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The Role of Wood Products in Zero Carbon Buildings



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FWPA Carbon Guides

Forest & Wood Products Australia's Carbon Series provides high-level insights into the opportunities for timber and wood products in Australia's built environment. This guide focuses on the role of wood products in zero carbon buildings, and is a valuable resource for design professionals wanting to specify wood products in sustainable buildings.

While not a comprehensive analysis, the intent of this publication is to provide high-level guidance on a broad range of topics relevant to the built environment, including: carbon in forestry and wood products; biogenic and fossil carbon; embodied greenhouse gas emissions in buildings and designing for net zero; embodied carbon policies; and green building frameworks and tools.

An overview of the different terms and definitions used in connection with carbon, greenhouse gas emissions and global warming is supplemented by a more complete Carbon Glossary at the end of the document.

Reducing embodied emissions in materials and construction is an essential step in decarbonising Australia's built environment. The guide provides commentary on embodied carbon across the different stages of the building life cycle. It explains why embodied carbon is important, how it is measured, and the value of reducing upfront carbon while designing with whole-of-life carbon in mind.

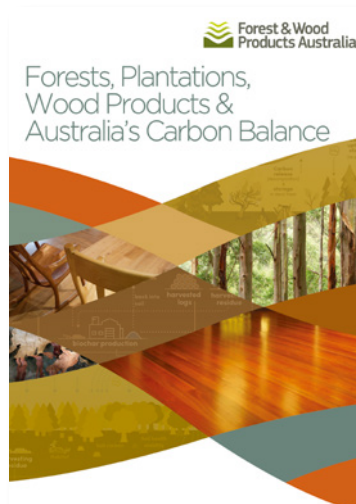
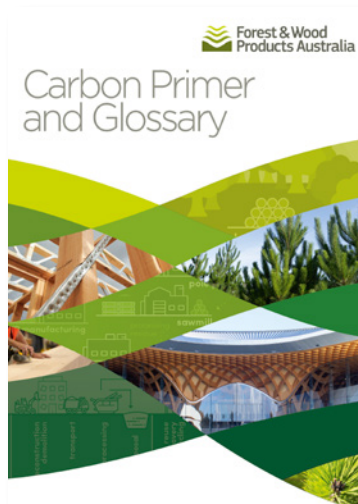
An understanding of the global carbon cycle, the importance of sustainable forest management, and the difference between biogenic and fossil carbon provides useful context to aid design decisions concerning bio-based and fossil-based building materials. So too is the inherent ability of wood products to store carbon for long periods, in both the built environment and landfill.

The importance of life cycle assessments and environmental product declarations in assessing the environmental impacts of materials and design is supported by discussion of accounting for biogenic carbon in use and at end of life, and approaches to biogenic carbon in green building frameworks in Australia and New Zealand.

There are various design options available to reduce embodied carbon throughout the life cycle of a building. The guide surveys pathways to carbon zero design, considers an engineered timber future, lightweighting and end-of-life options for timber buildings. It concludes that smart design using wood products in structural systems can reduce fossil fuel use and cut greenhouse gas emissions. A brief discussion of the carbon-reduction opportunities available through digital fabrication and modular construction strengthens the argument.

A scan of Australia's embodied carbon policies and frameworks, along with green building certifications and tools is provided in the closing sections of the guide.

Three recent Australian case studies located throughout the guide bring the discussion to life by illustrating some of the key topics covered in the guide and demonstrating that wood products can play an important role in the transition to zero carbon buildings.



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1 Introduction : Shaping the future.

The challenge of today is to limit global warming to well below 2°C with efforts to limit it to 1.5°C. This goal will only be achieved if greenhouse gas (GHG) emissions in the built environment are reduced dramatically. For those involved in the design and construction of buildings and cities, there is a deep responsibility to be aware of the drivers of climate change to accelerate the transition to net zero embodied emission buildings (from here on embodied greenhouse equivalent gas emissions are simply referred to as ‘embodied carbon’).

Of the global CO₂ emissions attributed to the construction sector, 28% come from energy consumed while the building is in use (**operational carbon**) and 11% are from building materials and the construction process (**embodied carbon**)¹.

The critical emission sources in the construction sector are the burning of fossil fuels for energy and use of carbon-intensive materials. Carbon emissions released before the building begins to be used (upfront carbon) are expected to account for half of the entire carbon footprint of new construction between now and 2050².

Approximately two-thirds of a building’s overall upfront carbon emissions are attributable to the substructure, superstructure and façade, making it vital for designers and developers to turn their attention to structural building materials and generate solutions that will reduce embodied carbon. Without decisive action, building materials used in new cities across the globe are likely to increase GHG emissions at a global average of 0.7% per year³.

Wood products are manufactured from natural, renewable raw materials. They are durable and recyclable, and, unlike their fossil fuel-based alternatives, store carbon throughout their lifetime. Manufacturing technology is adding to the traditional wood palette, offering lightweight, dimensionally consistent structural engineered wood products (EWPs) such as cross-laminated timber (CLT), laminated veneer lumber (LVL) and glued-laminated timber (GLT), which also have a low carbon footprint. The potential of nanocellulose as a bio-based alternative to synthetic polymers in coatings and adhesives is propelling the forest products industry into the 21st Century⁴.

It is an exciting time for wood as it reasserts itself as a key building component and demonstrates its value as an alternative to many of the carbon-intensive fossil-fuel based materials that have been used widely in the construction sector for many years.

In 2012 the UN forecast that increasing production and consumption of wood products will be part of a sustainable future⁵. Now ten years later, the building sector’s architects, engineers, planners, developers, and builders are encouraged to join with the forest and wood products sector to shape that sustainable future.



Bunjil Place, Melbourne image source: Laurello

2 Introducing carbon and greenhouse gases

A variety of terms and definitions are used in connection with carbon, greenhouse gas emissions and global warming. Some introductory terms are explained below.

Climate Change is the term used to describe changes in the Earth's climate resulting from human induced changes in greenhouse gas concentrations brought about by activities such as burning fossil fuels, clearing vegetation and changing land use.

Greenhouse Gases on the other hand, are emissions of any gas capable of absorbing and emitting radiation. Carbon dioxide and methane are the most important greenhouse gases created from human activities. As there are multiple greenhouse gases, each with a different effect on global warming, a measure is used to compare the relative impacts of each greenhouse gas. This measure is called **Carbon Dioxide Equivalence** (abbreviated to CO₂-eq).

Global Warming Potential (GWP) is the measure of greenhouse gas emissions, such as carbon dioxide and methane. Contributions to GWP can come from either fossil or biogenic sources. GWP is reported as a total as well as being separated into biogenic carbon (GWPB) and fossil carbon (GWPF). While the term **carbon footprint** refers to carbon, it is an expression of the total amount of greenhouse gases released as the result of a given activity. Similarly, the term **carbon emissions** typically refers to all emissions of greenhouse gases.

Addressing climate change in the building sector has traditionally focused on reducing carbon emissions from **operational carbon**, which are the emissions associated with heating, cooling and energy use of the building. As buildings become more energy efficient and the electricity grid decarbonises, operational carbon of new buildings will reduce significantly. Focus has shifted to tackling **embodied carbon emissions** and **upfront carbon** in particular. These concepts are discussed in detail in the following pages.

Carbon terminology from a forest and wood product perspective

Carbon (C)

Carbon is a non-metallc chemical element, with the symbol 'C' and the atomic number 6. It readily forms compounds with many other elements and is a constituent of organic compounds in all known living tissues (including wood).

Biogenic carbon

Biogenic carbon is the carbon that is absorbed and stored (sequestration) by plants and trees through the process of photosynthesis. All timber products contain biogenic carbon that has been sequestered through the growth of the trees.

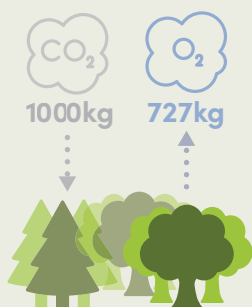
Carbon sequestration

Carbon sequestration is a process of capturing and storing carbon dioxide from the atmosphere. Trees in forests, utilising the solar energy from the sun, photosynthesise and breakdown CO₂, releasing the oxygen (O₂) that we breathe and sequestering the carbon (C) in the trees woody mass. After harvesting this carbon remains stored in the wood products - a very positive story.

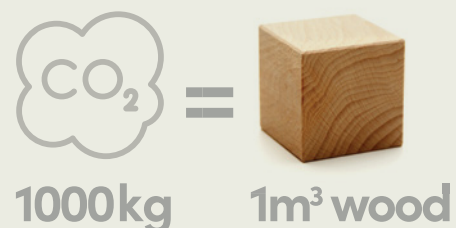
Carbon storage

Biogenic carbon remains stored in timber products for the life of the product. At the end of the first service life, wood products may be:

- salvaged and reused as is
- recycled into new products (i.e. solid wood into particleboard)
- used as a biofuel to provide renewable energy
- landfilled, where if there is no oxygen (anaerobic conditions) the carbon will remain stored for life.



On average, a typical tree absorbs, through photosynthesis, the equivalent of 1 tonne of carbon dioxide for every cubic metre's growth, while releasing the equivalent of 727 kg of oxygen



3 Embodied carbon and buildings

Life cycle assessment of buildings – and where GWP or embodied carbon fits

Life cycle assessment (LCA) is the accepted approach for investigation and comparisons of the environmental impacts of an individual product, or an assembly of products, such as a building.

While a full LCA includes the assessment of more than a dozen environmental impact categories, the one of most interest is the one related to climate change providing an indicator of global warming potential (GWP) due to emissions of *greenhouse gases* (GHG) to air.

A variety of definitions and terms are used in relation to GHG emissions from the different stage of the life cycle process.

It is important to clearly understand the different LCA stages for assessment of buildings, and the accepted terminology used globally. These stages are illustrated in the following figure from EN 15978¹ - specific to the life cycle of a building, along with some boundary terminology specifically related to 'carbon'.

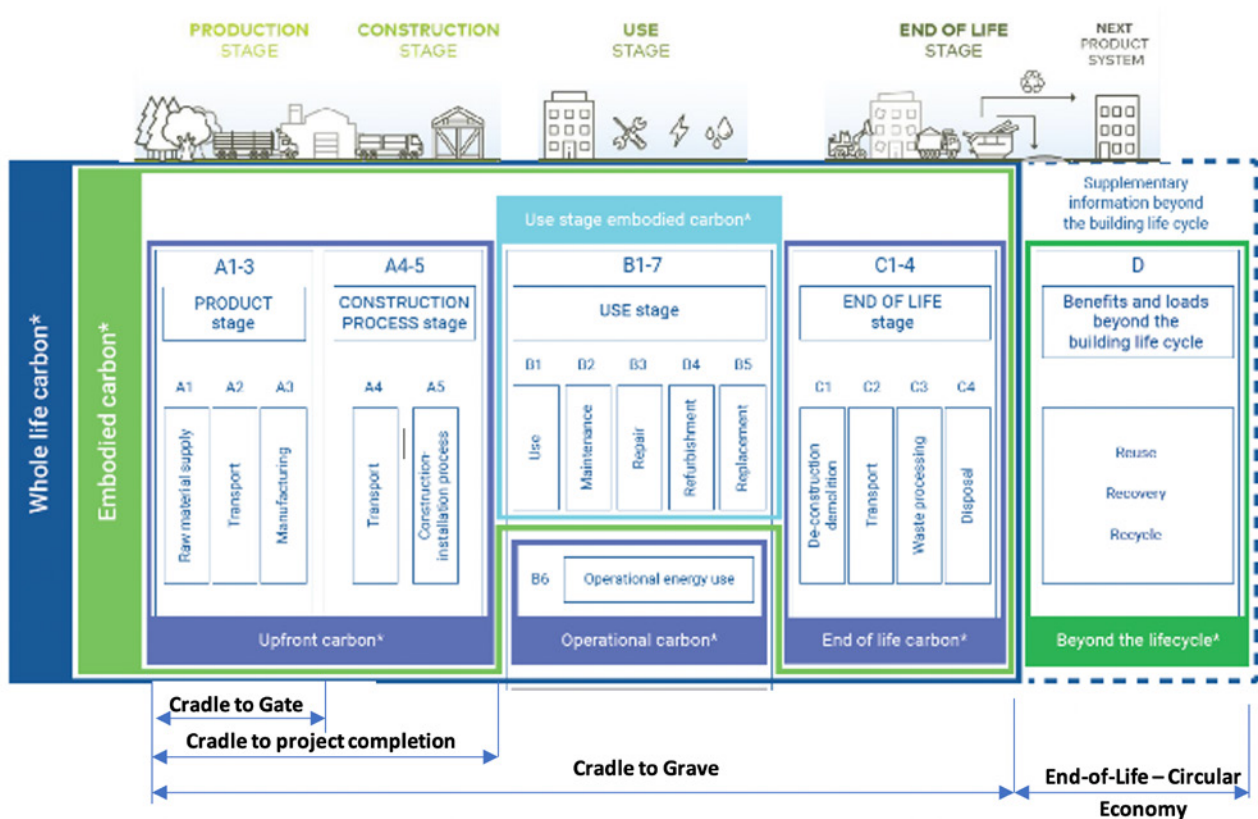


Figure 1: Terminology used in this Guide cross-referenced to terms and lifecycle defined in EN 15978.

3.1 What is embodied carbon?

Embodied carbon is a measure of the greenhouse gas (GHG) emissions associated with materials and construction processes throughout the whole life cycle of an asset (i.e. material extraction, transport, manufacture, construction, use (and replacement), demolition and end of life). Embodied carbon can be measured within different system boundaries, e.g. cradle to gate, cradle to site, cradle to practical completion, cradle to grave, or even cradle to cradle as illustrated in Figure 3.1.

Until recently these emissions have largely been overlooked but are thought to account for around 11% of all global carbon emissions⁶. As operational carbon is reduced through increasing use of renewables, embodied carbon will continue to grow in importance as a proportion of total emissions.

The product and construction phases represent upfront carbon, which are the emissions associated with materials production (A1-A3) and construction (A4-A5) stages before a building is used. These are key sources of embodied carbon and are 'frontloaded', unlike annual operating emissions (B6) or end-of-life emissions (C1-C4), which occur later and/or gradually over time.

