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Low Carbon Circular Construction

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Executive Summary

Introduction

Construction and demolition waste is responsible for up to half of waste generated in Aotearoa New Zealand. The greenhouse gas (GHG) emissions from all waste contribute approximately 4% of New Zealand's total GHG emissions. As a result, minimising waste is one of the New Zealand Government's top priorities.

Another large source of GHG emissions is buildings. They contribute up to 15% of New Zealand's total GHG emissions. Approximately half of these emissions are generated through manufacturing and disposing of building products (collectively known as 'embodied carbon'). Operating buildings accounts for the other half.

While the total amount of construction and demolition waste is significant, much of this waste is inert and does not release GHG emissions. This means that most of the embodied carbon in buildings comes from manufacturing construction products rather than disposing of them.

Moving to a low carbon circular economy

The circular economy is often seen as a potential solution to reduce waste while reducing carbon footprint. However, systems that keep materials in circulation can have a higher carbon footprint than conventional linear systems. The challenge for policymakers is to achieve both outcomes, i.e., a low carbon circular economy. Minimising construction waste is an activity that ticks both boxes.

What we did (our methodology)

We used a 'bottom-up' approach to calculate material flows and GHG emissions based on a small set of archetypal buildings. We then scaled this data to the national level using building consents for 2021.

We focused on the upfront carbon emissions generated from producing materials through to the building's practical completion. We refer below to carbon in a building's materials ('installed materials') and generated at the product's end-of-life when it becomes construction waste ('construction waste').

We calculated impacts at a:

- building level – residential and non-residential
- national level – residential and non-residential.

We used Global Warming Potential (GWP) as a measure of greenhouse gas emissions.

All findings relate to New Zealand in 2021.

Caveats

This type of approach is useful for providing indicative values at the national level. However, bottom-up approaches are highly sensitive to the data used. The small pool of archetypal buildings chosen will not fully reflect the diversity of real buildings. Further, using consents to estimate construction is an approximation and not all consented buildings will be built.

What we found

On average, around 4.2% of all materials used to build buildings are wasted.

By weight, 4.2% of materials were wasted across non-residential and residential buildings. Similarly, the embodied emissions of these materials were responsible for 4.2% of total whole-of-life embodied carbon emissions.

These wasted materials contribute 120,000 t CO_2e of GHG emissions.

Figure 1 shows that most of these emissions come from manufacturing the buildings' products (85%), rather than their disposal (15%).

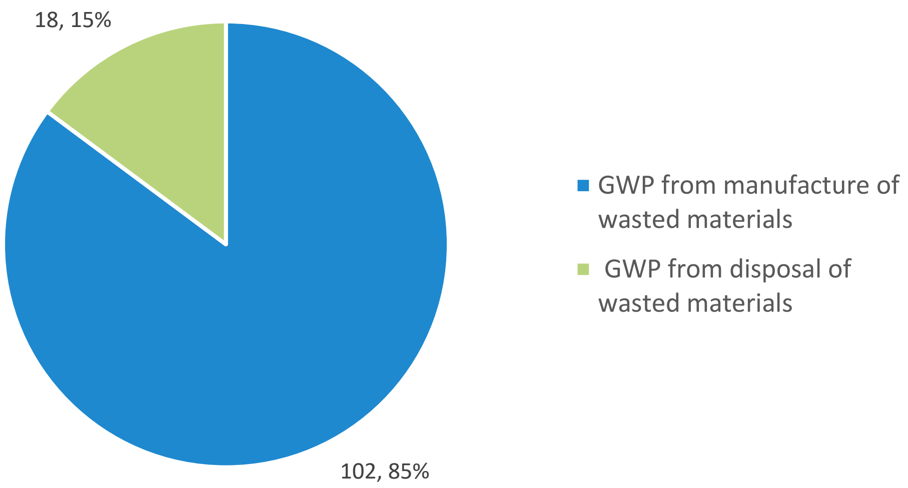

Figure 1: Proportion of construction waste GWP arising from manufacturing and disposing of materials, t CO_2e, %

Concrete, steel, plasterboard and timber are leading contributors.

Figure 2 presents the main contributors to construction waste, with mass flows in the left stacked bar and GHG emissions (measured as GWP) in the right stacked bar.

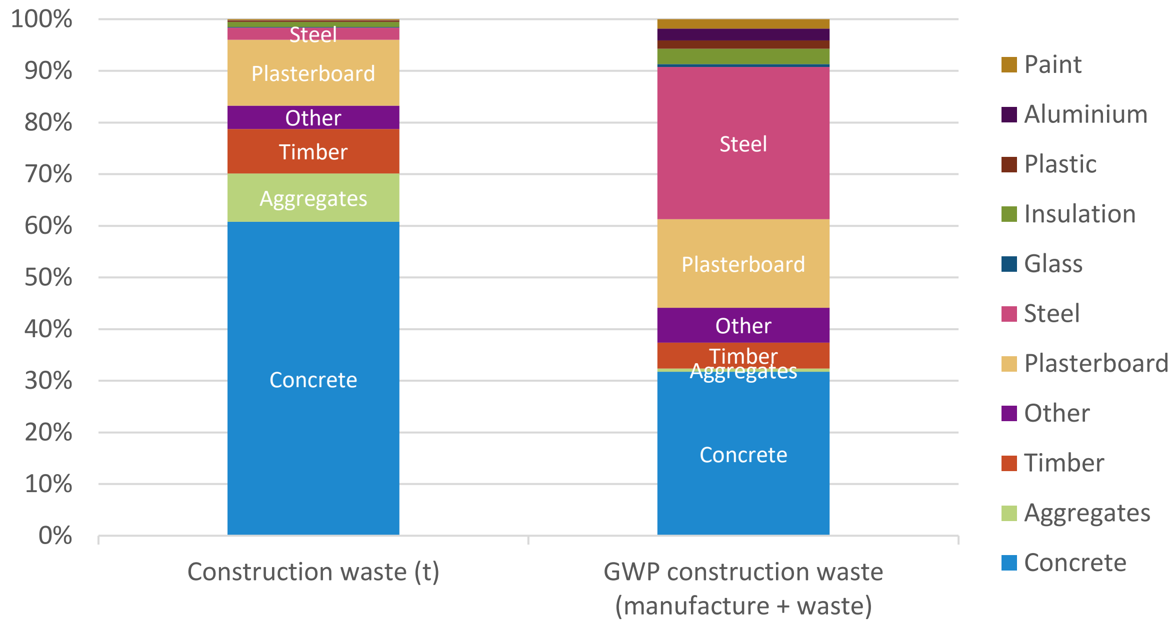

Figure 2: Breakdown of construction waste by mass (left) and GHG emissions (right)

Concrete was the largest contributor to construction waste by mass and GHG emissions. This waste is often unseen, as a significant portion returns to concrete batching plants in agitator trucks as unused wet concrete.

Other significant contributors to the GHG emissions of construction waste were steel, plasterboard and timber. Both steel and plasterboard contribute a higher share to GHG emissions than they contribute by mass of construction waste. For steel, this is due to its relatively high carbon footprint per kilogram (when compared with bulk materials like concrete and aggregates). For plasterboard, this is due to a combination of the GHG emissions of manufacturing and the GHG emissions of disposal in landfill.

