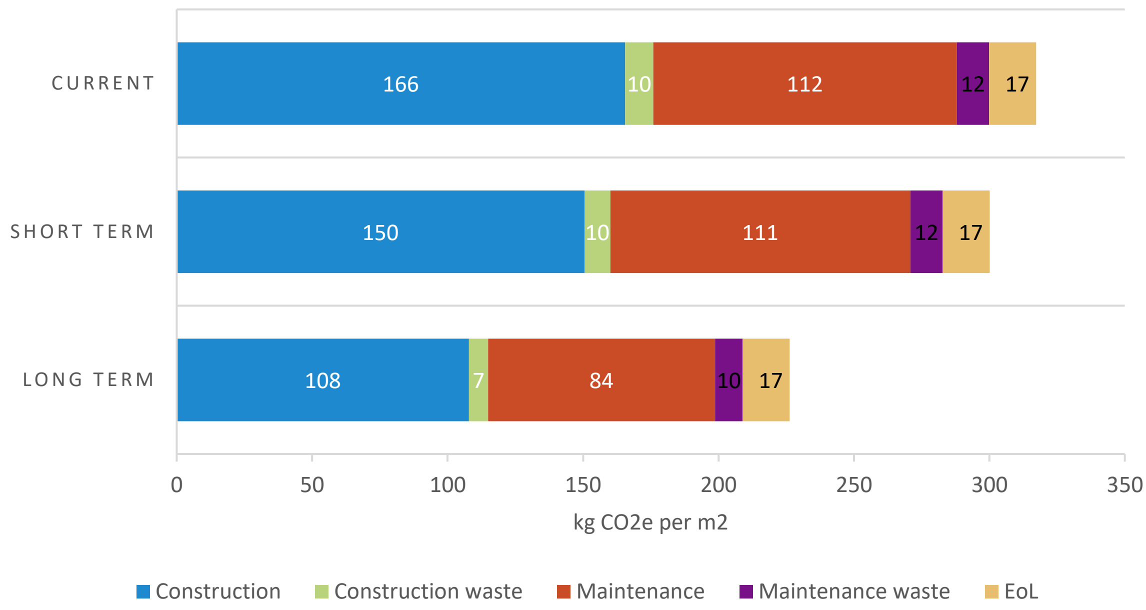


Figure 6-1: Breakdown of carbon footprint per 1 m² of gross floor area for residential builds, according to life cycle stage (excl. biogenic CO_2)

Non-residential builds

- Current scenario: The impact from non-residential builds is dominated by the construction stage (87%), followed by impact of maintenance/renovation (5%). Waste from construction, maintenance/renovation and building end-of-life makes up the remaining 8%.
- Short-term material improvements result in total savings of 19% when compared to the current scenario, largely thanks to improvements in concrete and aluminium manufacturing.
- Long-term material improvements result in total savings of 51%. These savings come through a combination of improvements to the carbon footprint of steel, concrete and aluminium.

