

Future Timber Hub

20 August 2020

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OF QUEENSLAND
AUSTRALIA

CREATE CHANGE

Cost Benefit Appraisal of four ARC Future Timber Hub research projects, Final Report



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Fortè residential apartment building in Melbourne constructed using engineered wood products (EWPs).

Contents

Glossary	vi
Executive summary	viii
What we've been asked to do	viii
The opportunity.....	viii
Market for engineered wood products	ix
Fire safety and the regulatory environment	x
Results of the economic evaluation	xi
1. Introduction	1
1.1 Future Timber Hub research	1
1.2 Terms of reference.....	1
1.3 Structure of this report.....	1
1.4 About the authors.....	2
2. Engineered wood products	4
2.1 Advantages of engineered wood products.....	4
2.2 Perceived disadvantages of EWPs.....	7
2.3 Future Timber Hub projects.....	8
3. The market for engineered wood products	11
3.1 The Australian forest and timber industry	11
3.2 The international market for EWPs.....	13
3.3 Domestic market and competitive analysis	15
4. Methodology	21
4.1 What we've been asked to do	21
4.2 What is a Cost Benefit Appraisal?	21
4.3 Types of impacts – General Overview	22
4.4 Approach to the study	23
4.5 Steps involved in undertaking the CBAs.....	26
4.6 General CBA parameters.....	27
5. CBA-1: Lowering the resources cost of engineered wood products (PR002 and PR015) 30	
5.1 General approach to CBA-1	30
5.2 Scenarios modelled	30
5.3 Incremental costs of PR002 and PR015.....	31
5.4 Incremental benefits assumptions	32
5.5 Incremental benefits estimates.....	34
5.6 Results of CBA-1	38
5.7 Sensitivity analysis.....	39
5.8 Conclusion.....	41
6. CBA-2: Providing greater industry confidence in exposed EWPs (PR014 and PR019) 42	
6.1 Introduction.....	42
6.2 Regulatory background	42
6.3 General approach to CBA-2	43
6.4 Scenarios modelled	45
6.5 Incremental costs of PR014 and PR019.....	45
6.6 Incremental benefits assumptions	46
6.7 Incremental benefits estimates.....	49
6.8 Results of CBA-2	52

6.9	Sensitivity analysis.....	53
6.10	Conclusion.....	54
7.	Combined CBA results and sensitivity analysis	55
7.1	Summary.....	55
7.2	Combined results, CBA-1 plus CBA-2	55
7.3	Combined sensitivity analysis, CBA-1 plus CBA-2.....	56
7.4	Conclusion.....	57
	References	58
B1	CBA-1	64
B2	CBA-2	68

Tables

Table 2-1.	Recently completed Mass Timber Buildings in Australia, as at 2018	7
Table 3-1.	Cost Comparisons CLT versus Concrete and Steel in Construction of Art Centre	17
Table 4-1.	Approach and data requirements, by FTH project.....	23
Table 4-2.	Measuring the incremental benefits and costs in CBA	25
Table 4-3.	<i>Steps involved in undertaking the CBAs</i>	26
Table 4-4.	Summary measures generally included in a CBA evaluation.....	27
Table 4-5.	Initial ARC and in-kind funding, and ongoing R&D, PR002 and PR015	31
Table 5-2.	Change in installed price of CLT-GLT composite, BAU v Central Policy Case (Year-1 v Year-20), CBA-1	36
Table 5-3.	CBA-1 growth in CLT-GLT production, CPC domestic manufacturing v imports (Year-1, Year-20).....	38
Table 5-4.	Results of CBA-1, PR002 and PR015.....	39
Table 5-5.	CBA-1 sensitivity analysis, variation in input parameters.....	40
Table 5-6.	CBA-1 Sensitivity analysis, (NPV, 7%)	40
Table 5-1.	Initial ARC and in-kind funding, and ongoing R&D, PR014 and PR019	46
Table 4-6.	Change in installed price of CLT-GLT composite, BAU v Central Policy Case (Year-1 v Year-20).....	52
Table 6-3.	Results of CBA-2, PR014 and PR019, CPC (NPV 5%, 7%, 9%).....	53
Table 6-4.	CBA-2 sensitivity analysis, variation in input parameters.....	53
Table 7-1.	Combined results of CBA-1 and CBA-2, (at NPV of 7%).....	56
Table 7-2.	Combined results of CBA-1 and CBA-2, (CPC at NPV of 5%, 7%, 9%).....	56
Table 7-4.	Combined results of CBA-1 and CBA-2, by policy scenario (at 7% discount rate).....	57