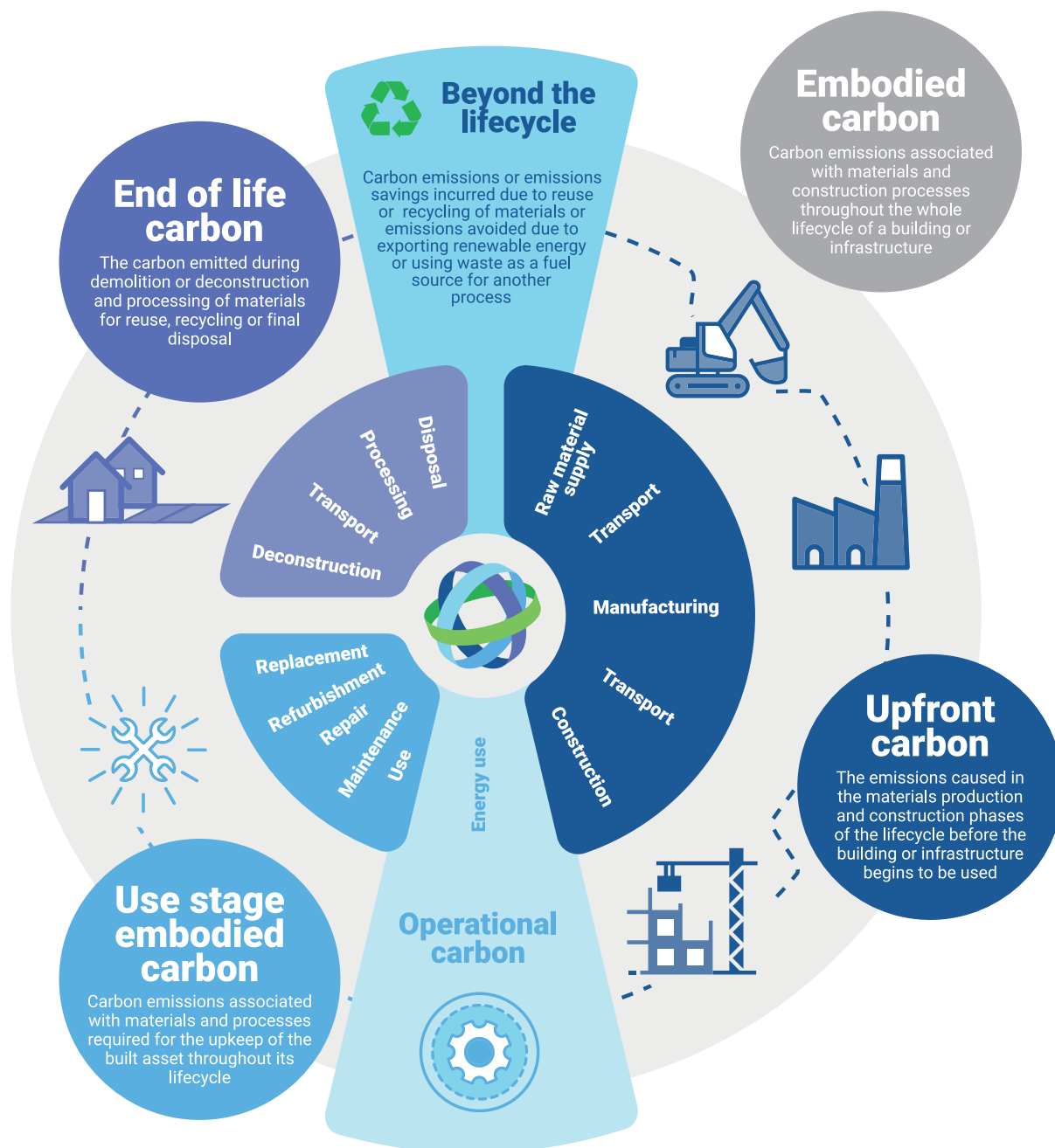


Figure 3.1: Scope of carbon emissions across different stages of the building life cycle 7.

World Green Building Council (2019) *Bringing embodied carbon upfront*. London: World Green Building Council

3.2 Why is it important?

Population growth, rising floor area per person and greater demand for energy services are all contributing to the construction sector's growing carbon emissions, which show no sign of declining. Over the next 40 years 230 billion square metres of new buildings are expected to be added to the global building stock, with more than 50% of this anticipated within the next 20 years.

This dramatic global population growth and urbanisation will result in a significant global spike in CO₂ emissions and unsustainable consumption of global raw materials if business as usual is practised. We need to act now to create embodied carbon strategies that reduce environmental impacts from the buildings we'll use well into the future.

However, by reducing embodied carbon in building materials and construction processes we can reduce greenhouse gas emissions with immediate effect. In Australia, for example, even a 10% reduction in upfront emissions in new buildings would correspond to at least 19.9 mt CO₂-eq avoided between 2022 and 2030 and at least 63.5 mt CO₂-e avoided between 2022 and 2050⁸.

3.3 Where is it?

The construction process, including the sourcing of materials and their conversion into products, systems, and buildings as well as transport and site works is a significant source of embodied carbon emissions. Some general trends are apparent both in the comparative carbon intensity of materials typically used in construction and the parts of buildings which are responsible for most embodied carbon emissions.

Building elements such as foundations, frames and other forms of superstructure represent the biggest contribution to embodied carbon⁹. This is due not only to the significant volumes of material used, but also because of the carbon intensity of many common structural materials, such as concrete, steel and masonry.

Increasingly, government regulators and asset owners are asking building and design professionals to consider the wider long-term environmental consequences of specifying a product, component or building system. Likewise, as buildings become more energy efficient, the upfront embodied carbon impact from materials will account for a higher proportion of a building's carbon footprint.

3.4 How is it measured?

To get a true picture of a building's energy and carbon emissions impact it is necessary to understand not only the operational and the embodied emissions on their own, but also the interrelationship between them. This means considering these emissions together to optimise their impacts and avoid the unintended consequences of assessing each in isolation. For example, the benefit of constructing a highly energy efficient building to lower emissions would be questionable if the design requires emissions intensive construction processes and materials, and vice versa.

Measuring embodied carbon is key to evaluating the highest-impact and most cost-effective solutions to reducing embodied carbon on a building project and typically involves a methodology called life cycle assessment (LCA). An LCA measures environmental impact across a range of issues such as impact on air quality, water usage and water quality, toxicity to human life and to ecosystem functioning, impact to climate or 'global warming potential' (GWP), as well as resource use. Embodied carbon is the GWP result (excluding operational carbon) and is measured for each stage of the asset or product's life cycle, allowing comparisons across any combination of stages.

Proposed Case Study 1: 25 King Street



Architect: Bates Smart

Engineer: Aurecon and
Lendlease DesignMake

Builder: Lendlease

Photos: Tom Rose
25 King St | WoodSolutions

Completed: 2019

**Embodied CO₂e
reduction 8,607 t CO₂e**

At 10 stories, and 14,965 m² NLA, 25 King Street is one of Australia's most impressive engineered-timber commercial buildings. It's also an exemplar in carbon emission reduction, delivering 74% reduction in carbon over a 60 year life (8,607 tCO₂e) compared to reinforced concrete building, and a 38.7% reduction excluding the sequestered carbon contribution of timber¹⁰.

The solution is a combination of cross-laminated timber (CLT – Stora Enso) and glued laminated timber (glulam - Wiehag). The glulam is used for the structural beams and columns, and the CLT for the floors, lift shafts and escape stairs utilising precise off-site prefabrication and safer on-site construction methods.

Comprising 3,097 individual timber elements (there are 33 timber columns on each floor, on a 6x8m grid, and 52 beams) – about 5,970 m³ of timber. The timber is sustainably sourced, PEFC certified and has a verified Environmental Product Declaration (EPD).

The building's environmental performance was calculated using a life cycle assessment comparative study completed in line with ISO 14040:2006, ISO 14044: 2006 and EN15978:2011, for the purpose of Green Star. The scope of the study included all modules as per EN15978, and the embodied carbon reduction referenced in this case study references Modules A1-A3. The Life Cycle Inventory was established from the building cost plan, preliminary bill of quantities and site construction bill of materials, as well as drawings, specifications, environmental product declarations and the like, using the GaBi Professional + Extension Database.



4 Climate, carbon and forests

Wood is a natural, renewable material that has a uniquely low impact processing cycle. It is an excellent bio-based substitute for many mineral-based building materials with high carbon emissions intensity, provided it is sourced from a sustainably managed forest. In addition, forests, forest soils and wood products are an integral part of the global carbon cycle and function as a key reservoir for carbon, acting as a 'carbon sink'.

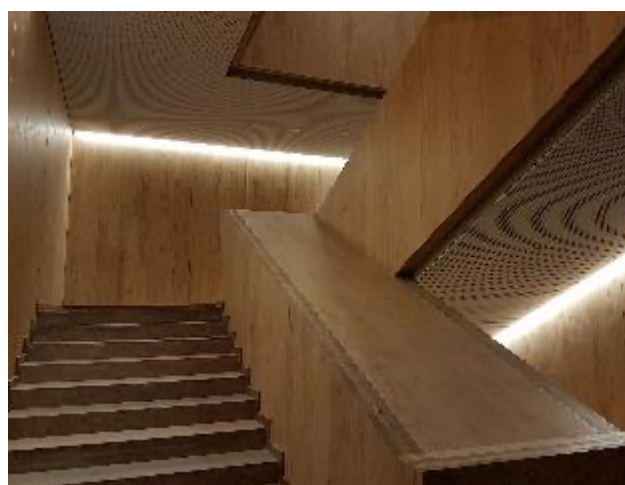
Terms specific to the role that trees and timber play in the global carbon cycle are explained below.

Carbon sequestration is a process of capturing and storing carbon dioxide from the atmosphere, for example in the form of trees, leaves or needles, roots and surrounding soil.

Carbon storage is the storage of carbon for long periods and occurs naturally in harvested wood products. The storage of carbon is an environmental attribute that does not currently exist in a comparable manner in competing structural products.



HVP Pine plantation, Woodend, Victoria.
Image source: Laurello



Monash University, Caulfield, Melbourne.
Image source: TPC Solutions

4.1 Forest growth and the carbon cycle

Forests are a major component of the global carbon cycle due to the ongoing absorption of carbon dioxide by growing forests and the large amounts of carbon they store. The rate and extent to which trees sequester carbon is influenced by many factors, but as a rule, young, vigorously growing trees take up carbon quickly, with the rate slowing as they reach maturity (typically 60–100 years, depending on species and environmental factors).

Carbon sequestered by trees is released back into the atmosphere through bushfires or decay. In sustainably managed forest systems, carbon that is emitted because of harvest activity is re-absorbed by replanting or regeneration. Productive forest systems contain trees at varying stages of growth, absorbing carbon at different rates. The cycles of harvest and regrowth over time lead to stable carbon levels across the forest estate, as illustrated in Figure 4.1.

Annual estimates of the stocks and flows of carbon in Australia's forests are made using the Full Carbon Accounting Model (FullCAM) and the data is used in the National Greenhouse Gas Accounts to report on Australia's greenhouse gas emissions.

With a sharp decline in land clearing in recent times, Australia's 2020 net GHG emissions from land use, land-use change and forestry were negative, at around 40 million tonnes CO₂-eq¹¹. 'Negative' emissions means that more carbon was stored than released. It is the only sector of the economy that is a net carbon sink.

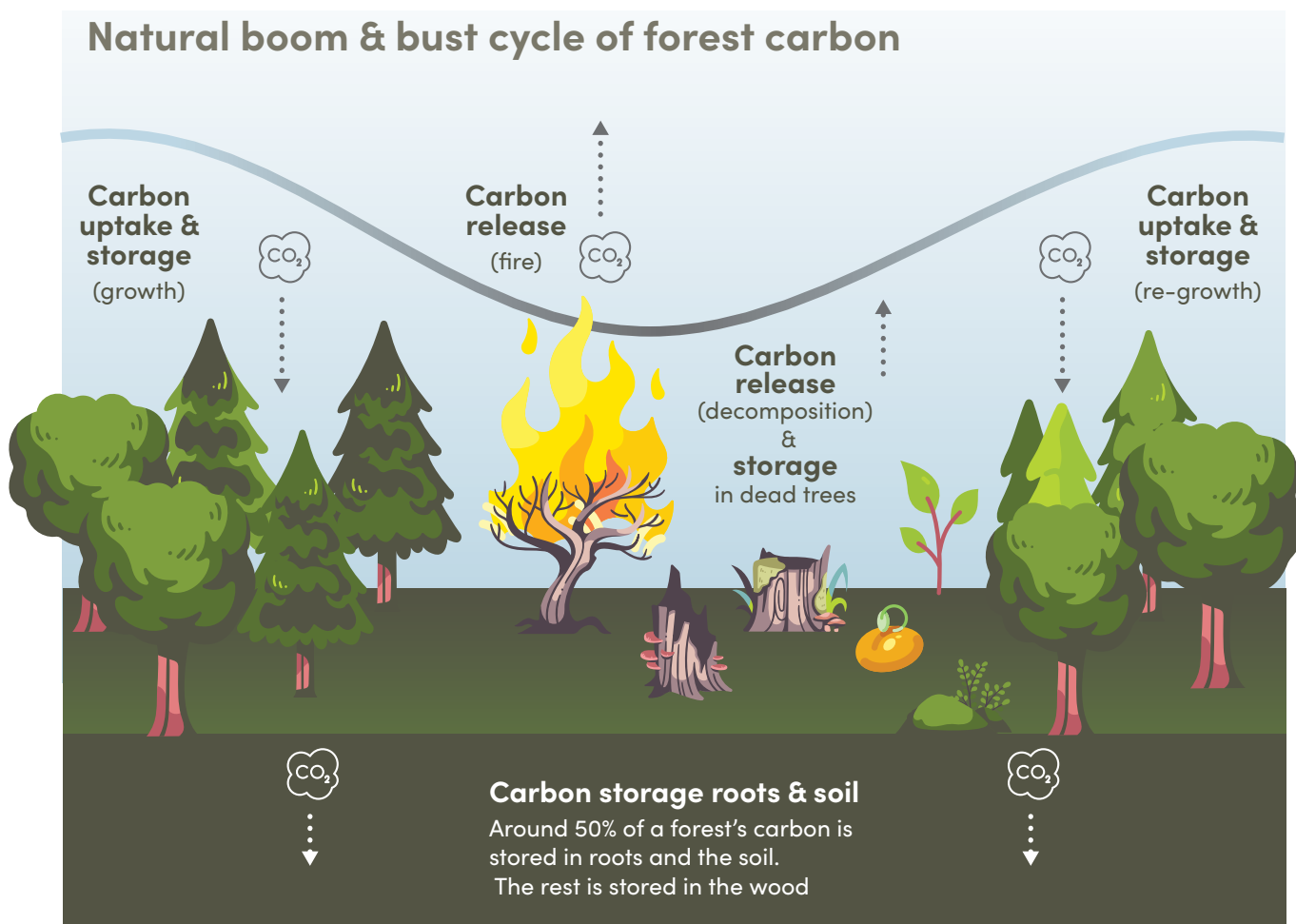


Figure 4.1: The natural boom and bust cycle of forest carbon.

4.2 The difference between biogenic and fossil carbon

Biogenic carbon is absorbed and stored by trees through the process of photosynthesis over relatively short periods of time. Biogenic carbon emissions are produced either through decomposition when a tree reaches the end of its life, or when the organic matter is combusted as biomass. By contrast, fossil carbon has been absorbed by living matter over millions of years and is available as fossil fuels in the form of mineral oil, coal and natural gas.

Biogenic carbon offers advantages over fossil carbon in that its emissions remain part of the 'closed loop' biogenic carbon cycle, rather than outside it (see Figure 4.2). Whether trees are harvested and used for products or decay naturally, the cycle is ongoing, as forests regenerate and young trees once again begin absorbing carbon.