What we recommend

Reducing construction waste is a win-win-win scenario:

- It contributes to a circular economy.
- It reduces the carbon footprint at the building level, by avoiding the GHG emissions associated with manufacturing and disposing of wasted materials.
- It can reduce the cost of construction by avoiding the need to pay for excess materials that are wasted and disposal fees for those wasted materials.

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1. Introduction

1.1. Background

Construction rates in Aotearoa New Zealand (NZ) have steadily increased for the last five years, peaking in 2021 with consents issued for over 49,000 residential buildings and approximately 3,111,000 m^2 of non-residential building floor area (Stats NZ, 2022).

Construction and demolition waste is estimated to represent up to 50% of all waste generated in NZ (MfE, 2022, Ch.12). The greenhouse gas (GHG) emissions from waste contributes approximately 4% of New Zealand's total emissions, though this figure covers all waste streams (MfE, 2022, Ch.15). Construction and demolition waste is responsible for up to half of waste generated in New Zealand (MfE, 2022, Ch.12). As a result, minimising this source of waste is one of the New Zealand Government's key targets, alongside reducing gross greenhouse gas emissions (MfE, 2022, Ch.15). Construction waste is a focus for NZ's Ministry for the Environment (MfE), with the Waste Minimisation Fund setting construction and demolition waste reduction as a key investment target.

The impacts buildings and construction have on national GHG emissions is becoming better understood. In 2018, thinkstep-anz published a report demonstrating that the built environment (buildings and infrastructure) contributes approximately 20% to NZ's carbon footprint on a consumption basis (thinkstep-anz, 2018). Approximately half of these emissions were generated through the manufacture and disposal of building products (collectively known as 'embodied carbon'), with the other half being emissions from operating buildings. Subsequent work by thinkstep-anz has shown the contribution from buildings alone (excluding infrastructure) is 15%, as illustrated in New Zealand's *Emissions Reduction Plan* (NZ Government, 2022, Figure 12.1). Most of these embodied emissions are due to the production of building products rather than their disposal.

The circular economy is tipped as a solution to national and global waste problems through its aim to keep materials in circulation. However, there is more to the circular economy than recycling, energy recovery and composting. The embodied carbon emissions within materials should be considered as well, where waste not only means a physical resource lost but also the loss of embodied carbon emissions associated with that material.

1.2. Purpose

This report aims to quantify the GHG emissions of New Zealand's construction waste, including both manufacture and disposal.

1.3. What is the Circular Economy?

The circular economy refers to systems that keep products and materials in circulation at their highest value, aiming to eliminate waste and pollution and to regenerate nature (Ellen MacArthur Foundation, 2022). Rather than relying solely to downstream activities, such as recycling, a circular economy tries to prevent waste and pollution from being created in the first place. This can occur through smarter design and manufacture methods, improved business models and increasing the lifespan of products and materials.

1.4. 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).

This report focuses on the upfront carbon footprint only. Upfront carbon is a partial carbon footprint that includes all activities until practical completion of the building. It includes the following life cycle modules from standards EN 15978:2011, EN 15804+A2:2019 and ISO 21931-1:2022 (see Figure 1-1):

- Manufacture of building products (modules A1-A3).
- Transport of building products to the construction site (module A4).
- Construction of the building, including disposal of building products and the GHG emissions from construction machinery (module A5).

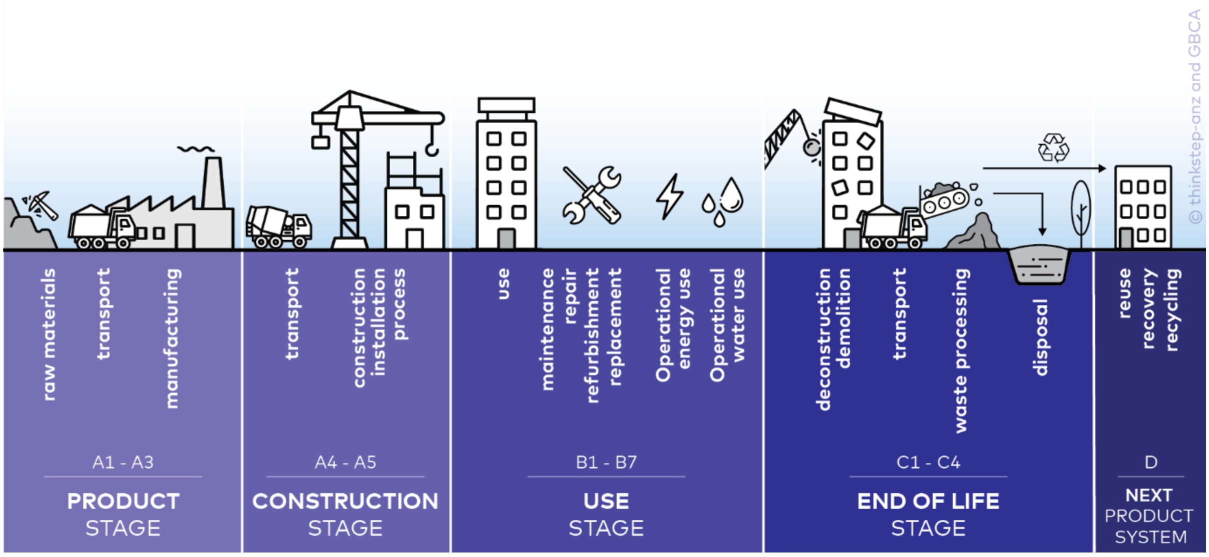

Figure 1-1: Life cycle modules (following EN 15978 and EN 15804)

Embodied carbon data for various materials is readily available in Environmental Product Declarations (EPDs), the BRANZ CO_2NSTRUCT database (BRANZ, 2021), and life cycle inventory databases, such as Sphera's GaBi Database (Sphera, 2022).

Table 1-1 shows the life cycle stages included in this report. The primary focus of this report is the impact of material wasted during new-build construction, which is included within the construction process stage (module A5). 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).

Table 1-1: Life cycle stages included in the scope of this study
(✓ = included in scope; ✗ = 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
✓	✓	✓	✓	✓	✗	✗	✗	✗	✗	✗	✗	✗	✗	✗	✗	✗

1.4.1. Biogenic Carbon

Biogenic carbon is the removal of carbon dioxide from the atmosphere through photosynthesis and the associated emissions of GHGs from biogenic sources, such as wood. This report does not consider long-term sequestration of biogenic carbon in buildings given that its focus is on upfront carbon – a partial carbon footprint under ISO 14067:2018.

Biogenic carbon is treated as follows in this study:

- Uptake of biogenic carbon has been excluded in modules A1-A3 and A5.
- Releases of biogenic carbon from landfill in module A5 have been included. This has been done to capture releases of biogenic carbon that are not carbon neutral, specifically where methane is produced in landfill.
- All other emissions of biogenic carbon have been excluded as these are typically carbon neutral (i.e., the sequestration of CO_2 during plant growth in module A5 is cancelled out by the release of CO_2 at end-of-life, e.g., through incineration).

