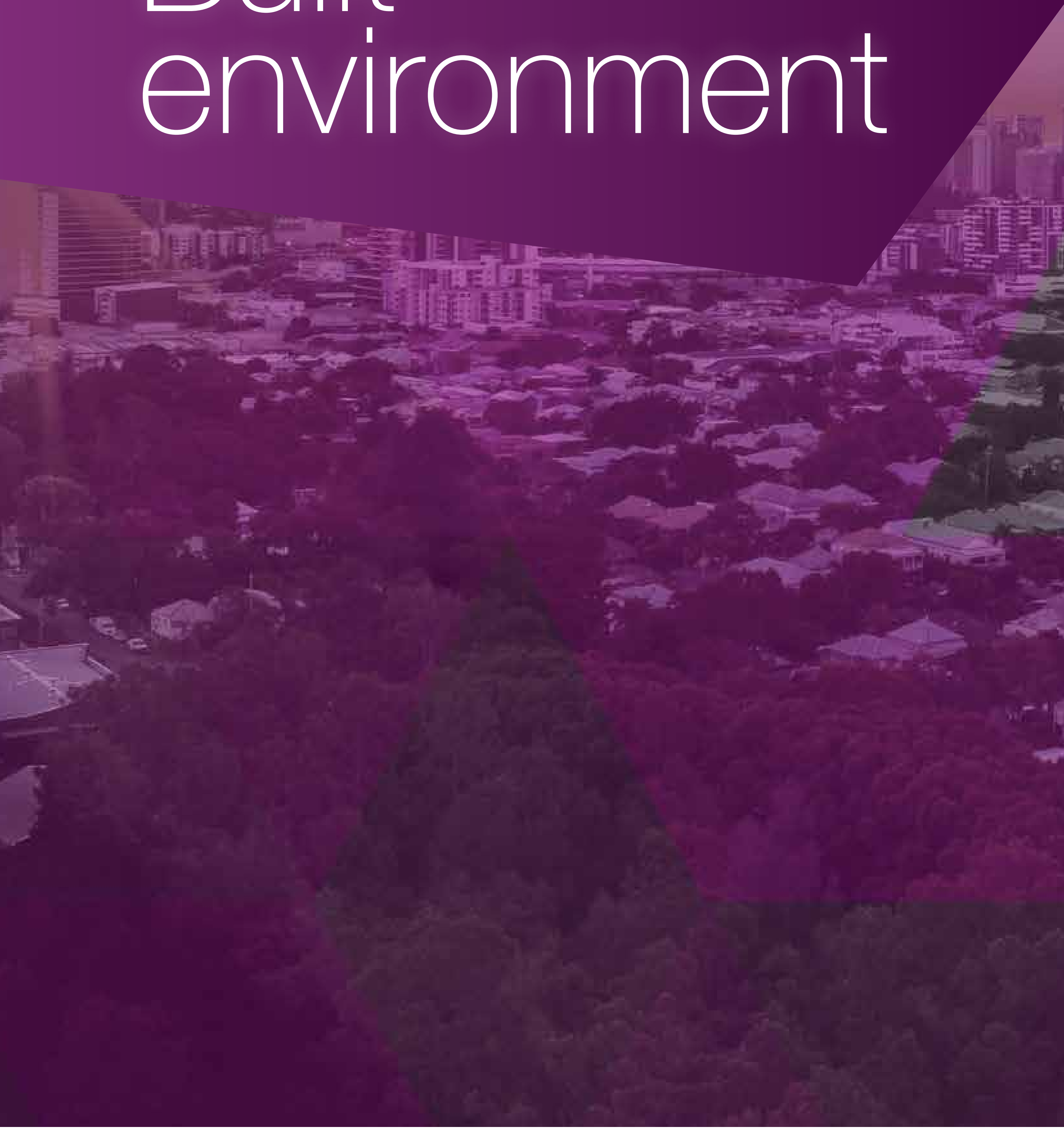
Built environment



BUILT ENVIRONMENT

Sector summary

The built environment sector has a clear and potentially rapid decarbonisation pathway, with the required technologies being almost all commercially available now. A net zero built environment would have high energy performance, be well-adapted to climate change impacts, and be highly liveable.

A decarbonised built environment requires a vision with a sequenced, national approach to drive abatement and unlock opportunities for businesses and consumers. This could deliver significant benefits for Australians, including improved living standards and wellbeing, lower costs of housing and energy, and resilience to climate change hazards.

Significant decarbonisation opportunities lie in electrification and energy efficiency, including by replacing gas appliances with high-efficiency and grid-integrated electric ones. Decarbonisation also requires abatement of refrigerant gas emissions by adoption of low-Global Warming Potential (GWP) gases and addressing gaps in end-of-life management of refrigerant gases in appliances.

The sector's decarbonisation is dependent on other sectors: it relies on decarbonisation of the electricity grid, and lower-carbon building materials manufactured by the industry sector. Other opportunities include consideration of climate change in urban planning. Planning has the potential to reduce emissions at the precinct level, including by improving building design and implementing circular economy principles to reduce embodied and lifecycle emissions of materials.

Challenges to reducing built environment emissions include high upfront costs for some technologies and retrofits, workforce shortages and supply chain pressures. There are also challenges arising from incomplete or non-existent data, including for comprehensive product comparisons, building energy efficiency ratings and embodied carbon ratings. Improving this information could aid consumers' choices for lower-emissions products and drive changes to building practices.

Greater coordination between levels of government on measures to drive decarbonisation provides opportunities to accelerate abatement in the built environment, including in relation to enhancements of the National Construction Code, expansion of energy rating schemes, data and disclosures, and phasing out gas connections in residential and commercial buildings.

BE.1 Sector state of play

The built environment is the residential and commercial buildings, and physical infrastructure (such as footpaths, roads and bridges), that provide the settings for human activities. This chapter discusses the direct emissions associated with the operation of the built environment (scope 1 emissions) and the emissions associated with electricity consumption in the built environment (scope 2 emissions). Emissions associated with the manufacture of the components of the built environment (e.g. cement and steel) are discussed in a reference Box BE.1 on scope 3 emissions and are covered in detail in the Industry and Waste chapter of this report.

Currently, there are about 11 million residential buildings and 1 million commercial buildings in Australia (ABS, 2022a; DCCEEW, 2022b). Most of these buildings have poor energy efficiency, with houses built before 2003 having an average Nationwide House Energy Rating Scheme (NatHERS) rating of 1.8 stars (CSIRO, 2021). The minimum requirement for new houses and apartments is 7 stars (ABCB, 2023a).

The sector contributes to Australia's economy through trades and the construction industry. Construction-related subsectors in the built environment sector account for about 7% of Australia's gross domestic product (Appendix B) (Master Builders Australia, 2024).

BE.1.1 Emissions profile

Scope 1 emissions in the built environment were 28 Mt CO_2-e in 2022, about 7% of Australia's emissions (see Table BE.1 and Appendix B) (CCA, 2024). The sector's scope 2 emissions, arising from the generation of grid electricity used by the sector, amounted to 77 Mt CO_2-e, or 49% of Australia's total emissions from electricity generation. These electricity-based emissions were the largest of any sector in 2022 (see Appendix B) (CCA, 2024).

Residential and commercial scope 2 emissions are 41 Mt CO_2-e and 35 Mt CO_2-e respectively, and together account for nearly all scope 2 built environment emissions. Scope 2 emissions from construction are relatively small at 1 Mt CO_2-e (DCCEEW, 2022a).

The authority has not quantified scope 3 emissions embodied in building materials or enabled by assets, as these emissions are counted in the scope 1 emissions of other sectors in this review. Embodied emissions are discussed in Box BE.1.

Table BE.1: Breakdown of the built environment's scope 1 and scope 2 emissions sources, and percentage share of total scope 1 and 2 emissions, 2022, see Appendix B. Source: (CCA, 2024; DCCEEW, 2024a)[1 2]

Subsector	Mt CO_2-e*	Subsector share of total scope 1 and 2 (%)*
Scope 1 emissions		
Construction	2	2
Commercial stationary combustion	6	5
Residential stationary combustion	11	10
Commercial refrigeration	6	5
Domestic refrigeration	0	0
Stationary air-conditioning	3	3
Fugitive emissions from fuels - natural gas	0	0
Aerosols and metered dose inhalers	0	0
Wastewater treatment and discharge - unsewered population	0	0
Total scope 1 emissions	28	27
Scope 2 emissions		
Construction	1	1
Commercial services (scope 2)	35	33
Residential	41	39
Total scope 2 emissions	77	73
Total emissions (scope 1 and scope 2)	106	100

* All values are greater than zero, but some subsectors are listed as zero in the table due to the authority's rounding. The subsectors listed as zero cumulatively account for a total of 1 Mt CO_2-e or 4% of scope 1 emissions.

BE.1.2 Current trends and future changes

There is significant work to do to decarbonise the built environment. Analysis indicates the sector could reduce emissions by 69% on 2005 levels by 2030 (DCCEEW, 2019). However, current and proposed Australian policies are projected to achieve only an 11% reduction on 2005 levels by 2030 (DCCEEW, 2019).