Since it does not contribute more carbon to the atmosphere than it sequesters, biogenic CO₂ produced in a sustainably managed forest is effectively carbon neutral. This is why sustainable forestry is seen as renewable compared to using fossil fuels. The burning of fossil fuels on the other hand, adds more carbon to the atmosphere than the feedstocks remove, given that they take millions of years to form.

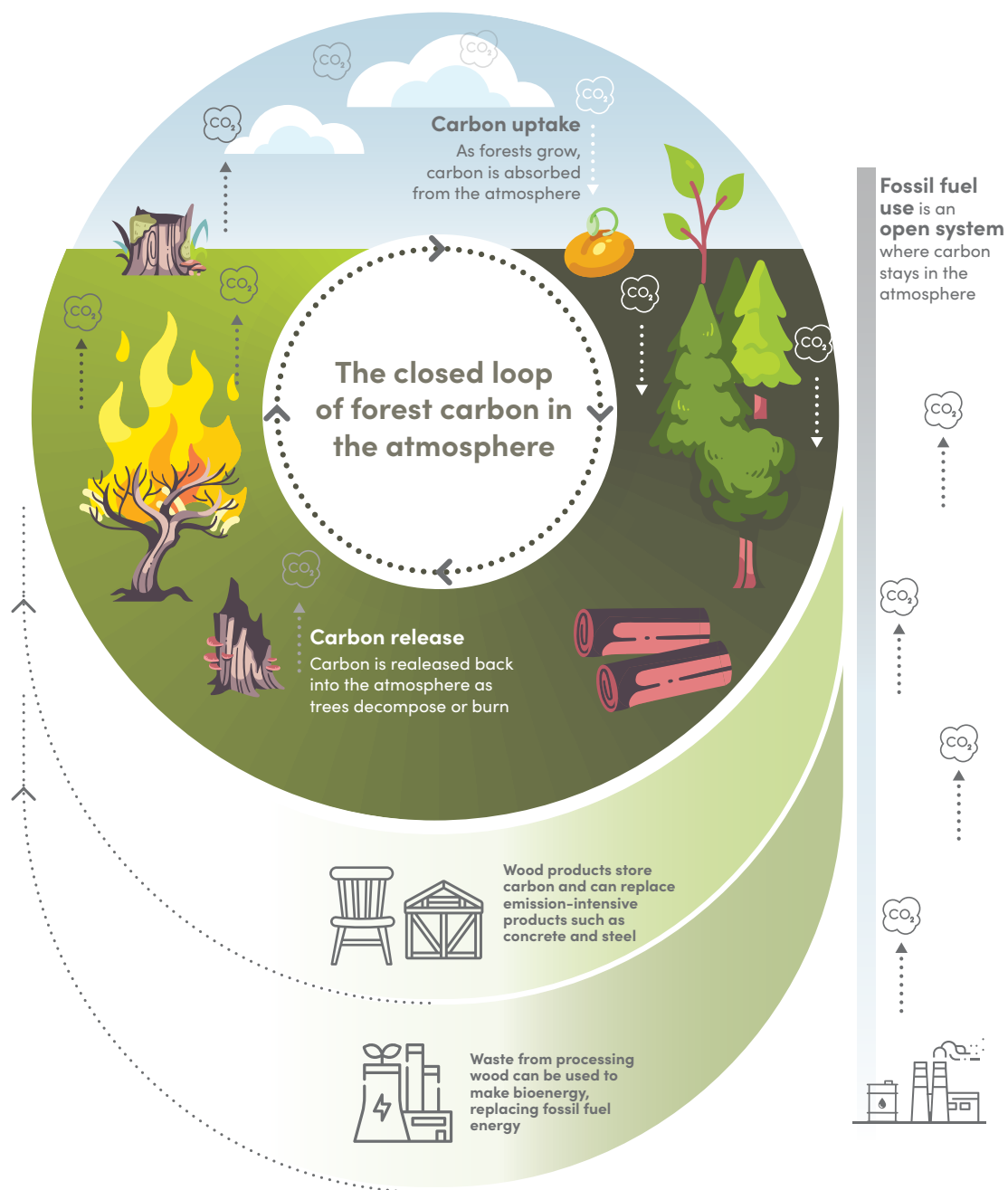


Figure 4.1: The natural boom and bust cycle of forest carbon.

4.3 Forest management and the carbon cycle

Forests can act as either net carbon sinks or net carbon sources. If trees are healthy and forests are managed sustainably, forests can act as carbon sinks, absorbing more carbon dioxide than they release. If forests are burned or degraded, or managed in an unsustainable way, they can also act as carbon sources, meaning that they have a net carbon release.

Australian forests store an estimated 7.8 billion tonnes of carbon (excluding below-ground biomass). Most of the carbon is stored in native forest stands, with the balance in plantations. Only 6% of Australia's 147 million hectares of forests is available for timber harvesting, with timber harvested from about 1% of these public native forests each year¹².

The perception that leaving forests alone will have the greatest climate change benefit has been challenged in recent years. In fact, active and responsible forest management may be more effective in capturing and storing carbon than hands-off management that excludes periodic harvests and use of wood products¹³. A decade of research suggests that the net accumulation of carbon in the atmosphere could be reduced by increasing sustainably harvested forests and the carbon stored by using timber in construction¹⁴.

This assertion is echoed by the IPCC, which claimed in 2018 that long-term, sustainable forest management aimed at maintaining or increasing forest carbon stocks, while producing an annual sustained yield of timber, fibre or energy from the forest, will generate the largest sustained mitigation benefit¹⁵.

4.4 Sourcing sustainable timber products

4.4.1 Sustainable forest management and forest certification

Forest management critically influences the climate effects of a forest system. The terms 'sustainable' or 'responsible' imply that the wood has been harvested in a way that ensures healthy, continued and sustainable growth. This steady-state management (i.e. management inputs and wood products produced are equal) not only keeps forests healthy, but also helps enhance carbon capture. Standards permit the inclusion of sequestration and carbon storage in life cycle analyses of wood products where wood is sourced from sustainably managed native forests or plantations. Where wood is not sourced from sustainably managed forests (i.e from land clearing), a steady state cannot be assumed, and therefore the assumption is that all carbon per m3 of wood is converted to CO₂.

One method of helping to ensure timber is sourced from sustainable and responsible forest management is certification to the forest management standards of Forest Stewardship Council® (FSC®), or a national forest management standard endorsed by the Programme for the Endorsement of Forest Certification (PEFC) such as Responsible Wood (endorsed by PEFC for Australia and New Zealand). Currently, all major Australian publicly owned native forest managed for timber production, as well as almost all of the softwood and hardwood plantations managed for timber to produce sawn hardwood, sawn softwood, particleboard, MDF, plywood and glulam are independently certified to one or both of the internationally accepted forest management standards¹⁶.



Sustainably managed native forest

Image Credit: Laurello



Softwood plantation

Image Credit: TPC Solutions

4.4.2 Chain of custody

Tracing of product origin is one way of responsible sourcing of forest products. For wood products, tracing systems are applied from forest and plantation to production and secondary processing via third-party chain-of-custody certification standards of FSC®, PEFC and Responsible Wood. These sustainable forest management and chain-of-custody certification systems are voluntary and are implemented by many in the timber supply chain at considerable expense.

5 Carbon storage in wood products

Sequestered carbon is removed from forests when trees are harvested to produce logs for processing. The carbon is stored in the harvested wood products for their lifetime. Wood products are about 50% carbon by dry weight. On average, each cubic metre of Australian sawn softwood and hardwood timber stores 0.9 and 1.22 tonnes respectively, of CO₂-eq sequestered from the atmosphere¹⁷.



**1 m³ softwood
stores 0.9 tonnes
of CO₂-eq**



**1 m³ hardwood
stores 1.22 tonnes
of CO₂-eq**

The life cycles of Australian plantation softwood and native hardwoods are illustrated in Figures 5.1 and 5.2.

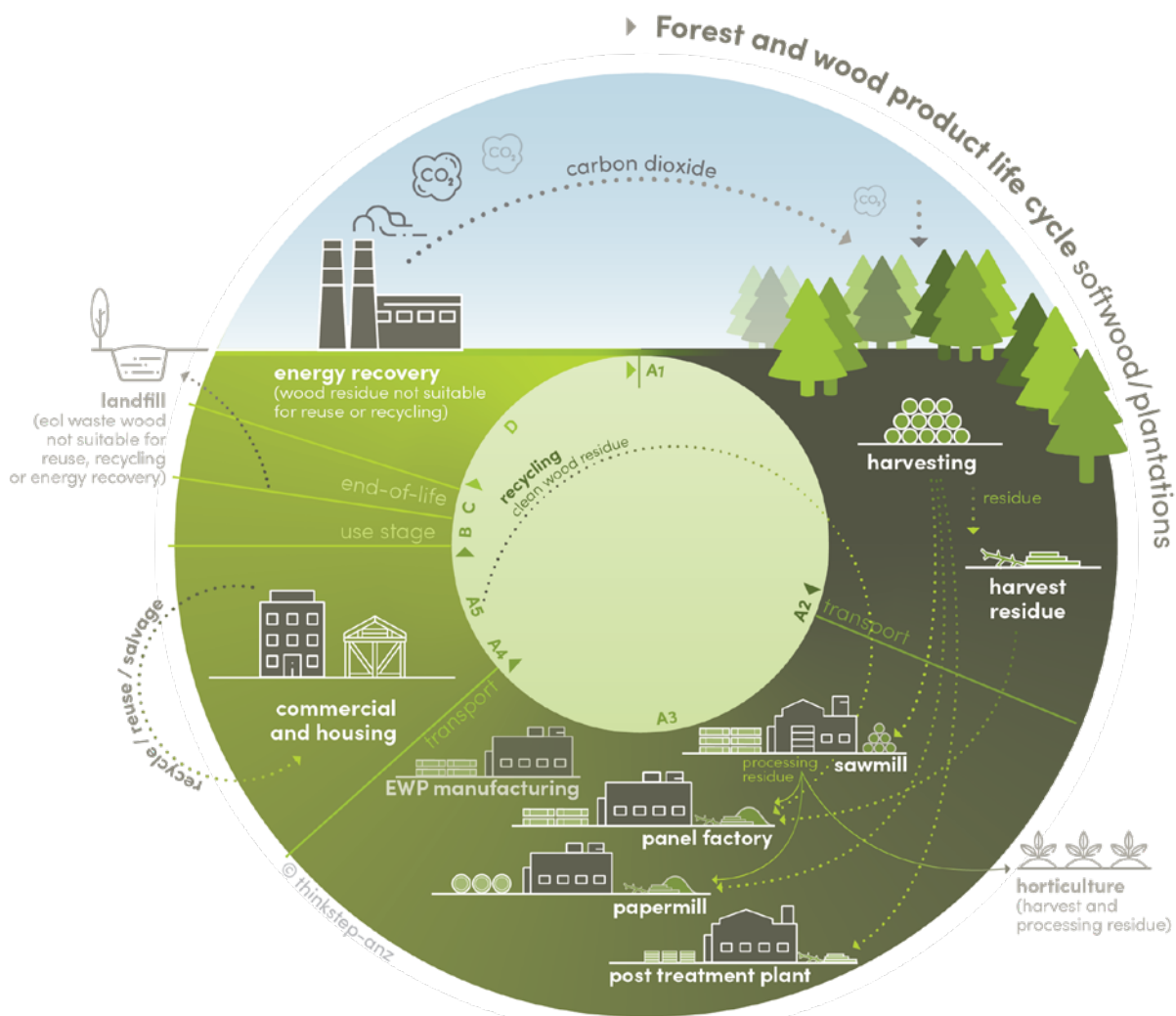


Figure 5.1 - Forest and wood products life cycle – softwood/plantations.

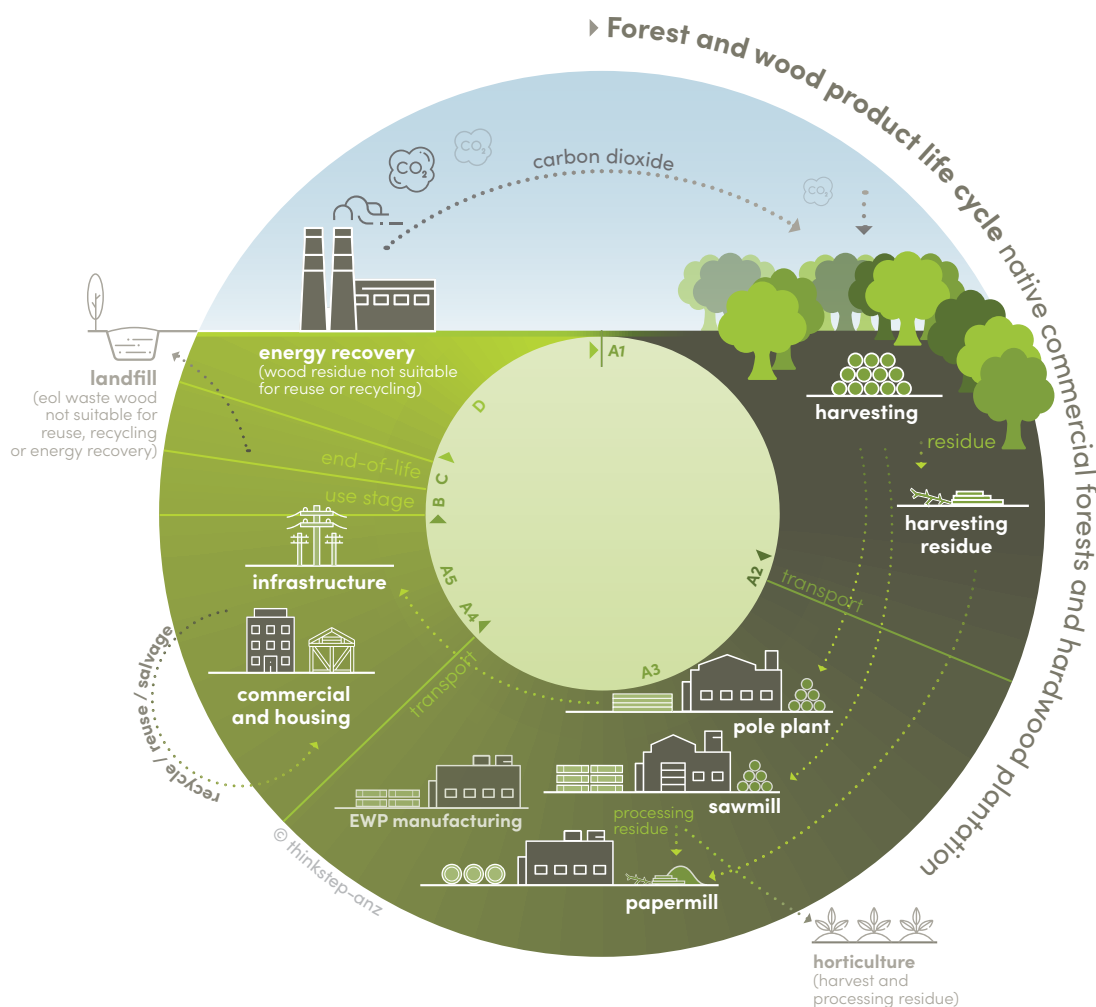


Figure 5.2 - Forest and wood products life cycle – hardwood/native commercial forestry.

