Australian buildings and infrastructure:

Opportunities for cutting embodied carbon

Industry report

About this report

This report has been prepared for the Clean Energy Finance Corporation in collaboration with the Green Building Council of Australia and the Infrastructure Sustainability Council.

It provides practical guidance and cost analysis on potential options for reducing embodied carbon, to support asset owners, investors and developers in understanding how embodied carbon can contribute to the achievement of their emissions reduction ambitions. This report has been developed by Edge Environment, which specialises in third party life cycle assessment, carbon and sustainable building and infrastructure. It draws on project data from the GBCA Green Star and ISC Infrastructure Sustainability Rating Schemes, complemented by extensive modelling and industry discussions. Edge Environment acknowledges the important contribution of existing analysis from ClimateWorks Australia, Lendlease, the NSW Chief Scientist and the World Green Building Council.

Prepared for:

cefc

Supported by:

Green Building Council Australia

Infrastructure Sustainability Council

Contents

From CEO Ian Learmonth

With the release in 2021 of the Sixth Assessment Report from the Intergovernmental Panel on Climate Change, we are again reminded of the scale of the emissions challenge ahead. It is clear that Australia must tackle greenhouse gas emissions right across the economy in order to meet that challenge and deliver on our international climate goals.

The building and construction sector accounts for 39 per cent of global emissions and represents a great opportunity to help Australia transition to a low emissions economy. Significant progress has already been made to reduce the sector's operational emissions. Our ability to achieve further reductions will depend on success in areas that have proven harder to abate, such as Scope 2 and 3 emissions. In that sense, embodied carbon is the next frontier in the task to decarbonise the sector.

Embodied carbon in the production of building materials is responsible for 28 per cent of emissions from the building and construction sector globally. Between now and 2050 it is expected to account for almost half of total emissions from new constructions, with concrete, steel and aluminium considered some of the more challenging materials to decarbonise.

This report helps quantify the challenge and identifies solutions and opportunities for builders to reduce the carbon footprint of construction. In an Australian first, it outlines a range of material and design initiatives that can reduce embodied carbon in new projects, as well as the cost of implementation.

Above all, it shows that Australian developers and builders do not have to choose between saving money and protecting the environment. Instead, they can take advantage of the latest in sustainable material and design innovations that will reduce emissions without incurring higher costs. It's a win for the environment and the building sector.

The CEFC has a strong track record of supporting the built environment sector to reduce emissions. Our investments finance projects that extend the benefits of clean energy across the commercial, industrial and residential property sectors, including through the uptake of international and homegrown innovation in design, materials and technology.

This includes an investment this year of up to $54 million in Northcote Place, Melbourne, to help build sustainable townhouses that have an impressive average 8 star rating under the Nationwide House Energy Rating Scheme (NatHERS), a rating achieved by less than two per cent of new homes built in Australia in 2020. The homes also feature Holcim ECOPact – a low carbon concrete that reduces embodied carbon by 30 to 60 per cent.

The CEFC also invests to reduce emissions across infrastructure projects, networks and assets, including $150 million to enable freight and logistics company Qube to implement clean energy solutions at Moorebank Logistics Park in Sydney.

The project aims to reduce freight truck emissions by increasing the use of rail networks to distribute containerised freight, and has been awarded an 'Excellent' Infrastructure Sustainability (IS) rating (for Design) from the Infrastructure Sustainability Council of Australia (ISCA).

This report is another important contribution to the further decarbonisation of the built environment sector. As a thriving industry that employs many Australians and adds significantly to the economy, it is critical that we make the transition to lower emissions as smooth as possible. By explaining the opportunities to decarbonise, this report is a valuable resource that will enable sustainable and cost effective development.

Ian Learmonth
Chief Executive Officer, CEFC

Investing to cut emissions across our built environment

The CEFC is a specialist investor with a deep sense of purpose: to be at the forefront of Australia's successful transition to a low carbon economy. With the backing of the Australian Government, the CEFC invests in new and emerging technologies and opportunities on behalf of all Australians, with a clear focus on delivering benefits for generations to come.

This has seen the CEFC become a leading investor across the built environment, with property and infrastructure related investment commitments featuring demonstration projects with the ability to deliver leading performance around energy efficiency and the integration of renewable energy into new and existing assets.

In the property sector, the CEFC is financing projects that extend the benefits of clean energy to commercial, residential, and public buildings including office, retail, industrial, healthcare, hotels, apartments, seniors living, student accommodation, universities, and social and affordable housing. Each of these asset classes has its own energy demands, requiring an approach that identifies and harnesses the opportunities presented.

In infrastructure, the CEFC is investing across the sector to influence clean energy standards for social and economic infrastructure assets, as well as transport and electricity.

Infrastructure assets are often long-lived and provide critical services for modern societies. These assets offer significant potential for emissions abatement, with improvements made to existing asset operations or efficiencies implemented at design and construction stages providing ongoing benefits.

The CEFC provides debt and/or equity finance in renewable energy, energy efficiency and low emissions technologies. The CEFC is active across the economy, including in agriculture, energy generation, transmission and storage, infrastructure, property, transport and waste. Given the size of the CEFC, direct investments in large-scale projects and funds are usually from $20 million and above. The CEFC is generally not the sole funder of a clean energy investment, with CEFC investments usually including co-financiers and/or equity partners. Finance for smaller-scale projects, range from $10,000 to $5 million and are delivered through intermediaries via the specialist asset finance programs.

CEFC finance in action

Low carbon concrete offers clean foundations for Perth's most sustainable industrial estate

CEFC commitment: $95 million

Hesperia, Fiveight and Gibb Group are setting new sustainability standards in the property sector with the construction of the 56 hectare, carbon neutral Roe Highway Logistics Park (RHLP) in Kwinana, Western Australia, using low carbon concrete, solar PV and sector-leading sustainability measures to create Perth's greenest industrial estate.

The developers will use the low carbon construction materials across at least five new warehouses. The use of low carbon concrete could reduce emissions by up to 42 per cent compared to traditional concrete.

Unlocking clean power, lower emissions for industrial tenants

CEFC commitment: up to $75 million

Frasers Property is targeting a minimum 15 per cent reduction in embodied carbon in two industrial projects – Rubix Connect in Victoria and the Horsley Park Estate in New South Wales. The developments will feature steel in the fibre concrete slabs to reduce the amount of concrete used, as well as the procurement of materials with embodied carbon disclosures.

A range of sustainability features will also be adopted to reduce the properties' operating emissions to zero, including passive design, energy monitoring systems, solar PV, battery storage, biodiesel generation and building electrification, as well as 100 per cent carbon neutral energy.

Landmark project to reduce road freight emissions

CEFC investment: $150 million

Leading infrastructure and supply chain and logistics company Qube is developing Sydney's Moorebank Logistics Park (MLP), the largest freight infrastructure project in Australia.

MLP is aiming to be a benchmark in environmentally sustainable design practices across every aspect of the development, from precinct wide initiatives to tenant led activity. Qube is forecasting lifetime abatement of 1.5 Mt CO_2-e from avoided embodied carbon.

The first stage of MLP received an Excellent Infrastructure Sustainability Design rating from ISC.

Future looks bright with Metro's 8-star homes

CEFC commitment: up to $54 million

Property developer Metro is showing how high sustainability standards and green design can be incorporated into the property sector with its Northcote Place project in Melbourne. Showcasing sustainable features, the homes will use an estimated 50 per cent less energy than a new home built to minimum building code requirements, allowing residents to benefit from lower utility costs and more comfortable indoor climates.

With an average 8 star rating under the Nationwide House Energy Rating Scheme (NatHERS), the homes feature Holcim ECOPact, a low carbon concrete that reduces embodied carbon by 30 to 60 per cent. They also include a range of features, such as all-electric induction cooking, heat pump hot water, rooftop solar systems with the option to add battery storage, wiring to be electric-vehicle ready, and rainwater tanks connected to both toilets and laundries.

At a glance

The story so far

The efforts to reduce carbon emissions in building and infrastructure projects have traditionally focused on the operational energy of a building or infrastructure asset. However, just as improvements to operational energy become common industry practice and net zero commitments become more mainstream, attention is turning to the embodied carbon of materials used to create buildings and infrastructure. This attention is driven by a range of factors including greater awareness of embodied carbon and its untapped potential, to global momentum to address climate change, to the wider economic value and pressure from investors.

In this report, embodied carbon is described as the greenhouse gas emissions (measured in carbon dioxide equivalent) that occur during the resource extraction, manufacturing and transportation to construction site of the materials used.

The potential is huge

Edge Environment estimate the embodied carbon emissions of materials used in Australia is 30 to 50 million tonnes of carbon dioxide equivalent (CO_2-e) per year (for domestic production), which is approximately five to ten per cent of national greenhouse gas emissions.

The analysis in this report indicates significant potential for reducing embodied carbon in Australia. This reduction can be achieved by supporting, developing and investing in Australia's growing low embodied carbon materials market.

The economic value of the construction materials sector is approximately $65 billion. With demand for low embodied carbon solutions expected to rise significantly, we estimate it could result in a billion dollar low carbon solutions market in the coming years.

5-10%

The estimated proportion of Australia's annual emissions linked to embodied carbon of materials

$65b

The economic value of the construction materials sector in Australia

There's a lot to learn from leading projects

This report provides an overview of the current state of embodied carbon reduction in Australia in infrastructure and building projects based on data from Infrastructure Sustainability Council (ISC) and Green Building Council of Australia (GBCA). Analysis for this report indicates that the industry is already implementing a wide range of embodied carbon reducing initiatives.

On average, the sustainability rated infrastructure projects assessed are achieving up to a 33 per cent reduction in embodied carbon compared to a similar design with no sustainability measures incorporated.

For building projects, the average reductions were up to 15 per cent, although some individual project emission reductions were significantly higher.

Beyond project level embodied carbon reductions, the data also enabled identification of key materials for embodied carbon reduction. It is worth noting that both ISC and GBCA utilise life cycle assessment (LCA) in their rating tools, which draw on standardised and verified industry data. With data from suppliers being provided through sources such as Environment Product Declarations (EPDs), these LCA models become more transparent, precise, and representative.

The case is clear

In an Australian first, this report outlines several material and design initiatives for reducing embodied carbon and the cost implications of implementing them. The material and design initiatives were identified based on available, practical, and reasonable applications in the current market.

Cost effective solutions are available today to substantially reduce embodied carbon. Depending on the initiatives implemented, it is possible to achieve five to 18 per cent reduction in embodied carbon whilst also achieving a 0.4 to three per cent reduction in material costs for typical building and infrastructure projects.

Our analysis also found that replacement of Portland cement with lower embodied carbon materials such as mid-range levels of fly-ash (or alternative Supplementary Cementitious Materials (SCM)) were often provided at little or no additional cost, dependent on the project scale and requirements. While higher rates of SCM provide increased carbon abatement, they may incur a cost uplift (dependant on myriad factors such as curing times, durability and early strength requirements, project location, and scale).

Several lower embodied carbon materials come with a price tag slightly higher than their conventional counterparts. Alternative solutions such as geopolymer concrete, concrete ad-mixtures, recycled materials, and high strength steels are emerging with the potential to mitigate substantial embodied carbon emissions when appropriately implemented on projects, though they may come at a cost premium of up to approximately $175 per tonne of CO_2-e abated (based on specific industry data we obtained).

From a project proponent's perspective, better embodied carbon outcomes can be demanded without adding cost to the project overall but recognising that this involves some carbon mitigation strategies that may otherwise not be undertaken if the project is only looking for cost optimisation. Ambitious embodied carbon targets can be met at lower cost by balancing cost negative and cost positive strategies.

With increased uptake and further research, these alternative and innovate materials and mitigation strategies will likely see a drop in cost, making them accessible to more projects and more financially feasible across the construction industry. Should projects invest money saved through use of cost negative strategies into implementing and improving these materials and technologies, larger embodied carbon savings can be achieved into the future.

Lastly, while every effort should be made to reduce embodied carbon through design and material initiatives, carbon offsets are a potential project-level solution. Offset-driven carbon neutral materials, such as concrete and steel, are recent additions to the Australian construction materials landscape but do come with additional cost. This provides designers and engineers direct options to immediately mitigate embodied carbon which otherwise cannot be removed from an asset's embodied emissions.

It is possible to realise the opportunity

In summary, the analysis identified that the transition to a lower embodied carbon market is financially accessible and, in many cases, already underway. While barriers still exist, there is significant opportunity to reduce embodied carbon through innovation and a renewal in the way we manufacture, design, build, specify, and procure infrastructure and building projects.

Understanding embodied carbon

What is embodied carbon?

There are many different definitions of embodied carbon.

In this report, embodied carbon is described as the greenhouse gas emissions (carbon dioxide equivalent) that occur during the resource extraction, transportation of resources to manufacturer, manufacturing, and transportation to construction site of materials (see Figure 1).[1]

We have taken a limited definition of embodied carbon in this report to maintain a consistent lifecycle scope for analysis of the data that underpins this report and to show a conservative view of the reduction opportunities possible. This report is a first step in quantifying the carbon and cost implications of several emission reduction initiatives. We recognise that there are many other opportunities in addition to those addressed and outlined in this report.

Figure 1: Lifecycle stages included in defining embodied carbon for this report

Product stage	Raw material supply	A1
	Transport	A2
	Manufacturing	A3
Construction stage	Transport	A4
	Construction / installation process	A5
Use stage	Use	B1
	Maintenance including transport	B2
	Repair including transport	B3
	Replacement including transport	B4
	Refurbishment including transport	B5
	Operational energy use	B6
	Operational water use	B7
End of life stage	De-construction and demolition	C1
	Transport	C2
	Re-use recycling	C3
	Final disposal	C4
Benefits and loads for the next product system	Re-use, recovery, recycling potential	D

[1] A broader definition of embodied carbon is provided by the World Green Building Council (WGBC) and other GBCs around the world including UK and Australia and is based on the EN 15978 standard:

Embodied carbon emissions are associated with materials and construction processes throughout the whole lifecycle of a building or infrastructure and include material extraction, transport to manufacturer, manufacturing, transport to site, construction, use phase, maintenance, repair, replacement, refurbishment, deconstruction, transport to end of life facilities, processing, disposal and end-of-life benefits due to recycling, reuse or recovery.

These life cycle stages are classified into modules A1-A3, A4-A5, B1-B5, C1-C4, and D respectively by EN 15978 standard for Sustainability of construction works – Assessment of environmental performance of buildings – Calculation method for whole building life cycle assessments (LCAs) and for Environmental Product Declarations (EPDs) by the EN 15804: 2012 + A2:2019 Sustainability of construction works.

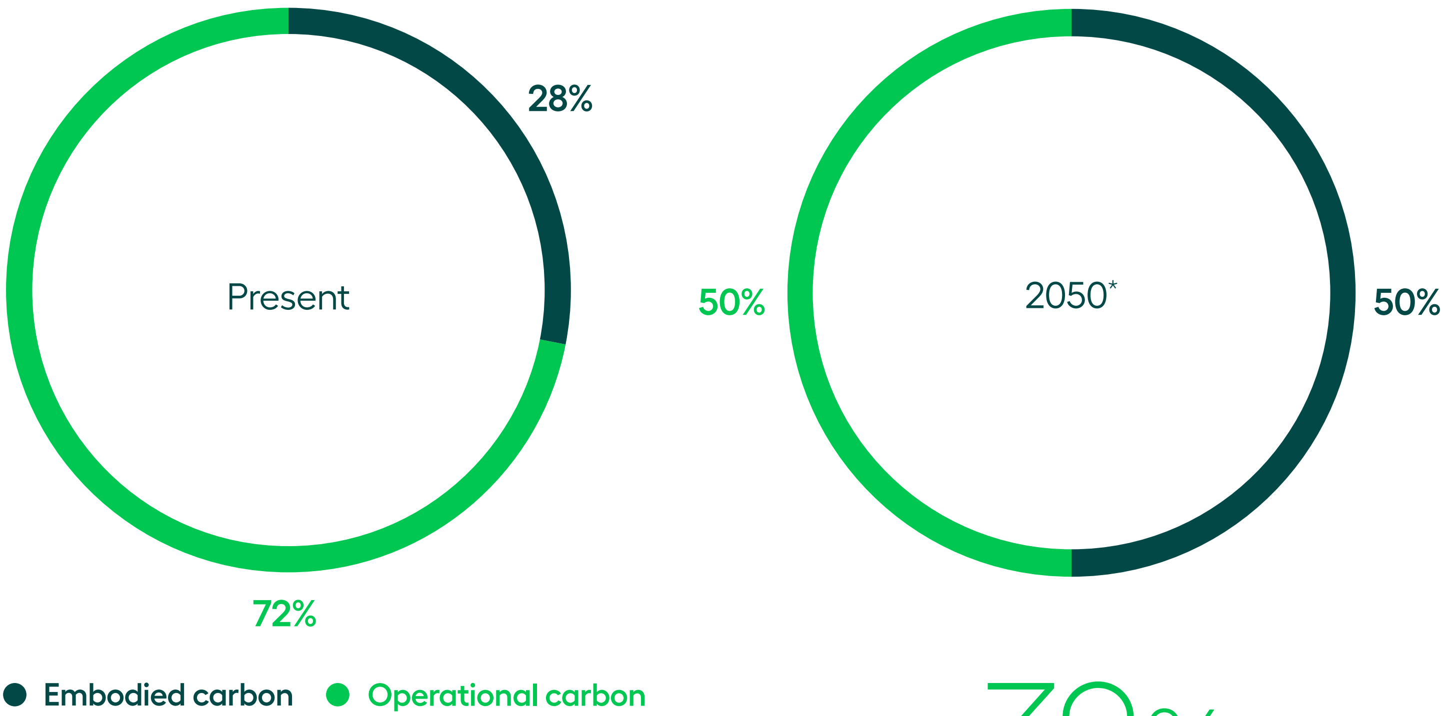
Why is embodied carbon important?

The building sector accounts for 39 per cent of global carbon emissions: 28 per cent from building operations and 11 per cent from embodied carbon in building materials and construction. Decarbonising this sector can be one of the most effective ways to mitigate climate change (UK Green Building Council, 2017; Architecture2030, 2019; World Green Building Council, 2019).

To date, the sector has been largely focused on reducing emissions related to the operational phase of buildings and infrastructure, driven by climate change policies for emission reduction strategies. Several factors such as the decarbonisation of electricity grids and incremental improvements in building efficiency are expected to further lower the share of operational carbon emissions compared to embodied carbon.

Looking to the future, embodied carbon will account for almost half of total emissions from new constructions between 2019 and 2050, and presents a significant opportunity for the sector to decarbonise. Figure 2 depicts the potential change in embodied vs operational carbon by 2050 (UK Green Building Council, 2017; Architecture2030, 2019; World Green Building Council, 2019).

Figure 2: Potential change in embodied vs operational carbon by 2050



39%

The estimated percentage of global carbon emissions from the building sector

*Distribution of embodied and operational carbon for 2050 based on new construction between 2019 and 2050.

What are the drivers for low embodied carbon projects?

The unique role of investors

Investors play a unique and critical role in Australia's decarbonisation journey. This includes, but is not limited to:

- factoring in climate risks and opportunities into decision-making
- mobilising capital to create the market for the supply of and demand for low embodied carbon materials and projects
- actively seeking transparency on scope 3 emissions[2]
- holding company directors to account on their fiduciary requirements in relation to climate change and supporting efforts to accelerate decarbonisation across the entire value chain.

The Task Force on Climate-related Financial Disclosures (TCFD) and subsequent adoption by organisations, like Principles for Responsible Investment and many more, have created global momentum for investor-led action on climate change. In Australia, TCFD reporting has been encouraged by the Australian Prudential Regulation Authority (APRA), the Reserve Bank of Australia (RBA), the Australian Securities and Investments Commission (ASIC), Australian Accounting Standards Board (AASB) and the Auditing and Assurance Standards Board (AUASB), demonstrating a monumental shift in the way carbon emissions are reported on and regulated in Australia.

Australia's construction sector will play a central role in this shift. The sector increasingly requires alignment to common goals, frameworks, and tools; and promotes transparency on the embodied carbon of materials and innovative collaboration to decarbonise.

The CEFC is also participating in the Materials & Embodied Carbon Leaders' Alliance (MECLA), which is a collaboration of over 70 organisations that have come together to drive reductions in embodied carbon in the building and construction industry. MECLA was initially funded by the NSW Government.

The economic and policy drivers of reducing embodied carbon

In addition to the key role investors play, there are many economic drivers for reducing embodied carbon. These include increased resource efficiency, dematerialisation, award of tenders and contracts, competitive advantage through innovation, increased preparedness for addressing climate risks and attracting low interest finance (UK Green Building Council, 2017).

For example, Transport for NSW requires that all projects with a capital expenditure greater than $15 million reduce construction related carbon emissions by a minimum five per cent from the project baseline (Transport for NSW, 2017). The NSW Government has set a commitment to 'leading a national strategy to achieve net zero embodied carbon in building materials' (NSW Government, 2020).

The Australia Government's Low Emissions Technology Statements under the Technology Investment Roadmap identified low emissions materials (steel and aluminium) as priority technologies that have high abatement and economic potential in areas where Australia has a comparative advantage and government can make a difference. Low emissions cement was also highlighted as an emerging technology that shows promise for future prioritisation (Australian Government, 2021).

70

Over 70 organisations from Australia have come together to drive reductions in embodied carbon

[2] Scope 3 emissions are the result of activities from assets not owned or controlled by the reporting organisation, but that the organisation indirectly impacts in its value chain.

Global momentum

Paris Agreement

Signed and ratified by the Australian government, the Paris Agreement sets an aim to limit warming to well below 2 degrees Celsius above pre-industrial levels, with an aspiration to limit to 1.5 degrees. Globally, the 1.5 degree scenario requires around 45 per cent reduction in greenhouses gases by 2030, from 2010 levels, and net zero by 2050 (Rogelj, Shindell and Kejun, 2018). Given that the building and infrastructure sectors are major contributors to global greenhouse gas emissions, it is imperative that they decarbonise to ensure alignment with the Paris Agreement. Put simply, the reductions required to meet the Paris Agreement targets cannot be achieved without lowering embodied carbon in buildings and construction.

Sustainable Development Goals

Reductions in the embodied carbon of buildings and infrastructure are a significant contribution to many of the Sustainable Development Goals (SDGs) and their related targets, adopted by Australia and other United Nations Member States in 2015. The World Green Building Council has identified nine out of 17 SDGs to be most relevant for the building sector. Alignment with these SDGs is equally relevant to the infrastructure sector for reducing embodied carbon.