Onsite electricity generation through residential rooftop solar photovoltaic (PV) systems has been an important driver of decarbonisation. There are over 3.4 million rooftop solar PV systems installed, generating over 9% of Australia's electricity in 2022 (CEC, 2023). In addition, an estimated 50,000 household battery systems were installed in 2022, up from 34,731 in 2021 (CEC, 2023).

Electrification and energy efficiency create reduced energy costs for consumers and emissions, but policy incentives to drive further improvements are needed. The 2022 National Construction Code (NCC) mandated new residential buildings meet 7-star equivalent energy ratings and ensure space is reserved for solar PV panels (ABCB, 2023a). However, jurisdictions have not uniformly implemented the NCC, and retrofitting buildings remains a significant challenge (ABCB, 2023b; Sustainability Victoria, 2015; C. White et al., 2023). Building Ministers have also agreed that climate resilience should be a specific objective for the Australian Building Codes Board from 2025 and this is expected to be reflected in future NCC requirements (DISR, 2024c).

1 The figures in Table BE.1 differ from those being used by the Built Environment Sector Plan as part of the Australian Government's Net Zero Plan. These differences are explained in Appendix B.

2 The consideration of scope 2 emissions by the built environment sector is in contrast to other sectors. These emissions occur in the electricity and energy sector.

All levels of government are currently implementing policies for the sector, including:

- Energy performance reporting programs such as NatHERS and the National Australian Built Environment Rating System (NABERS) (NABERS, 2024; NatHERS, 2024)
- Policies to improve energy efficiency, such as the Trajectory for Low Energy Buildings and the National Energy Performance Strategy (DCCEEW, 2018; DCCEEW, 2024e)
- The Greenhouse and Energy Minimum Standards (GEMS) program, which establishes minimum energy efficiency requirements for certain appliances (Australian Government, 2024a)
- 'White certificate' energy efficiency schemes in New South Wales, Victoria, South Australia and the Australian Capital Territory (S. White, 2024)
- The phase out of gas connections in buildings in the ACT and Victoria (ACT Government, 2021; DTP, 2023).

These policies remain patchy and inconsistent across jurisdictions and levels of government.

BE.2 Existing and prospective technologies

During expert consultation and research, the authority found that most technologies needed to decarbonise the built environment sector are already technically ready and commercially available (Table BE.2).

Table BE.2: Summary of the largest emissions sources in the built environment and identified abatement levers, see Appendix B. Source: (CCA, 2024; DCCEEW, 2022a)

Emissions source	Percent of sector emissions	Priority abatement lever to address emissions source	Readiness	Barriers to adoption
Residential and commercial stationary combustion (scope 1)	· ~58% of scope 1 BE emissions (2022) · 15% of total BE emissions (2022)	Electrification	Commercially available	· High upfront cost. · Challenges of retrofitting some buildings. · Absence of a gas phase-out plan.
Residential and commercial electricity use (scope 2)	· ~98% of BE scope 2 emissions (2022)	On-site electricity generation and storage	Commercially available	· High cost of storage options such as batteries can be prohibitively expensive. · Lower technical readiness of vehicle-to-grid storage systems.
		Energy performance and digitalisation	Most approaches are technically ready	· Lower technical readiness. · Potential workforce shortages.
		Grid integration	Technically ready	· Compatibility of local grid infrastructure and interoperability between systems. · Social license and approvals.
		Thermal efficiency	Commercially available	· High upfront cost. · Lack of financial or regulatory incentives for landlords to upgrade properties. · Standards and regulation vary across jurisdictions.
Residential and commercial refrigeration and stationary air-conditioning (scope 1)	32% of BE scope 1 emissions (2022)	Switching to lower GWP refrigerants	Technically ready/ Commercially available for most uses	Not all emissions can be abated through retrofits or appliance upgrades. High upfront cost for new systems, retrofitting, differences in gas costs. Poor maintenance and end-of-life practices.

BE.2.1 Building electrification

BE.2.1.1 Electrification

Electrification, or fuel substitution, refers to the replacement of fossil fuel appliances, processes, or products with electric equivalents, including water heating, air-conditioning and cooking (IEA, 2023a). The authority's research and consultation has indicated that although electrification has high upfront costs, in the long-term it is the cheapest way to decarbonise the sector's scope 1 emissions, including emissions from construction (Renew, People's Climate Assembly, Labor Environment Action Network, GBCA, ACOSS, submissions, 2024). As identified across this Review, decarbonisation of the Built Environment through electrification relies on the decarbonisation of the electricity system.

Some stakeholders suggested that both gas and electrical systems could be maintained with renewable gases (e.g. hydrogen or biomethane), that broad electrification is cost-prohibitive and faces significant workforce challenges (Australian Gas Infrastructure Group, Renewable Gas Alliance, submissions, 2024). The authority is of the view, however, that in the long-term complete electrification of buildings is the optimal decarbonisation approach and governments should develop strategies to efficiently and equitably realise this.

> *"Unlike in harder-to-abate sectors, zero-carbon new homes and large-scale retrofits of existing homes including electrification can be delivered immediately. Australia will not meet its existing targets nor the more ambitious targets required to align with 1.5 Degree climate scenarios if action is delayed on this immediate opportunity."*
>
> Renew submission, 2024

> *"… relying on electrification only is likely to be more expensive than maintaining a dual-fuel system and is also likely to result in higher emissions in some jurisdictions… network blending is a readily available and large-scale source of demand that can kickstart the deployment of renewable gas at scale and provides the stepping stone for other sectors to start their decarbonisation journey… From a household cost perspective, the upfront capital costs of electrification can be prohibitive."*
>
> Australian Gas Infrastructure Group submission, 2024

> The authority is of the view, however, that in the long-term complete electrification of buildings is the optimal decarbonisation approach and governments should develop strategies to efficiently and equitably realise this.

Achieving the required rate of electrification is a significant challenge and may require prohibiting new gas connections and appliance replacement in homes. CSIRO modelling commissioned by the authority projects a decline in emissions from gas consumption in buildings as buildings are electrified. Further information on the CSIRO modelling of emissions in the Built Environment is available later in this chapter. Approximately 5 million existing houses would need appliance replacement for full electrification to occur (ENA, 2021). While phasing out gas connections is not necessary to electrify buildings, phasing out the gas network minimises unnecessary ongoing operating and maintenance costs as well as reducing fugitive emissions from gas leaks across the network (Grattan Institute, 2023). Disconnecting buildings from the gas network in an orderly process is therefore the most efficient way to manage the electrification of buildings.

Assuming no further homes are connected, disconnecting all homes from gas networks by 2050 implies an annual disconnection rate of approximately 166,000 homes per year, an 11-fold increase on the current gross rate of disconnection (approximately 15,000 per year, which includes only abolishments and disconnections where the meter is removed) (AER, 2024). This is more ambitious than estimates from the Department of Industry, Science and Resources (DISR) which state that the east coast would need to disconnect gas from approximately 143,000 households annually over 20 years to meet household gas demand reductions laid out in AEMO's high-ambition modelling scenario (DISR, 2024b). However, the number of residential gas customers continues to grow, with approximately 68,000 households joining the gas network across NSW, Victoria, South Australia and the ACT in 2021 alone (DISR, 2024a). Further information on CSIRO modelling of gas consumption in the Built Environment is available later in this chapter.

Commercial building data is less readily available, but the subsector would require similarly significant declines in gas connections and use. An estimated 3.5% of Australia's current non-residential stock would also need to be retrofitted each year, a significant jump from the present rate of 1% (GBCA, 2023b). Australia's current rate of investment in retrofits ($500m per year) would need to increase to between $1.5b and $2b per year (GBCA, 2023b).

Most governments have been hesitant to mandate building electrification, except for the ACT and Victoria where new buildings cannot connect to the commercial gas network (see BE.3 barriers, opportunities and enablers). Even with limited policy action, gas demand on the east coast is still forecast to decline by between 49% and 72% on 2023 levels by 2043 in commercial and residential buildings (DISR, 2024a).

Electric technologies for water heating, air-conditioning and cooking are commercially available, demonstrated, and ready for deployment (ASBEC, 2016). Furthermore, electric appliances are becoming cheaper and more efficient (Butler et al., 2020), and can be 'cost positive' (i.e. the saved costs are larger than the cost of the appliance) over their lifetime (Denis-Ryan & Gordon, 2024; Krarti & Karrech, 2024). According to the Authority's ground-up analysis, this shift is already happening in residential buildings, with approximately 125,000 (3-year rolling average) residential gas hot water systems annually replaced with electric systems. Assuming a 12-year average appliance life (Sustainability Victoria, 2024b), this replacement rate could theoretically be accelerated to almost 408,000 units per year. Commercial buildings, strata and apartments face additional challenges to electrification, including technical limitations on retrofits, added costs and complex ownership or management structures (ACT Government, 2024; Grattan Institute, 2023).