1.5. Towards A Low-Carbon Circular Economy

Some types of products have a low carbon footprint but do not contribute to the circular economy. Other types of products can be highly circular but have a high carbon footprint. In the former category are many lightweight products that are difficult to reuse or recycle. In the latter category are many heavyweight products whose manufacture has a higher carbon footprint and whose recovery and reprocessing can also have a significant carbon footprint. The challenge for policymakers is how to incentivise the creation of systems that are both low carbon and circular, as shown in the Venn diagram in Figure 1-2.

This report will show that the most effective way to reduce GHG emissions in the built environment is through upstream, or 'top-of-the-cliff' activities, in the manufacture/production and construction phases, rather than relying on downstream, or 'bottom-of-the-cliff' activities, such as recycling, energy recovery, and composting.

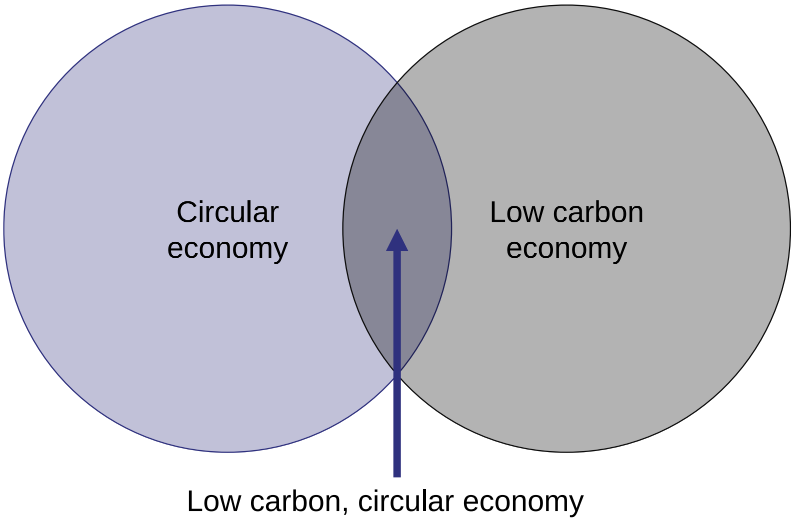

Figure 1-2: Towards a low-carbon circular economy

2. Analysis

2.1. Method

This report uses a bottom-up approach to quantify the GHG emissions from construction waste in New Zealand in 2021.

We calculated the carbon footprint of wasted construction materials as follows:

- Estimate total national construction waste per material type:
- Take material quantities from three archetypal buildings: a standalone residential house, a multi-storey building and a warehouse-type building.
- Normalise these material quantities to 1 square metre of gross floor area per building type.
- Classify national building consent statistics for 2021 into these three archetypal building categories.
- **Calculate 'installed materials'** by multiplying the material quantities per square metre per building type by the total floor area consented per building type in 2021.
- **Calculate 'construction waste'** by multiplying 'installed materials' by typical waste fractions per material type.
- Multiply the 'construction waste' quantity per building product by:
  - The carbon footprint of manufacturing that product (modules A1-A3), and
  - The carbon footprint of waste treatment (modules C1-C4).

We used several different sources of information, as described in Table 2-1.

Table 2-1: Information used in report to quantify impacts of construction waste

Section detailed in	Information required	Source of information used in this report
Buildings in New Zealand in 2021	Construction rate in identified period (2021)	Building Statistics (Stats NZ, 2022)
Archetypal Buildings	Representative building composition by material type	LCA case studies and thinkstep-anz calculations (Beacon, 2010; Durlinger, et al., 2013; thinkstep-anz, 2019)
Buildings in New Zealand in 2021	Construction waste rates	BRANZ's construction waste rates and method of disposal (landfill, reuse, recycling) (BRANZ, 2021)
Archetypal Buildings	Carbon footprint (GWP) of typical building elements and waste	EPDs and thinkstep-anz calculations

For material/product impact data sources, published EPDs that were geographically specific to New Zealand were prioritised. Where such EPDs were unavailable, material impacts were either modelled using GaBi or derived from EPDs with geographical scopes other than New Zealand (in the case of plywood).

2.1.1. Limitations

We acknowledge that this approach is a simplification. It has several limitations:

- Scaling up a small number of archetypal buildings and material carbon footprints to the national level will not represent the full diversity of buildings constructed and building products used to construct them. This means that some building products will be underrepresented, while others will be overrepresented.
- Construction waste fractions may not adequately reflect average performance in New Zealand in 2021.
- Just because a building is consented in 2021 doesn't mean it will be built in 2021, or even built at all.

A top-down approach that uses national material flows and carbon flows would be less susceptible to these limitations. However, top-down approaches are difficult in New Zealand due to a lack of national statistics for the manufacture of building products (except concrete) and construction waste (as separate to demolition waste). However, previous work (thinkstep-anz, 2019) has shown that the two approaches are well enough aligned for the purpose of this study.

2.2. Buildings in New Zealand in 2021

2.2.1. Construction Rates

New Zealand's construction rates in the calendar year 2021 were the highest recorded, with building consents totalling NZ$29,620 million (Stats NZ, 2022). By value, residential buildings were responsible for approximately 72% of buildings consented in 2021.

We used the floor area of building types consented during 2021 for the calculation of impacts of construction waste. We broke these figures into two broad categories:

a) Residential buildings, which had 7,536,000 m^2 of floor area consented.
b) Non-residential buildings, which had 3,111,000 m^2 of floor area consented.

The latest National Construction Pipeline Report (MBIE, 2022) projects that these rates will stabilise over the next five years, with residential consents expected to decrease from approximately 49,000 in 2021 to an average of 37,000 per annum until 2027. Non-residential activity is expected to peak in 2023, followed by decreasing until 2027. This report refers only to the consents issued in 2021.

2.2.2. Construction Waste

Waste occurring during module A5 (construction) of a building's life cycle is the primary focus of this report. Data from BRANZ was used for the construction waste percentage for each material type (e.g., plasterboard), along with the end-of-life treatment of materials (i.e., percentage of material that was reused, recycled or landfilled) (BRANZ, 2021). The specific data used is shown in Table 2-2.

The GHG emissions from material production and disposal were modelled primarily from EPDs. Where New Zealand-specific materials EPDs were unavailable, the GHG emissions profile of construction waste was assumed to be the same as what the end-of-life of the building would be (i.e., percentage recycled/reused/landfilled). The construction waste figures for non-EPD source data are derived from *Under Construction* (thinkstep-anz, 2019).