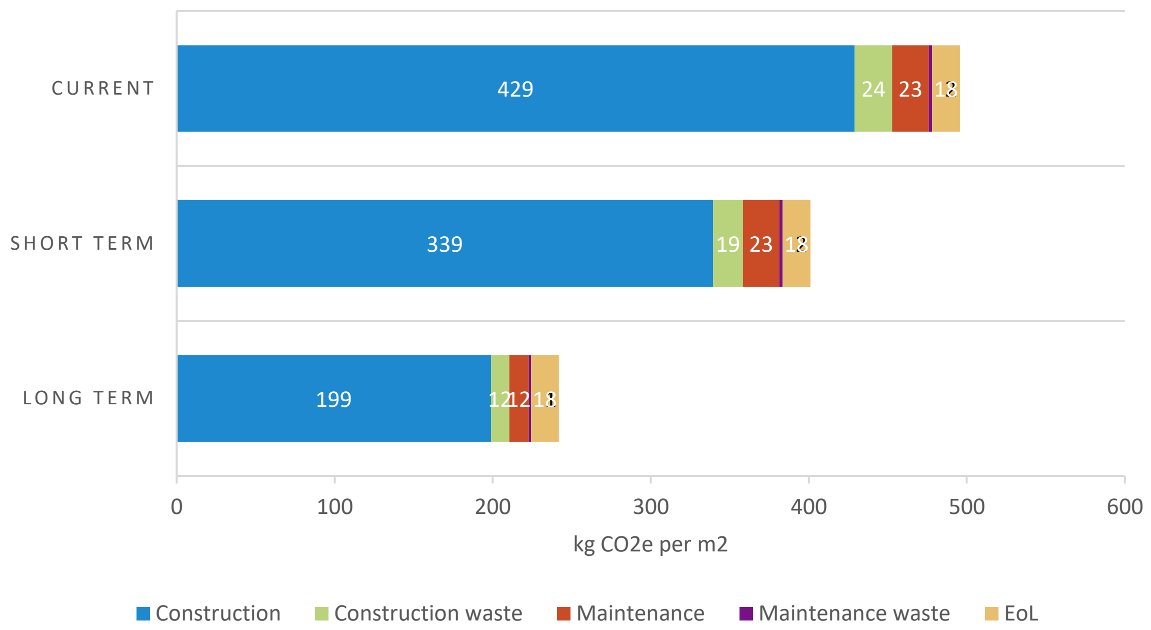


Figure 6-2: Breakdown of carbon footprint per 1 m^2 of gross floor area for non-residential builds, according to life cycle stage (excl. biogenic CO_2)

Note: The chart above shows a total carbon footprint for current non-residential buildings of 494 kg CO_2e/m^2 over the full life cycle (excluding operation). BRANZ previous work on office buildings found a range between 182 to 455 kg CO_2e/m^2 when including the same life cycle stages (Berg et al., 2016, Appendix F) with an unweighted average of approximately 350 kg CO_2e/m^2. However, it is important to note that the results above are for an average of two building types (reinforced concrete and portal-framed steel) and that the underlying emissions factors used are different.

6.3. Improvements by material type

Figure 6-3 and Figure 6-4 provide breakdowns of the total impact of short- and long-term material improvements for residential building and non-residential respectively. During the short-term, aluminium and concrete material improvements were made and this is reflected in the reduction of impact from aluminium and concrete. During the long-term, the accumulative impacts of aluminium, concrete, steel and plasterboard improvements lead to significant reduction in their carbon footprint when compared to their current footprints.

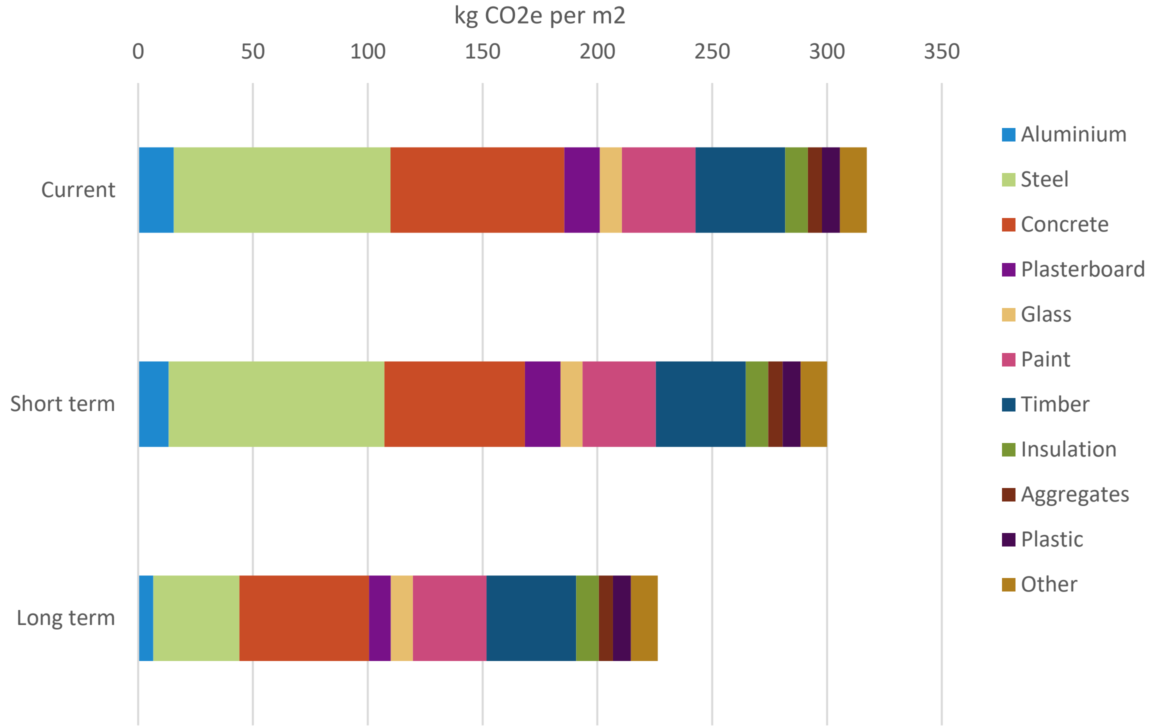


Figure 6-3: Breakdown of carbon footprint for current, short- and long-term improvements (excl. biogenic carbon) for residential builds