The task of electrification requires considerable coordination and investment. Electrifying a house can cost between $8,000 and $15,000 (Tildemann et al., 2022). Through expert consultation, the authority heard that electrification of a commercial building can cost between $100,000 and $5 million. However, new gas connections lock consumers into paying gas network and usage costs for up to 20 years and this is likely to be more expensive than the running costs of electric appliances (ATO, 2023; Gordon, 2024).

Electrification and replacement of liquid fossil fuels with low emissions alternatives such as biodiesel and hydrogen have the potential to decarbonise equipment and vehicles used in construction (Forsgren et al., 2019; GBCA, 2022). The use of electric construction equipment has been growing overseas, with several Scandinavian countries taking the lead to drive changes to conventional equipment and practices (Keegan, 2021). This equipment can have higher upfront costs than diesel equipment, but these costs can be offset over time by lower operational costs (Keegan, 2021). These opportunities are discussed in the Transport sector chapter.

The amount of abatement achieved by electrifying the built environment will depend upon the emissions intensity of Australia's electricity grids (see the Electricity and Energy sector chapter). The electricity system has been decarbonising and the authority's modelling indicates that renewable energy generation is likely to comprise approximately 99% of total generation in 2050. However, stakeholders have emphasised the importance of buildings being net zero-ready (i.e. electrified) before 2050, and it is important that this happens regardless of the emissions intensity of the system (UDIA, GBCA, ACOSS, Climateworks Centre, submissions, 2024).

BE.2.1.2 On-site renewable electricity generation and storage[3]

On-site renewable electricity generation and storage refers to the production and storage of energy at point of use, reducing the need for external electricity sources and increasing energy self-sufficiency. The authority agrees with expert consultation feedback that full self-sufficiency (i.e. complete disconnection from energy grids) for most buildings is not likely to be practical or necessarily the most efficient approach to operating electricity networks. However, increasing the uptake of on-site renewable energy generation technology is important for decarbonising the built environment and displacing the use of high-emissions energy sources.

Renewable electricity generation and storage technologies (especially solar PV and batteries) are mature and commercially available (Graham et al., 2024). Vehicle-to-grid technology also has the potential to complement stationary storage and provide benefits for households and the energy system. There has been significant growth in the capacity of rooftop solar systems and the Australian Energy Market Operator projects further growth in the National Electricity Market (NEM) (AEMO, 2024).

On-site generation has large abatement potential in the residential subsector due to the roof area available on suburban homes. For many commercial buildings and strata, generation and storage systems can displace only some of their grid-supplied electricity consumption. The authority heard during expert consultation that some commercial buildings often have technical and space limitations, and their energy needs are different to the needs of residential buildings. Some buildings however, like warehouses, have the potential to substitute all their grid electricity consumption with onsite renewable generation. Consultation for the 2025 NCC includes proposed changes requiring solar PV to be installed on buildings (ABCB, 2024).

3 On-site renewable electricity generation and storage is covered by the Electricity and Energy Sector Plan as part of the Australian Government's Net Zero Plan.

The costs of onsite generation and storage continue to fall, but there are still significant cost barriers to the deployment of on-site generation and storage systems, especially for low-income households and communities (Graham et al., 2024). The CSIRO have modelled rooftop solar PV costs falling from $1,505/kW in 2024 to between $513/kW and $702/kW in 2055 (Graham et al., 2024). Residential solar PV and battery system installation can cost between $15,000 and $30,000 (BVR Energy, 2023). The costs of commercial systems depend on the sizes of buildings and systems. Battery storage has high upfront costs, and returns on investment for generation systems can be slow or negligible depending on electricity prices and feed-in tariffs (Kaka & Pendlebury, 2022). Despite these cost barriers, adoption of these technologies can provide asset owners with greater energy independence and reduced power bills over the assets' lifetimes (CSIRO, 2024; Ma & Yuan, 2023).

Decentralised energy systems (at smaller scale than national or regional grids, but larger than individual buildings) can also improve the resilience of systems to natural hazards, especially when neighbourhood- or precinct-scale microgrids can be formed (Xu et al., 2024). Rooftop solar generation especially lends itself to working in decentralised systems. Battery storage technologies, known as orchestrated batteries, can also be used to trade power with the grid at optimal times to maximise savings for consumers sand provide benefits for the wider energy system (CEC, 2024). Managing consumer-owned resources is a significant economic opportunity for Australia. Effective deployment of distributed energy resources could avoid network, generation and other costs (IEEFA, 2024). These technologies should be a part of a diverse energy strategy, as outlined in the Electricity and Energy sector chapter.

The deployment of on-site renewable electricity generation and storage technologies could be supported through education initiatives (e.g. training programs for communities and organisations), more incentives for consumers, targets for both government-owned assets and for technology adoption, and greater participation options for consumers to match their choices of and uses for consumer energy resources (CEC, 2024).

BE.2.2 Energy performance

BE.2.2.1 Energy efficiency and digitalisation

Improving energy efficiency is the process of using less energy to perform the same tasks or amount of work (DCCEEW, 2024e). It is critical to decarbonisation and underpins sustainable and affordable buildings (C. White et al., 2023). The authority considers energy efficiency (and demand flexibility) to be an element of energy performance, and while some sources include fuel switching in energy performance, the authority considers this to be standalone (DCCEEW, 2024e).

Australia's energy policies have historically focused on supply, but the authority's consultation and research found that there is significant abatement potential in demand-side measures at the national level (ASBEC, 2022; C. White et al., 2023). A cost-effective means of reducing emissions is through adopting energy efficiency as a first principle (C. White et al., 2023).

The Australian Government recognised the importance of energy efficiency at the 28th Conference of the Parties in 2023, where it joined the Global Renewables and Energy Efficiency Pledge. Pledging countries committed to (28th Conference of the Parties, 2023):

- triple the world's installed renewable energy generation capacity to at least 11,000 GW by 2030
- work together to double the global average rate of energy efficiency improvements from around 2% per year to over 4% per year until 2030
- put the principle of energy efficiency as the "first fuel" at the core of policymaking, planning, and major investment decisions.

Improving energy efficiency can reduce the amount of energy consumed by buildings, delivering abatement by reducing emissions from fossil fuel electricity generation. Significantly improving energy efficiency across the built environment could reduce the amount of new electricity generation and transmission capacity that would otherwise be needed to service increased electricity consumption, balancing growing energy demand (IEA, 2020b). Efficiency can also reduce peak loads on electricity grids, which would further limit the need to use short-term (often non-renewable) peaking generation.

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Upgrading appliances can improve a building's energy efficiency. For example, LEDs require 75% less energy than halogen light bulbs and last 5 to 10 times longer (DCCEEW, 2024f). Heat pump hot water systems use 60% to 75% less electricity than conventional electric (i.e. resistive coil) hot water systems and are 300% to 400% more efficient than gas hot-water systems (ACT Government, n.d.; Sustainability Victoria, 2024a). Alongside replacement and upgrades, experts told the authority that timely maintenance of existing appliances is also a key means of improving and ensuring their operation at optimal energy efficiency over their lifetimes.

The adjusted cost of upgrading residential appliances and lighting in standalone and semi-detached houses is approximately $6,000 per household (Sustainability Victoria, 2015). For commercial buildings, costs for energy efficiency upgrades are expected to vary more widely depending on the building type and size. However, energy efficiency upgrades can provide cost savings over appliance lifecycles. The RACE for 2030 Cooperative Research Centre estimates that 'bespoke' residential retrofits can result in bill savings of $1,600 per year for average homes (RACE for 2030, 2021).

The authority's research and consultation found support for increasing minimum energy performance standards for space heating, hot water and cooking appliances (Climateworks Centre, Climate Council, GBCA, submissions, 2024). This action could ensure new dwellings are highly efficient and consumers receive long-term cost savings (Gordon, 2024). The Energy Efficiency Council has estimated that minimum appliance standards have saved consumers between $9.4 billion and $18.8 billion between 2000 and 2020 (EEC, 2023). The NSW Energy Savings Scheme saved over three million tonnes of CO_2 from efficiency measures in the years leading up to 2022 (IPART, 2024).

BE.2.2.2 Energy optimisation and behaviour change

Optimising the use of existing appliances is a low-cost demand-side measure to reduce emissions by reducing electricity use. This optimisation is enabled by technologies including the digitalisation of buildings using technologies like 'smart' thermostats and sensors for controlling lighting and air-conditioning systems to better align use with need (Otte et al., 2022; S. White et al., 2023). CSIRO reports that building digitalisation can potentially underpin new energy efficiency opportunities and save 6.6 Mt per year of CO_2 emissions at negative abatement cost (S. White et al., 2023). Distributed energy resources can also reduce electricity needs, providing flexible demand (IEEFA, 2024). There may be an emerging role for artificial intelligence to build on 'smart' technologies to automatically optimise energy use in buildings (IEA, 2019). Digitalisation in buildings has the potential to provide energy savings over the medium-to-long term by cutting energy use by up to 10% and there is evidence that it has already resulted in cost savings where it has been deployed in several locations–a residential complex in South Australia, a Wollongong shopping centre, a Sydney residential building, and a University of Wollongong building (ASBEC, 2016; IEA, 2017). Most emissions reductions activities related to digitalisation are technically ready and their use has been demonstrated, but deployment needs to be accelerated.