Table 2-2: Waste rates for common material types used in New Zealand construction

Material	Construction waste %	% of construction waste reused	% of construction waste recycled	% of construction waste landfilled
Aluminium	1%	0%	95%	5%
Bitumen	5%	0%	0%	100%
Brick	5%	90%	0%	10%
Building paper	10%	0%	0%	100%
Carpet	10%	0%	0%	100%
Ceramic	10%	0%	0%	100%
Clay	5%	90%	0%	10%
CLT	5%	0%	25%	75%
Concrete (all strengths)	4%	0%	10%	90%
Copper	1%	0%	95%	5%
Cork	10%	0%	0%	100%
Fibre cement	18%	25%	0%	75%
Glass	1%	0%	0%	100%
Glulam	5%	0%	25%	75%
Gravel	2%	95%	0%	5%
Hebel	4%	90%	0%	10%
Insulation	15%	0%	0%	100%
LVL	5%	0%	25%	75%
MDF	10%	0%	25%	75%
Mortar	5%	0%	0%	100%
Paint	10%	0%	0%	100%
Particleboard	10%	0%	25%	75%
Plasterboard	23%	0%	10%	90%
Polycarbonate	5%	0%	0%	100%
Plywood	10%	0%	25%	75%
Polyethylene	5%	0%	0%	100%
Polypropylene	10%	0%	0%	100%
Polystyrene	5%	0%	0%	100%
PVC	5%	0%	0%	100%

Material	Construction waste %	% of construction waste reused	% of construction waste recycled	% of construction waste landfilled
Rubber	10%	0%	0%	100%
Sand	2%	95%	0%	5%
Steel cladding	1%	0%	95%	5%
Steel (galv)	1%	0%	95%	5%
Steel roofing (NZ)	1%	0%	95%	5%
Steel wire (NZ)	5%	5%	95%	0%
Steel reinforcing bar (NZ)	5%	0%	95%	5%
Timber	10%	0%	75%	25%
Uniroll	10%	0%	0%	100%
Vinyl	5%	0%	0%	100%
Weatherboard	5%	0%	25%	75%

2.3. Archetypal Buildings

This report categories buildings into three broad archetypes:

- Residential buildings (specifically detached residential buildings).
- Multi-storey buildings.
- Warehouse-type buildings.

Using only three building archetypes is a significant simplification of reality. However, this choice was made to try to reflect the most significant differences in material composition per building type.

2.3.1. Residential Buildings

Residential buildings were modelled on the Waitakere NOW Home® (Beacon, 2010). This is a single storey, three-bedroom home with garage and a gross floor area of 146 m^2. The composition of this house was adjusted to reflect the standalone home market in New Zealand using the same approach as in our *Under Construction* report (thinkstep-anz, 2019).

The average floor area for standalone homes in New Zealand in 2019 was 182 m^2, based on building consents issued in that year (Stats NZ, 2022). It was 96 m^2 for attached homes like apartments. The median floor area across all home types was 148 m^2.

2.3.2. Non-residential Buildings

We used two categories of non-residential buildings to quantify the impacts of non-residential construction: multi-storey and warehouse-type. The archetypal multi-storey building used in calculations was a concrete mid-rise building (John, et al., 2009). The archetypal warehouse-type building was a steel portal-framed building on a concrete slab (thinkstep-anz, 2019).

Stats NZ provides dollars of construction per category, but not square metres per category (Stats NZ, 2022). The split between multi-storey and warehouse-type buildings follows the same approach as our previous *Under Construction* report (thinkstep-anz, 2019):

- It was estimated that multi-storey buildings contribute 47% to total non-residential floor area consented (M. Curtis, pers. comm., 12 August 2019). Multi-storey buildings were used to represent the following Stats NZ subcategories:
    - “Hostels, boarding houses, prisons”
    - "Hotels, motels, and other short-term accommodation"
    - "Hospitals, nursing homes, health"
    - “Education buildings”
    - “Social, cultural, and religious buildings”
    - “Medium/high density residential construction” (i.e., apartments)
    - “Shops, restaurants, and bars”
    - “Offices, administration, public transport”.
- It was estimated that warehouse-type buildings contribute 53% to total non-residential floor area consented (M. Curtis, pers. comm., 12 August 2019). Low-rise buildings were used to represent the following Stats NZ subcategories:
    - “Storage buildings”
    - “Factories”
    - “Farms”.

3. Material and Carbon Flows

The material and carbon flows of the construction waste of different materials in buildings (non-residential and residential combined) consented in 2021 are displayed in Figure 3-1.

Concrete was the largest contributor to construction waste by mass and GHG emissions. This waste is often unseen as a significant portion returns to concrete batching plants in agitator trucks as unused wet concrete (where it may be rinsed out, poured on the ground and later crushed, or poured into precast concrete moulds).

Other significant contributors to the GHG emissions of construction waste were steel, plasterboard and timber. Timber contributes a lower share to GHG emissions than its mass share as construction waste. Both steel and plasterboard contribute a higher share to GHG emissions than their mass share of construction waste. For plasterboard, this is due to a combination the GHG emissions of manufacture and the GHG emissions of disposal in landfill (as assumed in this study). For steel, this is due to its relatively high carbon footprint of manufacture per kilogram when compared with bulk materials like concrete and aggregates. (As this study focuses on upfront carbon only, avoided emissions from recycling of steel at end-of-life – which fall under module D – are not considered.) The representation of steel in the GWP of construction waste is largely due to the relatively high construction waste rate for steel reinforcing bar and mesh (5%) applied in BRANZ's *Module A5 Construction Site Waste Datasheet* (BRANZ, 2021).