5.1 Carbon stored in the built environment

The process of removing CO₂ from the atmosphere helps mitigate climate change. For long-lived products, such as those used in buildings, this atmospheric CO₂ will often be stored within the building for several decades and sometimes even hundreds of years. While the storage in the building is not permanent, removing CO₂ from the atmosphere and storing it for several decades can help to buy time for further carbon reduction technologies and methods to be developed.

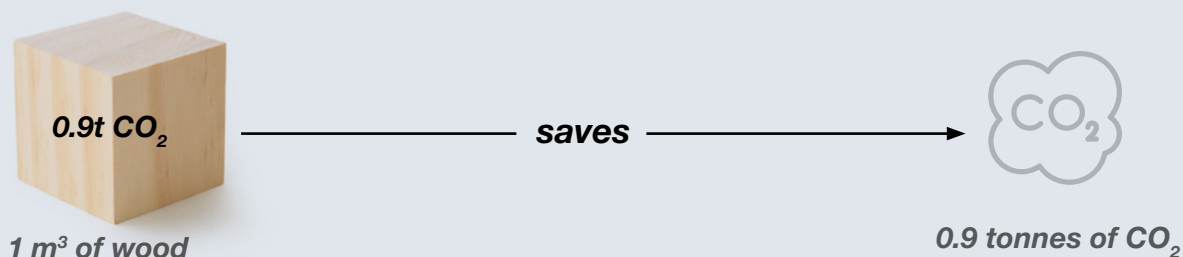
At the end of its service life, a wood product may be salvaged and reused, recycled into new products, used to provide a renewable carbon-neutral source of heat and power, or landfilled. The carbon stored in wood products remains in the wood for as long as it remains a solid product, even if this is as small particles. This is the case for salvage and reuse, recycling, and landfilling.

In 2020, 88 million tonnes of carbon were stored in wood products in service in Australia¹⁸. Over the past 15 years, the percentage of carbon stored in harvested wood products has increased annually, with the bulk stored in relatively long-lived products such as timber used for construction. With the uptake of mass timber in tall buildings, structural building elements such as CLT, GLT and LVL offer a valuable opportunity for long term capture and storage of carbon. The substitution of wood-based building materials for more carbon-intensive products can also reduce emissions. Modelling suggests the use of wood-based building materials can avoid emissions of nearly 500 million tonnes CO₂-e annually, via substitution effects¹⁹.

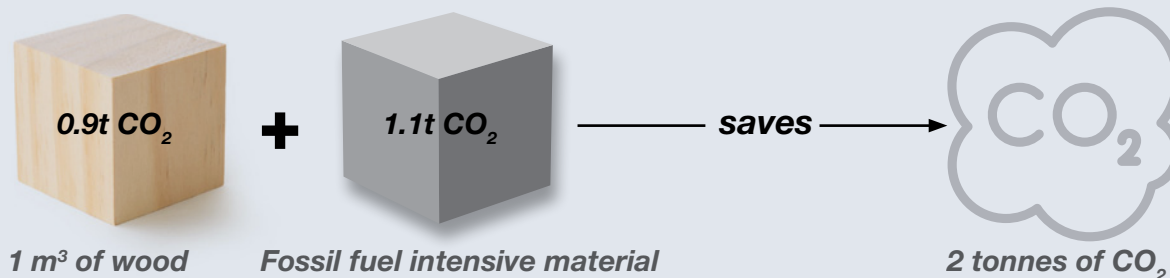
Carbon saved through substitution for other materials

While the carbon store effect of wood products helps keep CO₂ out of the atmosphere, an even greater carbon gain comes from the substitution effect of using wood in place of other, more fossil fuel-intensive materials. Data differ according to material as well as to country (because of differences in energy sources), however all agree that considerable CO₂ savings can be made by using wood where appropriate, instead of other materials. On average, the production of a cubic metre of wood creates around 1.1 tonnes less CO₂ emissions than the production of an equivalent amount of fossil fuel-intensive materials such as steel, concrete or plastics. This amount, coupled to the 0.9 tonne of CO₂ stored in the wood, means that every cubic metre of wood substituting for fossil fuel-intensive materials saves a total of approximately 2 tonnes of CO₂.

CO₂ saved as carbon store



CO₂ saved from combined carbon store and substitution effect



5.2 Carbon stored in landfill

Most of the wood waste disposed of in Australian landfills originates from industrial, construction and demolition sites. It is estimated that, over time, the annual quantities of carbon in wood products deposited in landfills in Australia have reduced from an average of 1.2 mt in 1990 to approximately 0.77 mt in 2020²⁰.

The scientific understanding of carbon dynamics of wood products in landfills has evolved considerably in recent years and demonstrates that the disposal of wood in Australian landfills results in long-term storage of carbon. Studies based on excavations of old landfills and experimental bioreactor work have shown that carbon loss from wood and wood products in Australian landfills is insignificant - a maximum of 1.4% of the carbon may be lost, with the remainder stored indefinitely.

The National GHG Inventory, which reports carbon stock in wood products in landfills, estimates that the disposal of wood products in Australian landfills has resulted in a carbon reservoir of approximately 51.5 mt. This estimate is conservative, as it assumes that 10% of the carbon has been lost and emitted as CO₂ and methane.

Case Study 2: Latrobe University Bundoora Student Accommodation



Architect: JCBA

Engineer:
Taylor Thomas Whiting

Builder: Multiplex

Photos: Glen Hester

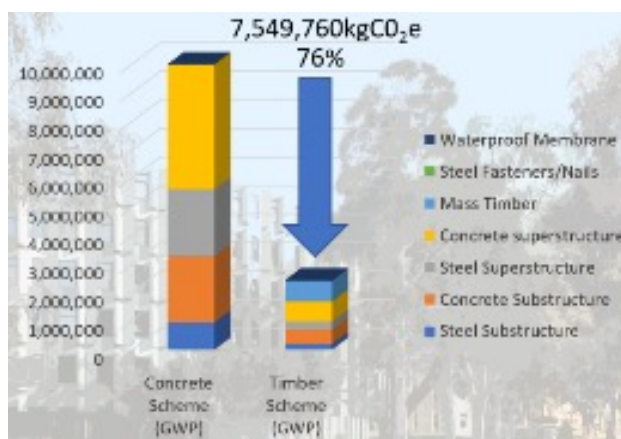
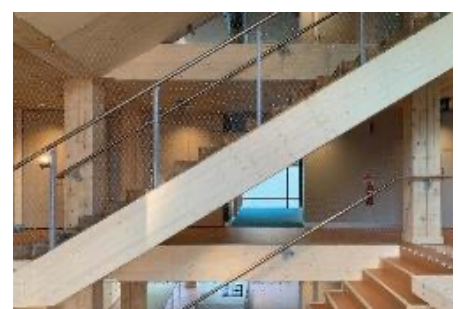
**Embodied CO₂e
reduction 7,500 t CO₂e**

Two separate six-storey radial buildings envelop a generous central courtyard, purposefully shaped to respect the existing campus gum trees. This project delivers a mix of one, four, five and six bed apartments (275 apartments, 624 new beds) supported by study areas, student kitchens and large communal spaces.

The project utilises 4,640 m³ of cross laminated timber (Xlam Dolomiti) wall and floor panels and glulam timber beams²². It delivers a significantly lower carbon footprint (7,500 tCO₂e) and a 76% lower Global Warming Potential (kg of CO₂ equivalents) than the corresponding concrete-based design.

The innovative structural solutions resulted in significant material and programmatic savings without compromising the architectural design intent²³.

The development has achieved a 5 Star Green Star as-built rating, while the use of mass timber construction and high-performance united facade system will substantially lower its carbon footprint during the building's lifespan²⁴.



6 Life cycle assessment and EPDs

6.1 What is a life cycle assessment?

A life cycle assessment (LCA) is universally accepted as the most effective tool for understanding the environmental impacts of a product system through its life cycle and is used in the construction industry to inform decision-making on design and materials. LCA is increasingly used in Building Information Modelling (BIM) and has been integrated into green building standards globally. In the building industry, LCA reports can be created for products, assemblies or completed buildings.

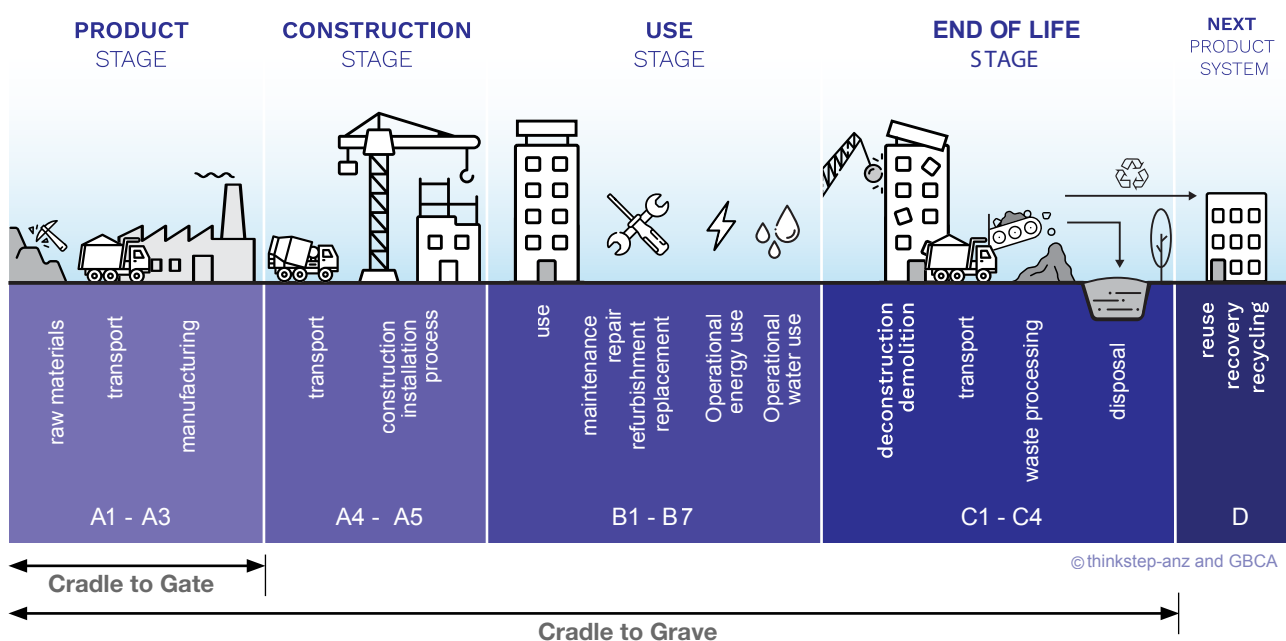


Figure 6.1 - Life cycle stages for forest and wood products.

European standard (EN) 15978:2011²⁵ is currently the best known and most widely cited standard for building LCA. Building-level LCAs are typically measured from cradle to grave (A1 to C4) and help designers understand the lifetime consequences of design decisions. A whole building LCA can be used to measure the embodied carbon savings from building re-use, identify hotspots at the beginning of a project, estimate the carbon footprint of a whole building, compare the carbon footprints of two building designs, and compare the carbon footprint impact of two systems (e.g. reinforced concrete versus mass timber, façade options, etc).

Because variables such as raw material sources, harvesting methods, supply chain processes, transportation distances, construction practices, design choices, maintenance schedule, location, and climate and operating practices all combine to determine the lifetime carbon footprint of a building, it's important to utilise LCAs in the project planning phase from concept through to completion of as-built models.

To ensure that an LCA is robust and to avoid trade-offs between impact categories or life cycle phases, the full range of environmental indicators assessed must be listed and justified, the different life cycle phases evaluated, upstream and downstream impacts measured and assessed and any comparisons between LCAs must be based on common functionality, scope, and methodology.

6.2 What is an EPD?

Environmental product declarations (EPDs) are third-party verified documents that summarise the results of a product LCA, essentially serving as an environmental label or declaration²⁶. An EPD is created and registered in the framework of a program such as EPD Australasia or the International EPD® System and is typically valid for five years.

Where EN 15978:2011 covers the assessment of the environmental performance of buildings, EN 15804:2012+A2:2019²⁷ covers the environmental performance of individual products. The scope of product or material-level LCAs can vary but the manufacture of the construction product will always be included (cradle to gate A1 – A3). Some studies will also consider the transport to (A4) and installation of the product on a construction site (A5), its maintenance and the impacts of disposal (cradle to grave).

EPDs are based on common rules known as Product Category Rules (PCRs). Results are reported for a particular product or material or an industry generic group of products (sector EPDs) in a common format. Because EPDs cover the impacts of product extraction, transportation and manufacturing (stages A1-A3), they are well-suited to capture manufacturing and supply chain strategies that prioritise material and energy efficiency, and low-carbon energy sources.

EPDs can only be compared when the same PCR has been used and all the relevant life cycle stages have been included. Additionally, products should not be compared unless their functionality, use and lifetime is considered. The products must be considered within a system at the building level, providing the same functionality, e.g. the mass of product needed to fulfil the same structural function.

EPDs for timber products provide an average sequestered carbon calculation for the product. GWP is reported as a total as well as being separated into biogenic carbon (GWPB) and fossil carbon (GWPF).

EPDs can be either industry average or product specific. WoodSolutions currently has developed seven industry average EPDs.



7 Accounting for biogenic carbon

7.1 Biogenic and fossil carbon in EPDs

The calculation methodology in EN 16449:2014²⁸ is the basis for estimating the benefits associated with stored biogenic carbon in wood and wood-based products. This standard provides the basis for that information as required by the product category rules for wood and wood-based products used in construction (EN 16485:2014²⁹) and partner standard EN 15804. A new version of EN 16485 is currently in preparation to partner with EN 15804, but it is not yet finalised.

When sequestered carbon is considered along with upfront embodied carbon, many wood products can have a negative CO₂-eq value for the cradle-to-gate stage. The biogenic and fossil carbon footprints of products are separated (see Figure 7.1). In this example from the Australian Sawn Softwood EPD, the cradle-to-gate carbon footprint or global warming potential (GWP) of 1 m³ of dressed, kiln-dried softwood is -718 kg CO₂-eq/m³. This is calculated by reducing the sequestered carbon (represented by a negative value of 875) by the 157 kg CO₂-eq/m³ fossil emissions released into the atmosphere through the production process (A1-A3).