Behaviour change also plays a role in optimising energy consumption. In expert consultation, the authority heard that at a consumer level, this can include simple behaviours such as using appliances during the day when there is ample renewable energy available, switching off appliances when not in use, using heating and cooling efficiently and making upgrades to homes.

BE.2.2.3 Grid integration[4]

Grid integration refers to shifting from passive use of energy in buildings to active management of that use in conjunction with the operation of the wider energy systems (GBCA, 2023a). It can present opportunities to improve energy performance. Grid-integrated – or grid-interactive – buildings are electrified, efficient, flexible, and incorporate some automation, allowing for 'load shifting' (shifting optional energy use to different times of the day) to ensure energy is used when it is cheap, abundant and low emission (GBCA, 2023a). Load shifting has the potential to reduce Australia's annual greenhouse gas emissions by 1.9% and lower the cost of supplying power to buildings by $1.7 billion per year (Denniss & Roussac, 2024). Grid integration can be achieved through a mix of energy efficiency, controls, digitalisation and distributed generation and storage technologies. In consultation, experts noted this type of integration can range from text messages to asset operators to lower their electricity consumption during peak periods, through to high-tech automation of entire buildings and remote appliance management (e.g. pool pumps).

Grid integration provides an opportunity to reduce scope 2 emissions while supporting grid stability by reducing demand at peak periods and soaking up excess generation at times of high solar and/or wind generation. For example, shifting a third of the energy load of buildings by three hours per day for five days each week could reduce Australia's annual emissions by 0.6% and save building operators $1.7 billion in energy bills (GBCA, 2023a). 'Consumer energy resources' are discussed further in the Electricity and Energy sector chapter. A leading example in Australia is the University of Technology Sydney's first grid-interactive building, the Dr Chau Chak Wing Building. This building is prepared for peak summer electricity demand and has achieved cost savings from its automated demand response system (Schultz, 2023).

Grid integration technologies vary in readiness. In expert consultation, the authority heard that most are technically ready for deployment, but more sophisticated options have low commercial readiness (GBCA, 2023a). In consultation with experts, the authority heard that challenges to deploying these technologies include: retrofitting buildings can be difficult; electricity tariffs do not incentivise consumers to change behaviours and use appliances and energy in the middle of the day, and load shifting can potentially reduce energy efficiency ratings. Delivering grid stability and abatement from this action requires collaboration between the built environment and electricity sectors (S. White et al., 2023). Costs for grid integration technologies are still relatively unknown due to limited grid-scale deployment around the world.

BE.2.2.4 Thermal efficiency

Australia's buildings have some of the poorest thermal efficiency in the world. Houses built before 2003 have an average NatHERS rating of 1.8 stars (CSIRO, 2021). The impact of poor thermal efficiency is that buildings consume excess energy (Rajagopalan et al., 2023). Inadequate thermal efficiency, as well as poorly designed efficiency interventions, can also adversely affect human health (Ren et al., 2014). Around 81% of Australian homes have average winter indoor temperatures below the World Health Organisation's safe minimum. Prioritising thermal efficiency and taking a 'fabric first' approach is a key means of reducing building energy demand and scope 1 and 2 emissions (Climateworks Centre, 2023a). According to modelling by RACE, retrofitting 1,000,000 homes over 5 years could reduce home energy use by up to 9,000 kWh per year per home, equating to an emissions reduction of 5.8 tonnes of CO_2-e per year per home, and saving an average home $1,600 per year on energy bills (RACE for 2030, 2021). The scale of upgrades can vary however and research from the Climateworks Centre found that 'quick fix' and 'modest' upgrades can be most cost-effective for most households and have real efficiency benefits (Climateworks Centre, 2023a).

Technologies to improve building thermal efficiency are commercially available and ready for deployment. Approaches range from simple draught sealing or window covering to significant home insulation and window glazing upgrades (Rajagopalan et al., 2023). The Climate Safe Rooms project by Geelong Sustainability offers free home energy upgrades for low-income households where at least one resident received home care support services due to risk from heatwaves and extreme cold (Geelong Sustainability, 2023). The project has led to substantial energy savings, lowered gas consumption and reduced exposure to unhealthy temperatures (Geelong Sustainability, 2023).

Although upgrading existing residential buildings from existing low average NatHERS ratings is technically possible, comprehensive upgrades are expensive and not all thermal efficiency upgrades are eligible for subsidies under state-run schemes (Sustainability Victoria, 2015). The cost to upgrade a home to a 6-star energy efficiency rating could be between $9,000 and $18,000 for a semi-detached house, and between $42,000 and $63,000 for a detached house (based on a study examining housing stock in Melbourne) (Harrison, 2018). Although costs of thermal 'shell' upgrades can be significant, when implemented in the design phase they can be substantially cheaper than retrofits (Rajagopalan et al., 2023). Minor residential upgrades for improved thermal efficiency can

4 Grid integration of buildings is covered by the Electricity and Energy Sector Plan as part of the Australian Government's Net Zero Plan.

provide net cost savings in three years (Rajagopalan et al., 2023). Thermal efficiency also improves health: for every $1 saved on energy costs $10 is saved by the healthcare system (Sustainability Victoria, 2022).

BE.2.3 Refrigerants[5]

Refrigerant gases are critical for the operation of refrigerators, air-conditioners and heat pumps. Refrigerant gases can leak during equipment installation, operation and maintenance and at the end of an appliance's life. These emissions contribute about 9 Mt CO_2-e or 32% of the sector's 2022 scope 1 emissions. While Australia is not a signatory to the COP28 Global Cooling Pledge, Australia is implementing a HFC phase-down in line with the Montreal Protocol as discussed in the Industry and Waste sector chapter (Cool Coalition, n.d.; DCCEEW, 2023c).

Many refrigerant gases have a high GWP (IPCC, 2021), meaning emissions of small quantities can have a significant global warming impact. For example, R-404a is commonly used in low- and medium-temperature refrigeration systems and has a GWP of 3,922 (based on IPCC AR4) (DCCEEW, 2024h). This means every 1 kg of R-404a emitted has the equivalent warming effect of 3,922 kg of CO_2 over a 100-year period.

The impact of refrigerant gases can be mitigated through the utilisation of low-GWP alternatives (IEA & UNEP, 2020). Low-GWP refrigerants are commercially available, but according to the authority's consultation, there are still some technical limitations that are a barrier to their wider implementation. Typically, different refrigerant gases or blends have different operating requirements. This almost always makes retrofitting existing systems impossible, meaning owners usually need to obtain entirely new systems to take advantage of these products. This has been put into practice in some commercial settings. For example, in Woolworths' Rouse Hill store, the installation of a cascade CO_2 refrigeration system has reduced the GWP of the refrigerant gas by 3,700 (CO_2 by definition has a GWP of 1) (Blundell, 2010).

Commercial refrigeration systems commonly use R-404a and some of these can be retrofitted with refrigerants that have a GWP of approximately 1,300 or about one-third the GWP of R-404a (Makhnatch et al., 2017). Some refrigerants are not replaceable due to context-specific safety or technical constraints. Therefore, high-GWP refrigerants are expected to be used in small amounts beyond the end of the HFC phase down in 2036 (DCCEEW, 2021). Environmental impacts unrelated to global warming are concerns for alternative refrigerants that contain highly persistent 'forever chemicals', per- and polyfluoroalkyl substances (PFAS) (Glüge et al., 2020). Governments around the world, including in Australia, are currently considering the regulatory approach to PFAS chemicals (DCCEEW, 2023f).

Refrigerant gases need to be addressed in both new appliances, and in the 'bank' or stock of gas in existing appliances and systems. The HFC phase-down discussed in the Industry and Waste sector chapter addresses new gases, but in expert consultation the authority heard that the existing bank poses a significant challenge that is only partially managed through a licencing system and end-of-life destruction. There are currently more than 62 million appliances with lifespans of 15 to 60 years using refrigerant gases in Australia (DCCEEW (unpublished), 2024c). The authority expects that this equipment stock will continue to grow, especially as the use of heat pumps increases due to electrification (CCA, 2023).

The refrigerant bank has the potential to be a significant source of emissions if inadequately managed. Australian appliances contain over 4 million kg of R-404a as of 2022, with the potential to release the equivalent of about 17 Mt of CO_2 into the atmosphere (DCCEEW (unpublished), 2024c). Despite the projected growth of the mass of the refrigerant bank until 2030, the HFC phase-down is expected to reduce the bank's potential climate impact (DCCEEW, 2023c). The authority's analysis found that under optimal circumstances, the bank could reach near zero in the early 2050s. The existing bank is managed through a licencing program and by end-of-life destruction (DCCEEW, 2023e; Ozone Protection and Synthetic Greenhouse Gas Management Act 1989). During expert consultation stakeholders estimated that the 530 tonnes destroyed in 2022 represents between 20% and 25% of gas reaching end of life (UNEP Ozone Secretariat, 2023). Increasing the rate of destruction is a significant opportunity to reduce emissions.