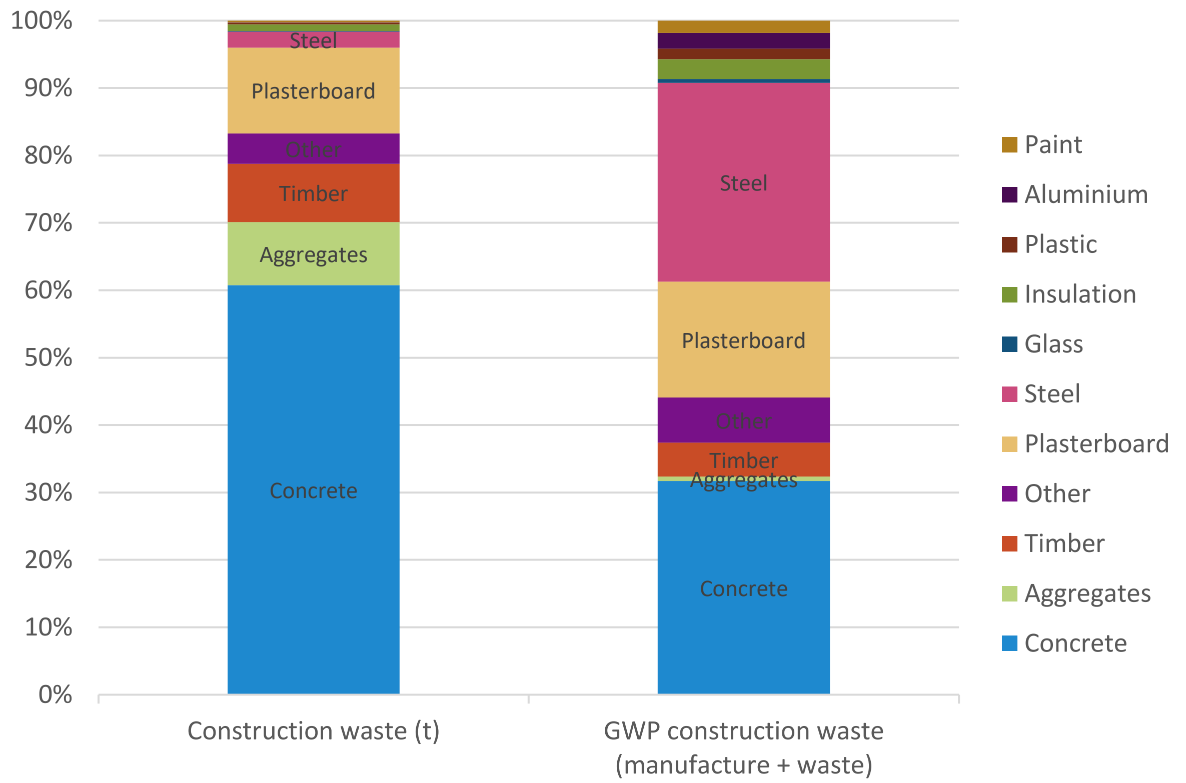

Figure 3-1: Material and carbon impacts of materials in buildings consented in New Zealand in 2021

The impact construction waste has in comparison to the impact manufacturing is often overlooked. As displayed in Figure 3-2, the GHG emissions generated during the manufacture of wasted construction materials was approximately 102 kt CO_2e; in comparison, the GHG emissions from waste disposal were only 18 kt CO_2e.

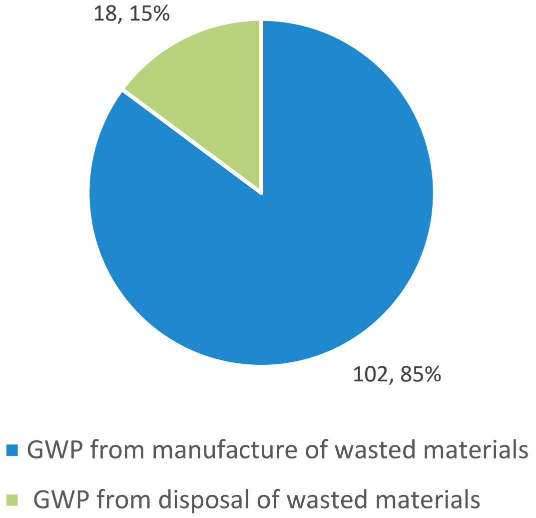

Figure 3-2: GWP generated during manufacture of building materials consumed in building consents in NZ in 2021, compared to GWP arising from disposal of those materials, kt CO_2e, %

3.1. Material Use and Carbon Emissions at the Building Level

3.1.1. Residential Buildings

Using the Waitakere NOW Home® (Beacon, 2010) as a reference point, the quantities of materials were scaled linearly to reflect the average residential standalone dwelling (i.e., 146 m^2 scaled up to 182 m^2). Using this representative building, we calculated the material impact and greenhouse gas emissions. In summary:

- **4.3% of the total material used in the building was wasted.** The total quantity of building materials used (installed and wasted) in a representative residential building is 133,000 kg, of which 5,730 kg was estimated as being wasted.
- **4.4% of the total embodied GHG emissions of products used in the building arose from wasted materials.** The total embodied GHG emissions of products used (installed and wasted) in a residential building is calculated as 35,900 kg CO2e, of which wasted materials were responsible for 1,660 kg CO2e.
- **Concrete was the most wasted material by weight.** 2,570 kg of concrete was wasted. Plasterboard (1,050 kg), timber (704 kg), and gravel (635 kg) were other materials with high levels of waste.

Note that all figures above have been rounded to either two or three significant figures.

A material breakdown is shown in Table 3-1.

Table 3-1: Material and carbon flows in an average 182 m^2 residential building

Material	Materials installed (kg)	Construction waste (kg)	Installed materials GWP (kg CO_2e)	Construction waste GWP (kg CO_2e)
Aluminium	239	2	1,336	13
Brick	3,488	174	887	44
Building paper	71	7	15	1
Carpet	108	11	254	25
Ceramic	181	18	50	5
Clay	166	8	42	2
Concrete	64,160	2,566	11,342	454
Copper	30	0	111	1
Fibre cement	704	127	417	75
Glass	743	7	829	8
Glulam	101	5	37	2
Gravel	31,759	635	620	12
Insulation	551	83	539	81
Paint	206	21	511	51
Particleboard	57	6	60	6
Plasterboard	4,550	1,047	2,003	461
Polycarbonate	9	0	37	2
Polyethylene	351	18	735	37
Polypropylene	10	1	19	2
Polystyrene	26	1	60	3
PVC	2	0	6	0
Sand	9,517	190	212	4
Steel (galv)	205	2	1,093	11
Steel cladding	13	0	71	1
Steel roofing (NZ)	1,577	16	8,412	84
Steel wire (NZ)	682	34	2,670	134
Timber	7,039	704	989	99
Vinyl	1	0	1	0
Weatherboard	957	48	875	44
Total	**127,504**	**5,732**	**34,232**	**1,663**

3.1.2. Non-residential Buildings

We calculated the material impact and GHG emissions for a weighted average non-residential building (refer to section 2.3.2 for methodology) of 2526 m^2. In summary:

- **4.0% of the total material used in the building was wasted.** The total quantity of building materials used (installed and wasted) in a weighted average representative non-residential building is 3,180,000 kg, of which 128,000 kg was estimated as being wasted.
- **3.4% of the total embodied GHG emissions of products used in the building arose from wasted materials.** The total embodied GHG emissions of products used (installed and wasted) in a residential building is calculated as 1,330,000 kg CO_2e, of which wasted materials were responsible for 45,200 kg CO_2e.
- **Concrete was the most wasted material by weight.** 115,000 kg of concrete was wasted. Steel (4,520 kg), plasterboard (4,380 kg), and fibre cement board (3,080 kg) were other materials with high levels of waste.

Note that all figures above have been rounded to either two or three significant figures.

A material breakdown is shown in Table 3-2.

Table 3-2: Materials used and wasted in a weighted average non-residential building of 2526 m^2

Material	Material installed (kg)	Construction waste (kg)	GWP of installed materials (kg CO_2e)	GWP of construction waste (kg CO_2e)
Aluminium	16,104	161	292,981	2,930
Concrete (other strengths)	2,159,650	86,386	381,777	15,271
Concrete, 17.5MPa	28,670	1,147	3,048	122
Concrete, 40MPa	675,290	27,012	100,553	4,022
Fibre cement	17,103	3,079	10,123	1,822
Glass	23,305	233	40,563	406
Insulation	1,610	242	1,575	236
MDF	940	94	19	2
Paint	344	34	854	85
Plasterboard	19,036	4,378	7,929	1,824
Plywood	1,922	192	2,038	204
Polystyrene	1,086	54	2,469	123
Steel (galv)	8,085	81	43,115	431
Steel roofing (NZ)	10,144	101	54,096	541
Steel wire (NZ)	58,013	2,901	227,005	11,350
Steel rebar (NZ)	28,711	1,436	114,355	5,718
Timber	5,557	556	781	78
Total	**3,055,570**	**128,086**	**1,283,281**	**45,165**

Where multi-storey buildings contribute 47% and warehouse-type buildings contribute 53% to the weighted average non-residential building.