	Production	Landfill (typical)	Landfill (NGA)	Energy recovery	Recycling
Parameter [Unit]	A1-A3	C4	C4	C3	C3
GWP [kg CO ₂ -eq.]	-718	57.9	364	906	906
GWPF [kg CO ₂ -eq.]	157	56.6	56.8	5.58	5.58
GWPB [kg CO ₂ -eq.]	-875	1.28	307	900	900

Figure 7.1: Environmental impacts, 1 m³ of dressed, kiln-dried softwood³⁰.

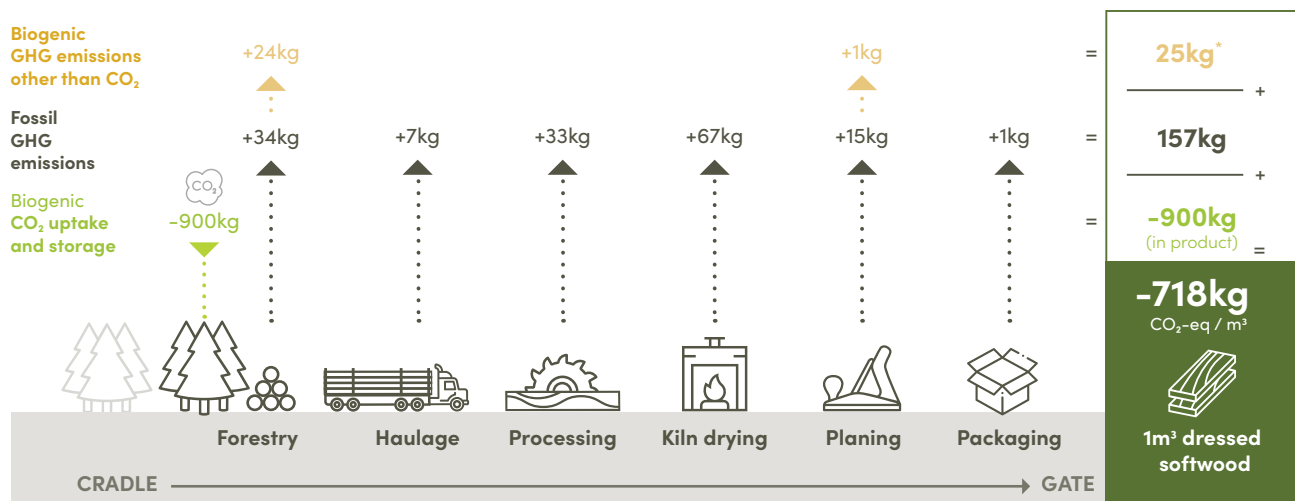
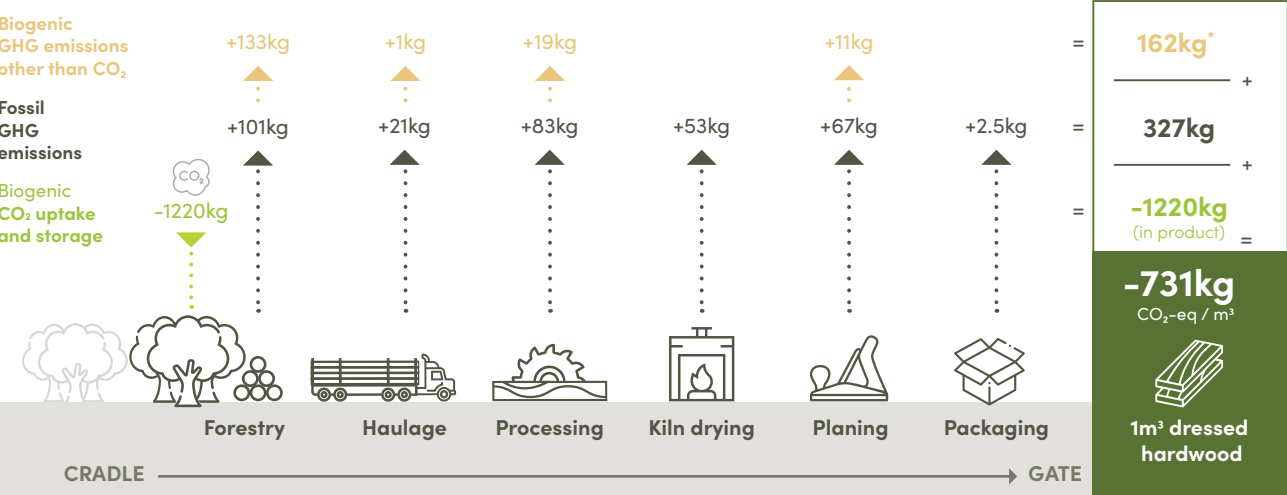


Figure 7.2: Carbon footprint of 1 m³ of kiln-dried dressed softwood³¹.

To quantify the upfront carbon footprint of wood products, the benefit of biogenic carbon uptake and storage in the product is reduced by the biogenic GHG emissions (nitrous oxide and methane) released in the forest and in processing, and the fossil GHG emissions released throughout production. Figures 7.2 and 7.3 show the average cradle-to-gate carbon flows associated with the production of 1 m³ of kiln-dried dressed softwood and hardwood products respectively. Figure 7.4 illustrates the average cradle-to-gate carbon flows associated with the production of 1 m³ of dressed white cypress .

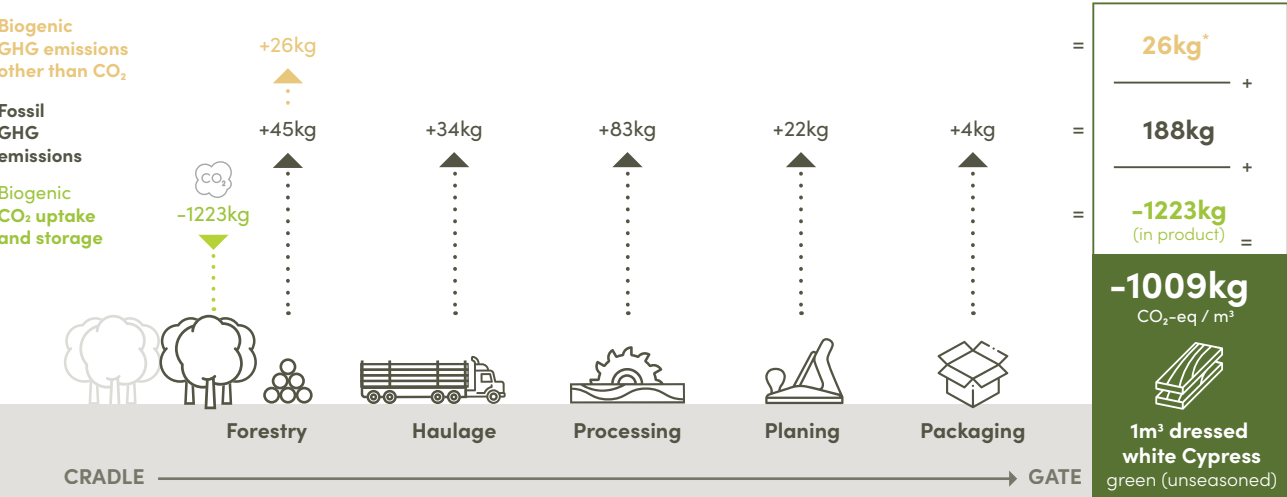
The cradle-to-gate carbon footprints of 1 m³ kiln dried dressed softwood and hardwood are relatively similar at -718 kg and -731 kg CO₂-eq respectively. However, the biogenic and fossil GHG emissions vary between the wood products, with biogenic emissions from hardwood during forestry stage higher than softwood. This can be explained by differences in forest management practices. Burning forest residues releases non-CO₂ GHGs (methane, nitrous oxide, nitrogen oxide) as well as biogenic CO₂. While the volume of residues burnt in softwood plantations is greater than in hardwood forests on a per hectare basis, there is a much greater area of hardwood forestry under management. The volume of timber produced in softwood plantations per hectare is also much greater than the volume of timber produced in hardwood forests. Hence the quantity of non-CO₂ GHGs is much greater per m3 of hardwood than softwood³².



Carbon footprint 1m³ of KD dressed hardwood
 'Cradle to Gate' A1 – A3

*CO₂ biogenic emissions from production (e.g. from combustion and degradation of residues) are excluded as they are balanced by uptake during tree growth (i.e., balance to zero)

Figure 7.3: Carbon footprint of 1 m³ of kiln-dried dressed hardwood³³.



Carbon footprint 1m³ of dressed, green (unseasoned) white Cypress
 'Cradle to Gate' A1 – A3

*CO₂ biogenic emissions from production (e.g. from combustion and degradation of residues) are excluded as they are balanced by uptake during tree growth (i.e., balance to zero)

Figure 7.3: Carbon footprint of 1 m³ of dressed white cypress³⁴.

The fate of the stored biogenic carbon also needs to be considered at the end of life of the product (modules C1-C4 in Figure 6). By considering only the production carbon footprint (modules A1-A3 in Figure 6), carbon released from the timber product after it has been used in the building (by decomposition in landfill or combustion when being burnt) is not included.

7.2 Biogenic carbon in building LCAs

Correctly accounting for the biogenic carbon stored in wood products in whole building LCA assessments is an area that is still developing. Treatment of stored biogenic carbon was not considered at the time EN15978:2011³⁵ was published and was introduced later through EN 16449:2014 and EN 16485:2014 and then EN 15804+A2:2019. These standards allow biogenic carbon storage to be included where the whole-of-life carbon assessment of the building includes the impacts of the end-of-life stage (Module C) and the timber originates from sustainable sources (certified by FSC, PEFC or equivalent).

A revised version of prEN 15978:2021 is currently in draft form³⁶. The draft splits Global Warming Potential into GWP-total = GWP fossil + GWP biogenic + GWP luluc, (where GWP-luluc is GWP from land use and land use change). Here, a GWP total can be reported so long as the component parts are also available.



Candlebark School Library, Victoria. image source: WoodSolutions

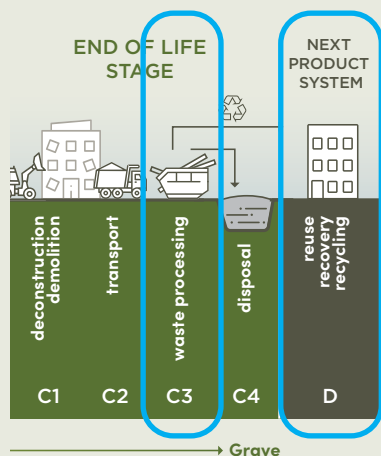
7.3 Biogenic carbon and end of life

In whole building LCAs, there are two main methodologies³⁷ for assessing the impact of biogenic carbon uptake and release. The carbon neutral approach (referred to as the 0/0 approach) assumes that the release of CO₂ from the wood product at the end of its life is balanced by an equivalent uptake of CO₂ during forest growth. In this approach, there is no consideration of biogenic carbon uptake (0) and release (0). In this method, emissions of biogenic carbon as methane (rather than carbon dioxide) are often accounted for, as such a release is not carbon neutral.

An alternative methodology (referred to as the -1/+1 approach) requires all biogenic carbon flows to be tracked over the building life cycle following the standardised calculation method (EN 16485:2014). Biogenic carbon uptake (-1) and release (+1) are considered throughout the building life cycle, and in the subsequent system (Module D at Figure 7-5). Biogenic carbon sequestered during forest growth is transferred to the building system and reported as a negative emission in Module A.

At the end of life of the building, the stored biogenic CO₂ is either released or transferred to the recovered product in Module D. In both cases it is reported as a (positive) emission in C3. This is to ensure that there is no double counting of the benefit of sequestration in both the original and recovered product.

There are other methodologies that consider the impact of timing of the carbon emissions and the rotation period of forestry growth. These are not discussed in this guide.



Designing for Deconstruction

Designing for Deconstruction upfront is a circular economy-based design innovation that allows maximisation of the recovery of systems, components and materials at the end of the building's life, ensuring that building components can be recycled as efficiently as possible. Engineered and off-site manufactured wood construction systems that are screw assembled on site provide significant future disassembly and reuse or recycle opportunities – extending the life span of the product and the continued storage of the biogenic carbon in the products.

Figure 7.5: Biogenic carbon and end of life.

7.4 Approaches to biogenic carbon in green building frameworks

A few approaches that are relevant to Australian builders and designers, and also an international approach being adopted in the UK are discussed here.

Australia

In Australia, the Green Building Council of Australia's new rating tool *Green Star Buildings* does not allow carbon stored in wood to be considered as an offset to other elements used in a building³⁸. Additionally, the wood products are certified as per Forest Stewardship Council (FSC®), Responsible Wood or Programme for Endorsement of Forests Certification (PEFC) forest certification scheme requirements.

NABERS, the National Australian Built Environment Rating System provides a simple, reliable, and comparable sustainability measurement of commercial building sector projects such as apartments, hotels, offices, shopping centres, etc.

NABERS is currently looking to implement an Embodied Carbon Tool and their consultation paper under Proposal 7 (see opposite) recognises the importance of biogenic carbon stored in timber utilising a greenhouse gas *Carbon Removal Indicator*.

Proposal 7 – Stored carbon and carbon neutral products will be disclosed on NABERS Rating Certificates via a Carbon Removal Indicator; they will not be recognised within the star rating on the certificate

NABERS Rating Certificates will report on building products with stored carbon and carbon neutral certification via a Carbon Removal Indicator. This indicator will sit alongside the NABERS Embodied Emissions tool's star rating.

The amount of stored carbon in products and from carbon offsets within carbon neutral certified products will be disclosed separately to the NABERS Embodied Emissions tool star rating. The star rating will include the greenhouse gas emissions from all products used but will exclude any stored carbon or carbon offsets.

An example of what the Carbon Removal Indicator could look like is illustrated below. Note that the Carbon Removal Indicator is currently an early concept, and its design, including its name, calculation methodology and visual representation of results, will be finalised later in the rating tool development phase.

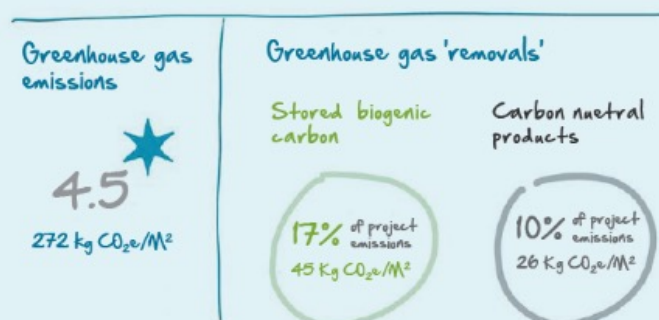


Figure 4.4.2: Example of how a Carbon Removal Indicator could look, based on the Renewable Energy Indicator

The stored carbon reported via the Carbon Removal Indicator will relate to a project's materials in relation to scope of works covered by the NABERS Embodied Emissions tool (see Section 4.3). This means that stored carbon occurring in A1-A5 is included at this time, and this includes stored biogenic carbon from timber. Cement re-carbonation is excluded from the calculation as it is outside the scope of life cycle stages considered in this tool. This will be reconsidered in conjunction with a review of life cycle stages as part of the NABERS Roadmap for Future Consideration (see Section 4.7). Stored carbon emissions reported in the Carbon Removal Indicator will be based on EPD data.