Figures

Table E.1	Combined results of CBA-1 and CBA-2 in CPC scenario, (20-year timeframe at NPV of 5% and 7%).....	xii
Box 2-1.	What is CLT and GLT?	4
Table 2-1.	Recently completed Mass Timber Buildings in Australia, as at 2018	7
Figure 2-1.	Perceived barriers to adoption of CLT, (number of respondents in parenthesis).....	8
Figure 3-1.	Australian log harvest, 2017-18.....	11
Figure 3-2.	Overview of the Australian wood products industry, 2018-19	12
Figure 3-3.	Global production of CLT, 1995 to 2015(f).....	14

Table 3-1. Cost Comparisons CLT versus Concrete and Steel in Construction of Art Centre	17
Figure 3-4. Cost per square foot comparison between MTC case studies and traditional site-built counterparts.....	19
Figure 4-1. Overview of the CBA evaluation framework.....	22
Table 4-1. Approach and data requirements, by FTH project.....	23
Table 4-2. Measuring the incremental benefits and costs in CBA	25
Figure 4-2. Measuring the incremental benefits and costs in CBA	25
Table 4-4. Summary measures generally included in a CBA evaluation.....	27
Table 4-5. Initial ARC and in-kind funding, and ongoing R&D, PR002 and PR015	31
Table 5-2. Change in installed price of CLT-GLT composite, BAU v Central Policy Case (Year-1 v Year-20), CBA-1	36
Figure 5-1 Market price of installed CLT-GLT composite (covered, m ³), BAU v Central Policy Case .	36
Figure 5-2. Total market demand (production plus imports) for CLT plus GLT, BAU v policy cases (Year-1 to Year-20).....	38
Table 5-3. CBA-1 growth in CLT-GLT production, CPC domestic manufacturing v imports (Year-1, Year-20).....	38
Table 5-4. Results of CBA-1, PR002 and PR015.....	39
Table 5-5. CBA-1 sensitivity analysis, variation in input parameters.....	40
Table 5-6. CBA-1 Sensitivity analysis, (NPV, 7%)	40
Box 5-1. NCC requirements for timber construction systems (2016 vis-à-vis 2019).....	44
Table 5-1. Initial ARC and in-kind funding, and ongoing R&D, PR014 and PR019	46
Figure 6-1. Australian market demand for domestically produced exposed CLT-GLT (m ³), Year-1 to Year-20.....	50
Table 4-6. Change in installed price of CLT-GLT composite, BAU v Central Policy Case (Year-1 v Year-20).....	52
Figure 6-2 Market price of installed CLT (covered, m ³), BAU v Policy Case	52
Table 6-3. Results of CBA-2, PR014 and PR019, CPC (NPV 5%, 7%, 9%).....	53
Table 6-4. CBA-2 sensitivity analysis, variation in input parameters.....	53
Table 7-1. Combined results of CBA-1 and CBA-2, (at NPV of 7%).....	56
Table 7-2. Combined results of CBA-1 and CBA-2, (CPC at NPV of 5%, 7%, 9%).....	56
Table 7-4. Combined results of CBA-1 and CBA-2, by policy scenario (at 7% discount rate).....	57
Table A-1 FTH seed funding for PR002 and PR015.....	61
Table A-2 FTH seed funding for PR014 and PR019.....	63
Table B.1 Summary of assumptions and evidence-base (CBA-1), page 1.....	64
Table B.2 Summary of assumptions and evidence-base (CBA-2), page 1.....	68
Table B.2 Summary of assumptions and evidence-base (CBA-2), page 2.....	69

Appendices

Appendix A	ARC FTH Project descriptions
Appendix B	CBA assumptions and evidence-base