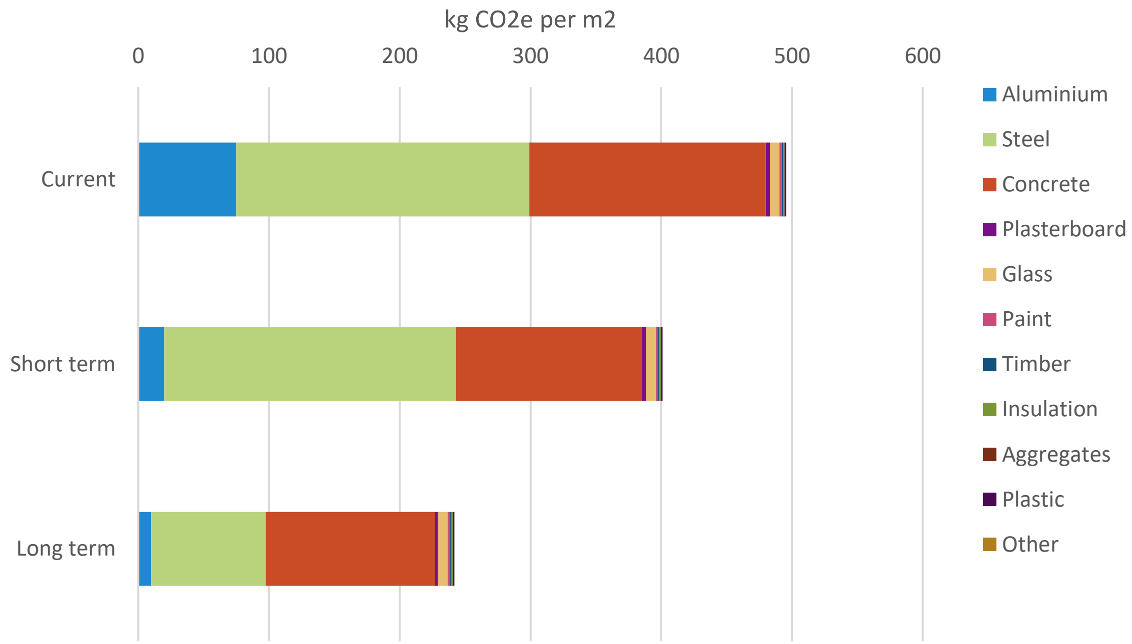


Figure 6-4: Breakdown of carbon footprint for current, short- and long-term improvements (excl. biogenic carbon) for non-residential builds

6.4. Top-down versus bottom-up approach to carbon footprint

In this study, carbon footprint is estimated by multiplying emissions from the construction of representative buildings by a construction rate, i.e. calculated from the bottom up. Our report published in 2018 (Vickers et al., 2018) applied a top-down approach where carbon footprint was estimated from published data on total carbon emissions for the sector.

Table 6-1: Comparison of top-down and bottom-up approaches (excluding biogenic carbon)

Calculation approach	Carbon footprint per year
Top down*	5,185 kt CO_2e
Bottom up	2,860 kt CO_2e

*The carbon footprint represents the material-only impact after adjusting for imports and exports

The bottom-up approach yields a figure that is almost half of the top-down approach. This lower total was expected, given that our 2018 paper also included the emissions associated with producing infrastructure. However, it seems likely that the analysis in this report also underestimates the impacts of New Zealand’s building stock, given that it excludes parts of the building such as the fit-out and building services. It should also be noted that the approach used in this report (i.e. using a small number of building types to represent the whole market) is a simplification of reality, particularly for non-residential buildings where there is much greater variability in building form across New Zealand than there is in the residential building stock. The analysis in chapter 3 shows that it is likely we likely underestimate economy-wide flows of key building materials.

6.5. Conclusions

The current, short-term and long-term carbon footprint results are presented as:

- Absolute savings, excluding biogenic carbon dioxide (Table 6-2);
- Absolute savings, excluding biogenic carbon dioxide and methane (Table 6-3); and
- Relative savings in the context of taking cars off the road and as a percentage of New Zealand's national carbon footprint (production and consumption perspectives) (Table 6-4).