Circular economy

The circular economy, a system designed to create closed-loop economic systems using material re-use, recycling, and remanufacture to improve resource use and reduce waste, presents unique opportunities to help tackle climate change by preserving the embodied carbon of products and materials already in the system. To create a circular economy for building and infrastructure projects, principles including utilisation, flexibility, lifecycle thinking and true cost accounting can be considered (Stopwaste and Arup, 2018).

1.5°C

Globally, the 1.5 degree goal requires net zero emissions by 2050

What role do materials play in addressing embodied carbon?

Several types of materials, including concrete, steel, glass and aluminium are commonly used in construction.

Cement and steel are the two most significant sources of embodied carbon emissions in construction. Cement manufacturing accounts for seven per cent of global carbon emissions, while steel accounts for seven to nine per cent (World Green Building Council, 2019). Different construction materials have different embodied carbon content per unit. Table 1 shows some indicative carbon intensities per tonne of material.[3]

7-9%

Share of global emissions from steel production

[3] It is important to note that all embodied carbon assessments and comparisons should be done considering the whole of life aspect of the whole asset or system. It is not appropriate to compare one tonne of structural steel with one tonne of reinforced concrete as the function achieved with each respective quantity is different. Additionally, embodied carbon profiles may change due production method, technological advances, geography, etc.

Table 1: Indicative embodied carbon content of key construction materials[4]

Carbon intensities per tonne of material

Material category	Material type	Embodied carbon (kg CO_2/t material)	Data source
Aluminium	Primary	20,000	AusLCI v1.31
PVC	Non-pressure pipe	3,600	Vinidex PVC non-pressure pipe EPD (2016)
	Pressure pipe (PVC-U)	3,500	Vinidex PVC pressure pipe EPD (2016)
	Pressure pipe (PVC-M)	3,500	Vinidex PVC pressure pipe EPD (2016)
Steel	Sheet	2,200	AusLCI v1.31
	Rebar	1,500	AusLCI v1.31
Glass	Double glazing	1,700	AusLCI v1.31
	General purpose	1,020	AusLCI v1.31
	Ordinary Portland	1,000	AusLCI v1.31
Timber	MDF	830	Forest and Wood Products Australia Ltd. EPD for MDF (2015)
	Hardwood	450	Forest and Wood Products Australia Ltd. EPD for hardwood timber (2015)
	CLT	930	XLAM EPD for CLT (2021)
Bitumen	Polymer modified	700	AusLCI v1.31
	Standard	550	AusLCI v1.31
Bricks	Clay	250	AusLCI v1.31
Concrete	40 MPa	200	AusLCI v1.31
	40 MPa (30% SCM)	150	AusLCI v1.31
Asphalt	With 5% binder (bitumen)	65	ISC Materials Calculator v2.0
	With 4% binder (bitumen) and 20–40% RAP	55	ISC Materials Calculator v2.0
Timber	MDF – with carbon storage	-660	Forest and Wood Products Australia Ltd. EPD for MDF (2015)
	Hardwood – with carbon storage	-1,000	Forest and Wood Products Australia Ltd. EPD for hardwood timber (2015)
	CLT – with carbon storage	-610	XLAM EPD for CLT (2021)

[4] Two entries for timber have been provided in the table to distinguish between its embodied carbon content with and without carbon storage (sequestration). Please refer to the respective product EPDs for more information on biogenic carbon and its sequestration.

Pathways to reduce embodied carbon

Leading businesses, researchers and organisations around the world have been working on pathways and strategies to reduce embodied carbon for over a decade.

A recent report by the World Green Building Council has outlined a pathway for such reduction using four key principles including: prevent, reduce and optimise, plan for the future and offset (World Green Building Council, 2019).

The best way to reduce embodied carbon is through prevention. This is also depicted in Figure 3, which shows that avoiding construction can eliminate the potential for embodied carbon. Through alternative strategies such as increased utilisation of existing assets by renovation or re-use, it can be possible to deliver the same function as a new build and thus eliminating the embodied carbon emissions associated with it.

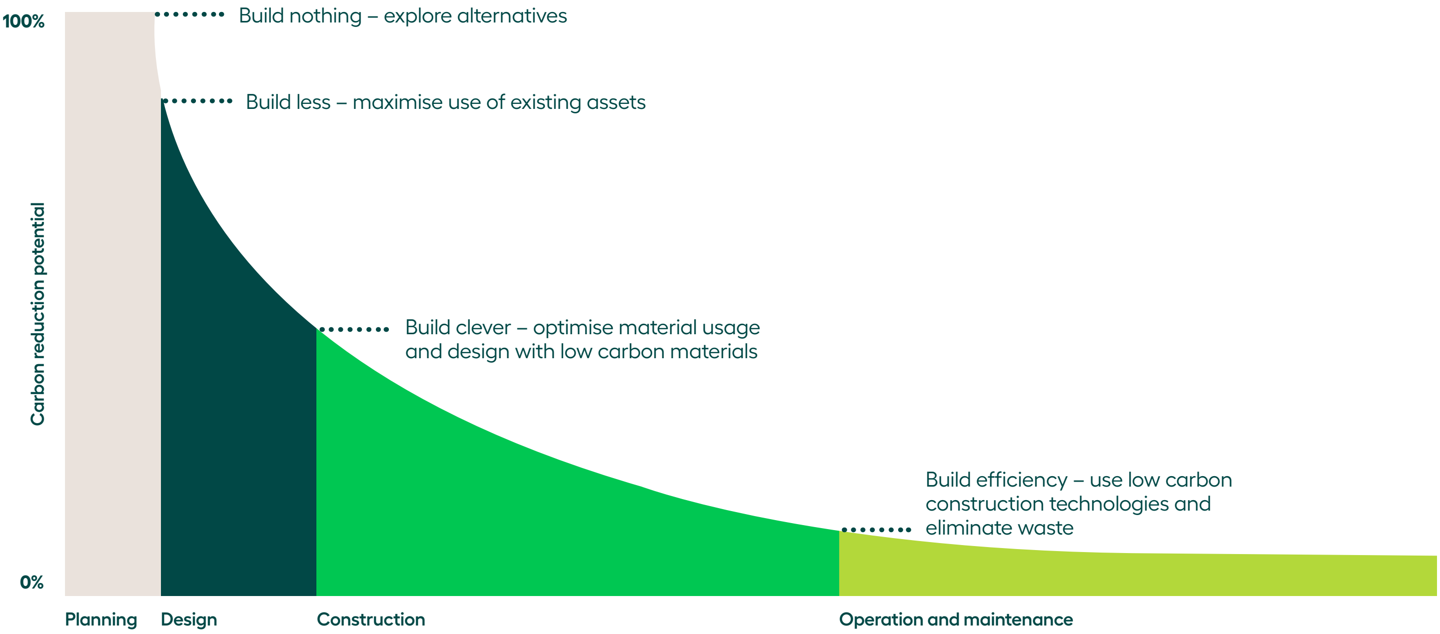
However, if renovation and re-use is not an option, other principles can help reduce embodied carbon during various stages of a building or infrastructure project. Leadership and innovation in the building and infrastructure sectors has led to development of tools and data for calculating embodied carbon and these are becoming increasingly available and accessible. This includes life cycle assessment based design tools and product labelling such as Environmental Product Declarations. Many low embodied carbon materials and solutions are entering the market, and flagship projects are having significant impacts using technology available today. Using such innovations, it is now possible to calculate embodied carbon upfront and use low embodied carbon materials to 'reduce and optimise' these emissions.

Although opportunities to reduce embodied carbon depend on various factors, including the type of project and location, the highest potential for reduction is generally at the start of a project. As depicted in Figure 3, it becomes more challenging to make design changes for embodied carbon reduction as the project progresses.

Careful consideration of future use and end-of-life scenarios during the design stage can help in further reducing the embodied carbon emissions in the later stages of a project. Designing for disassembly to facilitate future re-use and selecting materials which can be easily separated for processing and recycling are some of the strategies that can be employed while planning for the future of a project. Figure 4 demonstrates some key end-of-life strategies to reduce embodied carbon via resource use in various life-cycle stages of a building or infrastructure project.

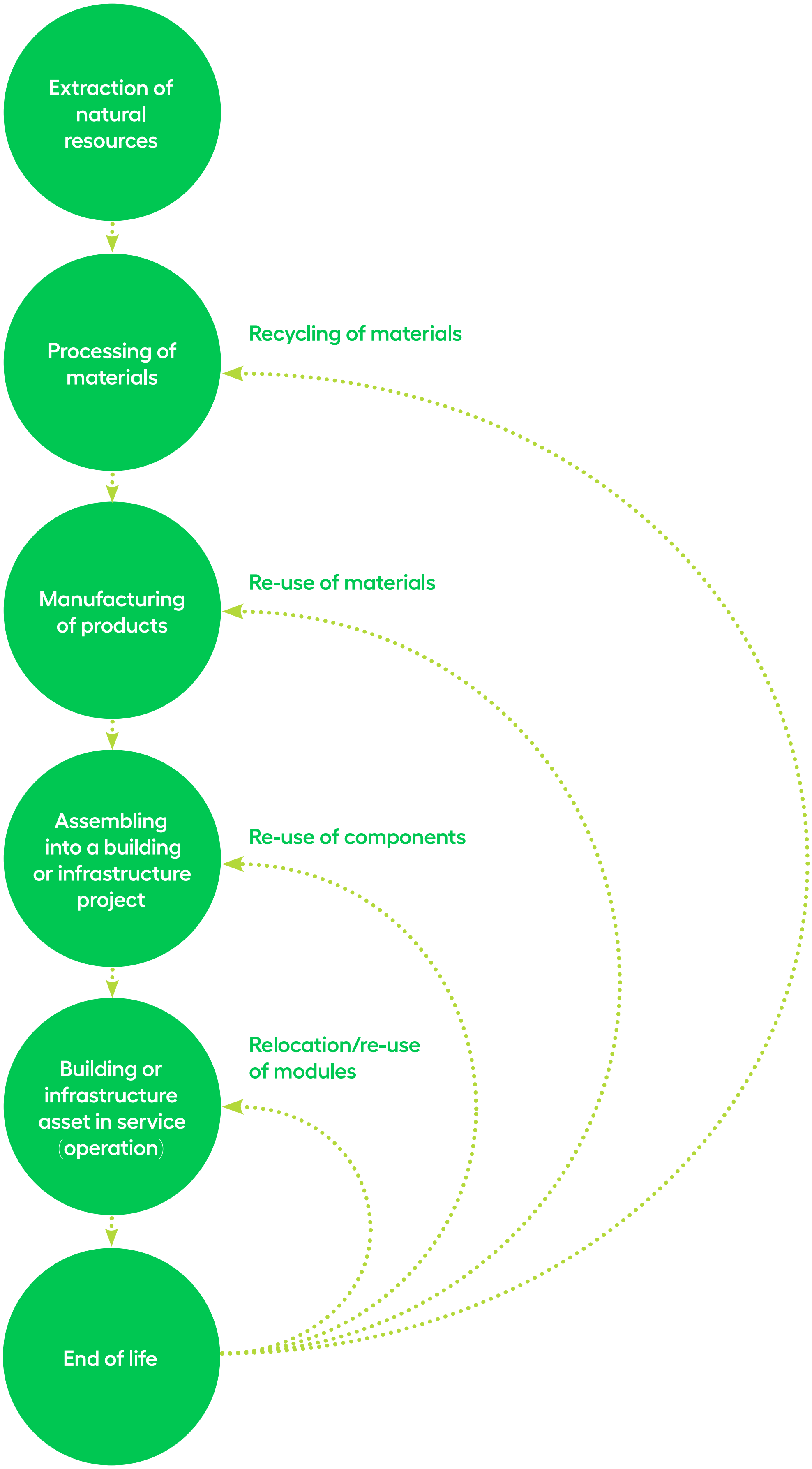
Embodied carbon reduction initiatives covered in this report, such as using renewable energy in manufacturing, high strength materials and increased recycled content can further amplify the effect of these end-of-life strategies. Lastly, this report considers offsets as the last resort in embodied carbon reduction.

Figure 3: Opportunities to reduce embodied carbon in different stages of a building or infrastructure project



Source: adapted from HM Treasury, 2013, Infrastructure Carbon Review

Figure 4: End-of-life strategies to reduce embodied carbon through resource use in various life-cycle stages of a building or infrastructure project



A billion dollar market

Materials suppliers stand to benefit from the growing demand for low embodied carbon solutions which are likely to dramatically increase over the next decade.

This growth is driven by a combination of global best practice, changing investor and project demands, evolving requirements in rating tools and a shifting policy landscape. However, until now, there has been little guidance on what the 'size of the prize' is for low embodied carbon reduction in Australia – both in terms of dollar value of this emerging market, and total tonnes of embodied carbon. Quantifying the size of the prize is a significant contribution to helping increase the supply of and demand for low embodied carbon solutions.

The whole Australian construction material industry is worth over $65 billion per year and accounts for 30 to 50 million tonnes CO_2-e per year. This is approximately five to 10 per cent of Australia's annual greenhouse gas emissions and around three per cent of GDP in terms of economic activity. An increasing share of that $65 billion market is looking for low embodied carbon options, resulting in an emerging multi-billion dollar market.

30-50m tonnes

Estimated annual emissions from Australia's construction materials industry

A closer look at the potential opportunity

As well as contributing to GDP, the construction materials sector directly employs over 240,000 people and indirectly employs close to half a million people (BPIC, 2020).

In addition to the $65 billion domestic market, approximately $10 billion in construction materials are imported, ranging from furniture to bridge structures (Workman, 2020). One key feature of the market for Australian finished construction materials is that there are significantly fewer exports than imports, as most Australian made finished construction materials are used domestically.

Our estimates based on Australian production and trade data (Workman, 2020) suggest that the embodied carbon emissions of materials produced in Australia is in the range of 30 to 50 million tonnes CO_2-e per year.

Currently, low embodied carbon materials are largely targeted by leading builders, developers, and asset owners. For building projects, Green Star ratings are a key driver for more sustainable buildings, and a reasonable proxy for the level of current activity in the green building market.

Going forward, the focus on embodied carbon is expected to increase, especially with the Green Star Buildings (GBCA, 2020) latest update released in October 2020. A major change in the latest release includes specific provisions to encourage reduced upfront embodied carbon.

Since the inception of Green Star in 2003, approximately 1,000 new buildings have been certified, with a clear year-by-year upward trend. In 2020, over 100 new assets achieved Green Star (GBCA, 2020) certification. These certifications were across GBCA's various buildings and communities rating schemes. Assuming an average floor area of 20,000 m^2, this would translate to the installation of approximately 500,000 m^3 of concrete, 150,000 tonnes of steel, 10,000 tonnes of aluminium and 2,000 tonnes of timber. The value of the materials for these 100 buildings is approximately $1 billion, all of which could have made use of low embodied carbon alternatives.

Infrastructure projects offer an arguably even larger opportunity for low carbon materials. The adoption of the IS rating scheme and initiatives from leading government departments are driving low embodied carbon material use in infrastructure projects. Since 2012, over $80 billion in infrastructure and civil works projects have become engaged in the IS rating scheme, and the forward-looking pipeline of IS rated infrastructure is significant.

To illustrate the opportunity, WestConnex, a 33 km motorway network due for completion in 2023, includes a focus on reducing the embodied carbon in materials. A large infrastructure project of this type can include well over 1,000,000 m^3 of concrete and 150,000 tonnes of steel, with a total materials contract value of approximately $1 billion over five years (Westconnex, 2019).

Leading manufacturers are positioning themselves to realise this opportunity and take a share of this emerging market. Leading building material suppliers are already making progress. Table 2 includes a list of companies who have committed to set science-based targets for emissions reductions, including building product and construction material suppliers. Collectively, this demonstrates the value manufacturers see in disclosing and communicating their carbon impacts.

Understanding what's possible

Along with the sizeable emerging market opportunity, there are further significant emission reduction opportunities available. It is possible to reduce embodied carbon emissions through a variety of strategies, though some are mutually exclusive. To give some indication of the potential, we have quantified some emission reduction scenarios for the building materials sector.

Scenario 1: All material manufacturers switched to green power today.

Switching from the average grid mix to renewable energy sources can significantly reduce the embodied carbon in materials. Many manufacturers in Australia are already ramping up their use of renewable energy mixes to power their existing plant. If the Australian materials industry transitioned from use of grid-based electricity supply to electricity generated from renewable sources in manufacturing, the annual carbon emissions could be reduced by more than seven million tonnes CO_2-e per year, which is close to one per cent of Australia's current emissions.

Table 2: Snapshot of material manufacturer's commitments to reduce emissions

Manufacturer	Commitment to reduce emissions
Kingspan Group Plc	Kingspan Group Plc commits to reduce absolute Scope 1 and 2 GHG emissions 90 per cent by 2030 from a 2020 base year. Kingspan Group Plc also commits to reduce absolute Scope 3 GHG emissions from purchased goods and services, use of sold products and end-of-life treatment of sold products 42 per cent within the same timeframe.
Saint-Gobain	French multi-national Saint-Gobain commits to reduce absolute Scope 1 and 2 GHG emissions 33 per cent by 2030 from a 2017 base year. Saint-Gobain also commits to reduce absolute Scope 3 GHG emissions 16 per cent over the same timeframe.
Holcim Ltd	Multinational company involved in the manufacture of building materials, Holcim Ltd commits to reducing Scope 1 GHG emissions 17.5 per cent per tonne of cementitious materials by 2030 from a 2018 base-year. Holcim Ltd also commits to reduce Scope 2 GHG emissions 65 per cent per tonne of cementitious materials within the same timeframe. Holcim Ltd's Australian portfolio includes low embodied carbon products such as ECOPact and Climate Active Certified Carbon Neutral concrete mixes.
Fletcher Building Ltd	Fletcher Building Ltd commits to reduce absolute Scope 1 and 2 GHG emissions 30 per cent by 2030 from a 2018 base-year. Fletcher Building Ltd also commits that 67 per cent of its suppliers, by emissions, will have science-based targets by 2024.
Heidelberg Cement AG	German multinational building materials company Heidelberg Cement AG commits to reduce Scope 1 GHG emissions 15 per cent per tonne of cementitious materials by 2030 from a 2016 base year. Heidelberg Cement also commits to reduce Scope 2 GHG emissions 65 per cent per tonne of cementitious materials within the same timeframe.

Scenario 2: The top 15 Australian material manufacturers reduced emissions in line with the Paris Agreement by adopting Science Based Targets.

If the top 15 Australian material manufacturers set and implement science-based targets, it would translate to 10 to 30 per cent reduction in the next five to 10 years, equating to approximately three to nine million tonnes CO_2-e per year (note: this may be achieved in part through switching to green power as outlined previously).

Scenario 3: Just one in 10 projects went carbon neutral on the materials by using offsets.

Although it is possible to go carbon neutral on materials today, this is not widely available through material manufacturers. However, projects can offset this through available offset programs at an additional cost, with carbon savings equating to three to five million CO_2-e per year for suggested uptake.

Scenario 4: Just one in 10 projects were awarded to the lowest carbon materials available, without the use of offsets.

There are options for low embodied carbon materials available in the market across materials categories such as concrete, steel, bricks and carpet to name a few. These materials demonstrate carbon reductions of approximately 30 to 90 per cent, without using carbon offsets. If just one in 10 projects were awarded to the lowest carbon materials available, there is the potential to achieve an embodied carbon reduction between one to three million tonnes CO_2-e per year.

Cutting embodied carbon in buildings

What was the approach?

To understand the extent to which building projects in Australia are reducing embodied carbon, data from Green Star submissions was analysed. This data set was provided by the GBCA and consisted of LCA outcomes from 69 projects across five different building types: industrial, office, retail, mixed use and residential. Based on the analysis of this LCA data, key insights into the scale of embodied carbon reductions and strategies used to achieve them were obtained.

What did we find?

Overall, between three to 15 per cent reductions in embodied carbon were achieved across the five building types. The majority of the reductions were realised through dematerialisation by using less material in the actual building compared to the reference case (e.g. reducing floor slab thickness). This is usually achieved by design optimisation of the building. Another contributor to emissions reduction is the substitution of carbon intensive materials for low embodied carbon materials (e.g. replacing cement with supplementary cementitious materials or replacing concrete and steel with cross laminated timber). Such reduction initiatives are centered predominantly around concrete, steel, and aluminium. Lastly, savings in both cost and carbon were found through the implementation of innovative methods to retain existing structures. Table 3 summarises the embodied carbon reduction findings for each building type.

Table 3: Summary of key findings for embodied carbon reduction in buildings

Building type	Number of projects analysed	Key findings
Industrial	20	• 12% reduction in embodied carbon emissions was achieved compared to reference. • Project specific changes in embodied carbon range from +10% to -19%. • Embodied carbon reduction initiatives target concrete, steel, and aluminium.
Office	22	• 7% reduction in embodied carbon emissions was achieved compared to reference. • Project specific changes in embodied carbon range from +13% to -19%. • Embodied carbon reduction initiatives target concrete, steel, aluminium, and glazing.
Retail	5	• Only 1 project exhibited a reduction in embodied carbon. • Embodied carbon reduction initiatives target concrete and steel.
Mixed use	16	• 3% reduction in embodied carbon emissions was achieved compared to reference. • Project specific changes in embodied carbon range from +10% to -25%. • Embodied carbon reduction initiatives target concrete, steel, and glazing.
Residential	6	• 15% reduction in embodied carbon emissions was achieved compared to reference. • Project specific changes in embodied carbon range from +25% to -41%. • Reduction initiatives target concrete, steel, and cladding.

3-15%

Reductions in embodied carbon achieved across the five building types

Who is leading the way?

25 King St, Brisbane

Brisbane project 25 King is a nine-storey plus ground superstructure, showcasing timber from roof to floor.

Finished in 2018 and built using Cross Laminated Timber (CLT) and glue laminated timber (Glulam), 25 King Street delivered a 74 per cent reduction in carbon over 60 year life compared to an equivalent conventional reinforced concrete building, with a 38.7 per cent reduction in embodied carbon which excludes the sequestered carbon contribution of timber.

Recognising the opportunity to be part of something special, Lendlease worked closely with Aurecon to develop a building that would visibly express sustainability and engineering, whilst providing a workplace that could enhance the health and wellbeing of its occupants.

To achieve their ambitious goals, Lendlease undertook a full comparative life cycle assessment of 25 King. This study found a significant improvement across all mandatory environmental indicators, driven largely by the use of CLT and Glulam rather than a traditional concrete structure.

For the portions of the design that remained concrete, there were significant improvements from using concrete mixes that contained waste materials such as fly-ash rather than Portland cement.