Glossary

ABS	Australian Bureau of Statistics
AIBE	Australian Institute for Business and Economics (University of Queensland)
ARC	Australian Research Council
ATO	Australian Taxation Office
BAU	Business as Usual
BCR	Benefit Cost Ratio
BEL	Business Economics and Law (Faculty of, UQ)
CAGR	Compound Annual Growth Rate
CBA	Cost Benefit Appraisal (or Cost Benefit Analysis)
CFTS	Centre for Future Timber Structures (University of Queensland)
CLT	Cross Laminated Timber
COAG	Council of Australian Governments
CPC	Central Policy Case (of the CBA)
CPI	Consumer Price Index
CRRDC	Council of Rural Research and Development Corporations
DAF	Department of Agriculture and Fisheries (Queensland Government)
DLT	Dowel Laminated Timber
EIA	Economic Impact Assessment
EWP	Engineered Wood Product
FTH	Future Timber Hub (University of Queensland)
GDP	Gross Domestic Product
GLT	Glue Laminated Timber
GVA	Gross Value Added
ICLT	Interlocking Cross Laminated Timber
ITRH	Industrial Transformation Research Hubs (ARC grant program)
LVL	Laminated Veneer Lumber
GDP	Gross Domestic Product
GVA	Gross Value Added
IRR	Internal Rate of Return

LVL	Laminated Veneer Lumber
MTC	Mass Timber Construction
NBC	National Building Code (Canada, 2015)
NCC	National Construction Code
NFC	National Fire Code (Canada, 2015)
NLT	Nail Laminated Timber
OBPR	Office of Best Practice Regulation (Department of the Prime Minister and Cabinet)
PIR	Post Implementation Review
PPI	Producer Price Index
QFES	Queensland Fire and Emergency Services
RIA	Regulation Impact Assessment
RIS	Regulation Impact Statement
RRDC	Rural Research & Development Corporations
UQ	University of Queensland

Executive summary

What we've been asked to do

The ARC Future Timber Hub (FTH or the Hub), which is based at the School of Civil Engineering at the University of Queensland, has commissioned the Australian Institute for Business and Economics (AIBE), based within the Faculty of Business, Economics and Law at the University of Queensland, to undertake an analysis of the potential economic, environmental and social impacts of four current marquee ARC FTH research projects. AIBE has engaged Tulipwood Economics to assist with the preparation of the report.

The work of the Hub is funded by direct Australian Research Council (ARC) grants, as well as cash and in-kind support from The University of Queensland, partner universities, government agencies and industry partners. The core objective of the Hub is to transform the timber construction industry in Australia by developing the skills, knowledge and resources that can overcome current technological and social barriers currently limiting the utilisation of timber, particularly new engineered wood products (EWPs), to mid-rise and tall residential and commercial buildings.

The purpose of this report is to evaluate four discrete FTH research projects and, consequently, support the promotion of the Hub's mission. These economic impact assessments are important and represent a stocktake of work undertaken so far that can be used to demonstrate the Hub's benefits to industry, the ARC and government agencies that may support further research and the broader Australian community.

The opportunity

The concept of EWPs is simple, yet the economic benefits are potentially significant. Timber is strong along the direction of the grain but weak in the cross direction. Cross Laminated Timber (CLT), is an engineered wood product constructed by layering multiple strips of timber crosswise, with perpendicular layers making it strong in two directions. CLT is used to make prefabricated timber walls and floors. Similarly, Glue Laminated Timber (GLT or Glulam), which is constructed by layering multiple strips of timber in parallel, provides prefabricated posts and beams of equivalent or greater strength to steel and concrete or traditional timber.

EWPs allow for the creation of structural beams and posts and prefabricated walls and floors that are potentially much larger than the trees from which the timber is sawn. This technology is increasingly useful given that access to large-diameter, old-growth trees that could provide large sawn timbers is limited, and the modern production method is to harvest smaller trees on much shorter rotations.

The potential benefits of EWPs like CLT and GLT, relative to its competitors concrete and steel or traditional timber frame construction, relate to a combination of factors, including: comparable or greater strength, lighter weight providing greater manoeuvrability, modular design, lower installation cost, faster installation, aesthetic properties as well as environmental benefits such as reduced waste and a lower carbon footprint. In addition, EWPs have an advantage relating to strength and flexibility over concrete and steel buildings in earthquake prone regions such as Japan, New Zealand, Indonesia, and Pacific island countries.