Overall, if construction material improvements are made for both residential and non-residential building types, a total carbon saving of 13% from all embodied emissions could be made in the short term and 41% in the long term (Table 6-2). This translates to taking approximately 5% or 15% (respectively) of all passenger cars in New Zealand off the road permanently (Table 6-4).

When comparing these figures to New Zealand's total emissions (Table 6-4):

- The current total carbon footprint of buildings (residential and non-residential) is approximately 6% of New Zealand's gross GHG emissions from a production perspective and 8% from a consumption perspective (Vickers et. al., 2018). Production emissions increase from 6% to 11% if methane is excluded.
- Over the long term, if the improvements presented in this report were implemented, there would be savings equivalent to 1.9% of New Zealand's total consumption emissions, 1.5% of New Zealand's total production emissions (excluding biogenic CO_2) and 2.5% of New Zealand's total production emissions (excluding biogenic CO_2 and CH_4).

It is important to note that the comparison to New Zealand's consumption emissions (i.e. a 1.5% reduction) is most meaningful as some of the GHG emissions reductions calculated in this report will occur outside of New Zealand's borders.

Table 6-2: Embodied carbon footprint reductions (excl. biogenic CO_2)

	Current	Short-term improvements	Long-term improvements
Embodied carbon footprint (kt CO_2e)			
Residential	1,330	1,260	947
Non-residential	1,530	1,240	747
Total	2,860	2,500	1,690
Absolute reduction in embodied carbon footprint vs today (kt CO_2e)			
Residential	-	72	381
Non-residential	-	292	785
Total	-	364	1,170
Relative reduction in embodied carbon footprint vs today			
Residential	-	5%	29%
Non-residential	-	19%	51%
Total	-	13%	41%

Table 6-3: Embodied carbon footprint reductions (excl. biogenic CO_2 and CH_4)

	Current	Short-term improvements	Long-term improvements
Embodied carbon footprint (kt CO_2e)			
Residential	1,310	1,240	928
Non-residential	1,530	1,240	747
Total	2,840	2,480	1,670
Absolute reduction in embodied carbon footprint vs today (kt CO_2e)			
Residential	-	72	381
Non-residential	-	292	785
Total	-	364	1,170
Relative reduction in embodied carbon footprint vs today			
Residential	-	5%	29%
Non-residential	-	19%	51%
Total	-	13%	41%

Table 6-4: Significance of embodied carbon footprint reductions in the New Zealand context

	Current	Short-term improvements	Long-term improvements
Savings presented as cars taken off the road			
Residential	-	28,400	150,000
Non-residential	-	115,000	309,000
Total	-	144,000	459,000
Savings relative to annual GHG emissions (consumption perspective)			
Residential	-	0.4%	1.2%
Non-residential	-	0.9%	1.7%
Total	8%	1.4%	2.9%
Savings relative to annual GHG emissions (production perspective)[2]			
Residential	-	0.1%	0.5%
Non-residential	-	0.4%	1.0%
Total	6%	0.5%	1.5%
Savings relative to annual GHG emissions (production perspective, excluding CH_4)[2]			
Residential	-	0.2%	0.8%
Non-residential	-	0.6%	1.7%
Total	11%	0.8%	2.5%

[2] This table shows the total savings calculated, divided by New Zealand's total gross GHG emissions from a production perspective. However, some of the GHG emissions reductions will occur outside of New Zealand's borders. This is particularly important for the aluminium improvement option, given that our only domestic aluminium smelter (at Tiwai Point) will already be operating at the low end of the GHG emissions spectrum.

6.6. Recommendations

A collaborative effort will enable us to achieve or exceed the 40% decarbonisation potential identified in this report. It is not only material suppliers who need to implement low-carbon manufacturing technologies, but also specifiers and customers who need to consciously choose those materials. This could be encouraged by including embodied carbon considerations in public and private procurement policies, and by ensuring that the New Zealand Emissions Trading Scheme accounts for the emissions embodied in imports. Government could also utilise life cycle assessment – such as that within Green Star – when specifying their building programmes, helping to lead the sector towards low-carbon.

Another prerequisite for specifying low-carbon materials is the availability of data. This has recently been improved through publication of product carbon footprints and Environmental Product Declarations (which include a figure for embodied carbon) for a number of New Zealand-made building products.

Improved public statistics would enable better benchmarking of the embodied carbon in New Zealand's building stock and tracking of improvements over time. This study included a material flow analysis to validate material consumption at a national level, which was made challenging by the lack of detail in publicly available statistics.