In addition to the reduction in embodied carbon, this people and planet-centered project achieved a 6 star Green Star Design and As-Built v1.1 rating, and Platinum WELL core & shell rating. Operational emissions were reduced by 46 per cent compared to the reference case, not including GreenPower, and potable water consumption was reduced by 29 per cent.

Surprisingly, this project also revealed that almost half the waste created during construction, in Lendlease's experience, resulted from the concrete portion of the project. At completion, 81 per cent of construction waste had been diverted from landfill with only 3.75 kg per m^2 of waste sent to landfill, exceeding the GBCA best practice benchmark of 5 kg per m^2.

By working with stakeholders and regulators to ensure the building met and exceeded all requirements and rethinking its use of traditional materials, Lendlease has demonstrated a reduction in embodied emissions, an overall sustainable build and strong investment returns.

Using engineered timber in construction can be an extremely effective option to reduce embodied carbon. The ability to sequester carbon provides timber with a negative carbon footprint, which can offset remaining emissions to provide a lower overall emission profile. However, there are several aspects which need to be considered while evaluating the carbon reduction potential of timber in a building project. These include structural and design parameters, responsible sourcing of timber, service life, and end-of-life scenarios of the timber components. Assuming all such aspects are taken into consideration, the embodied carbon emissions of an engineered timber building can be 60 to 75 per cent less compared to its conventional concrete-steel counterpart on a per m^2 basis (Durlinger, Crossin and Wong, 2013; Carre and Crossin, 2015).

Source: case study and imagery provided by Lendlease

Burwood Brickworks Retail Centre

Source: case study and imagery provided by Frasers Property

Attempting to be the world's first retail Living Building®, the Melbourne-based Burwood Brickworks Retail Centre required the whole project team to come up with innovative solutions that would enable them to meet the net-positive energy requirements of The Living Building Challenge®.

Finished in 2019, Burwood Brickworks generates renewable energy on and off-site, treats its own water, has a materials palette that has been deeply vetted for supply chain impacts, and includes an urban farm on the building roof.

By limiting carbon intensive materials, opting for carbon sequestering materials, reviewing Environmental Product Declarations, incorporating a significant number of salvaged materials, using high-recycled content materials, using structural materials as the final finish, and minimising waste, Fraser's Property was able to reduce the embodied carbon in the project by 50.5 per cent compared to the reference case.[5]

The team also created a Materials Conservation Management Plan and a 'Greensheet', thinking through the sustainability credentials of the entire build even to the point of end-of-design-life and introduction back into the circular economy.

This thinking beyond the usual use phase of the building also led to innovative design solutions. Using the mindset of 'adaptive reuse and appropriate durability', the project team focused on both the potential flexibility and disassembly of the base building, and guided tenants to undertake their fit-out designs with regard to material/product selection, and installation approaches that are accessible to allow easier maintenance as well as deconstruction. Natural 'honest' finishes were prioritised, which helped to avoid superfluous coatings that make items more bespoke and less likely to be attractive to future salvage. In turn, these materials can better retain value, making them more feasible for reuse and recycling.

The aim of the Burwood Brickworks Retail Centre is to reduce environmental burdens from the extraction, processing, and disposal of materials and turn waste into a valuable resource through beneficial reuse. Hence, embodied carbon has been considered throughout design, construction, operation, and end-of-life.

50.5%

Reduction in embodied carbon compared to the reference case

[5] A comparable building assessment, third-party independently reviewed and certified in accordance with ISO14044.

InfraBuild's Viribar™ 750 high-strength steel

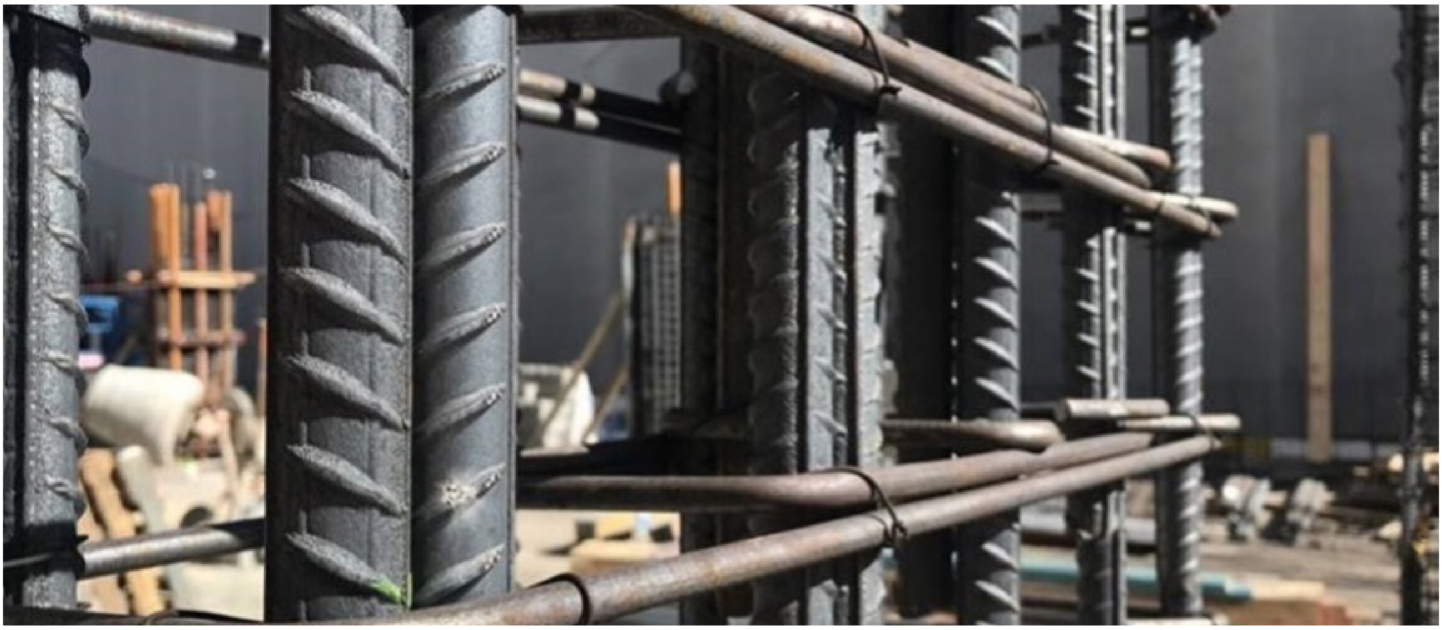
In a recent residential build contracted to structural engineering firm SCP Consulting, a small change in specification to purchase InfraBuild's new Viribar™ 750 high-strength steel fitments resulted in a 25 to 33 per cent reduction in carbon emissions per tonne of fitments.

This reduction in emissions comes from the 33 per cent reduction in mass of the fitments when compared with the equivalent 500 N fitment. This reduced weight also makes transport, craneage and handling easier, providing environmental, health and safety benefits to the project.

SCP Consulting chose to incorporate this new product into the design after learning that performance and safety requirements could be met whilst offering significant sustainability benefits.

A core part of InfraBuild's innovation was to ensure the substitution process would be simple, allowing businesses to specify the product without altering design and engineering requirements. This allows the carbon savings of this product to be realised easily across a broad range of applications.

In addition to the carbon savings realised through this product, InfraBuild has ensured that the product meets IS and Green Star requirements, allowing specifiers to more easily pursue these certifications.

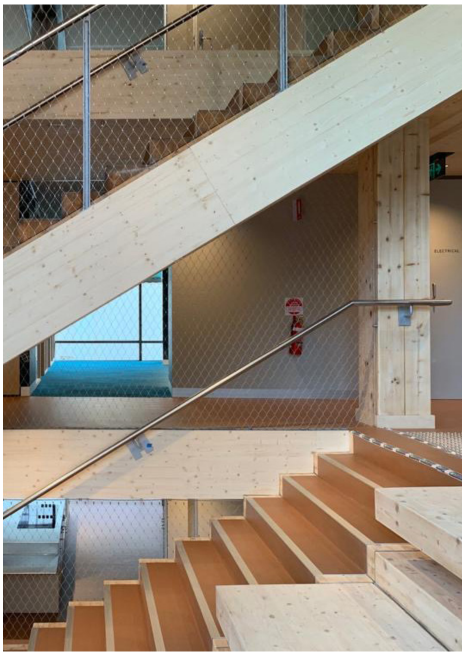


Source: case study and imagery provided by InfraBuild

25-33%

Reduction in carbon emissions per tonne of fitments of InfraBuild's Viribar™ 750 high-strength steel fitments

La Trobe University Student Accommodation



Source: case study and imagery provided by Multiplex and Wood Solutions

In 2019, La Trobe University announced a $75 million plan to reach net zero emissions by 2029, seeking to become the first Victorian University to achieve net zero.

Responding to the Request for Tender to develop new student accommodation, Jackson Clements Burrows provided an innovative design, utilising a mass timber structure made up of cross laminated timber (CLT) and glulam structural columns and beams, rather than the traditional materials of concrete and steel. Stantec, as services engineers for the project, undertook an analysis of the Global Warming Potential of the project, compared with a traditional concrete structure, the team assessed a 75.62 per cent reduction or, 7,500 tonnes CO_2-e when compared to a concrete benchmark.

The weight of the CLT structure was significantly less than an equivalent steel or concrete structure, resulting in a reduction in the sub-structure requirements; further reducing the carbon footprint by eliminating deep piling and large concrete footings.

Head Contractor, Multiplex, reported an excellent safety record through mass timber structure erection. Site resources were reduced in comparison with a traditional concrete structure build.

Not satisfied with these benefits alone, the design team and La Trobe introduced two 15 kW solar photovoltaic systems and water and energy efficient appliances to ensure both embodied and operational energy was improved.

Comprising 624 beds across two buildings, this project achieved a 5 Star Green Star As-Built Rating and has increased the number of beds available to students to over 2,000. Though there were initial reservations about the possibility of using CLT on such a large scale, these were quickly overcome by the benefits to reducing embodied carbon.

Multiplex were appointed Head Contractor in early 2019, under a D&C contract. They engaged Taylor Thomas Whitting (TTW) as structural engineers, and together with Jackson Clements Burrows and the mass timber supplier Xlam Dolomiti they designed, certified and produced the mass timber structure in alignment with an extremely tight program. The structure was delivered ahead of program, ensuring the performance and sustainability targets of La Trobe were achieved.

75%

Expected reduction in embodied carbon compared to a concrete benchmark

Quay Quarter Tower, Sydney

Targeting a 6 Star Green Star Office Design and As-Built rating, 5.5 Stars NABERS Energy Rating and Gold WELL core and shell rating, the Quay Quarter Tower (QQT) is a beacon for AMP Capital's Zero Net Carbon commitment.

As part of the AMP Capital 2030 Sustainability Strategy, AMP committed that all their funds and assets would become Zero Net Carbon by 2030 through phasing out fossil fuels, running on 100 per cent renewable energy and making their buildings highly efficient and resilient.

The QQT design, which incorporates a significant re-use of the existing building's structure, represents a 10 per cent reduction in embodied greenhouse gas emissions associated with the overall development compared to a business as usual demolition and new building approach.

The design of a new commercial office tower requires careful co-ordination between structure and services which considers future tenant flexibility and allows ceiling height to be maximised. The building services design for QQT was further challenged given the structure formed an existing constraint which new building services needed to be designed within. This included the re-use of existing vertical risers and an arrangement of on-floor servicing which respected the existing post tensioned concrete band beams in the existing component of the floor plates.

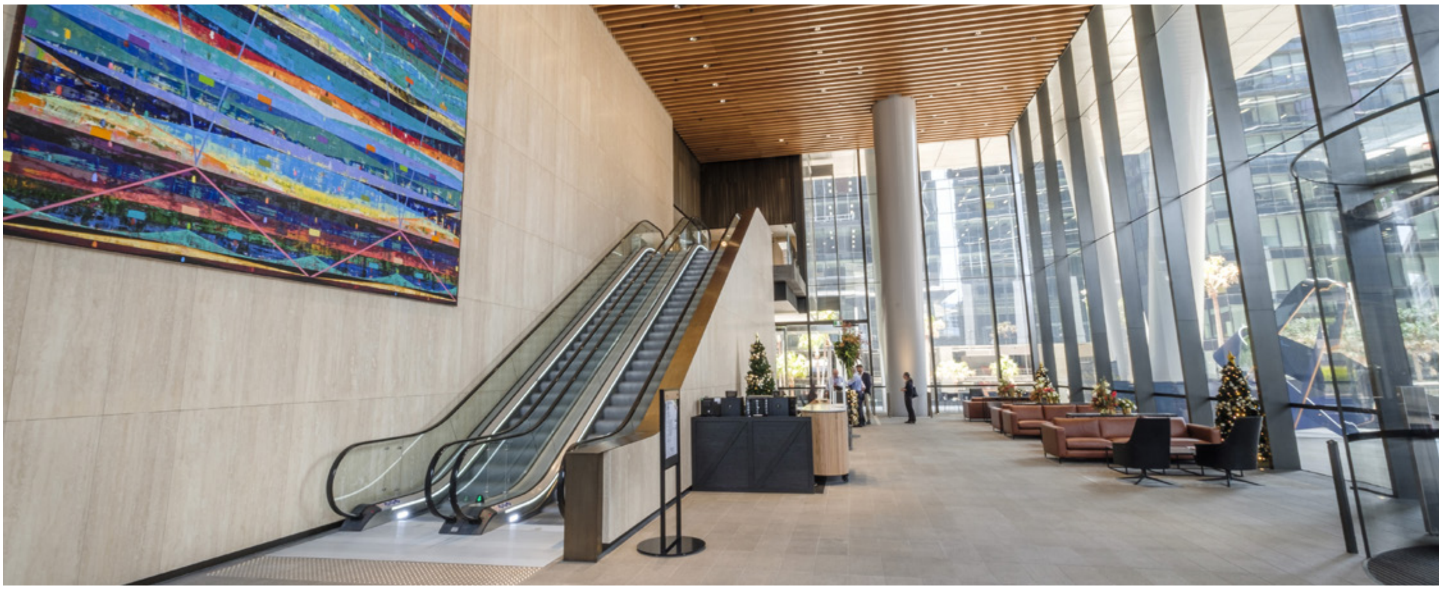
In addition to the embodied carbon savings from maintaining the concrete core and re-using other existing materials, the build reduced total annual solar radiation to the building by 30 per cent by using external shading hoods and a high-performance façade, eliminating the need for automated blinds, and providing thermal comfort. AMP Capital also made sure to use high efficiency, zero Ozone Depletion Potential (ODP), non-flammable and ultra-low Global Warming Potential refrigerants in chillers.

As founding signatories to the World Green Building Council, reporting to the Carbon Disclosure Project and Task Force for Climate Related Financial Disclosures, and aligning with the Sustainable Development Goals and the Global Reporting Initiative, AMP Capital continue to invest in projects that reduce their embodied and operational carbon.

The Quay Quarter development draws on CEFC finance, via an initial $100 million CEFC investment in the AMP Capital Wholesale Office Fund. As part of the CEFC investment, AMP Capital committed to include a range of initiatives across the portfolio, consistent with encouraging lower emissions and greater energy efficiency.

Source: case study and imagery provided by AMP Capital

4 Parramatta Square



Source: case study and imagery provided by Built

The Built Obayashi Joint Venture (BOJV) delivered 4 Parramatta Square: the first major stage of the new $2.7 billion Parramatta Square development and one of the largest urban renewal projects in the country.

The tender required embodied carbon to be addressed throughout the project. The office tower, part of the Parramatta Mall upgrade, used efficient design to reduce resource use, low carbon concrete to minimise emissions and redesigned the mechanical elements to remove steel and copper pipework, and active chilled beams.

These innovations reduced the embodied carbon of the project by 33 per cent when compared with the baseline, the equivalent of 302 kg CO_2-e m^2 GFA.

In addition to the significant embodied carbon savings, these innovations led to significant cost savings. In particular, changing from chilled beams to low temperature variable air volume (VAV) systems reduced capital costs with no modelled impact to the targeted NABERS energy rating.

Though there may be the perception that such a build would be significantly more expensive, BOJV found that there was no premium pricing associated with lower carbon concrete and the efficient design meant a significant saving in material costs.

To ensure the project would be a success, the team undertook a comparative lifecycle assessment of the build to compare the original design with a conventional build. This assessment offered a rich narrative upon which to set ongoing metrics and describe the sustainability initiatives and outcomes throughout the project.

Exceeding the client's requirements of a 5 Star Green Star Design & As-Built rating, the Built Obayashi Joint Venture delivered the project with 6 Stars As-Built and is currently operating more efficiently than forecasted, achieving a 5.5 Star NABERS rating target in its first year of performance, exceeding the project target.

$2.7b

The Parramatta Square development is one of the largest urban renewal projects in the country

What can we learn from the leaders?

1

Substantial emission reductions are possible and already happening in leading projects.

2

Targets to reduce embodied carbon should play a key role in the sustainability vision.

3

Targets and goals should be developed in the early stages of a project's life cycle.

4

All project stakeholders have a role to play in addressing embodied carbon.

5

Investments in embodied carbon reduction can reduce costs.

6

Investments by companies in building expertise and capability in reducing embodied carbon are paid for on the first project, but the benefits can be realised across all subsequent projects.

Cutting embodied carbon in infrastructure

What was the approach?

To understand the extent to which infrastructure projects in Australia are reducing embodied carbon, data from the Infrastructure Sustainability As-Built rating tool (by ISC) was analysed. This analysis included looking at multiple projects across different infrastructure types to understand the scale of embodied carbon reductions and strategies used to achieve them.

The projects analysed include roads, rail, water, and ports. The carbon reductions were calculated relative to the respective base case for the project. The scope of analysis was 'cradle to construction site' and impacts associated with direct construction activities such as land clearing, construction energy, transportation of excavation and fill, were excluded from the analyses.

The results showed that the majority of the initiatives for reducing embodied carbon emissions in infrastructure projects are based on dematerialisation: where better and efficient designing leads to less material being used. Another major source of reduction is material substitution, where carbon intensive materials such as cement and bitumen are replaced by low embodied carbon materials such as fly-ash and Recycled Asphalt Pavement (RAP). In addition to the impacts associated with the production of materials, the impacts of transport to construction site were also included in the analysis.

What did we find?

Road projects

Data from eight road projects across five states New South Wales, Victoria, Western Australia, South Australia, and Queensland were analysed.

It was found that five materials: asphalt, concrete, steel, aggregates and pipes (including concrete pipes); accounted for ~97 per cent of embodied carbon, with asphalt and concrete being the most significant contributors (see Figure 6).

Overall, a **23 per cent reduction** in embodied carbon emissions for this infrastructure type was achieved and project specific reductions ranged from 11 to 50 per cent. Table 4 provides a summary of embodied carbon emissions for the six most significant contributors and changes with regards to base case in road projects.

Figure 6: Embodied emissions contribution of materials for roads supply projects (Actual Case – As-Built data for roads)

Table 4: Embodied carbon changes in road projects

#	Materials	Change: actual vs base case		Total embodied carbon (tCO_2-e)	
		tCO_2-e	Percentage	Base case	Actual case
1	Asphalt	-231,318	-29%		
2	Concrete	-143,448	-30%		
3	Steel	-5,674	-3%		
4	Aggregates	4,362	6%	1,620,154	1,245,777
5	Piping	3,362	18%		
6	Others	-1,208	-4%		
7	**Total**	**-374,376**	**-23%**		

Figure 7: Embodied emissions contribution of materials for rail projects (Actual case – As-Built data)

Rail projects

Data analysed from six projects indicated concrete and steel accounted for ~96 per cent of the total embodied carbon emissions, while aggregates, pipes, and asphalt account for approximately four per cent (see Figure 7).

Table 5 provides a summary of embodied carbon emissions for the five most significant contributors and changes with regards to base case in rail projects. Overall, a **38 per cent reduction** in embodied carbon emissions was achieved for this infrastructure type and project specific reductions range from 16 to 46 per cent.

Table 5: Embodied carbon changes in rail projects

#	Materials	Change: actual vs base case		Total embodied carbon (tCO_2-e)	
		tCO_2-e	Percentage	Base case	Actual case
1	Concrete	-157,000	-45%	476,000	294,000
2	Steel	-24,400	-22%		
3	Aggregates	-346	-4%		
4	Piping	-202	-8%		
5	Asphalt	-705	-28%		
6	**Total**	**-182,000**	**-38%**		

Water supply projects

For major water supply projects, data from only one project was available for analysis.

It was found that concrete and steel accounted for 95 per cent of embodied carbon emissions, while aluminium for four per cent (see Figure 8).

Table 6 provides a summary of embodied carbon emissions for the five most significant contributors and changes with regards to base case in water supply projects. Overall, a **34 per cent reduction** in embodied carbon emissions was achieved for this type of infrastructure project.

Figure 8: Embodied emissions contribution of materials for water supply projects (Actual Case – As-Built data)

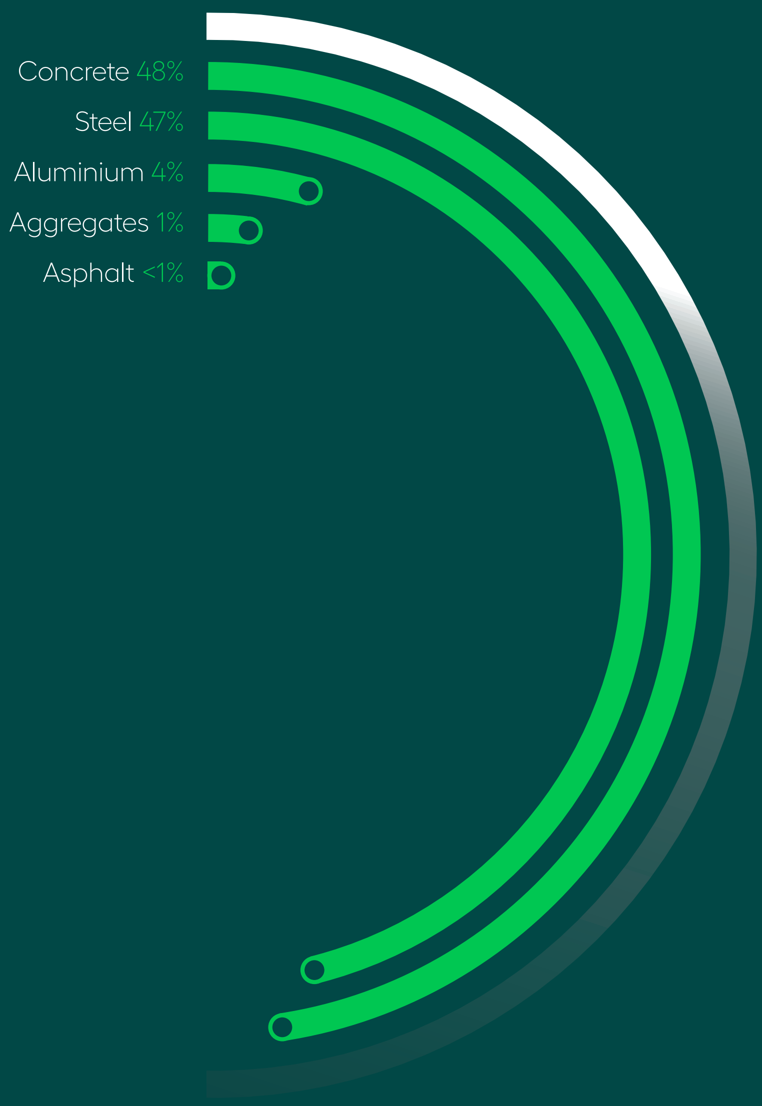


Table 6: Embodied carbon changes in water supply projects

#	Materials	Change: actual vs base case		Total embodied carbon (tCO_2-e)	
		tCO_2-e	Percentage	Base case	Actual case
1	Concrete	-887	-38%	4,670	3,090
2	Steel	-619	-30%		
3	Aluminium	-38	-22%		
4	Aggregates	-11	-29%		
5	Asphalt	-26	-100%		
6	**Total**	**-1,580**	**-34%**		

Port and wharf projects

For ports and wharves, data from only two projects were available.