Accordingly, for mid-rise commercial and residential buildings, EWPs have enormous potential to capture a significant portion of the construction market currently dominated by concrete and steel and traditional timber framing. This opportunity is particularly significant for 'exposed' EWPs, whereby the timber is not covered with fire-proofing plasterboard so that its aesthetic properties can be appreciated. The work of the Hub is, in part, focussed on developing EWPs with equivalent fire-resistance properties to plasterboard and concrete and steel designs.

A number of the most beautifully designed and aesthetically pleasing buildings constructed in this century have been built using exposed EWPs such as CLT and GLT. Prefabricated timber framed buildings such as the eight-story Wood Innovation and Design Centre in Prince George Canada and "The Tree", a fourteen-story residential apartment building in Bergen Norway, are highly celebrated as examples of all-timber construction utilising EWP technology.

In Australia, there are a number of notable mid-rise timber buildings that have been successfully completed, such as 25King Street in Brisbane (a commercial office building), the Forté mid-rise luxury apartment tower in the Docklands of Melbourne and the 'Library at the Dock', built on the waterfront of Victoria Harbour in 2014 and Australia's very first CLT public building. To date, it is estimated that hundreds of low-rise buildings (such as for education) and up to 100 mid-rise buildings have been constructed using EWPs since the turn of this century.

Large Australian construction companies are recognising the benefits of EWPs, particularly the combination of CLT and GLT. For instance, Lendlease Australia, which has been a long-standing supporter of EWPs, has committed to building 30 to 50 percent of its projects with EWPs. In 2012, Lendlease completed Australia's first CLT building being the ten storey Forte apartments in Melbourne, the tallest modern timber residential building in the world at the time at 32 metres high.

The EWP technology, originally developed in Austria in the mid-1990s, is still new and research continues to optimise the use of EWPs such as CLT, GLT, Laminated Veneer Lumber (LVL) and Nail Laminated Timber (NLT) and other variations of the technology. In Australia, there is potential for EWP manufacturers to lower costs through further industry R&D investment and close collaboration with the university sector.

Market for engineered wood products

Before the coronavirus pandemic impacted the global economy in 2020, the global EWP market had been growing strongly, particularly in Europe and North America.¹ Market estimates had forecast the size of the global CLT market to be USD\$2 billion by 2025, growing at 15 percent per year. The global GLT market is estimated to be even larger, with some forecasts at around USD\$8 billion by 2025.² Today, there are hundreds of examples of the use of EWPs for multi-story residential and commercial buildings across the world including in Australia. Sustainability and aesthetic factors have been key drivers of this trend in Europe, along with potential cost and time savings and construction flexibility.

While there is evidence from North America and Europe that EWPs can be a cheaper material to manufacture and install than alternatives, it appears that is difficult to realise comparable savings in the Australian construction sector at the present moment because EWP design and construction is currently largely bespoke with little commoditised 'at scale' mass production and a lack of widespread industry knowledge and experience in efficient installation.

That said, the opportunity is clear. Australia is a timber resources superpower. Our domestically-produced timber and wood products are utilised in residential and commercial buildings in Australia and exported overseas. A strongly growing domestic EWP manufacturing sector has the potential to further enhance Australia's forestry and timber manufacturing industries. In this regard, in 2018 XLam began manufacturing CLT panels at its Wodonga site in Victoria. In 2019, Hyne Timber opened its GLT Plant, which is located in Maryborough, Queensland. And in February 2020, Timberlink Australia announced that it would invest in a state-of-the-art CLT-GLT facility in the Green Triangle (South Australia and Victoria) confirming the growing market for EWPs in Australia.^{3,4}

Estimates of the current size of the market for EWPs in Australia vary. In fact, these types of products are so new that leading business statistics publishers such as IBISWorld and Rawlinsons do not yet produce a specific time series database for these products. Industry feedback in Australia and an analysis of overseas production suggests that the total market demand for CLT in Australia is currently 50,000 m³ per year, of which 30,000 m³ is imported and 20,000 m³ is domestically produced (in 2020). At a manufactured wholesale price of around \$1,250 per cubic metre, the CLT industry in Australia is estimated to be around \$25 million in terms of local manufacturing revenues. The total

¹ Naturally, COVID-19 has impacted negatively on all industry and economic forecasts in 2020. That said, the long-term prospects for EWPs are not directly impacted by COVID-19.