DCCEEW analysis suggests that routine maintenance of air conditioning equipment has a significant impact on equipment energy consumption (DCCEEW (unpublished), 2024c). A focus on proper installation and routine equipment maintenance is an opportunity to reduce refrigerant emissions, and it is expected that this will have limited imposition on the community. There is also a link between refrigerant selection and equipment efficiency, with over 80% of emissions from refrigeration and air-conditioning equipment deriving from energy use (Refrigerants Australia and AREMA submission, 2024). (DCCEEW, 2023b)

5 Refrigerant emissions are jointly covered by the Built Environment Sector Plan and the Industry Sector Plan as part of the Australian Government's Net Zero Plan.

Box BE.1: Scope 3 embodied emissions

Definition

Embodied emissions are the emissions generated during the material manufacture, construction, maintenance and demolition of buildings and infrastructure (GBCA & Thinkstep-anz, 2021). They are calculated as the 'sum of greenhouse gas emissions and greenhouse gas removals in a product system, expressed as CO_2-e and based on a life cycle assessment …' (ISO, 2018).

The problem

While the built environment may have lower operational (scope 1 and scope 2) emissions relative to other sectors, the sector is a major driver of emissions through high embodied-emissions materials, construction practices and upstream activities (scope 3 embodied emissions) (ASBEC, Property Council of Australia (PCA), GBCA, Better Futures Australia, PIA, submissions, 2024).

Scope 3 emissions in the built environment contributed an estimated 11% to national carbon emissions in 2022-23 (Infrastructure Australia – Hybrid Analysis, 2024). In another analysis, average annual upfront embodied carbon was estimated to be 51 Mt CO_2-e per year over the 5 years analysed, ranging from 40 Mt CO_2-e to 56 Mt CO_2-e (Infrastructure Australia – Hybrid Analysis, 2024). Of these emissions, 75% were generated during the manufacture of building materials (Infrastructure Australia – Hybrid Analysis, 2024). Most of these emissions are from concrete (~11 Mt CO_2-e per year) and steel (~12 Mt CO_2-e per year). The sectors with the highest scope 3 emissions in 2022-23 were calculated to be buildings (24 Mt CO_2-e), followed by transport infrastructure (10 Mt CO_2-e) and utilities (5 Mt CO_2-e) (Infrastructure Australia – Hybrid Analysis, 2024).

On average, there are 118 to 158 tonnes of emissions embodied in a typical detached home (Schmidt et al., 2020). Through the National Housing Accord, the Australian Government is aiming to build 1.2 million new homes by mid-2029, which equates to between 142 to 190 Mt CO_2-e of embodied emissions (The Treasury, 2023).

The opportunity

Across the sector there is growing awareness of and interest in addressing scope 3 emissions. This includes opportunities to reform the approach to design, planning and construction of buildings and infrastructure (NABERS, 2023b).

Demand for low-carbon construction materials could be driven by heightened building construction code requirements or by property seeking to reduce their scope 3 emissions. A 10% reduction in embodied emissions in new buildings is estimated to correspond to avoided emissions of at least 19.9 Mt CO_2-e between 2022 and 2030, and at least 63.5 Mt CO_2-e avoided between 2022 and 2050 (GBCA & Thinkstep-anz, 2021).

Embodied emissions are also crucial when considering the entire lifecycle of buildings and infrastructure. By repurposing or renovating existing buildings, as opposed to decommissioning or demolishing them, additional embodied carbon emissions can be avoided and existing materials can be re-used or recycled to provide a second (or extended) lives to material and structures (Dunn, 2023; NABERS, 2023b).

The solutions

Reducing embodied carbon in the built environment requires systemic changes at all stages of the construction process through both supply-side and demand-side interventions (GBCA & Thinkstep-anz, 2021). This will involve a shift in how we consume materials, as well as changes to how industry produces and delivers goods and services (DCCEEW, 2024e). Measurement of embodied emissions is fundamental to this and the authority notes the development from Building Ministers who have agreed that the NCC 2025 will include voluntary guidance to report and measure embodied emissions using the NABERS tool (DISR, 2024c). The Australian Sustainable Built Environment Council is currently leading development of a policy framework to manage embodied emissions (ASBEC, 2024).

> Reducing embodied carbon in the built environment requires systemic changes at all stages of the construction process through both supply-side and demand-side interventions (GBCA & Thinkstep-anz, 2021). This will involve a shift in how we consume materials, as well as changes to how industry produces and delivers goods and services (DCCEEW, 2024e).

Material substitutions mean swapping out high-carbon materials for those with lower emissions intensity (e.g. substituting fly ash for cement used in concrete mixtures) and are potentially a multibillion-dollar industry (CEFC, 2021; GBCA & Thinkstep-anz, 2021). However, this is only a partial abatement solution. As a demand driver, the greatest opportunities for reducing the sector's embodied carbon are in the initial stages of the design and planning process, where material requirements can be optimised for lower embodied emissions. This would require revising established approaches to building and development, alongside avoiding construction and reducing material use in the first place. Public sector investment in both buildings and infrastructure can drive this change.

1. Design and Planning

During expert consultation the authority heard that improvements in building design can reduce embodied emissions by up to an estimated 60%. The strategies for achieving net zero embodied carbon can be organised under four principles, which should be considered in the following order (Prasad et al., 2021):

- avoid building and/or build at the 'right' (smaller) size
- build less and/or dematerialise (use less material for the same functions)
- build low carbon or 'smarter' (adopting the lowest carbon elements, for example prefabricated elements)
- leverage supply chain and procurement methods (material substitution).

Design needs to consider sufficiency as well as resource efficiency to reduce embodied carbon, where sufficiency is about long-term non-technological actions that consume less in absolute terms (IPCC, 2022). Examples of sufficiency measures include avoiding construction by repurposing empty buildings, ensuring building size meets changing household needs, and encouraging multifamily homes (IPCC, 2022).

Australia has some of the largest houses in the world, averaging 84m^2 per person, many of which are in sprawling urban fringes (Wingrove & Heffernan, 2024). This means that Australian houses have higher embodied emissions compared to other countries, and that energy use is higher for a given level of energy efficiency performance (Wingrove et al., 2024). This highlights the need to reconsider design and building principles, including the size of houses being built and the scale of current and future development.

An example of effective design reducing embodied emissions is the Atlassian tower in Sydney, a 40-storey building made of hybrid concrete and timber, resulting in up to a 50% reduction in embodied carbon (Built Australia, n.d.). At a precinct level, the City of Vincent in Western Australia has had major successes in embodied carbon reduction. The City made changes to their planning approval processes via a voluntary mechanism which incentivises lower-embodied carbon projects by providing an opportunity to fast-track development application approvals (MECLA, 2023).

Further discussion on the role of design and planning in decarbonisation of the built environment is in Box BE.2 below.

2. Circular economy principles

Circular economy principles involve sharing, leasing, reusing, repairing, refurbishing and recycling existing materials and products for as long as possible when producing and consuming (European Parliament, 2023).

> *"Embedding circular economy principles and practices represents a substantial means of reducing carbon emissions through the application of embedded carbon in the buildingindustry."*
>
> Urban Development Institute of Australia submission, 2024

The built environment stands to gain significant abatement from implementing circular economy measures, including reducing embodied emissions (Henderson, 2023; Wang et al., 2022). The opportunity lies in avoiding the creation of new buildings and materials, and instead preserving and reusing products, materials and structures which have already been manufactured (Clean Energy Finance Corporation, 2021). This approach reduces lifecycle emissions, creates less demand for resources, and reduces waste.

Examples of how the built environment can reduce embodied carbon and increase circularity include:

- Rewarding investment in circular solutions and business models (e.g. by implementing standards and regulations to prioritise renovation, retrofitting and adaptive reuse) (CEF, 2024)
- Mandating consideration of embodied carbon through the NCC, as recommended in the Circular Economy Ministerial Advisory Group interim report (DCCEEW, 2024b)
- Reusing and repurposing buildings, as opposed to creating new buildings, saving up to 50% in embodied emissions (Tirelli & Besana, 2023)
- Using recycled asphalt in road construction, which can avoid 96,148 tonnes of CO_2 per year in New South Wales alone (Marsden Jacob Associates, 2022)
- Incentivising investment in circular building projects (e.g. cutting property taxes or providing tax credits for circular construction) (CEF, 2024)
- Targeting education and policy to support labour and skills needed for circular design and construction practices (Nicholson & Miatto, 2024; ICLEI, 2023).

This can also be tied to the manufacturing industry, of which the built environment is an end-user. Targeting manufacturing and increasing awareness of the built environment's end-user role can encourage products to be designed for circularity (easier to reuse, repair and recycle), and utilise pricing to promote sufficiency, and foster a cultural shift of production and construction through education and legislation (CEF, 2024).

Opting to renovate and retrofit existing buildings in place of demolition can save significant amounts of the embodied carbon of a rebuild approach (Pelly, 2023; Storck et al., 2023; Seo & Foliente, 2021). For example, the renovation of 50 Bridge St, Sydney into the Quay Quarter Tower maintained 60% of the existing core structure, saving 12,079 metric tons of embodied carbon, and reducing both construction time and environmental impact (CEFC, 2022; Quay Quarter, n.d.).