The analysis indicated that concrete and steel are the most significant contributors to embodied carbon emissions, accounting for ~85 per cent emissions, followed by pipes and composites which together account for approximately eight per cent (see Figure 9).

Overall, a **37 per cent reduction** in embodied carbon emissions for this infrastructure type was achieved. Table 7 provides a summary of embodied carbon emissions for the five most significant contributors and changes with regards to base case for ports and wharves.

Figure 9: Embodied emissions contribution of materials for port and wharf projects (Actual case – As-Built data)

Table 7: Embodied carbon changes in ports and wharves projects

#	Materials	Change: actual vs base case		Total embodied carbon (tCO_2-e)	
		tCO_2-e	Percentage	Base case	Actual case
1	Concrete	-12,200	-36%	61,875	39,285
2	Steel	4,500	67%		
3	Piping	407	32%		
4	Composites	1,479	100%		
5	Others	-16,800	-85%		
6	**Total**	**-22,590**	**-37%**		

Who is leading the way?

Humes saves over 7,250 tonnes of greenhouse gas emissions with carbon neutral precast products.

In partnership with Inland Rail, Humes, a material supplier, has saved the equivalent yearly emissions of 1,350 vehicles in the construction of the Parkes to Narromine rail line by supplying 22,625 tonnes of carbon neutral precast concrete culverts to 103 km of the project.

Humes achieved net zero emissions attributed to the production and manufacture of the precast concrete by:

- Reducing emissions in the production process through innovation and efficiency.
- Purchasing compliant offsets listed under the Climate Active Carbon Neutral Standard.
- Gaining certification of the above steps through a third-party verification process.
- Publicly reporting the carbon inventory, calculation methodology, assumptions and purchased offsets on an annual basis.

Importantly, Humes, a division of Holcim Australia, registered an EPD for precast concrete products in early 2020, following the world-first EPD for precast concrete pipes by Humes in 2017. This allowed for the quantification of embodied carbon through the entire supply chain and, therefore, a credible basis for the purchase of adequate offsets.

Inland Rail will complete the backbone of the national freight rail network between Melbourne and Brisbane via regional communities in Victoria, New South Wales, and Queensland. Comprising of 1,700 km of rail and 13 individual projects, it is the largest rail infrastructure project in Australia and will enhance the efficiency of Australia's geographically distributed supply chains.

Beyond the economic benefits of the project, Inland Rail and Humes were committed to building a project that also met voluntary environmental standards. Inland Rail's Parkes to Narromine project is the first ISC project to have achieved a rating for the use of carbon neutral precast concrete.

'What Humes achieved shows that the supply chain wants to do better and they see the value in pursuing the reach for sustainability and carbon reductions. At Inland Rail we encourage, support, and applaud the supply chain setting a new industry benchmark and this achievement is a real step-change.'

Brad Jackson
Inland Rail Delivery Manager

1,350

The equivalent yearly emissions of 1,350 vehicles has been saved in the construction of the Parkes to Narromine rail line

Source: case study and imagery provided by Holcim

Reconophalt – addressing circular economy and embodied carbon in Australia's roads.

Developed by Downer in partnership with Close the Loop, Reconophalt is a road surfacing and pavement material made of recycled asphalt, toner derived from used printer cartridges, soft plastics collected by the community and deposited in collection bins at Coles and Woolworths supermarkets, waste oil, recycled glass and even separated street sweeper waste and gully waste. By incorporating used materials into their product, they have facilitated the demand for a circular economy and lowered the embodied carbon compared to standard asphalt by up to 25 per cent.

At Downer, sustainability is a key priority. Teams are encouraged to innovate to enhance the services they deliver for customers. This includes the process, products and manufacturing involved in the production and laying of asphalt.

Increased energy usage disclosure associated with asphalt manufacturing has also driven innovation in the sector and Downer has responded with a Science Based Target, committing to net zero by 2050 which we seek verification by the Science Based Target Initiative. These factors led to the development of low CO_2-e asphalt, the first step in the move to addressing greenhouse gas emissions of asphalt which ultimately resulted in Reconophalt.

The key to Downer's success was their commitment to collaboration. Downer worked closely with the NSW EPA to develop an appropriate test method that investigated any potential environmental impacts including microplastics, leaching, fuming and more. As this was the first time that many of these tests had been conducted on asphalt, Downer had to seek expertise from overseas and identified an appropriate laboratory facility in Norway where the microplastic testing took place. Downer also needed to collaborate with customers to alleviate any concerns regarding Reconophalt's performance.

To address these concerns Downer developed the first cradle to grave Environmental Product Declaration (EPD) for this category. This provided the market with open, transparent interdependently verified information on the full life cycle impact of Reconophalt.

Downer continues to innovate, having completed a proof of concept of 99 per cent and 100 per cent recycled asphalt. The next step is to release a carbon neutral asphalt. Downer's Reconophalt and product pipeline demonstrate the important link between circular materials and reducing embodied carbon.

up to 25%

Possible reduction in embodied carbon compared to standard asphalt

Source: case study and imagery provided by Downer

Source: case study and imagery provided by John Holland and CPB Contractors Joint Venture (JHCPB)

Overcoming regulatory barriers to a low-carbon, circular future.

Innovation is a core value of John Holland and CPB Contractors Joint Venture (JHCPB), who are currently delivering the $3.9 billion Rozelle Interchange and Western Harbour Tunnel Enabling Works Project in Sydney, one of the largest infrastructure projects currently under construction in Australia.

As concrete is the most widely used construction material, JHCPB recognised early on that it represented the greatest opportunity for positive change through innovation. As a result, JHCPB has actively focused on the application of alternative concrete solutions on the project, including:

- The use of Boral ENVISIA concrete in TfNSW Specification R53: Concrete for General Works (R53) applications (with a bespoke supplementary cementitious material replacement of up to 70 per cent).
- The replacement of traditional reinforcing steel in R53 applications with recycled plastic fibres.
- The replacement of virgin sand in flowable fill for tunnel drainage with recycled crushed glass.
- UNSW Supported Research and Development into the use of Geopolymer Concrete (GPC).

Getting a complex major project to embrace an innovative approach to materials was not without its challenges. Whilst some stakeholders considered the project too large to take risks, JHCPB embraced the opportunity to make a real difference to the way roads are constructed in NSW. JHCPB worked closely with the client (TfNSW) and suppliers (Boral, Hanson and Emesh) to facilitate trials of the alternative materials, particularly when the proposals fell outside of current engineering specifications. Despite a strong driver from the NSW EPA in the form of waste diversion grants, sourcing fit-for-purpose and clean waste glass was also a challenge as EPA-endorsed suppliers were limited in Sydney.

Further, breaking down the decision-making drivers, building appetite, and connecting teams to create opportunities was also difficult. Understanding the fundamental complexities of cost, workability, durability, and project approvals pathways was therefore crucial for success.

JHCPB's goal is to leverage research and trials at Rozelle Interchange to enable approval of state wide low carbon concrete specifications by TfNSW. This will massively multiply benefits across the whole industry. Leaving a positive legacy for the residents of the Inner West was a significant driver for JHCPB. As well as providing a nine hectare green space improvement, the project was driven to find innovative solutions to provide value for money for the client and ultimate road users. As a result, JHCPB continues to explore opportunities to trial and prove performance of lower embodied carbon alternatives to traditional concrete, whilst setting the standard for future innovation in infrastructure.

What can we learn from the leaders?

1

Substantial emissions reductions are possible and happening – easily surpassing 20 per cent.

2

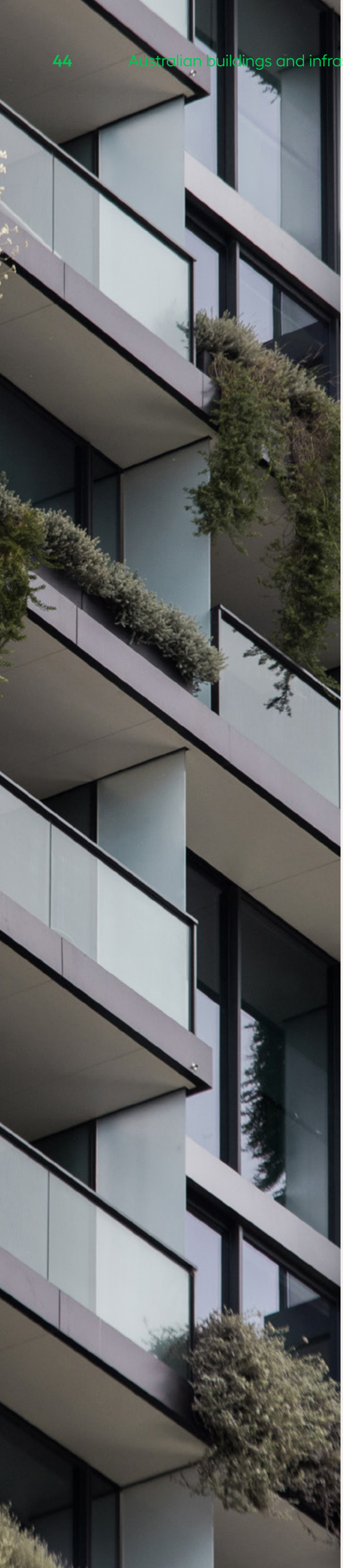
Concrete and steel are high focus materials for reduction, requiring collaboration between project designers, decision-makers, and material manufacturers in the early stages of the project.

3

Government tenders play a significant and critical role in driving further embodied carbon reductions.

Overview of opportunities and costs

This section evaluates the embodied carbon reduction potential of several design and materials initiatives as well as their cost implications in building and infrastructure projects. A discussion on the advantages, disadvantages, enablers and barriers is also included.



What did we find?

- Cost effective solutions are available today to substantially reduce embodied carbon. Depending on the initiatives implemented, it is possible to achieve five to 18 per cent reduction in embodied carbon whilst also achieving a 0.4 to three per cent reduction in material costs for typical building and infrastructure projects.
- There are already low embodied carbon materials and design initiatives available and successfully implemented. This is driving growth in market share for materials such as high SCM concrete, high strength steel and engineered timber in both building and infrastructure contexts.
- Ensuring that embodied carbon is front of mind from project inception is most effective for both cost considerations and to maximise carbon mitigation. While use of appropriate low carbon materials at any stage of a project can reduce project footprints, the most effective way to reduce embodied carbon is to consider it in a strategic way throughout an asset's life cycle.
- Some initiatives may not presently result in cost savings but can provide higher embodied carbon reduction (up to 38 per cent). As the technology and market matures, the cost of these initiatives may decrease.
- Each material has its own unique advantages and considerations when it comes to implementation. Through careful and early consideration of project-specific design requirements, both traditional and innovative materials can play a role in lowering whole-of-project embodied carbon.
- Even though considerable progress has been made to reduce embodied carbon across construction projects, it is still not yet possible to achieve carbon neutral builds without acquiring offsets. As such, offsets are still a fundamental part of achieving positive sustainability outcomes and should be considered in a holistic, project-wide embodied carbon strategy.
- While both cost negative and cost positive options are presented in this report, this should not be understood as a value judgement for one initiative or another. Individual requirements and characteristics will determine the most effective embodied carbon reduction initiatives for each project. Marginal Abatement Cost Curves (MACCs) are only one way to understand the carbon reductions and cost initiatives. Project/site specific characteristics will need to be considered to develop future projects' embodied carbon reduction strategies. Designers, proponents, and investors will need to work with individual projects suppliers to get the best outcomes.

5-18%

Possible reduction in embodied carbon whilst also reducing material costs

How were the carbon and cost implications calculated?

Figure 10: Methodology outline for quantifying emissions reduction and cost implications of initiatives

Carbon reduction potential of initiatives

1. Calculating embodied carbon emissions for reference case building and infrastructure projects
2. Identifying initiatives and opportunities for embodied carbon reduction
3. Quantifying emissions reduction potentials of the initiatives through life cycle assessment (LCA)

Cost implications of carbon reduction

4. Assessing current cost implications of initiatives through liaison with product manufacturers and suppliers
5. Outlining enablers and barriers to implementation of the initiatives

An outline of the methodology used to quantify the emissions reduction potential and cost implications of the initiatives is provided in Figure 10.

Typical building and infrastructure assets were identified as 'reference case' projects, and their embodied carbon emissions were considered as 'baseline'.

For each 'reference case' project the 'baseline' emissions were calculated and the potential of various initiatives to reduce embodied carbon in these projects was analysed. The initiatives entailed substitution of standard construction materials and design elements in 'reference case' projects with their low embodied carbon alternatives. Three levels of materials and design element substitution were analysed as a part of this report: 10 per cent, 30 per cent and 50 per cent.

The results for embodied carbon reduction for all levels of substitution are presented as percentage relative to the 'baseline' emissions. The 'Detailed findings: carbon implications' section in the later part of this report (Page 48) provides a detailed account of the reduction in embodied carbon due to the initiatives.

The initiatives' cost implications are further built on in the section, 'Detailed findings: cost implications' (Page 58). Using the 30 per cent substitution scenario, Marginal Abatement Cost Curves are produced cross-referencing the carbon and financial implications of the reported initiatives.

What are the design and material initiatives for reducing embodied carbon?

The materials and design initiatives included in this section are tailored for typical infrastructure and building projects. Feedback from nine leading industry representatives from steel, concrete, rail and road sectors was sought for developing these initiatives. A complete list of the initiatives is provided in Table 8.

Table 8: Complete list of initiatives modelled in this report

Initiative type	Project type	Material type	Initiative
Design	Building	Concrete	Precast elements instead of in-situ casting
			High strength concrete instead of standard concrete
		Timber	Engineered timber instead of steel
		Steel	High strength steel (750 N) instead of standard steel (500 N)
Material	Building	Concrete	Additives to lower cement content and increase strength
			Supplementary Cementitious Materials (SCM) in concrete mix*
			Carbon neutral concrete
			Geopolymer concrete
		Steel	Carbon neutral steel
			Produced via EAF and using renewable electricity
		Aluminium	Renewable electricity in aluminium production
Material	Infrastructure	Asphalt	Recycled Asphalt Product (RAP) in asphalt mix#
			RAP in asphalt mix and no lime addition
		Concrete	Additives to lower cement content and increase strength
			Supplementary Cementitious Materials (SCM) in concrete mix*
			Geopolymer concrete[6]
			Carbon neutral concrete
			Aggregates
		Steel	Produced via Electric Arc Furnace (EAF) and using renewable electricity
			Carbon neutral steel
		Plastic	Recycled plastic sleepers to replace concrete sleepers

20–40% RAP in asphalt mix | * 30% SCM in concrete mix

[6] Geopolymer concrete is a low embodied carbon content concrete that is usually made by reacting aluminate and silicate bearing materials with a caustic activator. Waste materials such as fly-ash or slag from steel or metal production are also used as geopolymer constituents. It does not require heat and does not produce CO_2 while curing.

The scope for LCA of the materials and design initiatives was 'cradle to construction site'. Energy required for construction was excluded from the scope as it is expected to have similar impact for the standard and alternative low embodied materials analysed in this report.

A list of relevant materials and their baseline specifications are provided in Table 9. These are the materials which will be substituted by low embodied carbon alternatives as outlined in the initiatives earlier.

Table 9: Standard materials and baseline assumptions for modelling

Materials/items	Baseline specifications
Concrete	Ready mix, 40 MPa, 0% Supplementary Cementitious Material (SCM)
Steel	Manufactured using grid electricity and mix of electric arc furnace, basic oxygen and blast furnace technologies
Aluminium	100% virgin and produced using grid electricity
Aggregates	Sourced from quarry/mine
Asphalt	Standard hot mix asphalt, 4–5% bitumen and 0% Reclaimed Asphalt Pavement (RAP)
Transport distance	100 km road transport by truck
Sleepers	Concrete sleepers

Before going through the findings, please note...

- The inventory of materials and design elements used to calculate embodied carbon emissions for most 'reference case' projects are based on actual building and infrastructure assets in Australia and has been sourced from respective industry representatives.
- The baseline assets for building and infrastructure projects analysed in the subsequent section of this report are assumed to be built with conventional materials described in Table 9. There are several structural and design aspects that need to be considered while substituting these materials with alternatives. As such, direct or like-for-like substitution is often not possible. For example, while the use of engineered timber can reduce the amount of steel required in a building, it cannot completely replace it. Industry case studies indicate that up to 60 per cent replacement of steel with engineered timber can be possible. It is for this purpose the calculation methodology considers only partial substitution of materials/design elements (i.e. 10 per cent, 30 per cent and 50 per cent). While this method cannot account for micro-level changes (such as changes to construction auxiliaries, formwork, bindings, etc.), it allows decision-makers to understand the broader implications of their choices at a high level.
- For graphical representation purposes, the initiative names have been shortened in the subsequent charts. Please refer to Table 8 for description of the initiatives and Table 9 for the standard materials or design elements being replaced.

Detailed findings: carbon implications

Building projects

Based on the analyses of data from GBCA, it was found that concrete, steel and aluminium are the major contributors to embodied carbon in buildings. As such, materials and design initiatives are focused first on these materials.

Office and mixed use buildings

Figure 11 and Figure 12 show the project-level embodied carbon reduction potential of design and materials initiatives as applicable to an office/ mixed use building project with a Gross Floor Area (GFA) of ~40,000 m².

Figure 11: Reduction in an office/mixed use building's embodied carbon due to design initiatives

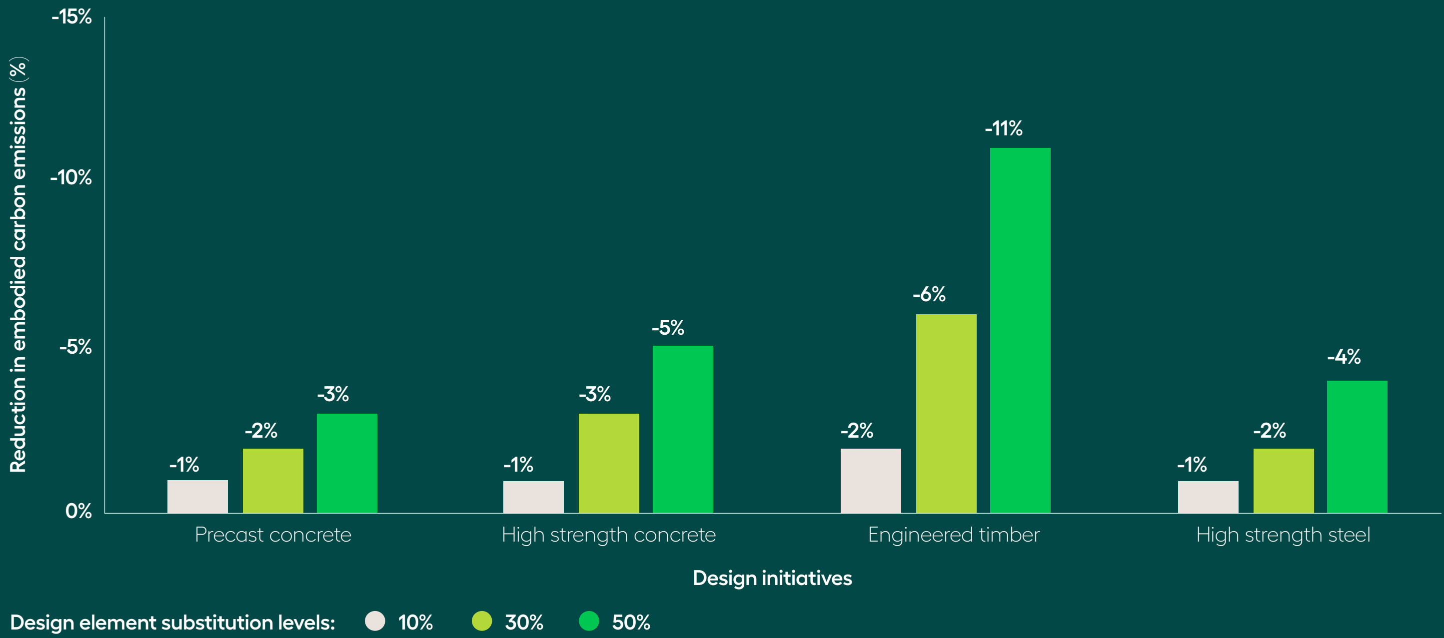
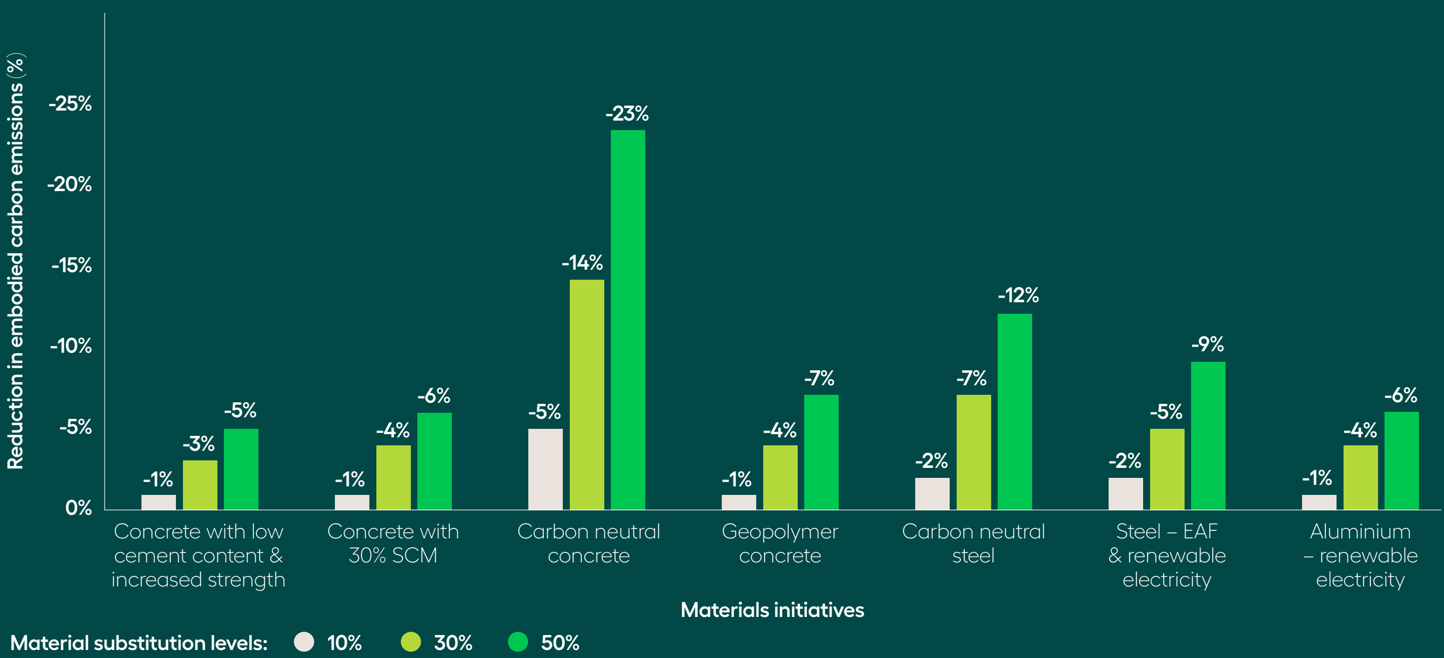


Figure 12: Reduction in an office/mixed use building's embodied carbon due to materials initiatives



Industrial buildings

Figure 13 and Figure 14 depict the embodied carbon reduction potential of design and materials initiatives in an industrial building project with a Gross Floor Area (GFA) of ~74,500 m[2].