Data could be improved in the following key areas:

- Floor area per type of construction considering framing, cladding, foundation, etc. (recognising that BRANZ has done considerable work in this area already);
- Annual production statistics for key New Zealand building materials (concrete used in buildings, steel roofing, aluminium windows and doors, etc.); and
- Categorisation for certain import/export statistics (e.g. curtain walls).

In summary, decarbonising the built environment is likely to require:

- Collaboration among all players in the building sector;
- Communication of good information and data;
- Innovation in the manufacturing sector; and
- Policy development encouraging the use of materials with low embodied carbon.

References

Allied Concrete (2018). Environmental Product Declaration: Ready mixed concrete using Holcim supplied cement. Revision 4 of 16 January 2018. EPD Australasia.

Berg, B., Dowdell, D., Curtis, M. (2016). New Zealand whole-building whole-of-life framework: Development of reference office buildings for use in early design. BRANZ Study Report SR350. Judgeford, New Zealand: BRANZ Ltd.

BRANZ (2019). BRANZ CO_2NSTRUCT. Available: https://www.branz.co.nz/co2nstruct.

Collins, N. and Blackmore, A. (2010). The environmental impact of the Waitakere NOW Home®: A Life Cycle Assessment case study. Publication SM3570/9 for Beacon Pathway Limited.

Dowdell, D., Berg, B., Marston, N., Shaw, P., Burgess, J., Roberti, J., & White, B. (2016). New Zealand whole-building whole-of-life framework: Development of datasheets to support building life cycle assessment. BRANZ Study Report SR351. Judgeford, New Zealand: BRANZ Ltd.

EN 15804:2012+A1:2013 (2013). Sustainability of construction works — Environmental product declarations — Core rules for the product category of construction products. Brussels: European Committee for Standardization.

ETC (2018a). Mission Possible: Reaching net-zero carbon emissions from harder-to-abate sectors by mid-century. Energy Transitions Commission.

ETC (2018b). Mission Possible: Reaching net-zero carbon emissions from harder-to-abate sectors by mid-century. Sectoral focus: Steel. Energy Transitions Commission.

GHG Protocol (2011). Product Life Cycle Accounting and Reporting Standard. World Resources Institute and World Business Council for Sustainable Development. Available: https://ghgprotocol.org/product-standard.

Ghose, A., Pizzol, M., McLaren, S. J., Vignes, M. and Dowdell, D. (2019). Refurbishment of office buildings in New Zealand: identifying priorities for reducing environmental impacts, *Int J Life Cycle Assess*, 24: 1480. Available: https://doi.org/10.1007/s11367-018-1570-5

Golden Bay Cement (2018). Submission Form: Productivity Commission – Low Emission Economy. Available: https://www.productivity.govt.nz/sites/default/files/sub-low-emissions-197-golden-bay-cement-331Kb.pdf

Hyder Consulting (2011). Construction and demolition waste status report. A report for the Department of Sustainability, Environment, Water, Population and Communities and Queensland Department of Environment and Resource Management. Available www.environment.gov.au/system/files/resources/323e8f22-1a8a-4245-a09c-006644d3bd51/files/construction-waste.pdf

Hyder Consulting (2012). Waste and recycling in Australia 2011. A report prepared for the Department of Sustainability, Environment, Water, Population and Communities. Available: www.environment.gov.au/system/files/resources/b4841c02-229b-4ff4-8b3b-ef9dd7601d34/files/waste-recycling2011.pdf

IAI (2017). Life Cycle Inventory Data and Environmental Metrics for the Primary Aluminium Industry. London: International Aluminium Institute.

IEA and WBCSD-CSI (2018). Technology Roadmap: Low-Carbon Transition in the Cement Industry. International Energy Agency and the Cement Sustainability Initiative of the World Business Council for Sustainable Development.

ISO 14067:2018 (2018). Greenhouse gases — Carbon footprint of products — Requirements and guidelines for quantification. Geneva: International Organization for Standardization.

John, S.M., Nebel, B., Perez, N. and Buchanan, A. (2009). Environmental Impacts of Multi-Story Buildings Using Different Construction Materials. University of Canterbury, Research Report 2008-02.

MacGregor, C., Dowdell, D., Jaques, R., Bint, L. and Berg, B. (2018). The built environment and climate change: A review of research, challenges and the future. BRANZ Study Report SR403. Judgeford, New Zealand: BRANZ.

MBIE (2018). National Construction Pipeline Report: A Forecast of Building and Construction Activity. 6th Edition. Available: https://www.mbie.govt.nz/building-and-energy/building/supporting-a-skilled-and-productive-workforce/national-construction-pipeline-report/.