3. Material substitutions

Embodied emissions can be lowered by replacing high-emissions materials with low-emissions materials, particularly steel, cement and aluminium. The supply side levers are discussed in the Industry and Waste sector chapter.

There has been significant effort in developing building products with lower embodied emissions. Cement is a key example of a material that has been engineered to lower its emissions intensity. The emissions intensity of cement produced domestically from Australian clinker fell 17% in the eight years to 2018-19, from 0.94 kg CO_2-e/kg cement to 0.77 kg CO_2-e /kg cement (GBCA & Thinkstep-anz, 2021; CIF, 2020). In addition, manufacturers such as Holcim Australia are planning further reductions by replacing general-purpose cement with supplementary cementitious materials (SCM) such as fly ash, slag, and silica fume (Climate Active, 2019).

As noted, material substitution has its limitations. While it can reduce embodied carbon, it cannot eliminate it, primarily due to the emissions associated with construction and transport of materials. In many situations, alternatives have different technical properties that mean they are not appropriate for the proposed application. There are also regulatory barriers to the use of alternative materials including lengthy timeframes to update Australian Standards. Economies of scale are expected to drive cost reductions and improve access to novel materials (CEFC, 2021).

Box BE.2: The role of building design and urban planning

Urban planning and building design play a crucial role in abating emissions in the built environment by shaping how individuals and communities consume energy (DITRDCA, 2024). In a submission to this review, the Australian Local Government Association (2024) explained that design changes can deliver a range of co-benefits including improved health and wellbeing outcomes for individuals and communities. Planning is also a key integrator to bring together actions across sectors.

Design can be considered from a 'macro' urban planning perspective to a 'micro' individual building design perspective.

Macro urban planning and precinct design

Urban planning and precinct design presents significant opportunities for driving decarbonisation in the built environment and other sectors (e.g., transport), while also delivering a range of co-benefits for individuals and communities.

- Effective planning can drive the adoption of lower carbon materials in the development of new precincts, communities, and infrastructure (Bunning et al., 2013).
- Designing compact cities and precincts can reduce transport emissions and encourage active or public transport rather than a reliance on driving (Fan & Chapman, 2022; Infrastructure Victoria, 2023b) and digitalisation can encourage 'mode shifts' such as sharing private transport (Reich, 2023). Active transport also has benefits for human wellbeing (Central Coast Health Promotion Service, 2024).
- Proactive planning of urban areas can encourage increased density and reduce urban sprawl, reducing embodied emissions (Infrastructure Victoria, 2023a). Higher density urban areas also enable other opportunities to reduce emissions, such as grid integration of buildings.
- Planning can create better adapted and climate resilient cities by employing a range of techniques such as shading, appropriate material use, and drought and flood resistance. Urban green infrastructure (e.g. tree cover) can reduce cooling demand (IEA, 2021; Feyisa et al., 2014; The Nature Conservancy submission, 2024). In this case, green infrastructure is a key link between climate mitigation, adaptation, and resilience.

Estimates indicate that improved urban design can reduce the average citizen's carbon footprint by up to 60% (IEA, 2021). Retrofitting costs for adding green spaces, walking and cycling infrastructure, and public transport (e.g. railways and tramways) to existing cities are enormous. Therefore, considering these factors at the planning phase can have significant cost benefits over long timescales.

Building design, planning and zoning should also consider future climate conditions and risk to ensure buildings have energy security and minimise exposure to climate and natural disaster risk.

Individual building design

Decisions made at the design phase can lock in emissions for the lifetime of the building. Poor building design frequently leads to draughts and poor solar efficiency which ultimately results in heat loss and excessive energy use (Brinsmead et al., 2023).

The design phase therefore presents the greatest opportunity for reducing operational and embodied emissions in buildings, whilst delivering co-benefits for building users. Building designers, contractors and developers should engage with consumers to ensure they understand the climate and energy implications of building design decisions.

While widespread construction of 'passive' houses may be unachievable, retrofitting poorly designed buildings is also difficult and expensive. The most effective time to implement technologies for improving thermal efficiency is early in a building or project's design phase.

It is also important to recognise current attitudes and cultural practices when designing homes. This is particularly relevant in Australia, where relatively large homes are commonplace, with some states and territories recording significant growth in the past two decades (Australian Bureau of Statistics, 2023). A 2024 study of Australian houses found that while houses are being designed to be more energy efficient, their increasing size has led to an overall increase in energy consumption (Wingrove et al., 2024). Improving building thermal efficiency can have unintended consequences by increasing material use and therefore embodied emissions, however lifecycle emissions still report large improvements (Kneifel et al., 2018).

For these reasons, emissions avoidance should be entrenched in all phases of the design, planning, building and certification process. By decarbonising across sectors and the supply chain, and by rethinking building practices, it is possible to reduce emissions from buildings even if they have greater energy requirements.

BE.3 Barriers, opportunities and enablers

BE.3.1 Green premiums

The lifecycle cost of electrified technologies is usually less than the lifecycle costs of existing fossil fuel-powered approaches (Grattan Institute, 2023). However, the upfront installation costs of high-efficiency electric appliances remain a fundamental barrier to adoption (IPCC, 2022). Upfront costs can also act as strong disincentives to implement entirely new systems, due to long payback periods relative to the useful lifetimes of appliances and equipment (BCG, 2021; Sustainability Victoria, 2019).

Financial incentives are a key enabler to overcoming high upfront costs, driving earlier adoption of commercially available emissions reduction technologies associated with retrofitting and energy efficiency upgrades. Appropriate financial instruments must recognise the differing incentives of various actors when determining how to spend public money (or concluding private finance is sufficient). The authority heard that owner-occupiers are likely to accept upfront capital expenditure, whereas lower income households, such as those in public housing or renting, will be less able to absorb those costs despite comparative reductions in lifetime operational costs.

To ensure equal opportunity across income groups and housing types, financing approaches for this sector will require a suite of tailored financial instruments for individuals' incentives. This may look like concessional loans, tax rebates or grants depending on the financing need. Local governments or community groups can work to receive and deliver this funding in their local area to improve administrative efficiencies and roll out for all parties.

> To ensure equal opportunity across income groups and housing types, financing approaches for this sector will require a suite of tailored financial instruments for individuals' incentives.

The role of low-income housing in reducing energy use is often overlooked, and barriers include limited financial resources of occupants as well as technical challenges such as retrofitting ageing and multiple-household buildings. Government support is a must. By building on the existing social housing retrofit funds, governments could also demonstrate best-practice upgrades and smooth approval processes by coordinating with development regulators. In consultation, stakeholders noted the recently established Housing Australia Future Fund Facility as an example of an existing government entity that could be modified to require minimum climate-resilient developments as part of eligibility criteria.

BE.3.2 Planning, approvals and coordination

All building types, including free-standing homes, commercial buildings and buildings under strata management will need to decarbonise. Strata arrangements face unique challenges that require planning and coordination across different levels of government. The authority has heard, for example, that "supporting the implementation of suitable technologies in strata buildings that serve to target emissions reductions can assist the Federal Government in reaching their goals of an electrified future and greener future" (Strata Community Association submission, 2024).

BE.3.3 Regulatory inconsistencies and gaps

The lack of nationally consistent and contemporary regulations impedes progress. For example, construction and planning experts raised concerns with the authority that material substitutions for building products and changes to urban planning are often prohibited due to outdated regulations and standards.

Improvements to the existing regulatory environment could drive a substantial uplift in building quality while also working to overcome the split incentive barrier (i.e. where a building owner pays for an upgrade, but the tenant receives the benefit, disincentivising the building owner from acting), cut administrative costs for development, boost housing supply and improve emissions outcomes. Examples include:

- Introducing and raising minimum standards for homes and rental properties, mandatory energy rating disclosures and net zero building standards (Climateworks Centre, PCA, ACOSS, Renew, GBCA, Climate Council, submissions, 2024).
- Building the existing refrigerant gas policy by placing further limits on the GWP of refrigerant gases in specific types of appliances (e.g. commercial refrigeration and stationary air-conditioning), with a similar approach to comparable countries such as the European Union, the United States and Japan (European Commission, 2024; EPA, 2016; Ministry of the Environment, n.d.).
- Strengthening minimum energy performance standards for appliances (Climateworks Centre, 2023a; GBCA, City of Sydney, IEEFA, PCA, submissions, 2024). This also reduces energy costs of the lifetime of appliances, as energy efficient appliances can reduce energy bills by reducing energy consumption (DCCEEW, n.d.). Standards can also help overcome data barriers for consumers and support supply chains (Climateworks Centre, 2023a). This could be achieved in part by expanding the GEMS to cover appliances such as space heaters and cooktops. Maximum benefit can be achieved by combining standards for electric and gas systems to recognise efficiency benefits and emissions savings. The costs of delaying minimum standards updates are $3.4 billion in lifetime costs that are locked in (Gordon, 2024). These accumulate for every year that the lifting of minimum standards is delayed. This figure does not consider the additional benefits of increased thermal efficiency or optimisation upgrades.
- Developing product and engineering standards to target embodied emissions by enabling alternative products and low carbon designs (GBCA & PCA, 2023). There is an opportunity to introduce further mandated maximum embodied carbon standards for buildings, following international examples such as Denmark, the Netherlands and Finland (Toth & Volt, 2021).
- Mandatory disclosures of building energy performance and efficiency - a low cost and foundational policy for sectoral decarbonisation (GBCA & PCA, 2023). Disclosures drive action in a competitive market striving for low carbon buildings, as seen by the national Commercial Building Disclosure (CBD) program driving a 40% reduction in average energy intensity from mandatorily rated buildings since 2011 (NABERS, 2023a). Expert stakeholders recommended the implementation of mandatory disclosures for home energy efficiency ratings and building performance (Climateworks Centre, ACOSS, PCA, Better Futures Australia, submissions, 2024). Stakeholders also told the authority during consultation that there is potential to expand the national CBD program to subsectors and introduce similar policies for residential buildings and the Australian Government is currently consulting on similar changes (PCA submission, 2024; DCCEEW, 2024d).