Carbon neutral products reported via the Carbon Reduction Indicator will relate to *building products* with carbon neutral certification, such as Climate Active Carbon Neutral. Only product level Carbon Neutral certifications are proposed to be recognised in this indicator.

NABERS Public Consultation 2023

New Zealand

The New Zealand Green Building Council, in an update to Credit 19 Life Cycle Impacts for its rating tool Green Star Design & As Built NZ v1.1 and Interiors NZ v1.1⁴¹, rewards projects that reduce upfront embodied carbon across module A1 to A5 (as per EN 15978). The methodology for calculating a building's upfront carbon emissions specifically excludes including the biogenic carbon stored in products such as wood.

A separate sub-credit (19.3 Long-term Carbon Storage) has been created that rewards carbon storage (through products such as wood) in the project.

For the allocated points to be awarded, projects must demonstrate a minimum level of atmospheric carbon storage for a forecasted period of at least 50 years. If these points are pursued, the long-term carbon storage must be calculated and reported separately from upfront carbon emissions calculations so as not to be included as a method of reduction.

The separation of carbon emissions from carbon removals (and carbon storage) is in line with the latest consultation documents produced by the New Zealand Government under its draft Building for Climate Change policy framework. As is the case in Australia for long-term carbon storage arising from wood sources, the wood products are required to be FSC®, PEFC, or Responsible Wood certified.

United Kingdom

The UK Royal Institution of Chartered Surveyors (RICS) has published a professional standards and guidance document for its members entitled Whole Life Carbon Assessment for the Built Environment⁴² that recognises carbon sequestration and biogenic carbon (Section 3.41) with the approach shown opposite and advises:

"Carbon sequestration must only be taken into account when the following criteria are met:

1. The whole life carbon assessment of the project includes the impacts of the EoL stage [C] and

2. The timber originates from sustainable sources (certified by FSC, PEFC or equivalent)."

"Where separate carbon sequestration figures calculated to EN 16449 are available from allowable data sources for the project-specific items, these can be used in the assessment. Otherwise, the carbon sequestered in timber elements should be based on the EN 16449 formula given."

Carbon sequestration must only be taken into account when the following criteria are met: 1. The whole life carbon assessment of the project includes the impacts of the EoL stage [C] and 2. The timber originates from sustainable sources (certified by FSC, PEFC or equivalent).

Robust audit trails in the timber supply chain will ensure that sufficient information is in place to support carbon sequestration reporting.

The biogenic carbon stored (sequestered) in timber elements must be calculated based on the formula provided in EN 16449:

$$P_{CO_2} = \frac{44}{12} \times cf \times \frac{\rho_w \times V_w}{1 + \frac{\omega}{100}}$$

P_{CO_2} : sequestered carbon dioxide – biogenic carbon oxidised at EoL

cf : carbon fraction of woody biomass (dry)

ρ_w : timber density at the given moisture content

V_w : timber volume at the given moisture content

ω : moisture content of timber product.

The default values to be used in the carbon sequestration calculations in the absence of more specific data for the timber element under study are as follows, according to EN 16449:

$cf = 50\%$; $\omega = 12\%$.

Whole Life Carbon Assessment for the Built Environment (rics.org)

8 Comparing embodied carbon in Australian buildings

8.1 Emissions footprints and substitution effects

Wood substitution is recognised as an important climate change mitigation strategy due to the benefits of carbon storage and substitution effects. For example, a meta-analysis of 51 LCAs found that using wood and wood-based products is often associated with lower fossil and process-based emissions compared to non-wood products. Determining a conclusive substitution factor for a given scenario in the construction sector is complex.

8.2 Embodied carbon comparisons in structural materials

Embodied carbon varies between materials, making material decisions key to achieving lower carbon buildings. There are several terms and concepts that need to be understood so that comparisons between alternatives result in material improvements.

8.2.1 Declared units

The embodied carbon emissions (GWP) associated with the production of construction materials (A1-A3 or cradle to gate) in Australia are often provided in Environmental Product Declarations (EPDs) by declared unit of production, e.g. kg, tonne, m³. Using declared units in EPDs for side-by-side comparisons to inform materials selection can be problematic. Materials comparisons using EPDs must consider equivalent functionality and contribution to overall building impacts for comparisons to be fair and meaningful.

For timber, the embodied carbon emissions for sawn softwood and hardwood products, aggregated from the WoodSolutions EPDs, are as follows.

Product	Embodied Emission Factor kgCO ₂ e/unit	Declared Unit	Embodied Carbon Emissions Biogenic kgCO ₂ e	Stored Biogenic Carbon kgCO ₂ e
Softwood, kiln-dried, dressed, (No Biogenic Carbon inclusion)	157	m ³	-875	-900
Softwood, kiln-dried, dressed, (Including Biogenic Carbon)	-718	m ³		
Hardwood, rough-sawn, green (unseasoned) (No Biogenic Carbon inclusion)	151	m ³	-851	1,114 ¹⁶
Hardwood, rough-sawn, green (unseasoned) (Including Biogenic Carbon)	-700	m ³		
Hardwood, rough-sawn, kiln-dried (seasoned) (No Biogenic Carbon inclusion)	209	m ³	-1,100	1,221 ¹⁶
Hardwood, rough-sawn, kiln-dried (seasoned) (Including Biogenic Carbon)	-891	m ³		
Hardwood, kiln-dried, dressed (No Biogenic Carbon inclusion)	327	m ³	-1,060	-1,220
Hardwood, kiln-dried, dressed (Including Biogenic Carbon)	-733	m ³		

Embodied carbon emissions for a range of engineered timber products, aggregated from the WoodSolutions EPDs, are as follows.

Product	Embodied Emission Factor kgCO ₂ e/unit	Declared Unit	Embodied Carbon Emissions Biogenic kgCO ₂ e	Stored Biogenic Carbon kgCO ₂ e
Softwood glulam (No Biogenic Carbon inclusion)	380	m ³	-992	-1017
Softwood glulam (Including Biogenic Carbon)	-612	m ³		
Hardwood glulam (No Biogenic Carbon inclusion)	527	m ³	-935	-1118
Hardwood glulam (Including Biogenic Carbon)	-408	m ³		
Particleboard (No Biogenic Carbon inclusion)	12.10	m ³	-19.30	-10.60
Particleboard (Including Biogenic Carbon)	-7.23	m ³		
Plywood (No Biogenic Carbon inclusion)	3.80	m ³	-6.98	-7.20
Plywood (Including Biogenic Carbon)	-3.18	m ³		
MDF (Medium Density Fibreboard) (No Biogenic Carbon inclusion)	10.30	m ³	-19.60	-19.80
MDF (Medium Density Fibreboard) (Including Biogenic Carbon)	-9.29	m ³		

The embodied carbon emissions (Australian data) for frequently compared structural materials such as steel, concrete and engineered timber products are provided in Table 8.1. The data has been reproduced from the quoted EPDs, and should be interpreted with care due to the mix of declared units in the table.

Table 8.1: Embodied Carbon (A1-A3) of steel, concrete and timber elements (Declared Unit). Thinkstep-anz

Product	Declared Unit	Embodied Carbon emissions fossil: kgCO ₂ -eq (GWPF)	Embodied Carbon emissions biogenic: kgCO ₂ -eq (GWPB)	Stored biogenic carbon: kgCO ₂ -eq	Data sources (all EPDs compliant with EN 15804)
Structural steel - welded beams and columns	kg	2.75	0	0	EPD S-P-00559 v2.0 (Page 15)
Structural steel - structural sections	tonne	3.72E+03	0	0	EPD S-P-00856 v1.1 (Table 4)
Concrete normal GP/fly ash blend	m ³	260	0	0	EPD S-P-02336 v1.0 (Table 3)
Concrete - normal class GP blend	m ³	314	0	0	EPD S-P-02336 v1.0 (Table 1)
Steel - reinforcing mesh	tonne	2.06E+03	0	0	EPD S-P-00858 v 1.1 (Table 8)
Engineered timber - AU Softwood glulam	m ³	380	-992	-1020	EPD S-P-00565 v1.0 (Table 4)
Engineered timber - NZ Radiata pine glulam	m ³	136	-804	-809	EPD S-P-00997 v1.1 (Table 24)
Engineered timber - AU Cross-laminated timber	m ³	447	-740	-779	EPD S-P-02326 v1.0 (Table 4)
Engineered timber - NZ Cross-laminated timber	m ³	65.9	-780	-786	EPD S-P-03711 v1.0 (Table 5)

8.2.2 Functional comparison – whole building

The most useful and objective comparisons are made between functionally equivalent whole building designs across the whole life cycle of the project.

Such a comparison should account for the different requirements each design must satisfy – whether that be aesthetic value or function, such as beam spacing, total floor area, different loads the structure must resist, as well as fire, thermal and durability performance requirements. As timber structures are often lighter than comparable reinforced concrete structures, effort should be put on ‘right-sizing’ the foundations, as foundations commonly account for a significant proportion of the embodied carbon footprint of the whole building.

Strictly speaking, accounting for embodied carbon should be done across the whole life cycle of a building. That is construction, use (including maintenance and replacements) and end-of-life treatment of each element (a cradle-to-grave assessment).

In practice, at the design stage many practitioners just compare the production stage (A1-A3 cradle-to-gate) impacts of materials. Increasingly this is extended to cover A4 transport to site and A5 construction process including site wastage (A1-A5 cradle-to-practical-completion). This allows Australian and international products to be compared fairly.

9 Designing to carbon zero

Net zero carbon is a term widely used in the building industry and typically refers to a building which is highly energy efficient in operation (i.e. the amount of carbon dioxide emissions released on an annual basis is zero or negative on a net (calculated) basis).

The term **carbon neutral** is typically used in the context of operational carbon only, though with increasing interest in embodied carbon this is likely to change over time.

The terms **carbon positive** and **carbon negative**, and more recently **climate positive**, are all used in different parts of industry, with all intended to refer to a state of 'better than carbon neutral'.

9.1 Pathways to reduce embodied carbon

Minimising upfront carbon is vitally important. Opportunities to reduce or eliminate embodied carbon can usually be maximised at the planning stages of a project and become more challenging and costly as the project moves beyond final design and into construction (see Figure 9.1). Reducing embodied carbon throughout the life cycle of a building requires careful consideration of the following factors⁴⁵ throughout the planning, design, construction, operation and decommissioning stages of a built asset.

Prevention: Consider embodied carbon emissions and reduction strategies from the outset. Explore options to reuse or optimise existing construction to deliver the same function as a new build, thereby reducing or eliminating the embodied carbon emissions associated with it.

Reduction: Evaluate design choices in terms of upfront emission reductions. Tools and data (such as EPDs) for calculating embodied carbon make it possible to calculate embodied carbon upfront and use low embodied carbon materials to 'reduce and optimise' these emissions and avoid waste generation.

Building 'smarter': Prioritise materials and systems that are low or zero carbon, responsibly sourced, and which have low life cycle impact in other areas.

End-of-life impacts: Consider future use/reuse scenarios and end of life, including repair, renovation, and flexibility for future adaptation to help in further reducing the embodied carbon emissions in the later stages of a project. Consider designing for disassembly and deconstruction, selecting materials that can be extracted and separated easily for reprocessing.

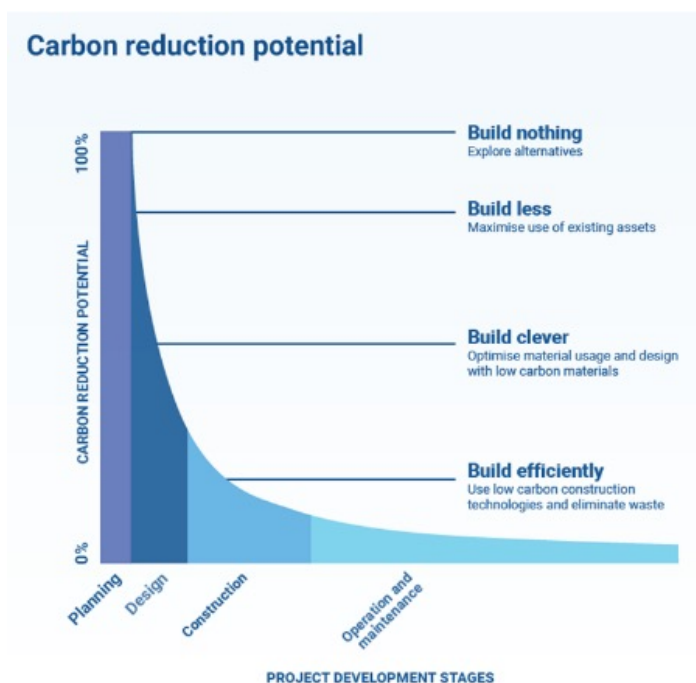


Figure 9.1: Opportunities to reduce embodied carbon from stage of design process⁴⁶.

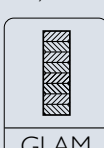
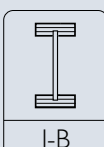
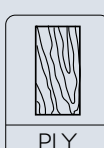
9.2 An engineered timber future

Wood is a fundamental construction material for a low-carbon future. Mass timber construction – using a defined category of engineered wood products (EWPs) such as cross-laminated timber (CLT), glued laminated timber (glulam), mass plywood and others – is becoming more common, with prominent examples of hybrid and tall wood buildings and infill and overbuilds present in many major cities.

Multi-layer laminated products are uniform and technically predictable and can compete with steel and concrete in increasingly demanding applications. The engineered timber products on the market are lightweight, yet very strong, with good seismic and thermal performance.

A wide range of engineered wood products (EWPs) and prefabricated timber systems exist the following provides a summary with typical acronyms⁴⁷.

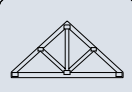
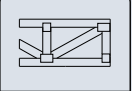
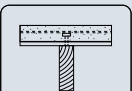
Table 1.1: Commonly used structural sawn and engineered wood products in mid-rise timber construction.
(see also WoodSolutions Technical Design Guide #46 Guide to Wood Construction Systems).