Figure 13: Reduction in an industrial building's embodied carbon due to design initiatives

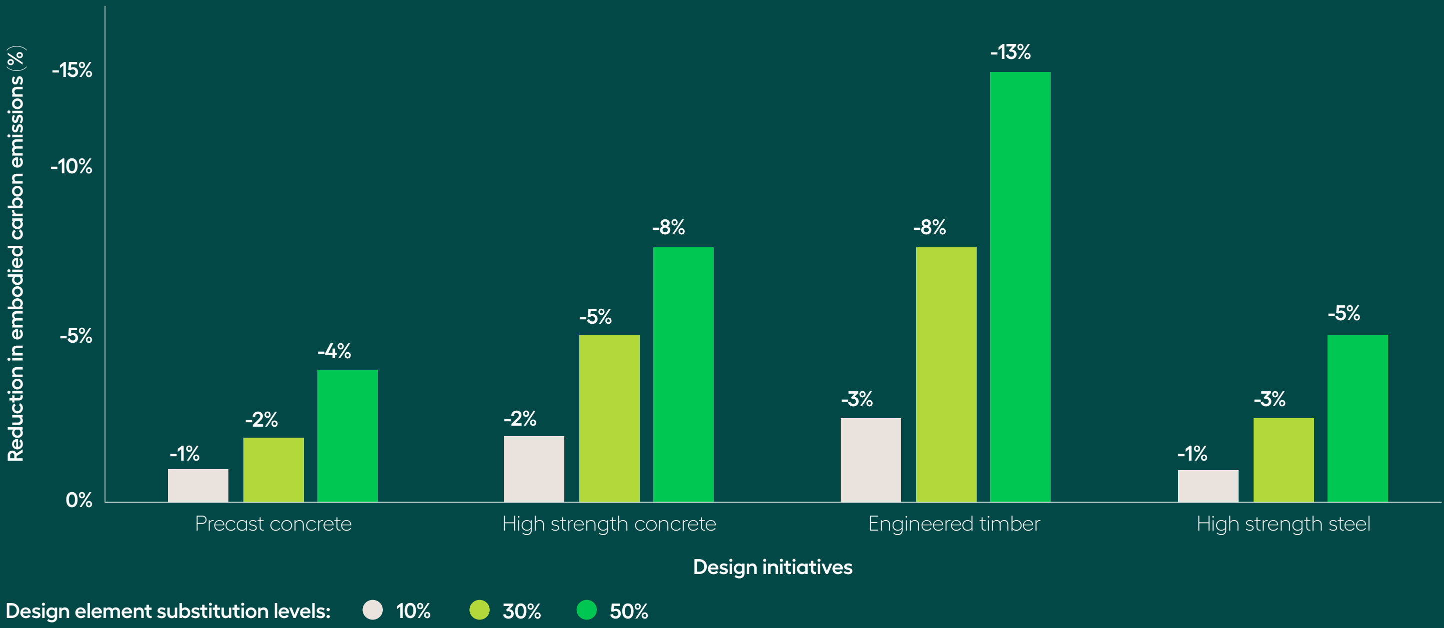
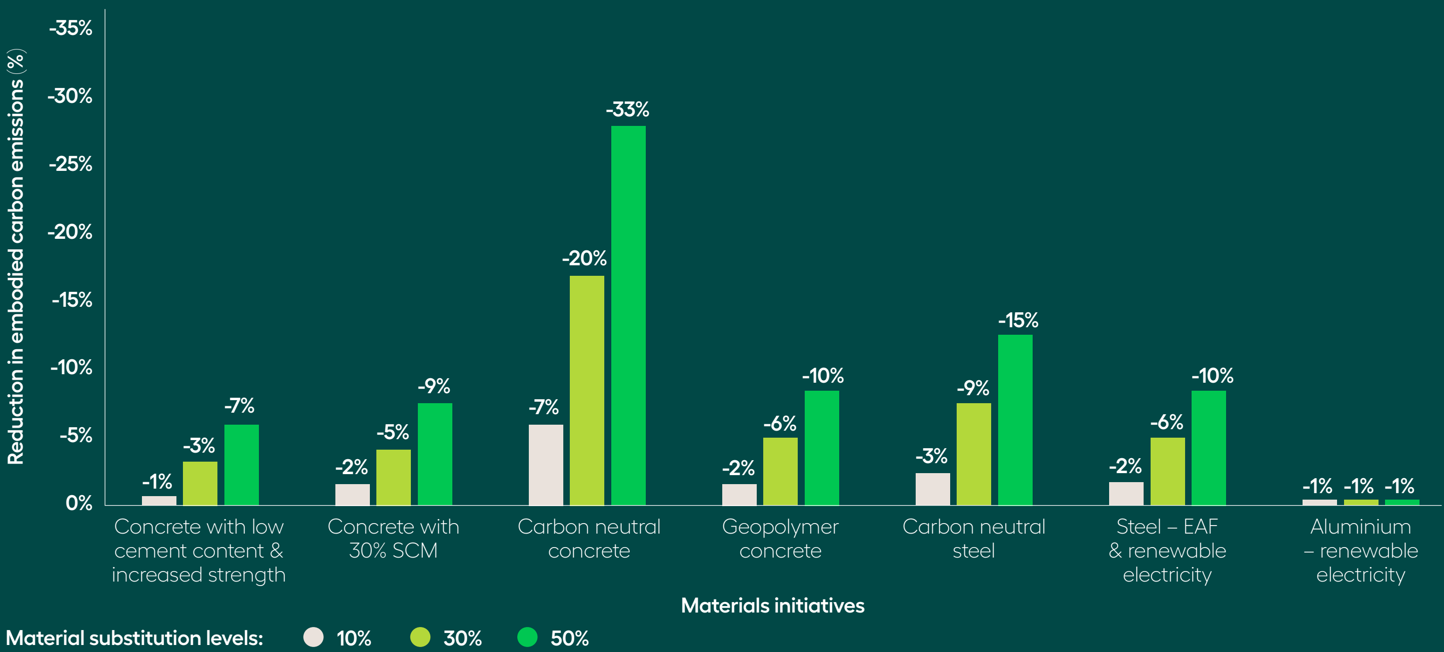


Figure 14: Reduction in an industrial building's embodied carbon due to materials initiatives



Infrastructure projects

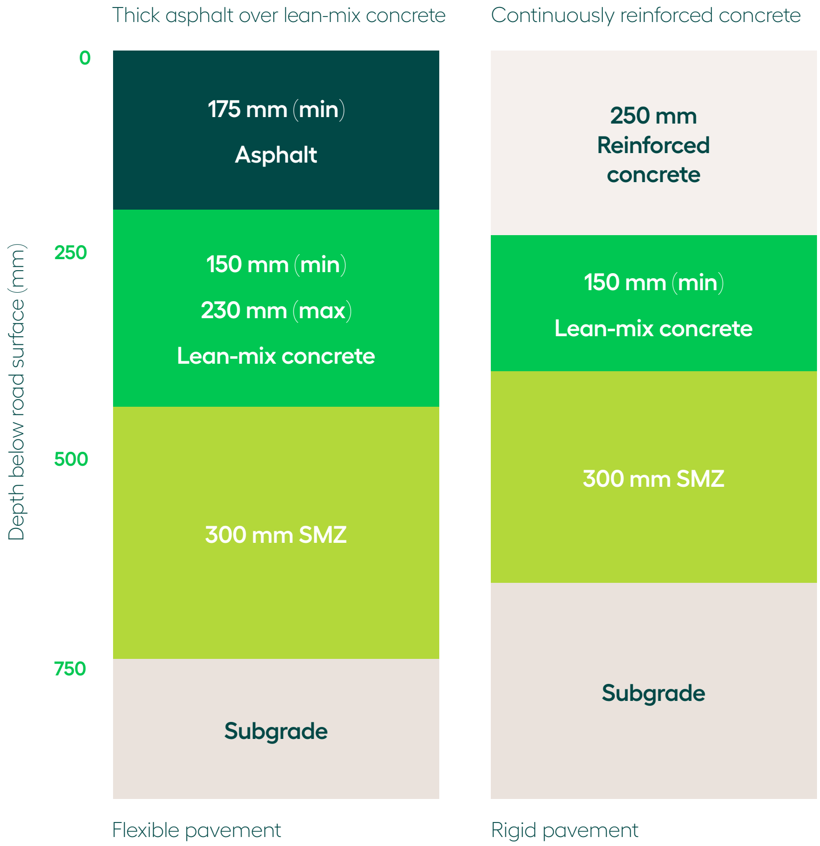
Two infrastructure projects, a four-lane 10 km road and a 11 km suburban double railway track, were considered for analysis.

For the road project, both flexible and rigid pavements were considered – see Figure 15 for the road structure, which is based on the NSW Roads and Maritime Supplement to Austroads Guide to Pavement Technology.

Road projects

Both flexible and rigid pavements were considered to ensure that the difference in materials used to construct each is captured in the modelling. Impacts from supplementary assets such as bridges, tunnels, platforms, railway stations, for example, were excluded in the analyses of infrastructure projects.

Figure 15: Structure of flexible and rigid pavements



As outlined in section Road Projects (Page 34), asphalt, concrete, steel and aggregates are the most significant contributors to embodied carbon in road projects. Hence the initiatives for lowering embodied carbon in road projects were applied to these materials. For example, replacing 10 to 50 per cent of standard concrete with carbon neutral concrete can result in seven to 38 per cent reduction in embodied carbon emissions of a road project. Figure 16 and Figure 17 depict the carbon reduction potential of initiatives for flexible and rigid pavements.[7]

Figure 16: Embodied carbon reduction due to materials initiatives in a road project – flexible pavements

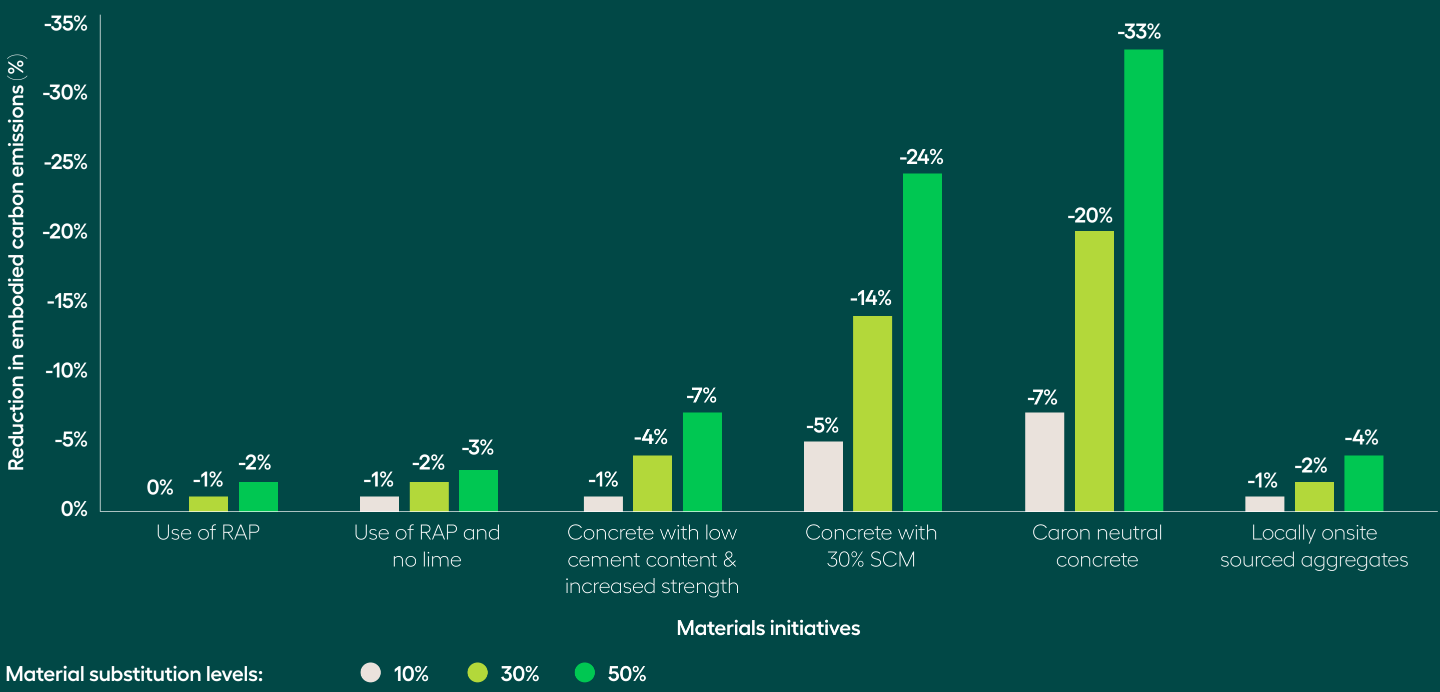
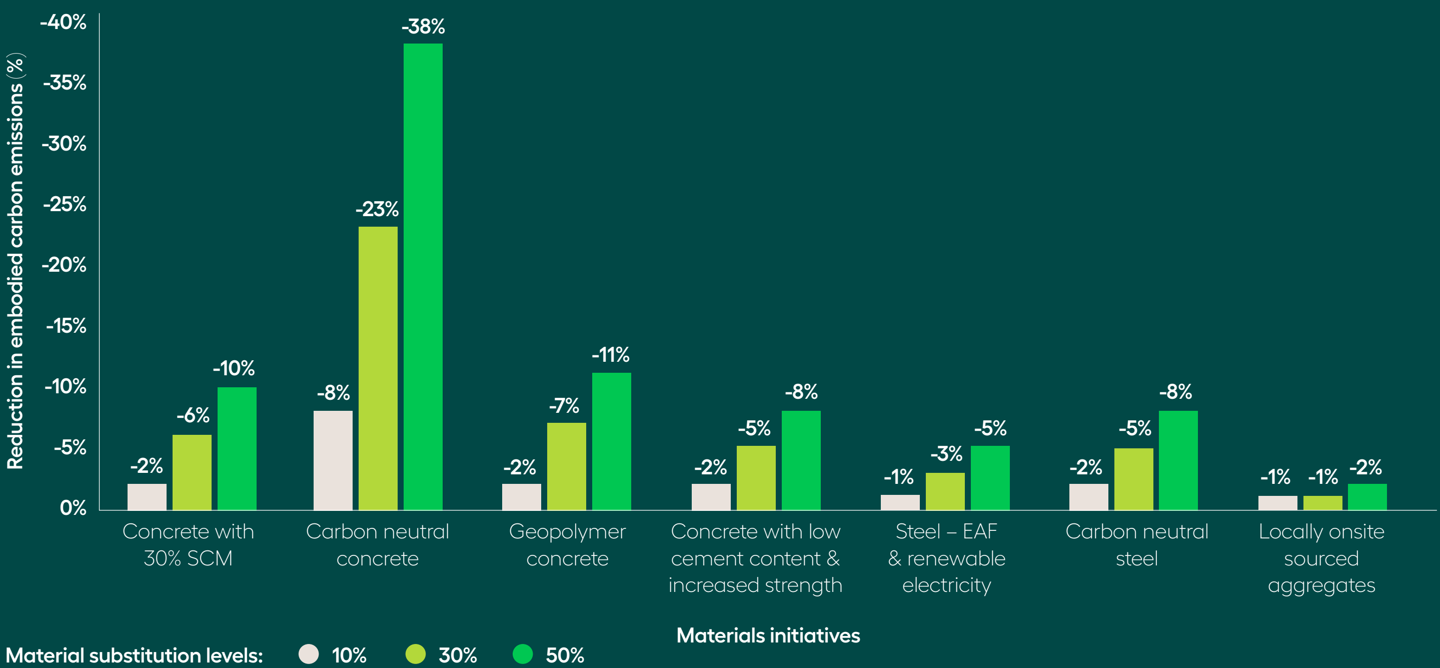


Figure 17: Embodied carbon reduction due to materials initiatives in a road project – rigid pavements

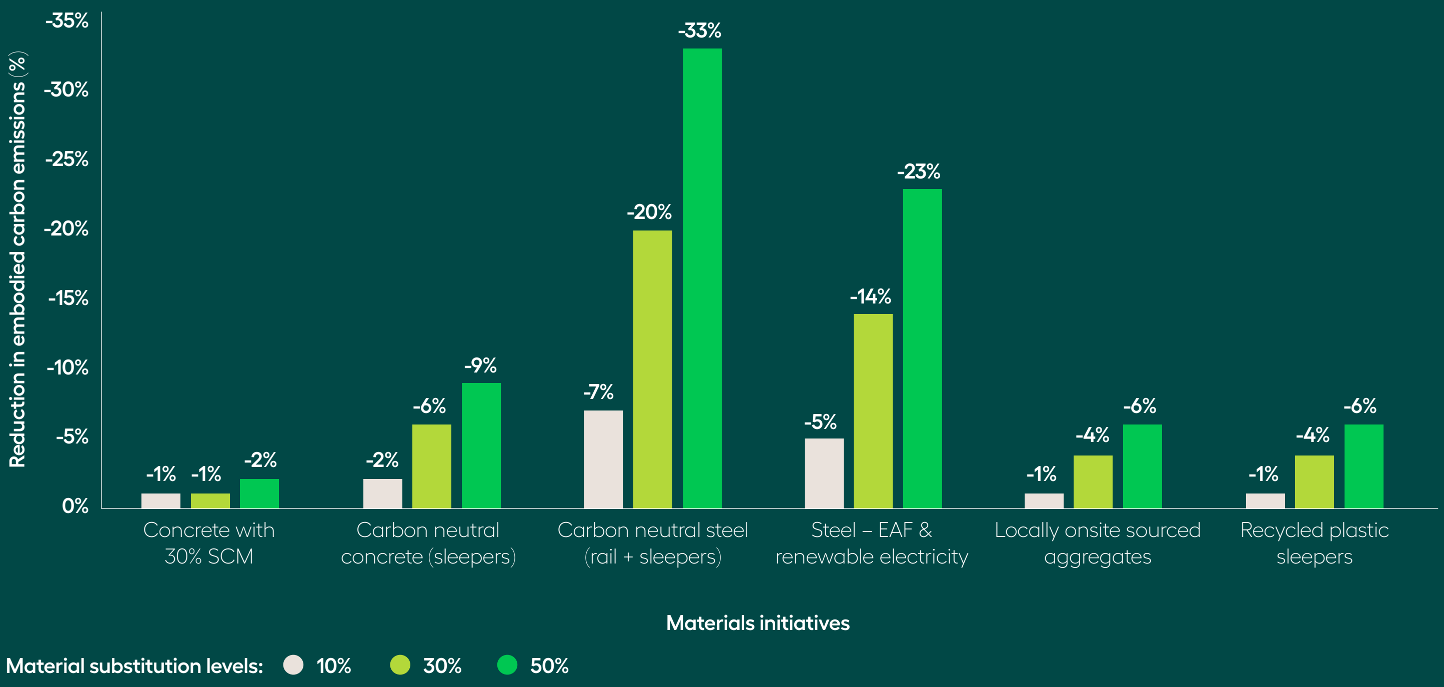


[7] Note that the reduction in embodied carbon due to the RAP initiatives is low because it used as a substitute for aggregates, which inherently have a low embodied carbon content.

Rail projects

The initiatives for lowering embodied carbon in rail projects are directed towards concrete, steel and aggregates. The rail project analysis considers materials required for constructing the actual railway track (i.e. steel for the rail, concrete for sleepers and aggregates for ballast). The construction and materials required for bridges, tunnels, platforms, etc. are not included in the assessment scope. Figure 18 depicts the carbon reduction potential of materials initiatives in a rail project.

Figure 18: Embodied carbon reduction due to materials initiatives in a rail project



Understanding the cost implications of the carbon reduction initiatives

Strategies to reduce embodied carbon in infrastructure and property assets inevitably come with cost implications, be the cost positive, neutral, or negative.

Table 10 summarises the report's findings for each asset type using only cost negative and cost neutral initiatives and shows that there are a range of initiatives that save both emissions and costs already available today. Note that neither cost positive initiatives nor offset-based initiatives have been included here.