The authority's 2023 Annual Progress Report recommended the Australian Government "work with state and territory governments to agree on a coordinated, nationally consistent approach to phasing out new gas connections for residential and small commercial buildings and phase-out for existing gas connections" (CCA, 2023). The government disagreed with this recommendation (DCCEEW, 2023a). Since this recommendation was made, the government has acknowledged that the current rate of conversion from gas to electric appliances is insufficient to meet Australia's net zero targets (DISR, 2024b).

The electrification of buildings is central to the sector's decarbonisation and the absence of a national plan to phase out gas connections to buildings remains a critical barrier (Australian Sustainable Built Environment Council, 2022; Climateworks Centre, GBCA, Renew, City of Sydney, Sydney Environment Institute, submissions, 2024). In this absence, jurisdictions are taking different approaches to decarbonising gas emissions. Some jurisdictions such as the ACT and Victoria are acting independently to phase out gas connections through policies banning new gas connections and enforcing adoption of electric appliances in new buildings (ACT Government, 2021; DISR, 2024b; DTP, 2023) and the Australian Building Codes Board (ABCB) is currently consulting on the 2025 NCC to include measures to support commercial building electrification (ABCB, 2024). In contrast, Tasmania's Future Gas Strategy committed to not regulate new gas connections and prioritises the deployment of renewable gases to decarbonise emissions (Tasmanian Government, 2023).

Box BE.3: High upfront costs on retrofitting poor quality housing

The French Government has legislated increasingly stringent regulation to support financial instruments to decarbonise the built environment. The Loi Climat et Résilience mandates increasingly stringent minimum rental standards over time to address split-incentives between investors and renters. To encourage retrofitting, from 2025, landlords will not be permitted to lease buildings with the lowest standard (Jousseaume, 2022). This baseline will successively be tightened, with the next lowest standard not permitted for leasing from 2028. In parallel, government grants of up to €35,000 ($58,200) are available to owner-occupiers or investors to complete energy retrofits (Government of France, 2023). The program aims to finance 370,000 fully renovated homes per year by 2030, eventually reaching 700-800,000 (IEA, 2023b).

BE.3.4 Supply chain constraints

Opportunities to decarbonise the built environment are inextricably linked to progress with reducing emissions in other sectors. For example, abatement via electrification relies on the decarbonisation of electricity supply, and reducing embodied emissions relies on the decarbonisation of industry (e.g. steel and cement).

The supplies needed to decarbonise the built environment will be in high demand across Australia and the decarbonising world. Regional and rural areas face additional supply challenges due to the additional freight. Proper prior planning and monitoring relevant supply chains will be key to overcoming these barriers.

BE.3.5 Workforce and skills shortages

The workforce necessary to enable energy efficiency upgrades, demand-side and energy management will be significant – and overlaps with the workforce for the renewable energy buildout detailed in the AEMO's Integrated System Plan (discussed in the Electricity and Energy sector pathway) (AEMO, 2024). The Institute of Sustainable Futures estimated that this energy efficiency workforce could be between 200,000 and 400,000 by 2030 (Rutovitz et al., 2021).

The installation of the critical technologies for the sector is carried out by tradespeople, including electricians and air-conditioning and plumbing professionals. The technologies are commercially available with many of these skills already in the market, but the challenge is scaling up a workforce that is already experiencing shortages. For example, hot water heat pump systems require a licenced plumber for installation (DCCEEW, 2023d), but plumbers are currently in shortage in all states and territories (JSA, 2023a). The Australian Sustainable Built Environment Council (ASBEC) calls for significant and well-planned government action to increase the availability of appropriate training and qualification frameworks to meet the retrofitting and electrification challenges (ASBEC, 2023).

Jobs and Skills Australia (2023b) identified that as governments move forward with energy efficiency and electrification standards like NatHERs and the NCC, the demand for energy auditors will rise (JSA, 2023b). Skilled roles in performance and energy management systems do not have dedicated national training courses, and training for these roles is being managed by the Energy Efficiency Council (EEC) (JSA, 2023b).

BE.3.6 Information and data gaps

A lack of accurate emissions data is a barrier for managing and reducing embodied emissions in the built environment. Trusted 'one-stop-shops' for information about building energy efficiency could help consumers navigate the complexity and drive the commercial readiness and scale of retrofits and new builds for all housing, including in low-income housing (ACOSS, 2024).

Inability to compare costs between products and services can prevent the uptake of commercially available abatement opportunities. For example, the Equipment Energy Efficiency (E3) program doesn't rate all appliances and does not allow for simple comparisons between gas and electric appliances (Australian Government, 2024b).

Information gaps about appliance and building energy efficiency could be addressed by expanding existing disclosure schemes and mandating disclosure of building energy performance at the point of sale or lease, or for some commercial buildings at periodic intervals.

BE.4 Emissions pathways

As gas is phased out and more buildings electrify, electricity is projected to dominate building energy supply by 2050 in the modelled scenarios. Scope 1 and scope 2 emissions are projected to reduce significantly. The scenarios modelled by the authority using AusTIMES broadly reflect the findings of the authority's ground-up analysis (Table BE.3).

Table BE.3: Comparison of change in annual emissions for the built environment and its subsectors based on the AusTIMES modelling and ground-up estimates. Ground-up estimates are determined from technology uptake in ideal conditions

Reference: emissions in 2022 were 28 Mt CO_2-e	Projected emissions reductions to 2050 (Mt CO_2-e)[1]		
	AusTIMES modelling (A50/G2 scenario)	AusTIMES modelling (A40/G1.5 scenario)	Ground-up
Residential buildings	9	9	11
Commercial buildings	3	3	6
Construction	2	2	2
Refrigeration and air-conditioning	7	7	8
Sector total	22	22	27

Note: [1] Abatement was calculated as the difference between base year emissions and the projected 2050 emissions from each model. In AusTIMES, the base year for the abatement calculation was 2025 and in bottom-up estimates the base year for estimates was 2022.

The modelled decarbonisation scenarios align with varying levels of global ambition (see Appendix C). The A50/G2 scenario aligns with global warming remaining below 2°C and Australia reaching net zero emissions in 2050. The A40/G1.5 scenario aligns with a 1.5°C world and Australia reaching net zero emissions in 2040.

Modelled final energy demand for commercial and residential buildings under different scenarios are shown in Figures BE.1 and BE.2. Building stock is projected to grow from 2021 to 2050, with the total number of residential buildings assumed to grow by 65% and commercial floor space by 56% (Climateworks Centre, 2023b). However, final energy demand decreases in both A50/G2 and A40/G1.5 scenarios for residential and commercial buildings. Energy performance is projected to improve across all scenarios.

Commercial buildings are not projected to see the same increase in electricity consumption over time as residential buildings. This is due to residential buildings moving to rely more heavily on electricity for energy as natural gas and liquid petroleum gas (LPG) are phased out, while some natural gas and oil consumption remain in commercial buildings. This discrepancy reflects the greater challenges in electrifying commercial buildings compared to residential buildings, as discussed in this chapter.

Oil consumption in commercial buildings is projected to decrease significantly from 20 PJ to under 2 PJ in both scenarios. Biomethane is an almost pure source of methane produced by purifying biogas or through the gasification and then methanation of solid biomass (IEA, 2020a). Biomethane is not projected to form part of the energy mix for residential or commercial buildings, as electrification is a cheaper way to decarbonise. Commercial buildings are projected to have a small amount (less than 1 PJ) of hydrogen consumption in 2050 which will be used in pipeline blending. Residential buildings, however, are not projected to consume hydrogen. LPG is typically a bottled fuel and is commonly used for water heating, space conditioning and cooking in regional and mobile applications, but LPG emissions in residential buildings are projected to be phased out in both scenarios due to electrification (GEA, 2023). Biomass as a residential fuel source (i.e. wood combustion) grows in both scenarios. This biomass growth is an artefact of the model, as there is no option for fuel switching from biomass. The model considers biomass to be a net zero energy source, although in reality there are other positive and negative effects associated with the use of wood as a fuel.