Product	Description	Common Application	Common grades	Common typical dimensions	Other
Seasoned softwood  SW	Structural sawn timber mainly pine species	Wall framing for upper storeys, non-loadbearing walls, truss elements	MGP10, MGP12 (AS 1720.1)	Lengths up to 6 m Depths: 70,90,120,140,190 Thick: 35, 45 mm	Treated available MC <15%
Seasoned hardwood  HW	Structural sawn timber from hardwood species	Wall framing for middle to lower storeys, high strength wall plates and truss elements	A17, F17, F27 (AS 1720.1)	Lengths up to 6 m Depths: 70,90,120,140,190 Thick: 35, 45 mm	Treated available MC <15%
LVL (Laminated veneer lumber)  LVL	Manufactured by gluing thin veneers with grain parallel to form beams or panels. Cross-banded LVL has a limited number of layers with grain perpendicular to the main grain direction	Wall and floor framing; billets can be glued together for use as panels in cores or floors.	Manufacturers' information	Lengths up to 12 m Panel (billet) width 1.2 m typ 2.5m max available Depths: 95–400 mm typical Thick: 35,45,63,75 mm	Treated available MC <15%
GLT (Glued laminated timber)  GLAM	Manufactured by gluing sawn timber laminates with grain parallel to form beams and columns	Beams and columns in post and beam construction	GL grades (AS 1720.1)	Lengths: 12 m stock, 27 m spec. Depths: variable 195–1,000 mm Thick: 65, 85, 115, 135 mm (typ)	Treated available MC <15% Camber possible
I-Beams  I-B	Top and bottom flanges from sawn timber or LVL, glued to webs made from light gauge steel, plywood or OSB	Floor joists and floor cassettes	Manufacturers' information	Lengths: 8.4 m typ, 12.6 m spec. Depths: 200,240,300,360,400 Thick Flange: 45, 51, 63, 90 mm	Treated available
Plywood  PLY	Manufactured by gluing thin veneers with alternate grain directions to form sheets	Bracing panels, flooring	Manufacturers' information	Panel lengths 2.4, 2.7 m Panel width 1.2 m, Thick: 3, 4, 6, 7, 12, 13, 15, 17, 19, 21, 25 mm	Treated available MC <15%
OSB (Oriented strand board)  OSB	Manufactured by gluing and pressing timber flakes to form sheets	Bracing panels, flooring	Manufacturers' information	Panel lengths 1.2 m Panel width: 2,440, 2,745 mm Thick: 9.5, 18.5 mm	

Recommendations: Only use seasoned structural timber in mid-rise buildings as it more dimensionally stable than unseasoned timber. At the preliminary design stage, it may be useful to provide timber sizing in more than one grade or size to provide flexibility to the fabricator for pricing.

Designers should discuss the availability of grades and sizes with suppliers and fabricators before specifying products in the design. The availability of products varies between states and will change over time.

Table 1.2: Prefabricated timber systems used in mid-rise timber construction (see also WoodSolutions Technical Design Guide #46 Guide to Wood Construction Systems).

Product	Description	Common mid-rise application	Common dimensions	Typical Spans (2kPa LL)	Source of supply
Nailplate trusses triangular  NPTR	Engineered trusses utilising lightweight framing (35, 45 mm thick) and nailplate connectors	Roof systems	Up to around 3 m in depth	25 m+	Frame & truss sector
Nailplate trusses parallel chord  NPTR	Engineered trusses utilising lightweight framing (35, 45 mm thick) and nailplate connectors	Floor systems (singularly laid or utilised in floor cassettes)	Typically, up to 12 m long* Depths 150 mm to 550 mm	Fl joists, 450crs, 2 kPaLL 300mm deep: 5.5m 400mm deep: 6.0m	Frame & truss sector
Cassette floor panels  CASSETTE	Prefabricated engineered elements using floor joists or trusses overlain by timber flooring	Floor systems (very quick to install and safe)	Typically, up to 12 m long* 3 m wide* Depths 300-550 mm	Span/depth: 15–18 4-8 m	Frame & truss sector, speciality builders
Timber-timber composite floors  SOLID	Prefabricated floor cassettes using a heavy timber floor slab (and/or ceiling) connected compositely to floor joists	Floor Systems	Typically, up to 12 m long* 3 m wide* Joist depth 150–600 mm	Span/depth: 12–20 6-9 m	Frame & truss sector, speciality builders
Timber-concrete composite floors (TCC)  T-CONC	Composite timber-concrete floor (conc acting in compression, timber in tension), connected by shear studs/keys	Floor Systems	Joist depth 150–600 mm Cast-in-situ or prefab	Span/depth: 12–20 5–10 m	Specialty builders
Nail laminated timber (NLT)  NLT	Sawn timber nailed together to form larger mass panel elements	Floor systems, wall systems, shafts and cores	Typically, up to 12 m long* 3 m wide* 75–300 mm thick	Span/depth: 24–30 4–7m	Frame & truss sector, speciality builders
Cross laminated timber (CLT)  CLT	Mass wood panels made by gluing layers of timber with the grain direction of alternating layers at right angles	Floor systems, wall systems, shafts and cores	Typically, up to 12 m long 3 m wide* 50 mm – 500 mm thickness	Span/depth: 24–30 4–7m	CLT manufacturers, speciality builders

While building and design professionals continue to evolve and advance its potential, mass timber construction can be grouped into three main trends⁴⁸:



Hybrid Construction

Combining wood and concrete or steel in hybrid construction provides a cost-effective and sustainable solution for many occupancy types and can improve building performance and design.



Tall Wood

The NCC permits construction to a height of 25 metres when using fire-protected timber building systems. Taller mass timber buildings have been constructed in Europe and North America since the mid-2000s.



Overbuilds and Infills

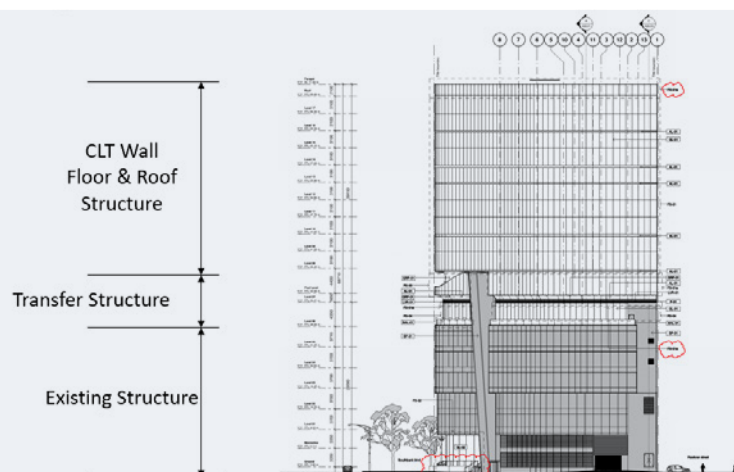
To address urban densification, overbuilds can provide additional stories on top of an existing building. Infills allow development of vacant lots surrounded by existing buildings.

Recent Australian analysis suggests the use of mass timber construction methods can cut as much as 75% in embodied carbon emissions compared with conventional steel and concrete designs⁴⁹. On the back of this research, the Clean Energy Finance Corporation (CEFC) has launched a \$300 million program to encourage mass timber construction across the property sector.

9.3 Lightweight timber design

Reducing the amount of material necessary to deliver a built asset is an important strategy to reduce embodied carbon. Lightweighting with timber and timber-composite structures offers significant opportunities to reduce emissions, particularly in existing urban environments.

Lightweight timber buildings and extensions can enable development where heavier conventional buildings are unviable. As population density increases in existing urban environments, building with engineered timber and timber-hybrid solutions make it possible to build on marginal sites, over or under existing buildings; and partially or completely replace existing buildings with a more densely occupied, taller, building.



55 Southbank, vertical extension, Melbourne, Victoria. Image source: Atelier Projects

Lightweight timber design often requires smaller foundations, which reduces a project's seismic loads and carbon footprint. For example, the seven-storey mass timber T3 Building in Minneapolis is 30% lighter than its equivalent in steel would have been and 60% lighter than post-tensioned concrete⁵⁰.

Timber buildings are lighter than concrete buildings or steel buildings with concrete decking and are lighter still where supplementary non-structural concrete mass is designed out. The bulk density (a useful basis for comparison that is determined by the gross building volume divided by dead load) of a typical concrete multi-storey building is $\sim 300 \text{ kg/m}^3$ compared to a conventional steel building with concrete decking at $\sim 160 \text{ kg/m}^3$. The glue-laminated timber mega-frame, 14-storey Treet building in Norway has an estimated bulk density of $\sim 140 \text{ kg/m}^3$ while the CLT seven-storey UEA building in the United Kingdom has an estimated bulk density of $\sim 126 \text{ kg/m}^3$. Significant supplementary non-structural concrete is included in the design of each building, with slabs of concrete ballast added to Treet, and concrete screed topping the floors at UEA. Without this supplementary concrete mass, the building densities would reduce to $\sim 110 \text{ kg/m}^3$ and $\sim 79 \text{ kg/m}^3$ respectively⁵¹.

9.4 Recycling and end-of-life options for timber buildings

An estimated 848 kilotonnes (kt) of timber waste was sent to Australian landfills in 2019⁵². Given the volumes of wood products being disposed of in landfills, much more recovery and reuse could take place.

Reuse and recycling of end-of-life timber can be problematic in some cases due to non-wood chemical components. However, some untreated wood (pre- and post-consumer) is incorporated into new wood products such as medium density fibreboard, particleboard and wood-plastic composite materials. Finger jointing and lamination also allows wood 'waste' to be recycled into new useful products.

The uptake of mass timber construction poses some questions about the end-of-life uses, given synthetic adhesives and chemicals makes recycling into biofuel and incineration for bioenergy unattractive. However, construction wood in general (and engineered wood in particular) can be dismantled relatively easily as it is used in layers, often used in modular assemblies (in standard dimensions) and is light-weight.

Careful, 'smart' design at the architectural and engineering design stages of a building's life can maximise end-of-life options for the various components. An analysis of wide-span timber roof structures showed that a sizeable amount of engineered wood can be reclaimed for a second-use phase⁵³. The authors recommend various considerations in the planning phase for new timber structures to extend the life cycle of the product:

- ***Design for reuse – consider modularity of the structural system and components.***
- ***Prefabrication – the replacement of single layers is possible through straight joints, so recycling becomes much easier.***
- ***Consider fixings and connecting devices.***
- ***Avoid composite materials and toxic substances.***
- ***Keep information about the building system through a building passport or sustainability certification.***

European policy encourages bio-based materials such as wood to be used according to their highest economic and environmental added value in the following order of priorities:

- ***Avoidance, which can take the shape of extended service life or as-a-service models***
- ***Regenerative sourcing***
- ***Re-use and composting***
- ***Remanufacturing and repair***
- ***Recycling – followed by downcycling***
- ***Energy recovery***
- ***Disposal.***

This 'cascading' approach has not been adopted as a policy in Australia, however there is growing interest in extending product life or providing a proper end-of-life recovery.

Case Study 3: T3 Collingwood



Architect: Jackson Clements Burrows Architects

Engineer: AECOM

Builder: Icon Construction

Developer: Hines

Completion: 2023

*Image credits:
T3 Collingwood, Hines*

T3 Collingwood⁵⁴ embodies character and sustainability with recycled construction materials and timber construction. The 18,000 m² precinct is in the inner-city suburb of Collingwood and is part of a broader trend towards developing institutional-grade assets on the outer fringe of cities. AECOM applied its structural and environmentally sustainable design skills, to reduce carbon emissions through a different approach to traditional structural engineering, designing an aggregation of buildings that celebrates the precinct's industrial past and modern future.

Inspired by the environmental benefits and versatility of timber, the companion building de-scales the entire precinct and was constructed using glue laminated timber (glulam - Australian Sustainable Hardwoods ASH Masslam) beams and cross laminated timber (CLT - XLam) flooring. The engineered timber has a lower carbon footprint than traditional building materials and is sourced from certified sustainably managed forests. It also allowed for precise offsite prefabrication and safer, cleaner and quieter onsite construction.

Using a life cycle assessment (LCA) comparative study completed in line with ISO 14040:2006, ISO 14044: 2006 and EN15978:2011, for the purpose of Green Star, it is calculated that the project has saved 47,400 tonnes of embodied carbon. The LCA study has demonstrated a 34% reduction of CO₂ equivalents via the decisions made as part of the design process. This is equivalent to taking about 10,300 cars off the road for a year or, alternatively, the annual emissions of 2,800 typical Australian households.



10 Timber, technology and carbon efficiency

10.1 Design software and digital fabrication

Digital fabrication is used in timber construction, with entire elements able to be fabricated by computer-aided systems.

Engineered mass timber products are dimensionally consistent and can be cut and shaped precisely by computer numerically controlled (CNC) equipment. Computerised factories produce mass timber products with consistent physical properties while optimising the use of forest resources. The industrial output per unit of wood input has increased by 40% over the last 50 years, resulting in a higher percentage of wood fibre manufactured into a building component.

Due to the off-site digital fabrication of mass timber building components, there is little to no waste once they arrive at the construction site.

10.2 Standardised, modular and prefabricated components

Mass timber building technology has fostered a growing interest in design for manufacturing and assembly (DfMA) and modular and off-site construction (MOC). These modular timber construction technologies provide various benefits, including high-quality assets that are easy to renovate and maintain, and have shorter construction timeframes, reduced on-site labour costs, re-use options and reduction in construction waste.

As the substructure, superstructure and façade make up the bulk of upfront carbon, reducing structural mass with DfMA timber and steel hybrid assemblies provides a real opportunity to lower the embodied carbon in buildings.

The use of DfMA and MOC, when compared to traditional building methods has been shown to lower embodied emissions over the lifetime of the asset. The upfront carbon emissions on a recent DfMA prototype were modelled at 80% less than conventional construction⁵⁵ and a study of embodied emissions during the materials production phase of a multi-unit residential building suggested a reduction up to 36% in embodied carbon emissions can be achieved where MOC is substituted for reinforced concrete construction⁵⁶.

The limited experience of the application of prefabrication in multi-storey and high-rise projects and the tendency to associate prefabrication with low quality have been barriers to DfMA and MOC uptake. However, as the uptake of digital technologies and the principles of designing for net zero become normalised, quality timber DfMA and MOC systems that maximise the long-term storage of carbon and lower embodied carbon in buildings will feature strongly.



Modular wall panels delivered to site, Phoenix Building, Sydney, NSW. Image source: TPCSolutions

11 Carbon reduction and embodied carbon policies

11.1 Australia's carbon reduction obligations

As a party to the Kyoto Protocol and Paris Agreement, Australia committed to reducing its GHG emissions, tracking progress towards those commitments, and reporting each year on Australia's GHG emissions. The National Greenhouse Gas Accounts track progress and assess compliance with Australia's emission reduction commitments. Reports summarising Australia's national emissions are published quarterly via the National Greenhouse Gas Inventory (NGGI).

11.2 Australia's carbon reduction policies

In 2021, Australia published a whole-of-economy Long Term Emissions Reduction Plan with an aim of achieving net zero emissions by 2050. It does not explicitly address upfront emissions in the building and construction sector, although investment in low emissions technologies are the cornerstone of the plan and low emission steel, aluminium and cement are mentioned.

The Australian Government is also leading the 'Trajectory for Low Energy Buildings', a national plan that aims to achieve zero energy and carbon-ready buildings in Australia.

Following a change of government in 2022, the Senate passed the Climate Change Bill, which legislates Australia's greenhouse gas (GHG) emissions reduction targets, being a 43% reduction from 2005 GHG levels and net zero by 2050. The Bill is not a detailed plan to address economic or industrial opportunities in the race to net zero. It does not include a mechanism to cut emissions from electricity, industry, transport, or agriculture.