Table 10: Summation of cost negative and cost neutral initiatives for each project type

Project type	Typical embodied carbon	Cost neutral/negative initiatives considered	Carbon abatement		Cost saving	
			Carbon savings per project	% of total project embodied carbon	Average $/t CO_2-e mitigated	% of total materials cost in a project
Office building (40,000 m² GFA)	39,000 t CO_2-e	• 30% SCM rate concrete. • Use of precast concrete elements as appropriate. • Use of engineered timber, where feasible.	4,500 t CO_2-e	12%	$119	2%
Industrial building (75,000 m² GFA)	20,200 t CO_2-e	• 30% SCM rate concrete, • Use of precast concrete elements as appropriate. • Use of engineered timber, where feasible.	3,030 t CO_2-e	15%	$120	3%
Flexible pavement (10 kms x 4 lanes of surface)	19,515 t CO_2-e	• Use of 20–40% RAP (no lime). • 30% SCM rate concrete. • Locally sourced materials.	3,500 t CO_2-e	18%	$116	2%
Rigid pavement (10 kms x 4 lanes of surface)	35,800 t CO_2-e	• Use of 20–40% RAP (no lime). • 30% SCM rate concrete. • Locally sourced materials.	2,600 t CO_2-e	7%	$30	0.4%
Rail (11 kms of double track)	9,100 t CO_2-e	• 30% SCM rate concrete. • Locally sourced materials.	486 t CO_2-e	5%	$134	0.7%

MACCs and how to use them

To show a more detailed view of the abatement potential of each carbon reduction initiative and the associated cost implications, Marginal Abatement Cost Curves (MACCs) are used. A MACC is a graphical representation of the potential and cost implications of opportunities to reduce emissions.

This kind of analysis is used to develop a high-level representation of both the cost and abatement potential of each option in a generic 'typical' project.

Each block on the graph represents a different initiative, with the width of a block representing embodied carbon reduction potential and the height showing the average net cost of abatement of one tonne of CO_2-e under that initiative. The graph is ordered left to right in order of low to high cost with any blocks below the central X-axis being cost negative.

While negative costs (savings) represent a profitable investment over the investment period, actions with positive cost implications may still be considered advantageous and be implemented if there are additional benefits to organisations (such as reputational advantages, first adoption of an advancing or ground-breaking approach, achievement of additional ratings points e.g. Green Star, LEED, or IS ratings, or to provide a stand-out feature for a tender process), or if the costs are linked to adhering to future policy changes, changes to operational environments and operational costs, or technological breakthroughs.

The limitations of MACCs

The purpose of MACCs is not to compare and contrast initiatives or materials; rather, it is to convey current status of ideas to drive and provoke discussion and highlight the urgency of the issue of embodied carbon in construction materials, promoting improvement across the industry.

It should be noted that a MACC represents a high-level view of the direct carbon mitigation and cost implications of a material strategy. Non-economic considerations such as additional regulatory or planning requirements, worksite scheduling or on-site considerations, lack of industry-wide expertise, or individual site or project considerations cannot be captured here. These non-economic considerations are discussed, in relation to each material strategy in Table 11 – Initiative Advantages and considerations. One of the goals of this report is to prompt dialogue around these non-economic barriers, exploring how best to overcome them and allow the construction industry to make best use of low embodied carbon materials.

How to interpret the data

The MACCs presented show the scale of potential carbon abatement and the cost implications associated with strategies outlined. All opportunities shown are calculated on a project level with an uptake rate of each initiative of 30 per cent. It should also be noted that materials and products have been modelled at 2019–20 prices.

Some embodied carbon reduction strategies will reduce projects costs, whereas others will require additional financial outlay. Strategies also have their inherent advantages and disadvantages, including those related to feasibility, utility, and cost-efficacy, which should be assessed according to the specific needs of each site and project. These factors are explored further in the 'Advantages and considerations' section and decisions around implementation should be taken in a broader context than generalised costing.

Additionally, the MACCs show the current carbon-saving potential of materials at current market prices. It should be understood that the financial considerations of each strategy will change with different scopes and scale of project as well as with changes to input factors such as electricity or transport costs.

Lastly, changes in costs and efficiencies of manufacturing technology and other dynamic factors will also change the results over time.

Detailed findings: cost implications

Building projects

The wider range of materials used in property and building construction brings greater scope for mitigation strategies. However, given the high proportion of metals and concrete in modern construction projects, the scales of these opportunities again revolve around steel and concrete.

Property assets do have the added option of high rates of precast elements. While the use of precast concrete elements gives a relatively conservative carbon mitigation rate directly through materials quantities, the ability to utilise low-carbon concrete in production, reductions in material waste, and improvements to construction schedules can lower project emissions. Additionally, improvements in quality control, better reliability for construction timelines, and lowered susceptibility to adverse weather conditions during curing give the potential to reduce project risk exposure and lead and construction times without compromising quality.

These advantages must be considered in line with the potential disadvantages of precast elements, such as wind affecting lifts, requirements for bespoke moulds and the associated resources, and the potential for steam curing to facilitate mould stripping, amongst others. As such, the use of precast concrete elements, while potentially a useful tool to reduce embodied carbon, should be assessed under site and project-specific lenses.

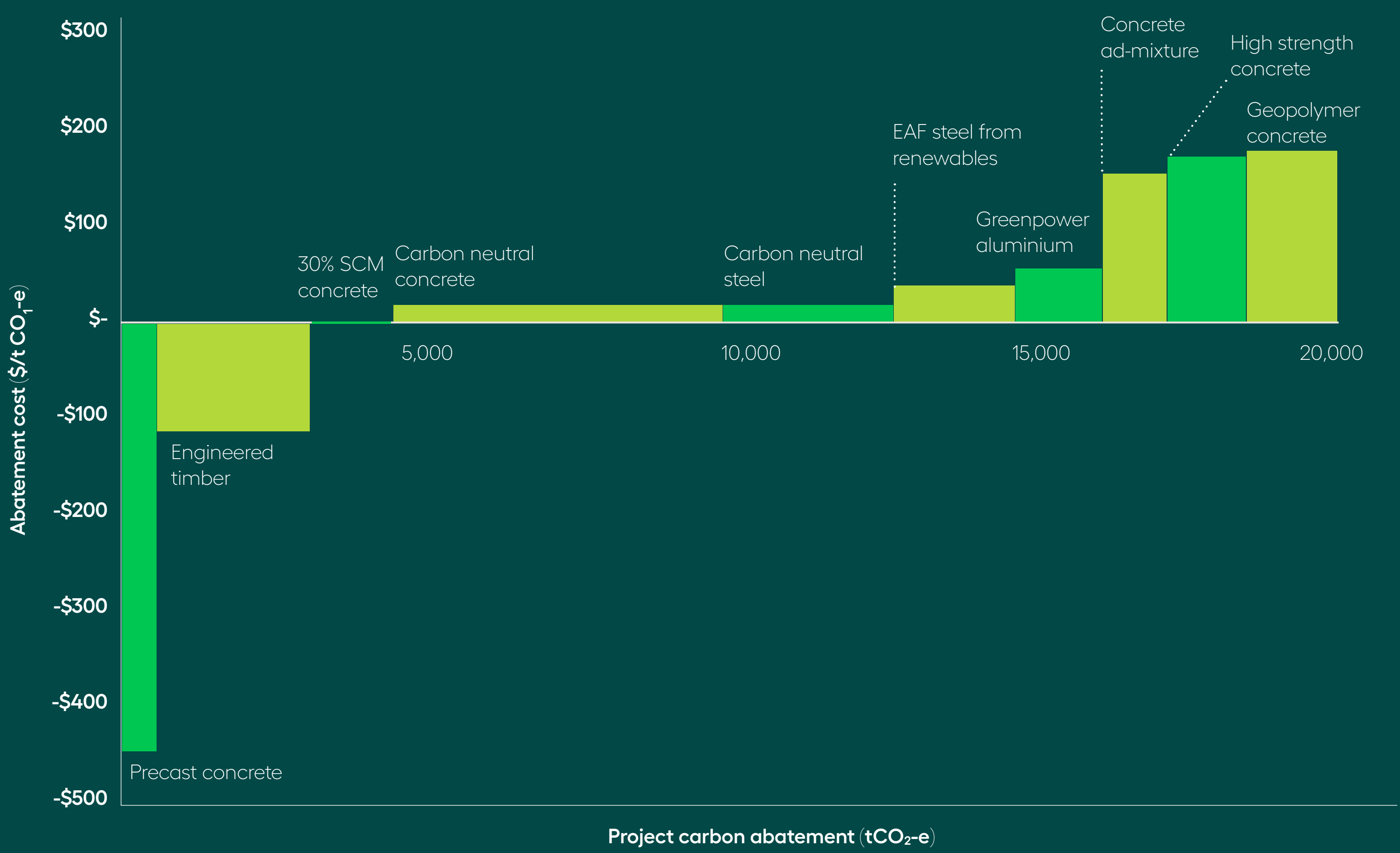
Office and mixed use buildings

The figures presented are based on modelling of an illustrative conventionally built commercial building, with a GFA of 40,000 m^2. This project would involve 39,000 tonne CO_2-e of embodied carbon. Implementing a 30 per cent uptake of the three cost-neutral and cost-negative initiatives (i.e. 30 per cent SCM rate concrete, use of precast concrete elements as appropriate, and the use of engineered timber, parenthesis where feasible) has the potential to abate approximately 4,500 tonne CO_2-e, a 12 per cent reduction in embodied carbon, at an average saving of $119 per tonne CO_2-e reduced, largely attribute to the use of precast concrete elements.

Across the project outlined above (i.e. commercial building with 40,000 m^2 GFA), a cost saving of approximately $540,000 could be found (approximately 1.6 per cent of project material costs). These savings could be re-invested in cost-positive abatement initiatives to further reduce the overall project footprint.

A portion of the reductions for this asset type are associated with a replacement of in-situ concrete with precast design elements at an uptake rate of 30 per cent. As such, reductions are subject to precast being applicable to project-specific asset conditions and design.

Figure 19: MACC for office/mixed use buildings



12%

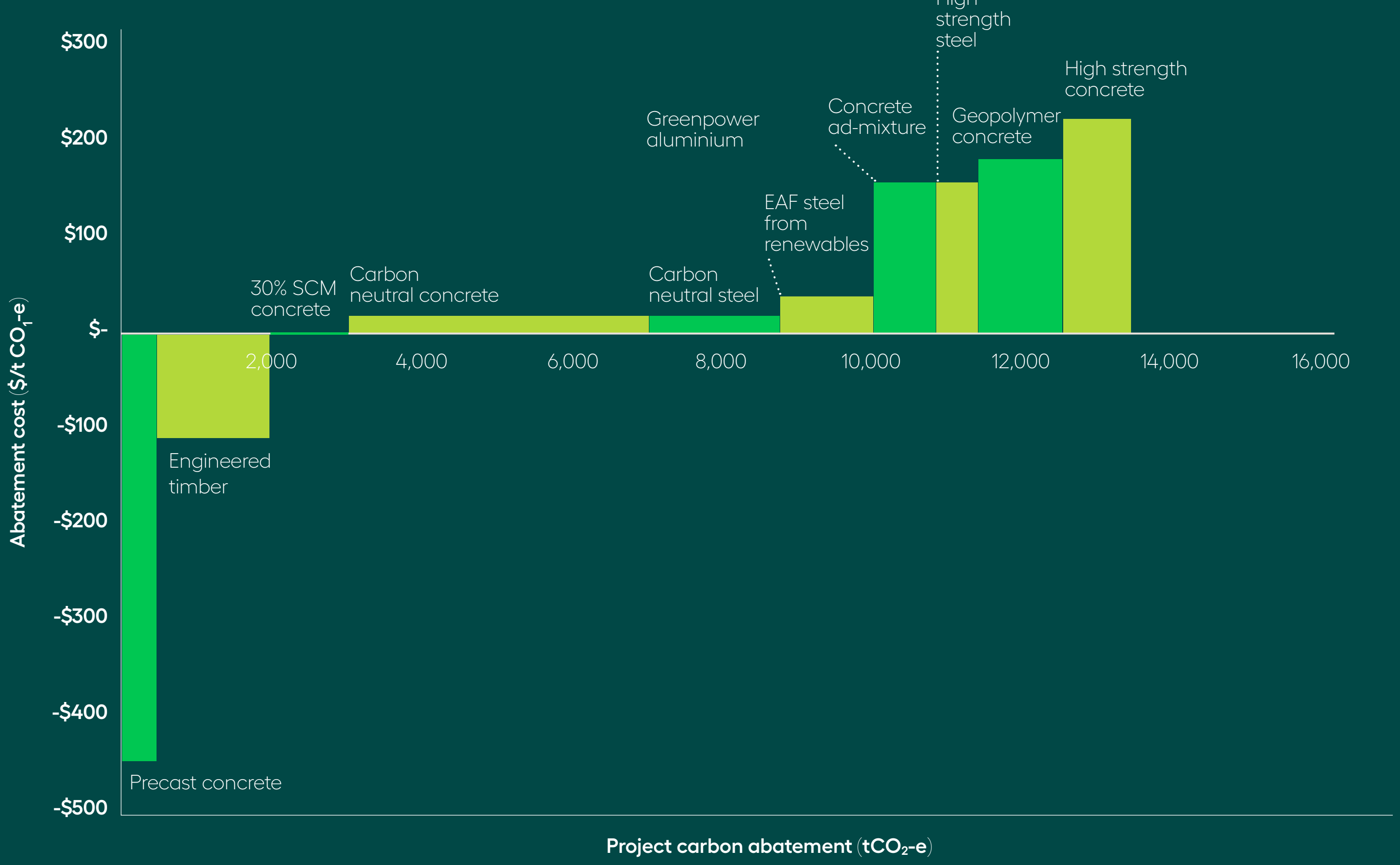
Implementing a 30% uptake of the three cost-neutral and cost-negative initiatives has the potential to abate approximately 4,500 tonne CO_2-e, a 12% reduction in embodied carbon

Industrial use

The figures presented are based on modelling of an illustrative conventionally built industrial/warehouse building, with a GFA of 75,000 m^2. This project would involve 20,200 tonne CO_2-e of embodied carbon. Implementing a 30 per cent uptake of the three cost-neutral and cost-negative initiatives (30 per cent SCM rate concrete, use of precast concrete elements as appropriate, and the use of engineered timber, where feasible) has the potential to abate approximately 3,030 tonne CO_2-e, a 15 per cent reduction in embodied carbon, at an overall saving of $120 per tonne CO_2-e.

Across the project outlined above (i.e. industrial building with 75,000 m^2 GFA), a cost saving of approximately $365,000 (approximately three per cent of project material costs) could be found. These savings could be re-invested in cost-positive abatement initiatives to further reduce the overall project footprint.

Figure 20: MACC for industrial buildings



$365k

Across the project, a cost saving of approximately $365,000 (approximately 3% of project material costs) could be found

Infrastructure projects

Rail

Strategies to reduce carbon impacts in rail project fall into similar categories as road building. Embodied carbon reductions can be found through engagement with steel and concrete procurement, through use of carbon offsets of purchased materials, and through cementitious material replacements in concrete.

The figures presented are based on modelling of 11 kms of dual track. For reference, under standard conditions, this project would involve 9,100 tonne CO_2-e of embodied carbon. Implementing the two cost-neutral and cost-negative initiatives (30 per cent SCM rate concrete and locally sourced materials) has the potential to abate approximately 486 tonne CO_2-e, a five per cent embodied carbon reduction, at an overall saving of $134 per tonne CO_2-e.

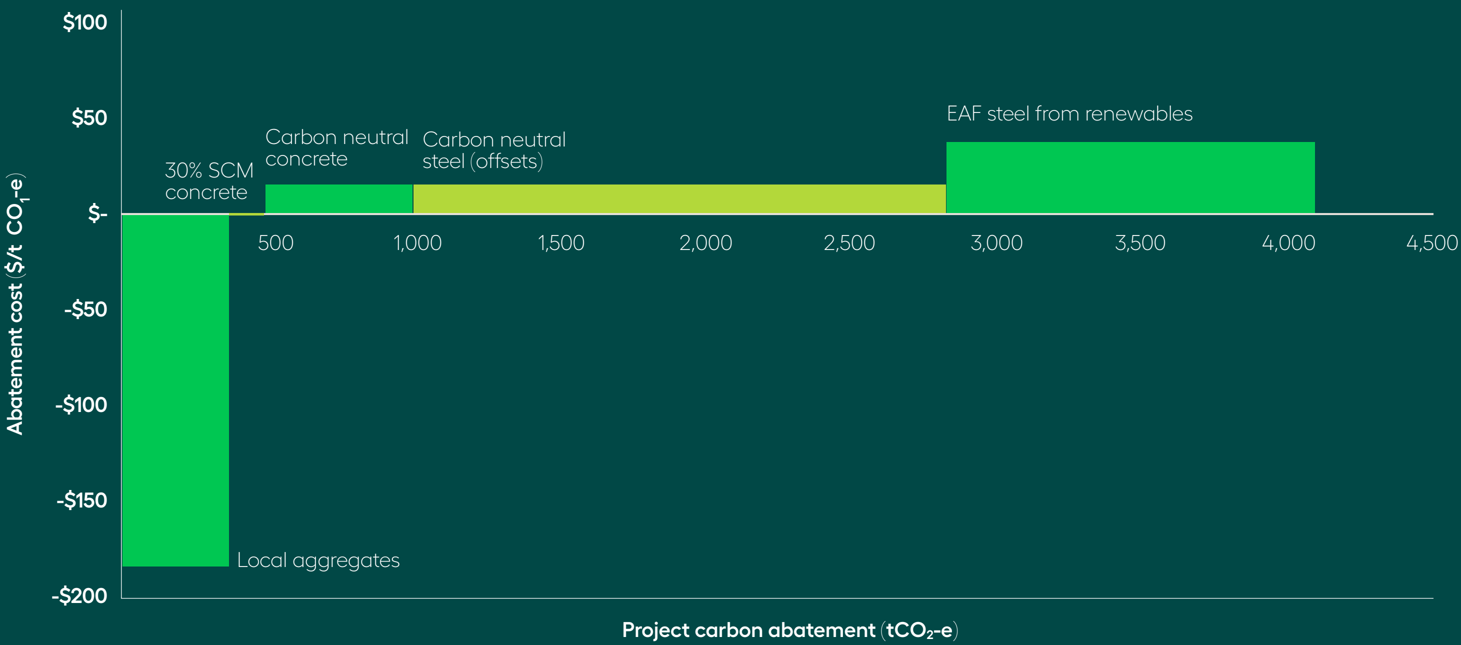
At a project level, a cost saving of $70,000 (approximately 0.7 per cent of project materials costs) could be found. These savings could be re-invested in cost-positive abatement initiatives to further reduce the overall project footprint.

Note that recycled plastic sleepers have not been factored into the reduction figure as market costings are not yet available. Their inclusion would bring the potential embodied carbon reduction to 8.9 per cent (813 tonne CO_2-e).

8.9%

Recycled plastic sleepers inclusion would bring the potential embodied carbon reduction to 8.9% (813 tonne CO_2-e)

Figure 21: MACC for rail projects



Novel products: e.g. recycled plastic sleepers

The use of recycled plastic sleepers is a novel innovation which is not yet commercially available. Thus-far successful type approval trials are ongoing through several of Australia's transport agencies. Though this initiative has considerable promise for carbon mitigation and materials re-use, it has not been included in the MACC above. However, it is likely that the products will be cost-competitive on completion of relevant trials.

The ongoing successful development of novel low embodied carbon materials and products will allow the construction industry to continually improve carbon intensity without compromising on quality, safety, or asset longevity.

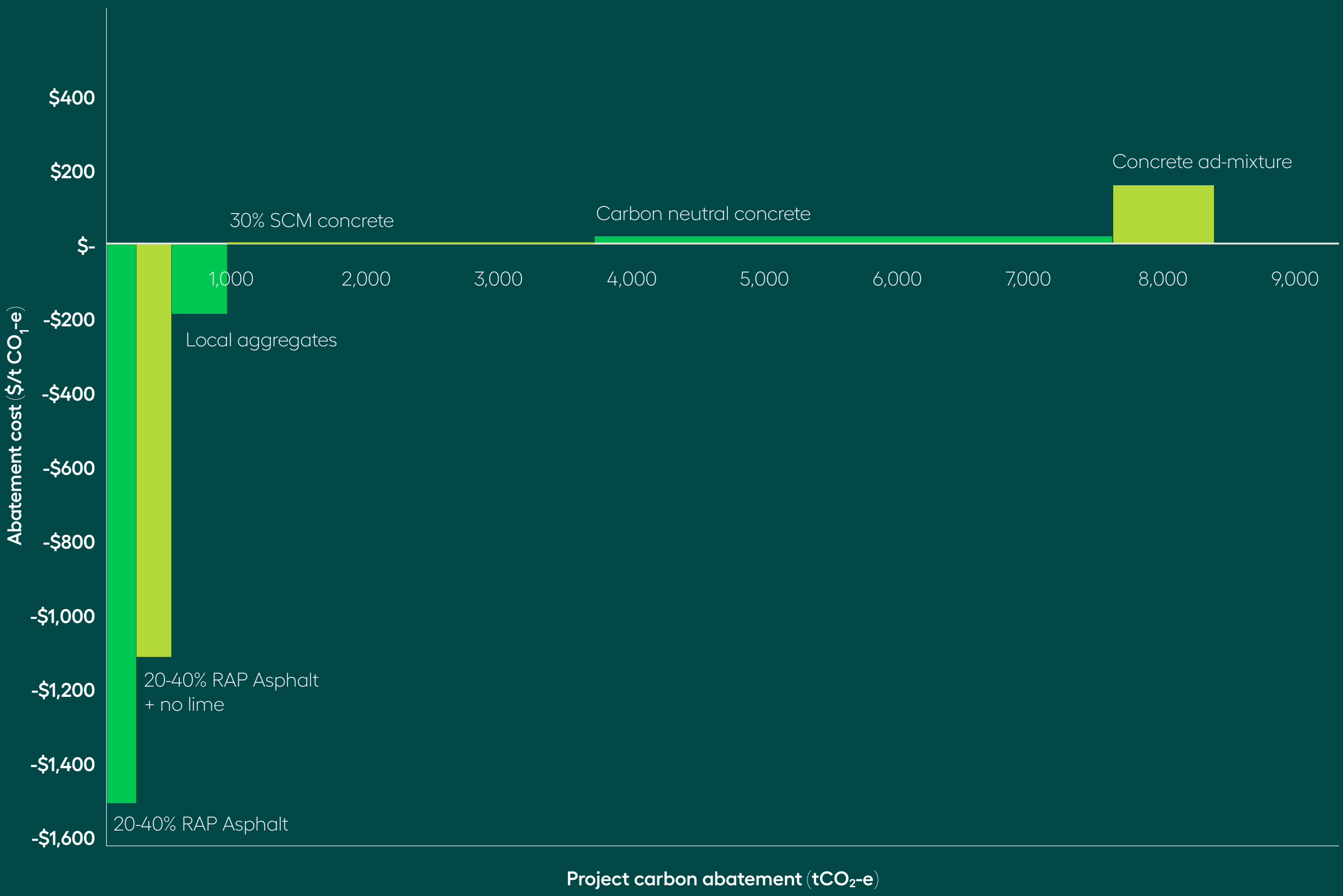
Road – flexible pavement

Cost-negative initiatives to mitigate carbon emissions in road building are largely limited to those already in practice across much of Australian road building works, namely use of RAP, local sourcing for aggregates, and removal of lime in asphalt. Cost-effective carbon mitigation is seen through use of cementitious replacement materials and offsetting of concrete-related emissions. Several concrete providers currently offer carbon neutral concrete through various offsetting regimes.