² <https://www.grandviewresearch.com/press-release/global-glue-laminated-timber-market>

³ <https://industryedge.com.au/new-cross-laminated-timber-facility-in-australia/>

⁴ The Green Triangle is one of Australia's major forestry regions spanning the border of Victoria and South Australia. See here: https://www.agriculture.gov.au/sites/default/files/sitecollectiondocuments/forestry/green_triangle_investment_ver8.pdf

Australian CLT market, when accounting for imports, as well as delivery and installation costs is estimated to be around \$100 million.

The GLT market in Australia is smaller relative to CLT. Local industry feedback and an analysis of overseas production indicates that the total market demand for GLT in Australia is currently 25,000 m³ per year, of which 20,000 m³ is domestically produced and 5,000 m³ imported (in 2020). At a manufactured wholesale price of between \$2,500 per cubic metre, the size of the GLT industry in Australia is estimated to be around \$50 million in terms of local manufacturing revenues. The total Australian CLT market, when accounting for imports, as well as delivery and installation costs is estimated to be around \$200 million.

In Australia, there are a number of factors influencing Australia's slower take-up of EWPs including: (i) a lack of an at-scale domestic manufacturing capability, (ii) reservations within the industry about the benefits of CLT-GLT as a building material and its cost, (iii) relatedly, perceptions of build complexity and, hence, increased risk from builders and installers, (iv) regulatory constraints have prevented the widespread adoption of CLT-GLT as a building material, although recent changes to the National Construction Code have relaxed these constraints, and (v) fire safety (see immediately below).

Fire safety and the regulatory environment

Perhaps in the public consciousness fire is the primary concern with the use of timber in tall residential and commercial buildings. The 2017 Grenfell fire in London that killed 72 people remains fresh in people's memory, although this tragedy had nothing to do with the use of timber, but rather the illegal external cladding that acted to accelerate and spread the fire throughout the building, combined with a 'stay in place' fire plan.

In fact, there is growing evidence that mass engineered timber panels can be just as safe as concrete and steel constructions, if not safer. While there is no avoiding the simple fact that timber burns, it is important to understand the characteristics of timber. EWPs have the capacity to self-extinguish before losing structural integrity, unlike steel which can melt and collapse at high temperatures. The Hub and other academic institutions globally are undertaking important work in this area to understand the strength and safety limits of EWPs.

While timber is combustible, it also chars at a rate which can provide the necessary two-hour fire protection required for evacuation under most building codes. This is because when timber is exposed to the heat of a fire, it goes through a thermal breakdown process and a layer of charcoal forms on its surface. This charred layer is the key to timber's fire resistance, acting as an insulator that protects the inner core. In addition, the safety of mid-rise commercial office buildings made with EWPs can be improved by, and will often necessarily require, additional sprinklers and, in some circumstances, escape routes, to meet fire safety regulations.

In Australia, the use of EWPs in tall residential buildings was effectively prohibited prior to 2016 under the National Construction Code (NCC), which was first adopted by the Australian States and Territories as a national code in 2011, and previous legislation introduced in the 20th century to reduce the incidence of fires in residential and commercial buildings. In 2016, changes to the NCC (via COAG agreement) were made which allowed their use as an exposed material for the first time.

A key provision of the 2016 changes was that fire-protected timber building systems must be encapsulated in a non-combustible fire-protective covering of at least two layers of fire-protective grade plasterboard. Under the pre-2016 Code, timber building systems had been restricted to three storeys under the NCC's deemed-to-satisfy provisions, with taller buildings requiring an 'alternative solution' to be designed and documented to gain approval. While practical on larger projects, alternative solutions were generally considered too costly for smaller jobs. The 2016 changes created a voluntary prescriptive performance (previously known as a 'deemed-to-satisfy' solution) for the use of timber building systems in Class 2 (apartments), Class 3 (hotels) and Class 5 (office) buildings up to 25 metres in effective height. Covering both traditional timber framing and innovative massive timber systems such as CLT and GLT, the 2016 provisions required the use of appropriate layers of fire-resistant materials (like plasterboard) and sprinkler systems.

In 2019, further changes were made to the NCC to move away from prescriptive measures and towards a performance-based code. This change has increased the range of buildings, up to an effective height of 25 metres, typically eight stories, in which fire-protected timber construction

systems can be used. The new classifications potentially add schools, retail premises, hospitals and aged care facilities to the previously approved multi-residential, hospitality accommodation and office buildings.