McCarthy, A. and Börkey, P. (2018). Mapping Support for Primary and Secondary Metal Production. OECD. Available: https://www.oecd-ilibrary.org/environment/mapping-support-for-primary-and-secondary-metal-production_4eaa61d4-en

McKechnie, 2019. McKechnie website statement: http://www.mckechnie.co.nz/

MfE (2019a). Climate Change Response (Zero Carbon) Amendment Bill: Summary. Wellington: Ministry for the Environment.

MfE (2019b). New Zealand's Greenhouse Gas Inventory 1990–2017. Wellington: Ministry for the Environment.

MoT (2018). The New Zealand 2017 Vehicle Fleet: Data Spreadsheet. Wellington: Ministry of Transport.

NZS 3122:2009 (2009). Specification for Portland and blended cements (General and special purpose). Wellington: Standards New Zealand.

PCR 2012:01 Construction Products and Construction Services 2012:01, Version 2.3, 2017-05-30 (valid until 2020-03-20). Stockholm: International EPD System.

Scoop (2013). NZ Steel and CarbonScape 'Green Coke' Initiative. Available at: http://www.scoop.co.nz/stories/BU1302/S00340/nz-steel-and-carbonscape-green-coke-initiative.htm

Smith, C., Miller, K. A., Greig, M. S., Thorn, P., Yuen, D. and Wansbrough, H. (2017). Plaster and plasterboard production. Available: https://nzic.org.nz/app/uploads/2017/10/9D.pdf

Stats NZ (2019a). Building consents issued: April 2019. Statistics New Zealand. Available at https://www.stats.govt.nz/information-releases/building-consents-issued-april-2019.

Stats NZ (2019b). StatsNZ Infoshare: Group: Building Consents – BLD. Available at: http://archive.stats.govt.nz/infoshare/SelectVariables.aspx?pxID=97c4e4f7-b491-4d0c-8556-e2bcb7b67df7.

thinkstep (2019). GaBi Life Cycle Inventory Database 2019 Documentation. Leinfelden-Echterdingen, Germany. Retrieved from thinkstep AG: http://www.gabi-software.com/international/support/gabi/gabi-database-2019-lci-documentation/

Vickers, J., Fisher, B. and Nebel, B. (2018). The carbon footprint of New Zealand's built environment: Hotspot or not? Wellington: thinkstep. Available: https://www.thinkstep.com/content/carbon-footprint-new-zealands-built-environment-hotspot-or-not

WorldGBC (forthcoming). Bringing embodied carbon upfront: Coordinated action for the building and construction sector to tackle embodied carbon. World Green Building Council.

worldsteel (2019). worldsteel Short Range Outlook April 2019. World Steel Association. Available: https://www.worldsteel.org/media-centre/press-releases/2019/worldsteel-short-range-outlook-april-2019.html

WWB (2018). Environmental Product Declaration for GIB® Plasterboard. Auckland: Winstone Wallboards.

Annex A Material data

Table 6-5: Bill of quantities for residential and non-residential construction types

Materials	Residential, timber-framed (kg)	Non-residential, portal-framed (kg)	Non-residential, multi-story (kg)
Gross floor area	**146 m²**	**1,000 m²**	**4,247 m²**
Aluminium	192	332	33,890
Brick	2,798	-	-
Building paper	57	-	-
Carpet	87	-	-
Ceramic	145	-	-
Clay	133	-	-
Concrete	51,469	-	4,595,000
Concrete, 15MPa	-	-	61,000
Concrete, 40MPa	-	672,000	679,000
Copper	24	-	-
Fibre cement	565	-	36,390
Glass	596	2,266	47,030
Glulam	81	-	-
Gravel	25,477	-	-
Insulation	442	112	3,300
MDF	-	-	2,000
Paint	165	38	690
Particleboard	45	-	-
Plasterboard	3,650	1,483	38,830
Plywood	-	-	4,090
Polycarbonate	7	-	-
Polyethylene	282	-	-
Polypropylene	8	-	-
Polystyrene	21	-	2,310
PVC	2	-	-
Sand	7,634	-	-
Steel cladding	11	-	-
Steel (galvanized)	164	536	16,598
Steel roofing	1,265	13,708	6,126
Steel wire	547	8,000	114,410
Steel reinforcing bar	-	38,700	17,446
Timber	5,647	226	11,570
Weatherboard	768	-	-
Other	43	-	-
Total	**102,327**	**737,398**	**5,669,680**