However, the Government has indicated that it is separately working on a range of policies and programs to drive emissions reduction. The Bill is complemented by the Climate Change (Consequential Amendments) Bill 2022 which will require some Commonwealth Government agencies to consider Australia's emissions reductions targets as part of their functions. This includes the Australian Renewable Energy Agency, the Clean Energy Regulator, CSIRO and the Northern Australia Infrastructure Facility.

All Australian state and territory governments are now committed to net zero emissions by 2050 or earlier. These commitments cover all emissions produced within Australia's borders. Most states and territories have also set interim emissions targets.

11.3 NSW Government Accelerating Net Zero Buildings

In 2021, the New South Wales Government announced funding for the National Australian Built Environment Rating System (NABERS) to develop a framework for measuring, benchmarking, and certifying emissions from construction and building materials.

The framework is being designed with the aim to be incorporated into NABERS, and to align with other widely used industry standards, such as Green Star. The Accelerating Net Zero program will also include NABERS initiatives to drive new buildings towards high energy performance and reduce emissions in existing buildings.

Scheduled to be completed by June 2023, the framework will initially be rolled-out to commercial buildings including offices, hotels, shopping centres and warehouses, with a view to expand to residential buildings in the future.

11.4 NZ Whole-of-life Embodied Carbon Emissions Reduction Framework

In New Zealand, the Building System Performance (BSP) Branch of the Ministry of Business, Innovation and Employment (MBIE) is in consultation with the building and construction sector to develop a program to reduce carbon emissions in line with the national commitment to net zero emissions by 2050. To achieve this, the MBIE proposes to regulate the embodied carbon of buildings through mandatory reporting for building projects, to raise the sector's awareness of the impacts of embodied carbon. The embodied carbon data collected will be stored in a national repository, to enable greater understanding of the relative impacts of different buildings. When a sufficient level of understanding is in place, the first set of embodied carbon caps for buildings will come into force. These caps will tighten over time.

11.5 Outlook for embodied carbon reduction policies

The past five years has seen embodied carbon and LCA become a standard feature of commercial as well as governmental green building systems.

The first regulatory limits for LCA-based materials impacts such as embodied carbon are emerging in Europe and some US states such as California. The direction of regulatory development is to be able to regulate embodied carbon in the same way as energy efficiency ratings, using standardized calculation methods and cost-efficient, transparent processes.

Voluntary green building certification systems are becoming more demanding in terms of methodology of the embodied carbon and LCA methods applied. This move is motivated by the need to have a vigorous basis to rate projects based on carbon performance.

12 Green building and infrastructure certifications

12.1 Australian green building certifications

Australian building regulations mandate energy efficiency performance standards for new construction, with tools for calculating and minimising embodied carbon limited to elective green building certifications such as Green Star. While minimum energy efficiency standards have been effective in reducing operational carbon in buildings, they do not prevent emissions-intensive materials from being used to construct energy efficient buildings, negating much of the benefit of energy efficiency gains. Ensuring that embodied carbon is represented in Australian building regulations will be critical to decarbonising Australia's buildings, as operational carbon is reduced through grid decarbonisation and embodied carbon grows in importance as a proportion of total emissions.

12.1.1 Energy rating certification

Mandatory energy efficiency ratings certifications such as the Nationwide House Energy Rating Scheme (NatHERS) and the National Australian Built Environment Rating System (NABERS) have operated in Australia for some time and are used to demonstrate compliance with National Construction Code (NCC) energy efficiency requirements in residential and commercial buildings respectively. The tools have been effective in driving energy efficiency improvements in built assets. At the time of writing, a NABERS embodied carbon rating tool for buildings is under development.

The mandatory NSW online BASIX assessment tool (developed to assess the energy and water use and thermal comfort of residential homes) has recently proposed higher standards and a materials index to assess environmental impacts of materials in its rating system. The index can be used to meet an embodied carbon reduction target, which will increase over time.

12.1.2 Green Star Buildings and the Responsible Products Framework

In 2021, significant changes were made to the Green Star rating system with the release of the Green Star Buildings tool. All new Green Star rating tools include or will include an Upfront Carbon Emissions credit. The credit aims to reduce upfront carbon emissions of a proposed building, when compared against a benchmark or a reference building in Australia.

Green Star Buildings includes a revised and expanded framework that includes a greater social awareness, increased stringency for the highest rating, and an increased focus on reducing carbon emissions.

Developed to help the supply chain evolve to address embodied carbon in building products, the GBCA's Responsible Products Framework rewards products that have lower environmental impact, are transparent, respect human rights, and are taking action to reduce carbon content.

12.1.3 The IS rating scheme

The Infrastructure Sustainability Council's IS Design and As-Built rating tool is applied during the design and construction phases of a project, and considers the full asset life cycle, including operation and decommissioning. Embodied carbon is assessed in the materials category of the tool.

13 Tools and process LCA databases

13.1 Carbon measurement tools

Historically, building LCA and building carbon footprinting was performed by a small number of LCA and carbon footprinting specialists. These studies were performed in LCA expert tools, such as SimaPro and GaBi. In the past 3-5 years, a much wider range of building professionals have started performing LCAs of buildings, enabled by software tools focused specifically on LCA of buildings, e.g. eTool, One Click LCA, Tally and EC3. An overview of established tools which use Australasian data is provided in Table 13.1.

Table 13.1: Carbon measurement tools.

Software	Data Source	BuildingTypology	Skill Level
EC3	Verified EPDs AusLCI	Precinct, Commercial Infrastructure, Fitout	Moderate
e-ToolLCD™	Verified EPDs AusLCI	Precinct, Whole Building Fitout	Moderate
GaBi	Verified EPDs, Sphera databases	Precinct, Building Fitout	Advanced
OpenLCA	Verified EPDs, AusLCI, Ecoinvent	Precinct, Whole Building Fitout	Advanced
One Click LCA	Verified EPDs	Precinct, Whole Building Fitout	Moderate
SimaPro	Verified EPDs, AusLCI, Ecoinvent	Precinct, Whole Building. Fitout	Advanced

13.2 Databases

EPD Australasia, The International EPD® System, ECO Platform

EPDs serve as readily available, independently verified sources of information which provide objective environmental data and explain the impacts of production processes. They are process-based and universally recognized as a means of communicating environmental performance claims.

Process-based LCA data is also available from several databases, including AusLCI, Ecoinvent and GaBi.

Glossary of carbon terms

Term	Definition
Absolute Zero Carbon	Achievement of zero carbon/GHG emissions, using a whole-of-life basis or other defined boundary, without any carbon offsets or other compensation mechanisms.
Anthropogenic	Relating to or resulting from the influence of human beings on nature.
BECCS	Bioenergy Carbon Capture and Storage: CCS from burning biomass.
Bioeconomy	Production of renewable biological resources and their conversion into food, feed, bio-based products and bioenergy.
Biogenic carbon	Carbon sequestration into biomass, including natural building materials (e.g. timber) as well as any emissions associated with this sequestered carbon.
Biomass	Material of biological origin excluding material embedded in geological and/or fossilized formations.
Bioenergy	Energy generated from biomass, such as electricity or heat.
Biofuel	An alternative fuel that is developed from biological, natural, and renewable sources. Biofuels are an attractive option due to their high energy density and convenient handling and storage properties. Biofuels can be used on their own (with some precautions or restrictions) or blended with petroleum fuels.
Carbon (C)	Carbon is by definition a non-metallic chemical element, with the symbol 'C' and the atomic number 6 that readily forms compounds with many other elements and is a constituent of organic compounds in all known living tissues (including wood).
Carbon Capture and Storage (CCS)	Capture and storage of carbon (greenhouse gas) emissions from industrial processes by injecting the captured greenhouse gases back into the ground for permanent storage.
Carbon dioxide (CO₂)	A naturally occurring gas, CO ₂ is also a by-product of burning fossil fuels (such as oil, gas and coal), of burning biomass, of land-use changes (LUC) and of industrial processes. It is the principal human produced (anthropogenic) GHG that affects the Earth's radiative balance. It is the reference gas against which other GHGs are measured and therefore has a global warming potential (GWP) of 1.
Carbon dioxide equivalents (CO₂-eq)	A measure that quantifies the global warming effect of different greenhouse gases in terms of the amount of carbon dioxide (CO ₂) that would deliver the same global warming effect.
Carbon emissions	An industry term that refers to greenhouse gas (GHG) emissions. Not all GHG emissions contain carbon.
Carbon footprint	The total carbon emissions caused by an organisation, event or product in a given time frame.
Carbon negative	See carbon positive.
Carbon neutral	Balanced between emitting carbon and absorbing carbon from the atmosphere in carbon sinks.
Carbon offsets	An action intended to compensate for carbon emissions, meeting criteria as part of a commercial scheme.
Carbon positive	A city, development, building, or product that goes beyond being Carbon Neutral to intentionally remove CO ₂ from the atmosphere and turns it into useful forms (also referred to as 'carbon negative').
Carbon reduction plan or framework	A government or organisation's plan or framework for achieving the GHG Emissions reductions it has committed to including actions and milestones.
Carbon sequestration	The process of removal and storage of CO ₂ from the atmosphere in carbon sinks (such as forests, woody plants, algae, kemp, mangroves or soils).

Term	Definition
Carbon sink	Carbon sinks are forests and other ecosystems that absorb carbon, thereby removing it from the atmosphere and offsetting CO ₂ emissions.
Carbon storage	Carbon sequestered from the atmosphere and stored in wood or other ecological or artificial sinks. Carbon stored in harvested wood products changes with time based on the product, age and decay rates.
Certified wood	Certified wood is one where the wood used has been verified as harvested in a sustainable way – including the impact of harvesting on the surrounding environment in terms of protecting the biodiversity of an area, erosion control and preserving water resources. The wood has been certified to a recognised forest certification scheme such as FSC®, PEFC or Responsible Wood.
Cradle to Gate	The scope of measurement of impacts in an LCA or Carbon Footprint from raw material acquisition to a finished product at the exit gate of the manufacturing facility
Cradle to Grave	The scope of measurement of impacts in an LCA or Carbon Footprint across the entire lifespan of the product, from raw material acquisition through to final disposal, reuse or recycling.
Embodied carbon	Carbon emissions associated with materials and construction processes throughout the whole life cycle or a building or infrastructure, excluding operational energy.
Embodied energy	The total energy necessary for an entire product life cycle, including both non-renewable and renewable energy.
Emission factors	Emission factors are used to convert a unit of activity into its emissions equivalent (e.g. a factor that specifies the kilograms of CO ₂ -eq emissions per unit of activity).
End of Life carbon	The carbon emissions which occur after an asset's lifetime – whether associated with deconstruction/demolition, transport from the site, waste processing, or disposal
Environment Product Declaration (EPD)	An independently verified and registered document that communicates transparent and comparable information about the life-cycle environmental impact of products and services in a credible way. An EPD is compliant with the standard ISO 14025 and is a Type III environmental declaration.
Forest carbon stock	Forest carbon stock is the amount of carbon that has been sequestered from the atmosphere and is now stored within the forest ecosystem, mainly within living biomass and soil, and to a lesser extent also in dead wood and litter.
Global Warming Potential (GWP)	The Global Warming Potential (GWP) of a greenhouse gas is its ability to trap extra heat in the atmosphere over time relative to carbon dioxide (CO ₂).
Greenhouse gases (GHG)	Greenhouse gases are those gaseous constituents of the atmosphere, both natural and anthropogenic, which cause the greenhouse effect, as detailed in the IPCC Glossary. Carbon dioxide (CO ₂), nitrous oxide (N ₂ O), methane (CH ₄), ozone (O ₃) and water vapour (H ₂ O), are the primary GHGs in the Earth's atmosphere. GHG emissions are often referred to as 'carbon emissions' in general usage.
Life cycle assessment) or analysis (LCA)	An analysis of the environmental and/or social impacts of a product, process or a service for its entire life cycle. It looks at the raw material extraction, production, manufacture, distribution, use and disposal of a product.
Net Zero Carbon	A calculated result of zero carbon emissions, including netting of inward and outward flows of GHG, the use of carbon offsets or other compensation mechanisms.
Operational Carbon	GHG emissions arising from all energy consumed by an asset in-use, over its life cycle.
Process-based LCA	The starting point for Process LCA is the unit process: a single process (typically a manufacturing process) that transforms inputs into outputs. Process LCA is the aggregation of these different unit processes to create an often-complex production chain. An inventory is compiled by summing together the resource use, energy use, and emissions incurred through every step in a product's life cycle. This inventory is then multiplied by characterisation factors (emission factors) to calculate potential impacts on the environment, such as the product's contribution to climate change.

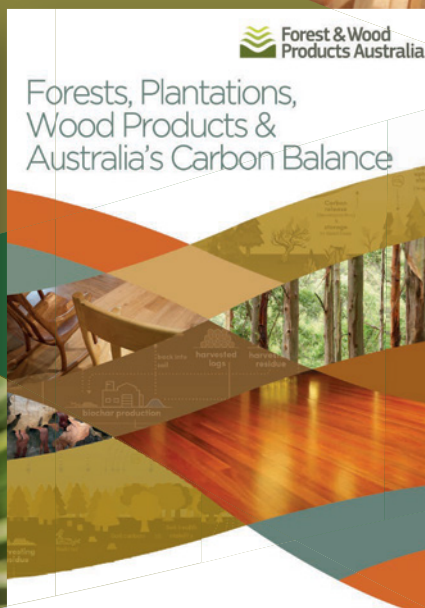
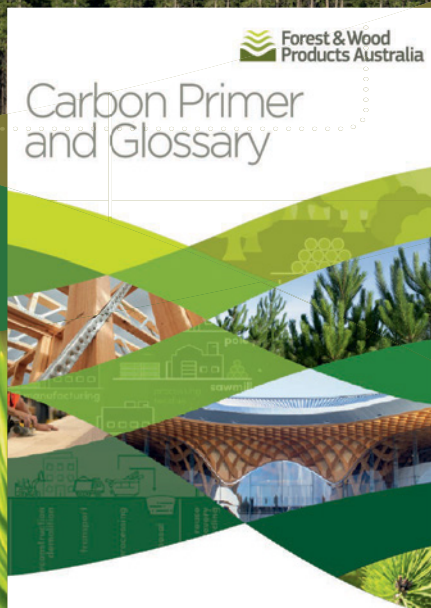
Term	Definition
Scope 1, 2 & 3 emissions	A term used in relation to organisation-wide carbon emissions. Scope 1 emissions are direct emissions from owned or controlled sources. Scope 2 emissions are indirect emissions from the generation of purchased energy (electricity, heat, steam, heating, cooling sources) consumed by the reporting company. Scope 3 emissions are all indirect emissions (not included in scope 2) that occur in the value chain of the reporting company, including both upstream and downstream emissions.
Upfront Carbon	The emissions caused in the materials production and construction phases (modules A1-A5) of the life cycle before the building or infrastructure begins to be used.
Whole of Life Carbon	Whole Life Carbon emissions are the sum total of all asset-related GHG emissions and removals, both operational and embodied over the life cycle of an asset including its disposal.

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