The figures presented are based on modelling of a 10 km, four-lane road project. Under standard conditions, this project would involve 19,515 tonne CO_2-e of embodied carbon. Implementing the three most impactful cost-neutral and cost-negative initiatives (use of 20 to 40 per cent RAP (no lime), 30 per cent SCM rate concrete, and locally sourced materials) has the potential to abate approximately 3,500 tonne CO_2eq, a 18 per cent reduction in embodied carbon, at an overall saving of $116 per tonne CO_2-e, largely attributed to use of RAP in roadbuilding.[8]

Across the project outlined above, a cost saving of approximately $400,000 (approximately two per cent of project material costs) could be found. These savings could be re-invested in cost-positive abatement initiatives to further reduce the overall project footprint.

Figure 22: MACC for road projects – flexible pavements



[8] The reduction in embodied carbon due to the RAP initiatives is low because it used as a substitute for aggregates, which inherently have a low embodied carbon content.

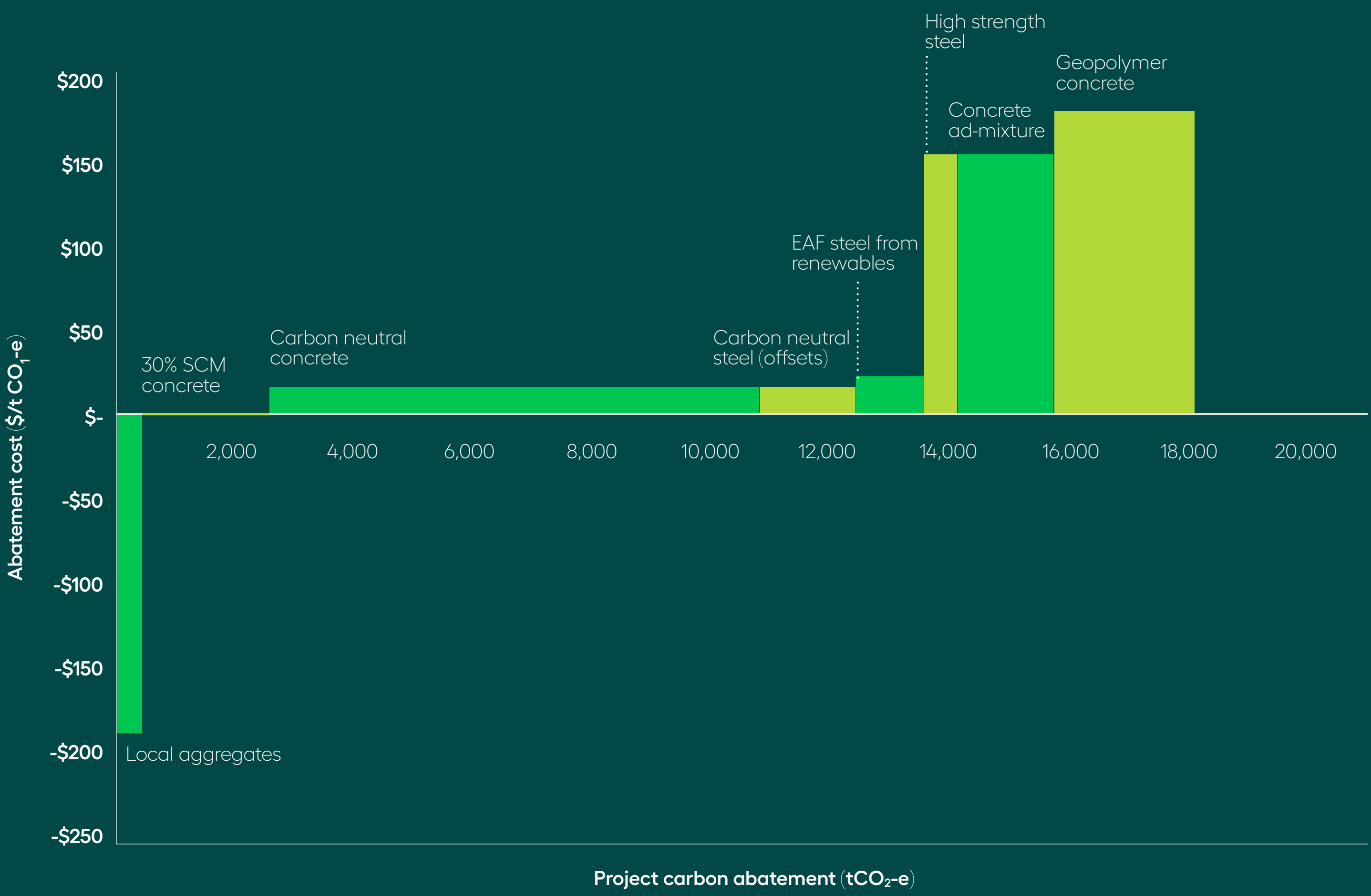
Road – rigid pavement

Outside of opportunities to use RAP, similar opportunities to those seen in flexible pavements exist through materials choices for rigid pavements. The biggest opportunity currently comes through purchase of concrete with impacts offset prior to purchase, while use of cementitious material replacement is the most cost-effective method to directly reduce an asset's embodied carbon.

Under standard conditions, this project would involve 35,800 tonne CO_2-e of embodied carbon. Implementing the two cost-neutral and cost-negative initiatives (30 per cent SCM rate concrete and locally sourced materials) has the potential to abate approximately 2,600 tonne CO_2-e, a seven per cent reduction in embodied carbon, at an overall saving of $30 per tonne CO_2-e.

Across the project outlined above (i.e. a four-lane road of 10 km length), a cost saving of approximately $80,000 (approximately 0.4 per cent of project materials costs) could be found. These savings could be re-invested in cost-positive abatement initiatives to further reduce the overall project footprint.

Figure 23: MACC for road projects – rigid pavements



2600t CO_2-e

Implementing the two cost-neutral and cost-negative initiatives has the potential to abate approximately 2600t CO_2-e

Advantages and considerations

This report gives an overview of the carbon mitigation potential of lower embodied carbon materials and associated costs. However, each of these strategies have additional advantages and considerations beyond embodied carbon and costs. These will require thought throughout the design process. Table 11, below, outlines some of these additional considerations.

Table 11: Initiative advantages and considerations

Material type	Initiative	Advantages	Considerations
Asphalt	Recycled Asphalt Product (RAP) in asphalt mix	Reductions in quarried aggregates, reducing project-level embodied carbon.	Potential supply issues as demand increases against a backdrop of decreasing stocks.
	RAP in asphalt mix and no lime addition	Reductions in quarried aggregates, reducing project-level embodied carbon.	Potential supply issues as demand increases against a backdrop of decreasing stocks.
Concrete	Additives to lower cement content and increase strength	Reductions in cement volumes, reducing embodied carbon.	Slightly increased cost of concrete per m^3.
	Supplementary Cementitious Materials (SCM) in concrete mix	Reductions in cement volumes, reducing embodied carbon.	Changes to curing times, potentially affecting construction schedules.
			Increasing demand for fly-ash and other SCM materials with simultaneous reduction in availability and supply – this may affect the cost of SCM replacement.
	Geopolymer concrete	Reductions in cement volumes, reducing embodied carbon.	May require specialised construction processes due to pumping and workability considerations.
	Carbon neutral concrete	Reductions in project's net embodied carbon.	Costs subject to the carbon credit market conditions. With increasing demand, costs of credits are likely to increase.
	Precast elements instead of in-situ casting	Several indirect benefits such as: • Independence from environmental conditions and inclement weather • Reduced safety risks with lower time on scaffold for lower rise construction projects • Reduced material waste • Increased consistency of quality and surface finish, and ease of casting for repetitive non-standard shapes • Increased productivity • Increased opportunity for reuse • Potential for use of higher SCM rates or novel concrete mixes without affecting construction schedule, dependent on project-specific suitability and availability • Potential faster payback rates due to earlier practical completion and rent collection for commercial buildings/assets.	• Most suitable for construction with uniform and repetitive forms, thus unsuitable for irregular concrete uses such as winding roads • Potential for cambers in slabs or beams • Heavy concrete members require increased and often specialised transport options • Can be limited by labour and commercial availability • Implication on construction programme is not always positive with a variety of factors affecting this consideration. As such, precast concrete elements should be assessed on a project-by-project basis.
	High strength concrete instead of standard concrete	Reductions in amount of concrete required in construction projects.	Increased upfront costs to the project, though this may be, in part, offset by the potential to slim slabs and reduce volume of concrete required.
		Increases to asset longevity due to increased material durability.	

Material type	Initiative	Advantages	Considerations
Aggregates	Locally/onsite sourced aggregates	Reduced transport requirements.	May not have uniformity of quality that is available with quarry-won materials.
			On-site processing may incur increased energy/fuel requirements.
Steel	Produced via Electric Arc Furnace (EAF) and using renewable electricity	Increased use of renewables in steel-making will reduce embodied carbon.	Technological limits on proportion of the steel-making can efficiently be transferred to electricity.
	Carbon neutral steel	Reductions in project's net embodied carbon.	Subject to carbon credit market fluctuations. With increasing demand, costs of credits are likely to increase.
	High strength steel instead of standard steel	Reduced material mass requirements allowing reductions in total asset weight and embodied carbon of an asset.	Higher unit cost, though this is balanced through lower material required making this option generally cost-neutral.
Plastic	Recycled plastic sleepers to replace concrete sleepers	Increases market from Australian recycled materials.	Not current commercially available – product is still in testing with promising results across several Australian transport agencies.
		Reduces upfront embodied carbon and may have longer design life than conventional sleepers.	
Aluminium	Renewable electricity in aluminium production	Increased use of renewables in aluminium-making will reduce embodied carbon.	Feasible cost limits on proportion of the aluminium-making can efficiently be transferred to renewable electricity.
Timber	Engineered timber instead of steel	Lighter, lower embodied carbon materials allow for reduced material requirement in non-timber design elements, such as foundation slabs, etc.	Structural capacity of CLT and timber frames is lower than steel and concrete, with limits of approximately six storeys for a timber-only frame. Benefits are best found when timber and steel/concrete frames are hybridised to reduce overall asset weight.

Realising the opportunity

Barriers to overcome together

Despite the availability of several low embodied carbon material alternatives, their uptake in construction and building has been relatively slow. Certain barriers have been identified that are limiting uptake, which can broadly be classified into five types (Lendlease Building, 2020):

1. Tendering and procurement barriers
2. Economic barriers
3. Technical and performance barriers
4. Knowledge and perception barriers
5. Governance barriers

Tendering and procurement barriers

- Increased risk exposure for contractors and suppliers.
- Typically limited time to engage with supply chain for low carbon alternatives.
- Limited innovation time in a construction project.
- Focus on cost and not on value across operating life of an asset.
- No clear guidelines in tender assessment criteria for preferencing low embodied carbon products.
- Lack of specifications to undertake whole-of-building or other types of LCAs to inform design decision making.

Technical and performance barriers

- Lack of established standards, design guides and tools to assess embodied carbon.
- Existing construction and materials standards may not cover materials with recycled content.
- Unproven performance and risk exposure due to implementation of new and innovative materials such as high strength steel.
- Lack of material performance data such as Environmental Product Declaration.
- Lack of full-scale demonstration projects for some alternatives.
- Shortage of specialist skills with product, LCA, embodied carbon assessment and Building Information Modelling (BIM).
- Poor local availability of materials and low carbon manufacturing technologies.

Economic barriers

- Low demand for reduction in embodied carbon and high cost for bringing in new projects to market.
- Focus is predominantly on lowest cost option.
- Training and research costs for new products.
- Higher design and consulting fees due to increased specification.
- Insufficient comparative information on cost.
- Difficulty in obtaining insurance for novel and re-used material.
- Small market dynamic within Australia.

Knowledge and perception barriers

- Lack of awareness and practical knowledge of alternatives.
- Negative perceptions – low carbon materials are alternatives and not mainstream, don't perform well and cost more.
- Lack of confidence in builder to verify low carbon outcomes.
- Perceived unreliability or risk due to innovative materials e.g. Cross Laminated Timber (CLT).
- Perceived sourcing and availability concerns.
- Early adopter failure discourages people from re-trying.
- Complexity and nuances of embodied carbon can be challenging to understand.
- Lack of product selection and practical design guide for low embodied carbon materials.

Governance barriers

- Lack of regulations and regulatory support.
- Lack of incentives – not much focus on embodied carbon in voluntary building rating schemes.
- Lack of government mandates on utilising Building Information Modelling (BIM) in construction projects.
- Lack of leadership and mandate from investors / developers / clients and suppliers.
- Embodied carbon and LCAs are not adequately considered in building codes.

The question of offsets

With increasing numbers of companies and corporations announcing commitments to net carbon neutrality, carbon offsetting is often seen as a contributing method to achieve these goals.

While on the surface, counteracting carbon emissions in one place with reducing, sequestration or capture in another might seem like a simple calculation, there is considerably more complexity to the issue.

Under many carbon certification methodologies, such as Climate Active's Carbon Neutral Certification, offsets are considered a last option in the carbon-neutral process. Direct emissions avoidance or reduction is the first tactic. Process efficiencies such as dematerialisation, changes to material choice, uptake of renewable energies, and similar reduction strategies need to be explored before offsets are considered. Only after carbon reduction has been achieved through use of reasonable and feasible initiatives and innovations are carbon offsets utilised.

This is also how offsets in construction should be approached. Offsets inherently come with costs due to requirements for certification, verification, and retirement of credits (for 2018–19, the average of Emission Reductions Fund (ERF) Australian Carbon Credit Unit (ACCU) index was approximately $16.10 per tonne of CO_2-e (Clean Energy Regulator, 2019). The use of offsets will not directly reduce a project's emissions footprint, however, offsets and the funds raised by their sale, have played a major role in countless positive and important ecological, energy, and carbon sequestering projects such as afforestation, investments in renewable energy projects, and natural habitat protection and rejuvenation. Investment in carbon offset schemes also send clear messages that corporate intent to play a role in climate change mitigation exists and is underway. Furthermore, the cost implications of carbon offsets can encourage companies to reduce this liability by introducing cost-effective carbon reduction initiatives in the first instance.

As such, offsets are suggested as an additional option to reduce the remaining emissions after implementing direct emissions reduction strategies.

A closer look at specific enablers

In this section, we provide information on some additional enablers which can help drive the transition to low embodied carbon materials.

Building Information Modelling

Building Information Modelling (BIM) is a digital representation of physical and functional characteristics of a facility. A BIM is a shared knowledge resource for information about a facility forming a reliable basis for decisions during its life-cycle; defined as existing from earliest conception to demolition (National Institute of Building Sciences, 2013).

BIM can contain geometric (e.g., dimensions) and non-geometric (e.g., material type) data about a building's components and reflect any changes in their information or specification on all related components. As such, the entire building information can be reconfigured. This enables informed decisions to be made, especially at an early design stage when design decisions determine a great amount of asset's life-cycle impact. When embodied carbon data of materials is incorporated into the BIM model, whole-of-life embodied carbon can be estimated with greater ease. Furthermore, aggregation of carbon calculations from materials to building level using BIM can significantly reduce the time required to perform whole-of-asset embodied carbon calculations compared with using traditional design methods (Banteli and Stevenson, 2017).

Unlike other countries such as United Kingdom, United States and South Korea, the uptake of BIM on Australian construction projects is still nascent. However, in 2016 the Australian Government's Standing Committee on Infrastructure, Transport and Cities proposed to make BIM compulsory on government funded infrastructure projects exceeding $50 million in costs (Morrissey Law, 2019). Similarly, the Queensland and New South Wales governments have issued draft policies and guides for use of BIM in construction projects. The NSW Government also mandated the use of BIM for Sydney Metro Northwest, a $8.3 billion project (Morrissey Law, 2019). The Victorian Government also released a digital asset strategy to aid adoption of BIM (NBS, 2019).

Environment Product Declarations

An Environmental Product Declaration (EPD) is an independently verified and registered document that transparently communicates comparable information about the life-cycle environmental impact of products.

Within the built-environment sector, EPDs support carbon emission reduction by making it possible to compare impacts of different materials and products through a sustainability lens. They provide builders, architects, designers, and other decision makers the opportunity to easily identify and therefore make informed choices regarding low embodied carbon materials. EPDs also allow manufacturers to understand where they can optimise the environmental impact of their products and services and present it in a transparent and reliable manner (One Click LCA, 2021). EPD Australasia also provides a shorter and concise version of EPDs (i.e. Climate Declaration for manufacturers), which includes information particularly related to embodied carbon.

Products with EPDs contribute to the achievement of credits under Green Star ratings and IS rating tools. EPDs are being increasingly used for modelling in LCA tools, such as eTool, and are also being requested by leading developers and builders for infrastructure projects. Legislation in overseas jurisdictions, such as 'Buy Clean California Act', requires EPD based evidence for certain materials for state construction projects. (US Green Building Council Los Angeles, 2020).

Third-party product certifications

Third-party certification of products and services can enable customers to make informed choices around product sustainability and help manufacturers convey their environmental credentials in a transparent manner. Australian relevant certifications include Climate Active's Carbon Neutral Certification. Sustainable procurement strategies with commitments to procure products with third-party certifications or re-used products can contribute to the achievement of several credits under Green Star ratings and IS Rating tools. Products with carbon footprint information or carbon neutral product certifications are currently limited in the market, however the potential to drive competitive advantage could be significant.

Science Based Targets Initiative

The Science Based Targets Initiative (SBTi) is a collaboration between the Carbon Development Project (CDP), the United Nations (UN), World Resources Institute (WRI), and the World Wide Fund for Nature (WWF) and one of the We Mean Business Coalition commitments. Science-based targets enable companies to clearly define and chart a pathway to future-proof growth by specifying the amount and the rate at which they plan to reduce their greenhouse gas emissions.

Targets adopted by companies to reduce carbon emissions are considered 'science-based' if they are aligned to the latest climate science targets necessary to meet the goals of the Paris Agreement – to limit global warming to well-below 2°C above pre-industrial levels and pursue efforts to limit warming to 1.5°C (Science Based Targets, 2020b). Over a thousand companies are taking science-based climate action by setting or getting their science-based carbon reduction targets approved by the SBTi. About 140 of these companies are from the building and infrastructure sector (Science Based Targets, 2020a).

There are several advantages of setting and committing to a science based target (SBT), including increased innovation, increased regulatory resilience to climate change, boosting investor confidence and improving profitability (Science Based Targets, 2020c). More than 50 per cent of the companies that have started their SBT journey have gained competitive advantage by ensuring a lean, efficient and durable company and have also boosted investor confidence (Galvin, 2018). Similarly, more than 60 per cent of the companies have experienced increased innovation in their organisation due to SBTs and ~35 per cent have increased their regulatory resistance to climate change by staying ahead of future policies to limit greenhouse gas emissions (Galvin, 2018; Science Based Targets, 2020c). Furthermore, 29 per cent of the companies committing to SBT are already seeing bottom-line savings (Galvin, 2018).

Green Star

Launched by Green Building Council of Australia (GBCA) in 2003, Green Star is Australia's largest voluntary and holistic sustainability rating system for buildings, fitouts and communities. As of June 2021, Green Star has issued 3,000 Green Star certifications, representing 44 per cent of commercial business district office space, 20 per cent of retail space, and more than 17,000 hectares of certified precincts. Green finance mechanisms, construction approvals, tenant requirements, and building owners use Green Star to demonstrate the delivery of green buildings. Ratings for new assets are awarded on a scale of 4 star (best practice), 5 star (national excellence), and 6 star (world leadership).

In March 2018, GBCA released a roadmap to decarbonise new buildings, fitouts, and communities by 2030. In addition to a wide-ranging advocacy platform in partnership with Australia's property sector, the roadmap called for updating Green Star. The update, called Green Star Future Focus, outlined a set of decarbonisation requirements that would be introduced over the next decade for all buildings seeking a rating. The goal of the update was to create climate positive new buildings by 2030 – or fossil fuel free, highly efficient buildings and communities powered by renewables, built with low upfront carbon emissions, with remaining emissions compensated by nature.

Green Star Buildings, released in late 2020, was the first to introduce these requirements. All buildings are required to have 10 per cent less upfront carbon than a building built to code, with 6 star rated buildings needing to achieve at least 20 per cent. Over the next decade, this threshold increases so that by 2030 all buildings will need to have at least 40 per cent less upfront carbon emissions than a building built to code.

The requirement also applies to any building that is finished at or after January 2030. The introduction of these requirements over the next decade aims to ensure Australia can decarbonise new building construction. The targets, and the consensus around them, would serve to prepare industry, create knowledge, and identify best practice solutions to enable a future update to Australia's National Construction Code.

The update to Green Star serves as an example of how holistic rating tools, together with a wide advocacy agenda, can serve to transform the market and deliver the goals of the Advancing Net Zero program.

World Green Building Council's Commitment for Net Zero Carbon Buildings

In September 2018, World Green Building Council released the global Commitment for Net Zero Carbon Buildings that specifically targeted buildings in operation. At the time, the commitment required all existing buildings to commit that by 2030, their building operations would be net zero – or efficient buildings preferably powered by renewables, with remaining emissions offset. Since then, over 100 signatories, with a quarter of them Australian companies and cities, have signed on the commitment.

The commitment is soon to be expanded to include new building construction as well. The update to the commitment requires signatories who develop new buildings to ensure that all buildings are net zero embodied carbon, and built to be net zero in operations, by 2030. These targets align with the requirements set out in Green Star to ensure there is alignment between international commitments and local practices.