Total scope 1 emissions for buildings decrease in both scenarios at almost the same rate (Figure BE.3). This is consistent with the strong ambition needed and potential for the sector that many expert stakeholders emphasised to the authority during consultation.

This chapter has identified electrification coupled with decarbonisation of the electricity system as critical to decarbonising the built environment. The modelling shows that in both scenarios the decarbonisation of electricity generation is critical to reducing the built environment's scope 2 emissions. As expected, the A40/G1.5 scenario sees electricity sector emissions reduce further and faster than the A50/G2 scenario (Figure BE.3).

The 2021 Census found that 70% of private dwellings were separate houses, 16% were apartments and 13% were townhouses (ABS, 2022b). Consistent with this data, approximately 82% of residential building emissions come from detached dwellings, 8% from apartments and 10% from semi-detached dwellings (Figure BE.4). While the A40/G1.5 scenario sees slightly faster decarbonisation of residential buildings, both scenarios project that the three residential building types almost completely decarbonise due to electrification.

Figure BE.1: Final energy demand by commercial buildings

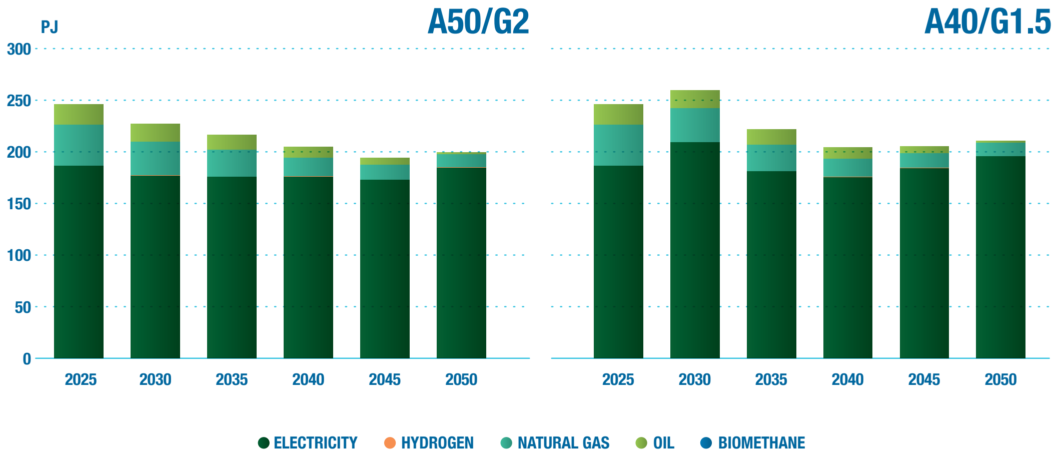


Figure BE.2: Final energy demand by residential buildings

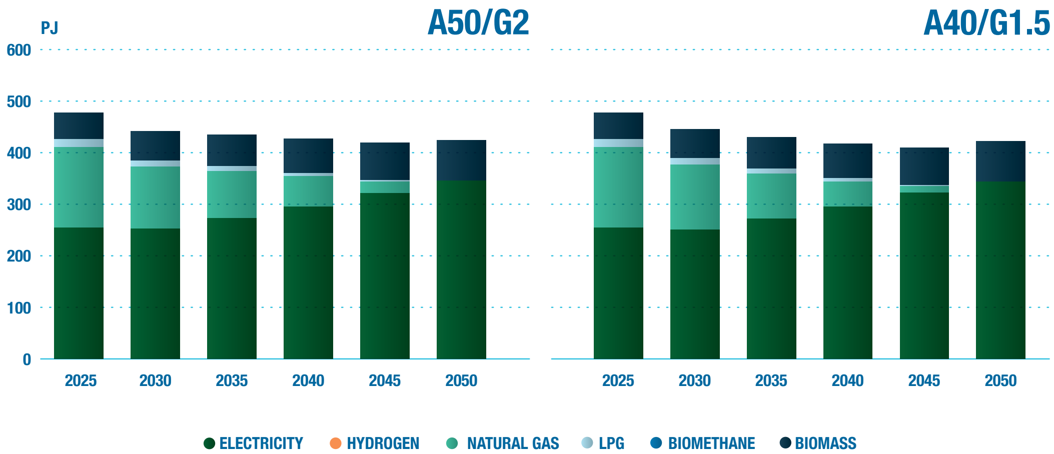


Figure BE.3: Total building emissions, scope 1 and scope 2 emissions (Mt CO_2-e)

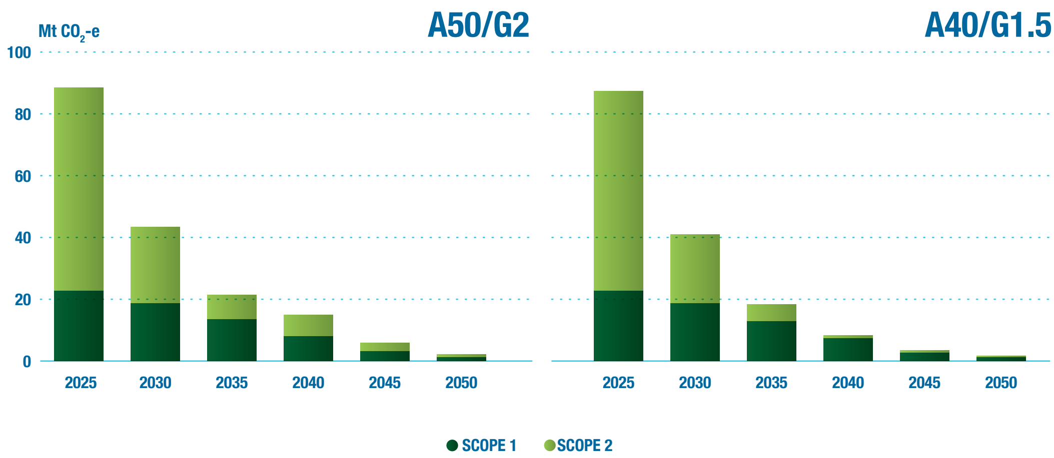
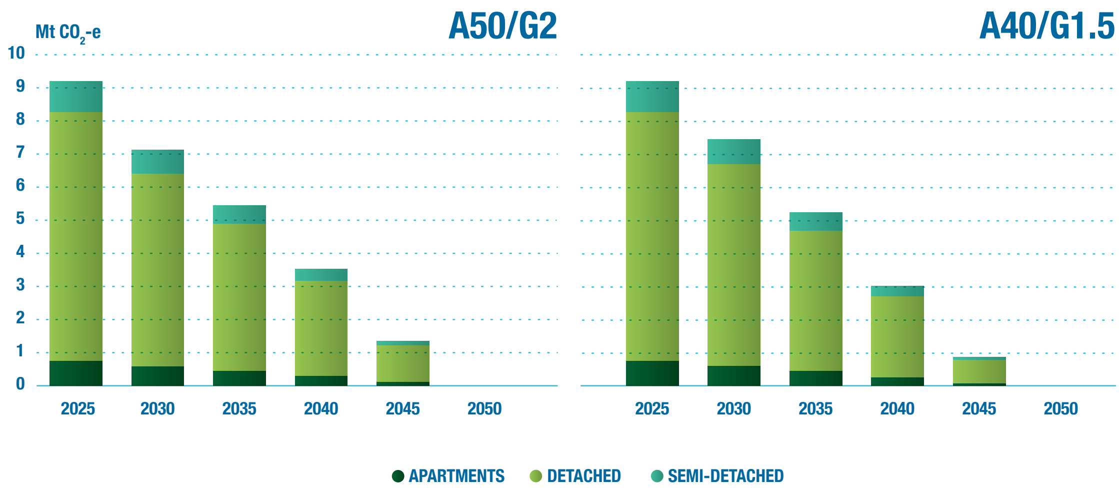


Figure BE.4: Residential building scope 1 emissions, split by building type (Mt CO_2-e)



Source: CSIRO modelling in AusTIMES commissioned by the Climate Change Authority

The built environment sector has many data gaps and areas of incomplete information. While the authority has made every effort to ensure the robustness of this analysis, there are many relevant data sets that are simply not collected.

BE.4.1 Residual emissions

The authority's analysis and most other relevant analyses indicate there could be approximately 1 Mt CO_2-e of residual emissions in the built environment sector by 2050 (Table BE.4), potentially comprising refrigerant gases, consumption of biomass and biomethane in residential buildings, and diesel and biomethane in commercial buildings. These could be further addressed by accelerating building electrification, improving management of refrigerant gases, a faster asset replacement cycle for assets with refrigerants, and a coordinated national gas phase out.

Table BE.4: Estimates of built environment residual emissions

Source	Residual emissions by 2050 (Mt CO2-e)
CCA scenario A50/G2	1
CCA scenario reference A40/G1.5	1
CSIRO Rapid Decarbonisation (CRD) scenario (Brinsmead et al., 2023).	2.2 (0.7 from residential and 1.5 from commercial buildings)
Climateworks Decarbonisation Futures (1.5°C warming scenario) (Climateworks Centre, 2023b).	0.3
Climateworks Decarbonisation Futures (<2°C warming scenario) (Climateworks Centre, 2023b).	0.9

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