Table 6-6: EPD data used in this study

Material	EPD owner	EPD registration
Carpet	Shaw Europe Ltd	S-P-01240
Concrete	Allied Concrete	S-P-00555
Glulam	WPMA	Soon to be published
Insulation	Tasman Insulation	S-P-01169
MDF	Daiken	S-P-01168
Paint	Resene	S-P-00720 Soon to be published
Particleboard/Fibreboard	FWPA	S-P-00562
Plasterboard	GIB	S-P-01000
Plywood	FWPA	S-P-00564
Softwood	WPMA	Soon to be published
Steel (galv)	New Zealand Steel	Soon to be published
Steel roofing	New Zealand Steel	S-P-01001
Steel wire	Pacific Steel	S-P-01002
Steel reinforcing bar	Pacific Steel	S-P-01002
Weatherboard	James Hardie Industries Ltd	S-P-00849

Table 6-7: GaBi datasets used in this study (thinkstep, 2019)

Material	Dataset name	Year	Geography
Aluminium	Aluminium ingot mix IAI 2015	2015	Global
	Aluminium ingot mix IAI 2015	2015	CA
Building paper	Kraft paper (EN15804 A1-A3)	2018	EU-28
Ceramic tiles	Stoneware tiles, glazed (EN15804 A1 – A3)	2018	DE
Construction waste to landfill	Inert matter (construction waste) on landfill	2018	DE
Copper	Copper mix (99,999% from electrolysis)	2018	DE
Fibre cement	Fibre cement façade panel (coated) (A1 – A3)	2018	DE
Glass	Window glass simple (EN15804 A1 – A3)	2018	EU-28
Gravel	Gravel 2/32	2018	EU-28
Plastic waste to landfill	Plastic waste on landfill	2018	EU-28
PVC	Polyvinyl chloride granulate (Suspension, S-PVC)	2018	DE
Rubber	Natural rubber foam	2018	EU-28
Sand	Sand (grain size 0/2) (EN15804 A1 – A3) (dried)	2018	EU-28
Demolition	Demolition/deconstruction	2018	EU-28

Table 6-8: Replacements per material type (excluding original installation)

Material	Residential	Non-residential
	Life = 90 years	Life = 60 years
Aluminium (windows and doors)	1	Not replaced
Brick	20% replaced	N/A
Concrete blocks	20% replaced	N/A
Concrete tile roofing	1	N/A
Floor coverings: carpet, tiles, vinyl	5	Not assessed
Glass (windows and doors)	1	Not replaced
Foundations	Not replaced	Not replaced
Glulam	Not replaced	N/A
Insulation	1	1
MDF	N/A	1
Paint	10	6
Particleboard	2	N/A
Plasterboard	1	1
Plastics	1	1
Plywood	N/A	Not replaced
Steel framing and bracing	Not replaced (as used for external walls)	20% replaced (for internal walls)
Steel reinforcing	Not replaced	Not replaced
Steel roofing	1	50% replaced
Timber – finishing	1	1
Timber frame – external walls	Not replaced	N/A
Timber frame – internal walls	1	25% replaced
Weatherboards (fibre cement)	1	1
Weatherboards (timber)	1	N/A

*Table provides the total number of times a material is replaced for the two building types. For the non-residential building, replacement values are calculated based on data for maintenance frequency (e.g. paint) or typical service life from BRANZ Study Report SR351 and associated Excel datasheets (Module B2 and Module B4) (Dowdell et al., 2016) with some adjustments for practical reasons. For the residential building, assumptions based on Dowdell et al. (2016) and NOW Home study report are used.

For material such as concrete, aluminium, fibre cement, glass, plywood and paint, the typical service life from Dowdell et al. (2016) has been used. Adjustments were made for a number of materials as follows:

- Insulation is replaced depending on accessibility. For the non-residential case, where metal sheet or concrete roofing are applied, the typical service life is 60 years. However, where there are suspended ceilings, typical service life of insulation is 30 years. Similarly, insulation for sheet metal cladding, typical service life is 60 years. As a conservative measure, it is assumed that both buildings have one replacement of insulation during life time.

- MDF used in lining and ceilings are expected to have a typical service life of 60 years. However, this study assumes that MDF is replaced, primarily due to potential issues such as moisture resistance.
- According to Dowdell et al. (2016), profiled sheets for roofing and structural steel, have a typical service life of 60 years. For roofing, this study assumes that 50% of roofing is replaced. The warrantee period for roofing materials can be as low as 15 years.
- Timber doors, windows, partitions can have a typical service life of 60 years (Dowdell et al., 2016). However, for this study, it is assumed that 25% is replaced, with the remaining 75% being roof frame (59% not replaced) and door and windows (25% not replaced).
- Plasterboard is also assumed to be replaced once over the building life time despite it being considered as having a 60-year typical service life.
- For the residential building it is assumed that 20% of brick and 20% of concrete blocks (hollow) are replaced.