10%

In late 2020, Green Star Buildings introduced requirements for all buildings to have 10% less upfront carbon than a building built to code

2030

The commitment for Net Zero Carbon Buildings required all existing buildings to commit that by 2030 their building operations would be net zero

Leadership to lower embodied carbon

While great strides have been made in understanding and reducing operational carbon implications of infrastructure and buildings, tackling embodied carbon is fast becoming the next frontier of decarbonising Australia's built environment.

There is a part to be played in every part of the construction industry's value chain, as the opportunities identified in this report exist across all stages of asset development, from concept design and planning through to specific material and design choices. Together, we can achieve a step-change in addressing embodied carbon in building and infrastructure projects.

Though individual institutions and companies are making headway in addressing embodied carbon in their projects, the large-scale, wholesale transitions will rely on all stakeholders filling much needed leadership roles.

From government agencies procuring, mandating, and approving lower carbon materials; to REITs and investors demanding a low carbon value chain; to designers and consumers selecting and specifying lower carbon materials, leadership and informed decision-making throughout the construction industry will be required to reduce embodied carbon in property and infrastructure projects.

Industry-wide

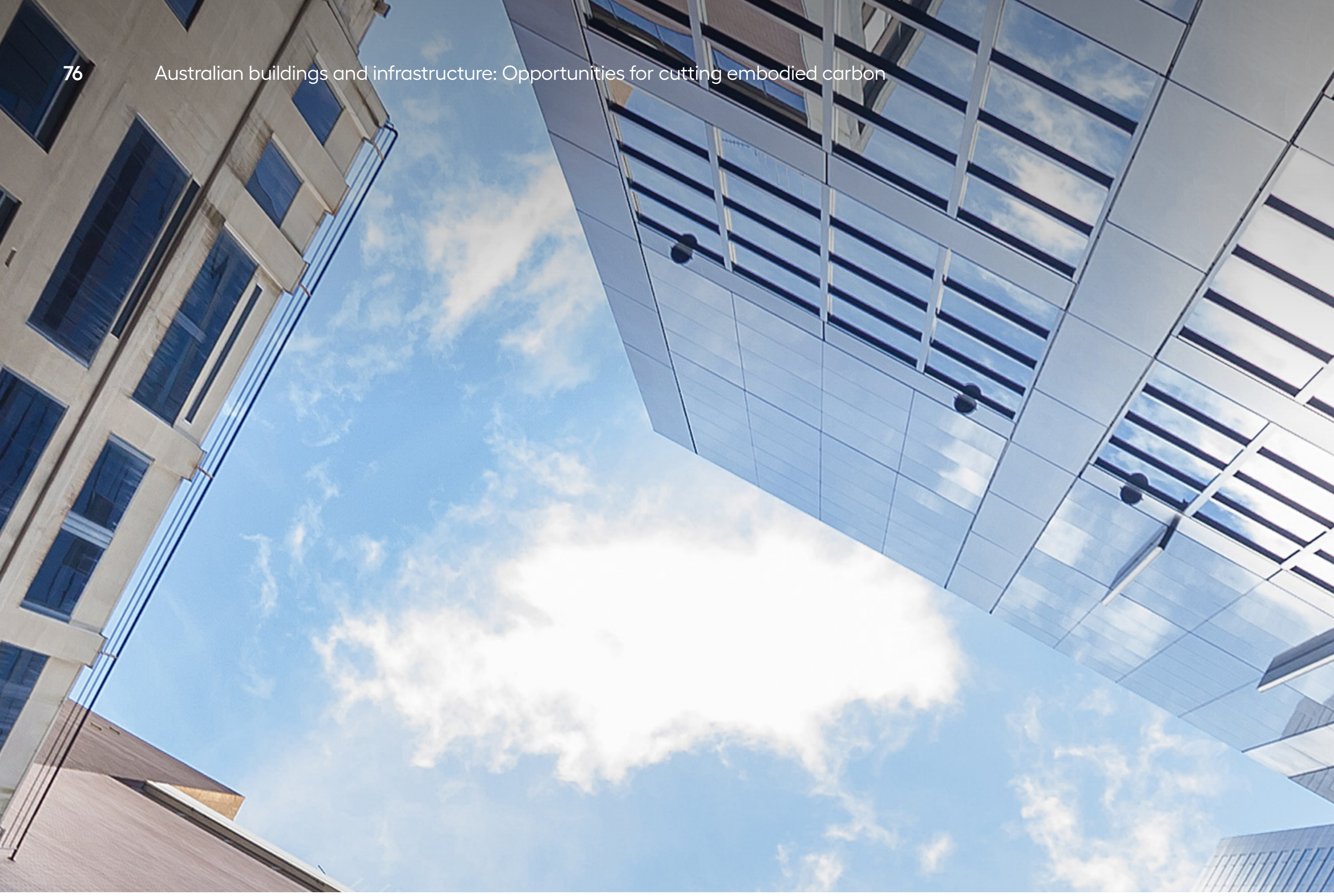
- Encourage collaboration to facilitate the multi-pronged approach necessary to overcome barriers and increase uptake of low embodied carbon construction strategies.
- Utilise whole of building/asset life cycle assessment and carbon modelling to inform design decision-making.
- Engage with all construction partners on upcoming government-driven projects and establish industry forums / use existing forums to gather a collective industry voice.

Investors and assets owners

- Take action by setting ambitious embodied carbon reduction targets and reporting for projects.
- Ensure that embodied carbon implications of the investment decision process are understood and well-presented from both a long-term asset risk and a financial perspective.
- Encourage supply chains that are decarbonising by direct emission reductions as opposed to a carbon offsets strategy.
- Collaborate with and prioritise products and suppliers who have committed net zero and targets for non-offset emissions reductions.

Private-sector operators

- Develop a clear and consistent pathway to increase demand for low embodied carbon products.
- Encourage the mainstream use of low embodied carbon materials and products through ecolabelling and EPDs.
- Encourage consumer and construction partner knowledge of both cost and carbon implications relating to carbon mitigating materials and products.
- Partner with suppliers in development of low carbon alternative materials.
- Provide adequate scope, time and budget for designers, builders and consultants to investigate, assess and propose low carbon alternatives; promote the use of early contractor engagement.
- Encourage and incentivise the application of circular economy principles to the building and infrastructure sector.



Project developers

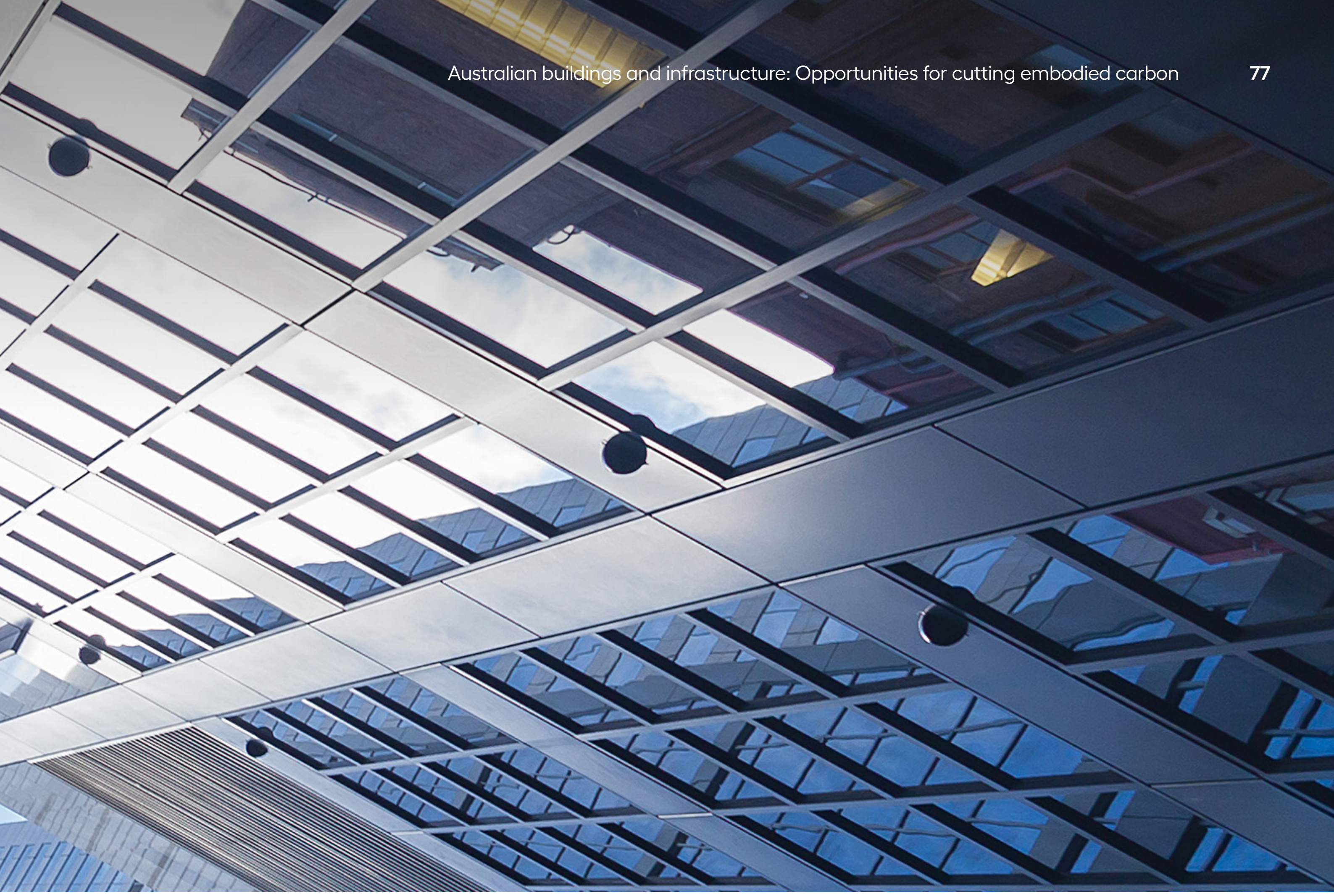
- Start at concept design phase to set project targets relating to embodied carbon and to ensure inclusion of carbon reduction initiatives throughout an asset's construction.
- Engage early with suppliers to understand, encourage, and adapt to low embodied carbon materials and products.
- Become a conduit for consumers to see, choose, and access low embodied carbon materials.
- Engage with consumers to ensure that implications of various material choices are understood, and promote the use of low embodied carbon materials where appropriate.

Designers/engineers

- Specify low embodied carbon materials throughout designs, ensuring that performance-based specifications are met.
- Consider whole-of-life implications of materials and design choices.
- Establish training and skilling program for low embodied carbon, measurement, means and methods and link to Continued Professional Development (CPD) credits within engineering and architectural fields.
- Engage with project developers and material suppliers to ensure low embodied carbon materials are available and used on projects.

Rating tools

- Continue to drive the adoption of low embodied carbon practices across all project types in all markets.
- Continue to incentivise creating assets and material knowledge banks for the future.
- Continue to incentivise reductions in embodied carbon in rated assets.



Building material manufacturers and suppliers

- Increase the uptake of programs which allow the publication of the embodied carbon of materials.
- Partner with government agencies and grant-providers to develop low carbon alternative materials.
- Publish cost vs benefit analysis, address perceptions that using low-carbon materials is more expensive.
- Over the longer-term, aim to meet demand with lower embodied carbon materials.

Planners/regulators

- Adopt new construction techniques and materials.
- Seek the update of Codes & Standards to include carbon definition language for low and zero-carbon products, materials and systems.
- Update the National Construction Code (NCC) to include embodied carbon in materials as measured performance targets, similar to targets as set through NatHERS or NABERS in relation to operational performance.
- Establish design specifications to preference lower embodied carbon intensities for products with high volumes of materials such as concrete, steel, aluminium and glass.
- Consider mandating of maximum embodied carbon rates as a condition of approval.

Government and government procurement

- Encourage the mainstream use of low embodied materials and products through access to and provision of grants, funding, and advisory services.
- Encourage and incentivise the application of circular economy principles to the building and infrastructure sector.
- Establish tendering criteria that evaluate, reward and drive low-carbon product/ material selection.
- Mandate provision of EPDs / embodied carbon declarations on all high carbon intensity building products and materials.
- Increase the rate of embodied carbon reduction to be achieved by tenderers.
- Set embodied carbon targets within project briefs.
- Mandate that embodied carbon is measured and reported.
- Align across government departments to create consistency.

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Methodology and assumptions

Inventory data

Table 12 to Table 16 provide the inventory data used to model the reference case scenario for all infrastructure and building projects in this report.

Table 12: Inventory data for reference case modelling of rail projects

Rail

Material/transport	Quantity	Unit	Comments and source
Steel	63	kg/m	Based on data from South West Rail Link project and most commonly used rail profiles in Australia. 5% extra for tie ins Source: - Liberty OneSteel Rail - EM Rails, Australia
	126,000	kg/km	Multiplying by 2 as two rail tracks required
	126	t/km	
Concrete	1,500	sleepers/km	Economic Regulation Authority Western Australia
	374.4	t/km	260 kg sleepers for 160 km/h trains: Concrete sleepers – Rail One
	156	m^3/km	
Reinforced steel for sleepers	15.6	t/km	100 kg of steel per m^3 of concrete
Ballast	1,600	m^3/km	Based on data from South West Rail Link project
Transport distance – normal	100	km	
Transport distance – local	11	km	Assuming max distance i.e. length of the rail track

Table 13: Inventory data for reference case modelling of road projects (flexible pavements)

Roads: flexible pavement

Material/transport	Quantity	Unit	Comments and source
Materials layer thickness			
Asphalt	175	mm	NSW RMS
	0.175	m	
Concrete	190	mm	
	0.19	m	
Subbase (aggregates)	300	mm	
	0.3	m	
Road dimensions			
Width of 1 lane	3.5	m	
Length of road	1,000	m	
Materials volume			
Asphalt volume	612.5	m^3	
Concrete volume	665	m^3	
Subbase (aggregates) volume	1,050	m^3	
Materials weight			
Asphalt weight	1,470	t	Density of asphalt = 2200-2400 kg/m^3
Concrete weight	1,596	t	Density of concrete = 2400 kg/m^3
Subbase (aggregates) weight	1,680	t	Density of aggregates = 1600 kg/m^3
Transport			
Distance assumed – normal transport	100	km	Truck transport
Distance assumed – local batching	10	km	Truck transport

Table 14: Inventory data for reference case modelling of road projects (rigid pavements)

Roads: rigid pavement

Material/transport	Quantity	Unit	Comments and source
Material layer thickness			
Reinforced concrete	250	mm	NSW RMS
	0.25	m	
Ready mix concrete	150	mm	
	0.15	m	
Subbase (aggregates)	300	mm	
	0.3	m	
Road dimensions			
Width of 1 lane	3.5	m	
Length of road	1,000	m	
Materials Volume			
Reinforced concrete	875	m^3	
Ready mix concrete	525	m^3	
Subbase (aggregates)	1,050	m^3	
Materials weight			
Reinforced concrete	2,100	t	Density of concrete = 2400 kg/m^3
Reinforcing steel	70	t	Density of steel = 8000 kg/m^3
Concrete	1,260	t	Density of concrete = 2400 kg/m^3
Subbase (aggregates)	1,680	t	Density of aggregates = 1600 kg/m^3
Transport			
Distance assumed	100	km	Truck transport

Table 15: Inventory data for reference case modelling of office/mixed use buildings

Office/mixed use building

Material/transport	Quantity	Unit	Comments and source
Area			
GFA of the building	40,000	m^2	
Materials weight			
Aluminium	385	t	
Cabling	46	t	
Carpet tiles	138	t	
Ceramic tiles	1,505	t	
Glazing	926	t	
Paint	14	t	
Plasterboard	75	t	
Steel reinforcement	3,512	t	
Steel structural	1,331	t	
Timber	85	t	
PVC	4,337	t	
Concrete	86,960	t	
Transport			
Distance assumed	100	km	Truck transport

Table 16: Inventory data for reference case modelling of industrial buildings

Industrial

Material/transport	Quantity	Unit	Comments and source
Area			
GFA of the building	74,400	m^2	
Materials weight			
Aluminium	7	t	
Cabling	6	t	
Ceramic tiles	0.02	t	
Glazing	18	t	
Paint	12	t	
Plasterboard	70	t	
Steel reinforcement	660	t	
Steel structural	2,340	t	
Timber	49	t	
PVC	134	t	
Concrete	65,100	t	
Transport			
Distance assumed	100	km	Truck transport

Modelling assumptions

Table 17 provides an overview of key assumptions used for modelling the emissions reduction initiatives.

Table 17: Assumptions for emissions reduction initiatives modelling

Materials initiatives

Material	Initiative	Initiative applicable to	Comments on emissions reduction modelling
Steel	100% renewable electricity for steel	Road/rail/buildings	Electricity used for steel manufacturing was assumed to be generated entirely from renewable sources i.e. hydro, wind, and/or solar. Ecoinvent v3.5 library and SimaPro v9.1 used for quantifying emissions reduction.
	Carbon neutral steel (offsets)	Road/rail/buildings	All emissions in the 'cradle to construction site' life cycle were offset through purchasing of carbon credits.
Concrete	30% SCM concrete	Road/rail/buildings	Replacing cement content with supplementary materials such fly-ash to reduce carbon emissions. Ecoinvent v3.5 library and SimaPro v9.1 used for quantifying emissions reduction.
	Geopolymer concrete	Road/buildings	Embodied carbon values for geopolymer concrete were sourced from literature and compared with the base case. Although there is significant variation in literature, the embodied carbon values used in this report are sourced from a highly cited research paper by McLellan et al (2012) and CRC-LCL report. An average value of the range reported in the paper was utilised for calculations.
	Carbon neutral concrete	Road/rail/buildings	All emissions in the 'cradle to construction site' life cycle were offset through purchasing of carbon credits.
	Concrete + 2% D5 neocrete admixture	Road/rail/buildings	Using Necocrete D5 ad-mixture reduces the amount of cement required resulting in 16-20% decrease in the embodied carbon emissions of the concrete mix. Source: Neocrete LCA report
Concrete/ Plastic	Recycled plastic sleepers	Rail	Use of recycled plastic in manufacturing of sleepers instead of concrete results in lower embodied carbon emissions. Embodied carbon values for plastic sleepers sourced from DuraTrack (manufacturer).
Aluminium	100% renewable electricity for Al	Buildings	Electricity used for aluminium manufacturing was assumed to be generated entirely from renewable sources i.e. hydro, wind, and solar. Ecoinvent v3.5 library and SimaPro v9.1 used for quantifying emissions reduction.
Asphalt	20-40% RAP asphalt	Road	Use of recycled content in asphalt reduces embodied carbon emissions. Modelling performed using AusLCI v1.28 library and SimaPro v9.1.
	20-40% RAP asphalt (no-lime)	Road	Use of recycled content in asphalt and elimination of lime content reduces embodied carbon emissions. Modelling performed using AusLCI v1.28 library and SimaPro v9.1.

Table 17 (cont): Assumptions for emissions reduction initiatives modelling

Design initiatives

Material	Initiative	Initiative applicable to	Comments on emissions reduction modelling
Concrete	Precast elements	Buildings	10–12% reduction per m^3 of concrete assumed while using precast vs in-situ elements. Reduction value based on literature: Ahmed et al., Dong et al. and Lopez et al.
	High strength concrete 80 MPa	Buildings	Use of High Strength Concrete can result in 20% less cement being used. This equates to ~18% reduction in CO_2-e emissions per m^3. Modelling based on data from Beyond Zero Emissions (BZE) report and SimaProv v9.1 calculations.
Steel	High strength steel	Buildings	Utilising high strength steel (750N) instead of standard (500N) reduces the amount of steel required and results in 33% reduction of emissions. Modelling based on consultation with Infrabuild and published data at Infrabuild Viribar.
Steel/Timber	Engineered timber instead of steel	Buildings	The modelling methodology for this initiative acknowledges the fact that replacing steel with timber is not a direct substitution and that there are several design parameters to be considered while doing so. It considers three partial replacement scenarios wherein 10%, 30% and 50% of steel is assumed to be replaced by engineered timber. These assumptions are fairly conservative as published data indicates at least 60% reduction in amount of reinforcing steel for timber buildings. Source: Forté building LCA and Parkville building LCA

Glossary of acronyms and key industry terms

Acronym	Industry term
AASB	Australian Accounting Standards Board
ACCU	Australian Carbon Credit Unit
APRA	Australian Prudential Regulation Authority
AUASB	Auditing and Assurance Standards Board
BIM	Building Information Modelling
BPIC	Building Products Industry Council
CEFC	Clean Energy Finance Corporation
CLT	Cross Laminated Timber
CO_2-e	Carbon dioxide equivalent
CPD	Continued Professional Development
EAF	Electric Arc Furnace
EPD	Environmental Product Declaration
GBCA	Green Building Council of Australia
GDP	Gross Domestic Product
GFA	Gross Floor Area
GHG	Greenhouse Gas
ISC	Infrastructure Sustainability Council
LCA	Life Cycle Assessment
MACCs	Marginal Abatement Cost Curves
MDF	Medium Density Fibreboard
MECLA	Materials & Embodied Carbon Leaders' Alliance
NABERS	National Australian Built Environment Rating System

Acronym	Industry term
NatHERS	Nationwide House Energy Rating Scheme
NCC	National Construction Code
PVC	Polyvinyl Chloride
RAP	Reclaim Asphalt Pavement/Recycled Asphalt Product
REITs	Real Estate Investment Trusts
SBT	Science Based Targets
SBTi	Science Based Targets Initiative
SCM	Supplementary Cementitious Materials
SDGs	Sustainable Development Goals
SMZ	Selected Material Zone
TCFD	Task Force on Climate-Related Financial Disclosures
UN	United Nations
WGBC	World Green Building Council
WRI	World Resources Institute
WWF	World Wide Fund for Nature

About the CEFC

CEFC has a unique mission to accelerate investment in Australia's transition to net zero emissions. We invest to lead the market, operating with commercial rigour to address some of Australia's toughest emissions challenges. We're working with our co-investors across renewable energy generation and energy storage, as well as agriculture, infrastructure, property, transport and waste. Through the Advancing Hydrogen Fund, we're supporting the growth of a clean, innovative, safe and competitive hydrogen industry. And as Australia's largest dedicated cleantech investor, we continue to back cleantech entrepreneurs through the Clean Energy Innovation Fund. With $10 billion to invest on behalf of the Australian Government, we work to deliver a positive return for taxpayers across our portfolio.
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