3.2. Material and Carbon Flows at National Level

We used a bottom-up approach to estimate national-level material quantities and impacts. This was achieved by combining:

- Material and carbon flows from single-building analyses
- Gross floor area data for archetypal buildings
- Build rate data

We calculated total material flows at the national level 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.

For residential buildings, the square metre material usage rate was multiplied by the number of new dwellings consented and then multiplied by the average dwelling gross floor area.

For non-residential buildings, the square metre material usage rate for each subcategory (high- and low-rise) was multiplied by the total non-residential buildings floor area and then multiplied by the proportion of value that could be attributed to the respective building subcategory.

This bottom-up approach is sensitive to the buildings that are selected to be scaled up from. The other common method to conduct national level analyses – top-down – have previously been found to be in the same order of magnitude as bottom-up calculations of building material consumption, although bottom-up calculations are expected to be on the low side (Gamage, et al., 2019). Therefore, the calculations of emissions associated with construction waste are likely to underestimate impacts and actual emissions.

The relative material and carbon impacts vary among different materials. For example, concrete is responsible for 44.8% of residential construction waste by weight. However, concrete construction waste is responsible for 27.3% of emissions generated by residential construction waste. In contrast, plasterboard construction waste is responsible for 18.3% of residential construction waste by weight, but approximately 27.7% of the carbon emissions generated by wasted materials. This is due to a variety of reasons, including:

- Disposal methods of materials: some materials have greater recovery, reuse, and recycling rates when compared to others, leading to differences in the amount of emissions generated during the end-of-life treatment of materials.
- The organic (biogenic) content of materials: when organic material enters landfill, GHG emissions are released. Unless landfill gas capture is fitted, a significant amount of methane – a potent greenhouse gas – can be released.

The total whole-of-life embodied carbon emissions of non-residential construction in 2021 were higher than those of residential construction. A breakdown of the emissions generated by installed products in residential and non-residential construction compared to wasted materials is displayed in Figure 3-3.

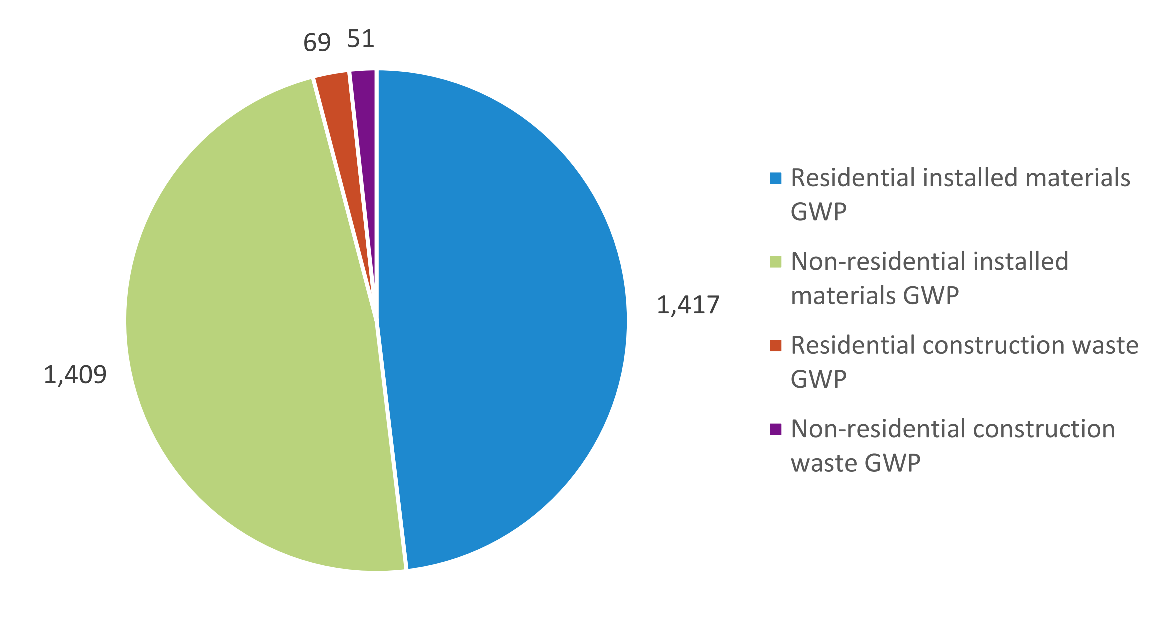

Figure 3-3: Upfront carbon emissions of buildings consented (installed materials and construction waste) in 2021, kt CO_2e

3.2.1. Residential Buildings

The national level material quantities and impacts associated with residential buildings are shown in Table 3-3. In summary:

- We used the total floor area of residential building consents in combination with material per square metre rates to calculate the impacts associated with residential construction in 2021.
- **By weight, concrete was the most wasted building material.** 106,000 tonnes of concrete was wasted in the construction of residential buildings. Plasterboard (43,300 tonnes), timber (29,100 tonnes), and gravel (26,300 tonnes) were other major contributors to waste.
- **The GWP of installed materials was dominated by steel** (including roofing, cladding, wire and other galvanised products). Installed steel generated 507,055 t CO_2e across its life cycle. Concrete (469,635 t CO_2e) and timber (including weatherboard, timber, and glulam, approximately 82,935 t CO_2e) were other large contributing materials.
- **The GWP of wasted construction materials was dominated by plasterboard and concrete.** 19,100 t CO_2e of plasterboard and 18,800 t CO_2e of concrete could be attributed to construction waste. Steel (including roofing, cladding, wire and other galvanised products) was another large contributing material (9,490 t CO_2e).

Further detail is provided in Table 3-3.

Table 3-3: National material quantities and carbon footprint of residential buildings in 2021