Annex B Net GHG results

The study focuses on ‘gross’ GHG emissions: i.e., GHG emissions, excluding biogenic carbon. This negates the benefits from using wood-based materials, which sequester biogenic carbon during tree growth. This annex provides results including biogenic carbon, sometimes referred to as ‘net’ GHG emissions.

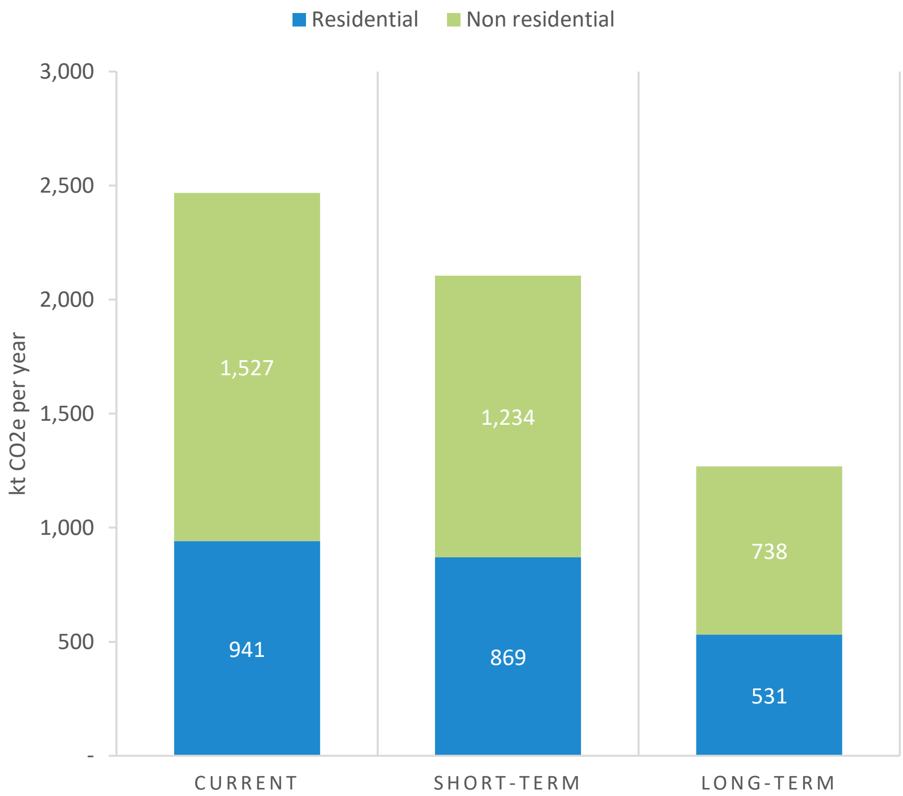


Figure 6-5: Carbon footprint comparison when short- and long-term improvements are applied (including biogenic carbon)

The carbon impact for the materials for these calculations include biogenic carbon from wood-based materials. The end-of-life stage of the building life cycle includes a portion of carbon sequestered in respective materials, with a portion (25%) released during incineration.

The total current carbon impact from the residential and non-residential builds are:

- Residential: 941 kt CO_2e per year
- Non-residential: 1,527 kt CO_2e per year

A breakdown of annual improvements is provided in Table 6-9. Overall, if improvements are made for both residential and non-residential building, a total saving of 15% GHG emissions could be made in the short -term. This increases to a total saving of 49% when including the long-term improvements. This translates to the removal of approximately 15% of the light vehicle fleet from the road with the long-term improvements.

Table 6-9: Embodied carbon footprint reductions (incl. biogenic CO_2 and CH_4)

	Current	Short-term improvements	Long-term improvements
Embodied carbon footprint (kt CO_2e)			
Residential	941	869	531
Non-residential	1,527	1,234	738
Total	2,468	2,104	1,269
Absolute reduction in embodied carbon footprint vs today (kt CO_2e)			
Residential	-	72	410
Non-residential	-	292	789
Total	-	364	1,199
Relative reduction in embodied carbon footprint vs today			
Residential	-	8%	44%
Non-residential	-	19%	52%
Total	-	15%	49%

We enable organisations to succeed sustainably.

www.thinkstep-anz.com