Building material	Building material installed (t)	Construction waste (t)	GWP of installed material (t CO_2e)	GWP of construction waste (t CO_2e)
Concrete	2.66E+06	1.06E+05	4.70E+05	1.88E+04
Steel roofing (NZ)	6.53E+04	6.53E+02	3.48E+05	3.48E+03
Steel wire (NZ)	2.83E+04	1.41E+03	1.11E+05	5.53E+03
Plasterboard	1.88E+05	4.33E+04	8.29E+04	1.91E+04
Aluminium	9.91E+03	9.91E+01	5.53E+04	5.53E+02
Steel (galv)	8.48E+03	8.48E+01	4.52E+04	4.52E+02
Timber	2.91E+05	2.91E+04	4.09E+04	4.09E+03
Brick	1.44E+05	7.22E+03	3.67E+04	1.84E+03
Weatherboard	3.96E+04	1.98E+03	3.62E+04	1.81E+03
Glass	3.08E+04	3.08E+02	3.43E+04	3.43E+02
Polyethylene	1.46E+04	7.28E+02	3.04E+04	1.52E+03
Gravel	1.32E+06	2.63E+04	2.57E+04	5.13E+02
Insulation	2.28E+04	3.42E+03	2.23E+04	3.35E+03
Paint	8.52E+03	8.52E+02	2.11E+04	2.11E+03
Fibre cement	2.91E+04	5.25E+03	1.72E+04	3.10E+03
Carpet	4.47E+03	4.47E+02	1.05E+04	1.05E+03
Sand	3.94E+05	7.88E+03	8.78E+03	1.76E+02
Copper	1.24E+03	1.24E+01	4.62E+03	4.62E+01
Steel cladding	5.51E+02	5.51E+00	2.94E+03	2.94E+01
Polystyrene	1.09E+03	5.47E+01	2.49E+03	1.24E+02
Particleboard	2.35E+03	2.35E+02	2.48E+03	2.48E+02
Ceramic	7.48E+03	7.48E+02	2.07E+03	2.07E+02
Clay	6.88E+03	3.44E+02	1.75E+03	8.75E+01
Glulam	4.18E+03	2.09E+02	1.53E+03	7.67E+01
Polycarbonate	3.61E+02	1.81E+01	1.52E+03	7.59E+01
Polypropylene	4.13E+02	4.13E+01	7.69E+02	7.69E+01
Building paper	2.94E+03	2.94E+02	6.13E+02	6.13E+01
PVC	1.03E+02	5.16E+00	2.54E+02	1.27E+01
Vinyl	2.12E+01	1.06E+00	3.93E+01	1.97E+00
Total	**5.28E+06**	**2.37E+05**	**1.42E+06**	**6.88E+04**

3.2.2. Non-residential Buildings

The national level material quantities and impacts associated with residential buildings are shown in Table 3-4. This table combines multi-storey and warehouse-type building data to demonstrate the total impacts from non-residential construction.

For the building subcategories weighted average methodology (i.e., high-rise buildings and warehouse-type buildings), refer to Section 2.3.2 Non-residential Buildings.

In summary:

- **By weight, concrete was the most wasted building material.** 118,000 tonnes of concrete (across all strength categories) were wasted in the construction of non-residential buildings. Steel, including roofing, cladding, wire and other galvanised products (6,430 tonnes), plasterboard (3,640 tonnes) and fibre cement board (2,260 tonnes) were other major contributors to waste.
- **The GWP associated with the manufacture of installed materials was dominated by steel.** Steel was responsible for 651,000 t CO_2e of GHG emissions. Concrete (all strength categories, 482,000 t CO_2e) and aluminium (222,000 t CO_2e) were other large contributing materials to the total GWP of installed materials in non-residential buildings.
- **The GWP of wasted construction materials was dominated by steel**, including reinforcing bar, roofing, wire and other galvanised products. Steel wasted during construction was responsible for 25,800 t CO_2e of embodied emissions. Other large contributing materials included concrete (including all strength categories, 17,200 t CO_2e) and aluminium (2,220 t CO_2e).

Table 3-4: National material quantities and carbon footprint of non-residential buildings in 2021

Building material	Building material installed (t)	Construction waste (t)	GWP of installed material (t CO_2e)	GWP of construction waste (t CO_2e)
Aluminium	1.22E+04	1.22E+02	2.22E+05	2.22E+03
Concrete	1.58E+06	6.33E+04	2.80E+05	1.12E+04
Concrete, 17.5MPa	2.10E+04	8.40E+02	2.23E+03	8.93E+01
Concrete, 40MPa	1.34E+06	5.37E+04	2.00E+05	7.99E+03
Fibre cement	1.25E+04	2.26E+03	7.42E+03	1.33E+03
Glass	1.99E+04	1.99E+02	3.47E+04	3.47E+02
Insulation	1.32E+03	1.98E+02	1.29E+03	1.94E+02
MDF	6.89E+02	6.89E+01	1.37E+01	1.37E+00
Paint	2.99E+02	2.99E+01	7.43E+02	7.43E+01
Plasterboard	1.58E+04	3.64E+03	6.59E+03	1.51E+03
Plywood	1.41E+03	1.41E+02	1.49E+03	1.49E+02
Polystyrene	7.95E+02	3.98E+01	1.81E+03	9.04E+01
Steel (galv)	6.60E+03	6.60E+01	3.52E+04	3.52E+02
Steel reinforcing bar (NZ)	6.98E+04	3.49E+03	2.78E+05	1.39E+04
Steel roofing (NZ)	2.47E+04	2.47E+02	1.32E+05	1.32E+03
Steel wire (NZ)	5.26E+04	2.63E+03	2.06E+05	1.03E+04
Timber	4.36E+03	4.36E+02	6.12E+02	6.12E+01
Total	**3.17E+06**	**1.31E+05**	**1.41E+06**	**5.11E+04**

Where multi-storey buildings contribute 47% and warehouse-type buildings contribute 53% to the weighted average non-residential building.

4. Case Study – Winstone Wallboards

The Challenge

As the country's only manufacturer of gypsum plasterboard, under the GIB® brand, Winstone Wallboards (WWB) has a responsibility to reduce carbon in the built environment.

Reducing the company's carbon emissions cuts down emissions in thousands of residential, commercial and industrial buildings across the country too. Circular economy thinking is helping WWB reduce this source of emissions: **construction waste**.[1]

Identifying Carbon 'Hotspots' in the Plasterboard Life Cycle

WWB's Designing out Waste programme[2] looks at how the business designs its product and transports it to its customers, and how its customers use and dispose of product on site. Our thinkstep-anz team helped WWB identify five 'hotspots' of greenhouse gas emissions (GHGs) for construction waste.

These hotspots are shown in Figure 4-1 and Table 4-1.

Figure 4-1: Hotspots of greenhouse gas emissions

[1] Demolition waste at the end of a building's life is a source of emissions too. This case study focuses on construction waste only.

[2] Supported by Ministry for the Environment, Canterbury Joint Waste Committee, Auckland Council, WasteMINZ, AUT and BRANZ.

Table 4-1: Hotspots of greenhouse gas emissions

Stage of life cycle	Hotspot
Manufacturing	1. Making the plasterboard 2. Disposing of manufacturing waste
Sales	3. Specifiers estimating the amount of plasterboard needed for a build 4. Customers signing contracts to build
Use and disposal	5. Customers using plasterboard and disposing of construction waste to landfill

Embodied Carbon

The emissions these activities release are examples of ‘embodied carbon’ in building products. Embodied carbon includes emissions from sourcing materials, making and distributing products, and using and disposing of them. One factor links these five carbon hotspots: waste.

So WWB set itself a challenge. The company wanted to reduce plasterboard wasted in construction across New Zealand by 30% without changing the design of its product.

Using the Circular Economy to Tackle Carbon Hotspots

Example 1: Using and Disposing of the Plasterboard

On an average residential building site, around 23% of all materials, including 700kg of plasterboard waste, end up in a skip bound for landfill.[3] Much of this waste is created when builders cut down sheets of plasterboard. Even when things go to plan, this results in waste: they cannot typically reuse the offcuts. Add in mistakes such as cutting a board to the wrong size or damaging it during storage and the waste ratchets up fast.

Circular economy strategy: product application, sales and logistics processes

In a circular economy, sending construction waste to landfill is a 'leakage' from the product's 'system' (the processes involved in converting inputs to outputs). To reduce this leakage WWB offers a wide range of plasterboard lengths and widths. Customers can order custom sizes if they buy 100 boards or more. This means they can use a size that is most efficient for their project and reduce or eliminates offcuts.

WWB is also pushing for changes across the industry. These include:

- clauses in construction contracts to focus project teams on minimising waste
- encouraging modular design based on material sizes
- supporting 'materials logistics plans' so that builders receive the right amount of materials at the right time. This reduces the risk of mislaying product, over-ordering, and damaging plasterboard stored on site.

The result

- Fewer plasterboard offcuts, fewer mistakes, less damage
- Less plasterboard construction waste going to landfill
- Fewer greenhouse gas emissions. While the gypsum in plasterboard is inert in landfill (it does not release greenhouse gases), paper and starch do.

3 Wastage Rate Report (Construction Resources and Waste Platform), REBRI – BRANZ

Example 2: Reducing Average Emissions at the Manufacturing Stage

High rates of construction waste mean building projects often use more plasterboard than they need to.

Circular economy strategy: recovering value

There is a virtuous circle at play. As the industry reduces the amount of plasterboard it wastes, WWB reduces the volume of plasterboard it needs to make and transport to create the same buildings.

For example, if 100 boards are needed to build the average house and 20% end up in landfill, a customer needs to order 125 boards to complete their build. If the waste rate falls from 20% to 10%, the customer can complete the project with 112 boards, saving 13. This allows Aotearoa New Zealand to construct more buildings from the same amount of plasterboard.

The result

- Fewer carbon emissions generated to support the same amount of building activity
- WWB adapts production processes and offers customers value with ‘make to order’ plasterboard. These activities help maintain market position and reduce waste.

Example 3: Disposing of Plasterboard Waste at the Manufacturing Stage

The manufacturing process creates waste, including gypsum.

Circular economy strategy: recovering value

Gypsum releases sulphur and calcium. This improves soil structure and helps the soil retain air and moisture.

With these benefits in mind, WWB wanted to give its waste gypsum a ‘second life’. It is now working with partners in Auckland, Bay of Plenty, Waikato, Nelson, Canterbury and Central Otago to recycle manufacturing and plasterboard site waste for agricultural and horticultural uses. The company wants to make this service as widely available as possible.

The result

WWB is contributing to a circular, biological system. Instead of going to landfill, the gypsum supports New Zealand’s land-based industries.

How WWB's Business is Benefiting

Circular economy thinking is helping WWB:

- **Reduce its carbon emissions.** These emissions include:
  - Scope 1 emissions: the natural gas the business uses to dry plasterboard and the LPG it uses to operate forklifts
  - Scope 2 emissions: the electricity it buys
  - Scope 3: the raw materials it buys, such as paper and gypsum, and the plasterboard customers buy to construct their buildings
- **Reduce its costs.** The company pays less to dispose of its waste.
- **Reduce its risks.** WWB is anticipating changes in government policy and acting now to reduce waste.
- **Build brand value and loyalty.** WWB customers can make their plasterboard go further, spend less to dispose of their waste, and 'buy more responsibly'.
- **Build resilience in the industry.** Reducing waste increases WWB's capacity to meet its customers' demand.
- **Keep investors happy.** This programme is helping WWB meet its ESG (environmental, social and governance) targets.
- **Attract and retain employees.** The WWB team values being part of a business that is working to 'do the right thing'.

Looking Ahead – Extending Circular Economy

WWB will open its new plant in Tauriko, Tauranga in 2023. Once this plant is operating, the company will be able to recycle waste plasterboard into new plasterboard. This is an example of a circular technical system.

5. Conclusions

This study identified that, in 2021, residential buildings contributed 1,490,000 t CO_2e of upfront GHG emissions, of which 68,800 t CO_2e could be attributed to construction waste. Non-residential buildings contributed 1,460,000 t CO_2e in 2021 but had lower waste rates, with approximately 51,100 t CO_2e attributable to construction waste.

Reductions in both physical waste and emissions are required to achieve a low carbon circular economy. This study identified that construction waste is responsible for approximately 5% of the embodied emissions of buildings. The emissions generated during the manufacture of construction products is significantly larger. While efforts to improve the recovery and disposal of construction waste are important, greater potential to reduce emissions lies in reducing waste in the first place.

While saving materials from landfill has the potential to reduce GHG emissions, the emissions generated when products are made in the first place are often overlooked. In fact, in the construction industry, emissions generated during the manufacture of products tend to be significantly larger than the emissions generated when products are disposed. This study identified that the disposal of construction waste is responsible for approximately 15% of the total embodied emissions of the wasted materials, with the other 85% coming from the manufacture of the products. While increasing recycling rates is important, the most effective way to achieve a low carbon circular economy is through upstream activities. From a construction perspective, if all materials are utilised and none are wasted, then greater levels of construction can be achieved with the same manufacturing output.

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Our mission is to enable organisations to succeed sustainably. We develop strategies, deliver roadmaps, and implement leading software solutions. Whether you're starting out or want to advance your leadership position, we can help no matter your sector or size.

Why us? Because we are fluent in both languages of sustainability and business. We are translators.

We've been building business value from sustainability for 15 years, for small or large businesses, family-owned and listed companies, or government agencies.

Our approach is science-based, pragmatic, and flexible.

Our work helps all industries in Australia and New Zealand, including manufacturing, building and construction, FMCG, packaging, energy, apparel, tourism, and agriculture.

Our services range from ready-to-go packages to solutions tailored to your needs.

As a certified B Corp with an approved science-based target, we make sure we are walking the talk.

Our services cover:

Product

- Life Cycle Assessment (LCA)
- Environmental Product Declarations (EPD)
- Carbon footprint
- Circular Economy (CE)
- Cradle to Cradle (C2C)
- Water footprint
- Packaging
- Independent reviews

Carbon

- Carbon Footprint
- Scope 3 emissions
- Reduction strategy
- Carbon targets
- Science-based targets (SBT)
- Offsetting strategies
- Inventory verification

Strategy

- Materiality assessment
- Green Star
- Sustainable Development Goals (SDGs)
- Foresighting & regenerative futures
- Roadmaps & action plans
- Responsible procurement & supply chain engagement

Software & tools

- GaBi LCA software
- GaBi Envision
- Material Circularity Indicator (MCI)
- OpenLCA
- eTool
- Packaging calculator
- SoFi sustainability reporting

Reporting & disclosures

- Task Force on Climate-related Financial Disclosures (TCFD)
- Global Reporting Initiative (GRI) & Integrated reporting (<IR>)
- B Corp
- Voluntary & compliance reporting
- CDP

Communications

- Short form reports
- Case studies
- Infographics
- Workshops
- Storytelling
- Stakeholder engagement
- Sustainability reports

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