State bodies responsible for fire safety, such as QFES in Queensland, seem ready to assess these new EWP buildings on their merits in terms of safety. For example, in the case of 25King Street in Brisbane, at the project inception there were approximately thirteen variations from prescriptive building compliance clauses being proposed. However, as the building was predominantly timber, laminated and considered significantly different from the prescriptive code basis, the fire safety design needed to be demonstrated against fire performance targets, rather than assessed against a standard code-approved building process. This has been an important change to the regulations, because it allows building designers to demonstrate that an EWP building meets a safety standard rather than meet a list of prescriptive requirements.

Results of the economic evaluation

The economic evaluation of the four ARC FTH research projects has applied cost benefit analysis, which is a widely recognised and accepted approach for assessing the economic merits of a proposal or initiative. Of the four projects, two pairs of projects are quite similar in scope and potential economic impact. Accordingly, two CBAs were undertaken, being CBA-1 (relating to FTH projects PR002 and PR015) and CBA-2 (relating to FTH projects PR014 and PR019). The two sets of analyses are additive. The analysis focuses on the commercial potential of the two major EWPs, being CLT and GLT.⁵

To summarise here:

- CBA-1 is related to lowering the cost of producing and installing covered EWPs whereby plasterboard is still used as a protective covering material in residential and commercial building construction; and
- CBA-2 is related to expanding the use of *exposed* EWPs where plasterboard is not used as a covering material and the timber can be appreciated for its aesthetic properties.

In the CBA-1 analysis, it is assumed that domestic EWP production gains market share at the expense of imports such that the overall growth in market demand over the 20-year period is at the same level under the business as usual (BAU) and Central Policy Case scenario in Year-20. In a high-growth scenario, EWPs also begin to 'crowd-out' concrete and steel construction, thus gaining a higher overall building material market share by Year-20.

In the CBA-2 analysis, the 'exposed EWP market' gains market share at the expense of both the 'covered EWP market' and substitutes such as concrete and steel and traditional timber framing in the Central Policy Case and high-growth scenarios.

The combined results of the two CBAs are presented in Table E.1 below. The results are additive and presented in real net present value terms (in \$2020) at the widely accepted social discount rate of 7%.⁶ The analysis has been undertaken over a 20-year timeframe, to allow for the full effects of the academic research, industry research and development, and commercial response to pass through the industry.

In the Central Case Scenario (CPC), the **net benefits** of undertaking the four ARC FTH research projects is estimated to be **\$152.0 million** (at the standard social discount rate of 7%). This figure represents the difference between the present value of total benefits (of \$189.2 million) and the

⁵ Full descriptions of the ARC FTH research projects are at Chapter 2 and Appendix A.

⁶ All figures reported are in real \$2020 dollars. A detailed discussion about the appropriate choice of a social discount rate is provided in Chapter 3. Because of the inherent uncertainty around academic research successfully translated into future commercial and broader economic benefits and the general economic uncertainty and risk created by COVID-19, a 7% discount rate has been applied in the central case (rather than a 5% discount rate).

present value of total costs (of \$37.3 million). The benefit-cost ratio (BCR), which divides benefits by costs, is calculated to be **5.1 times**. The internal rate of return (IRR) is calculated to be **25%**.

In all three scenarios (LPC, CPC, HPC), net benefits remain positive at the 5%, 7% and 9% social discount rates.⁷ Taken together, the analysis and estimates of the net benefits of the four ARC FTH projects are robust to changes in the value of input parameters. Based on these estimates, in our opinion the four ARC FTH projects represent a good use of taxpayer and private resources from society's point of view (Table E.1).⁸

Table E.1 Combined results of CBA-1 and CBA-2 in CPC scenario, (20-year timeframe at NPV of 5% and 7%)

Central Policy Case scenario	CBA-1		CBA-2		Total CBA-1,2	
Parameter (\$m, NPV)	NPV, 5%	NPV, 7%	NPV, 5%	NPV, 7%	NPV, 5%	NPV, 7%
Net benefits (NPV)	\$171.1	\$119.9	\$43.3	\$32.1	\$214.5	\$152.0
Present value of total benefits	\$204.0	\$148.9	\$52.1	\$40.3	\$256.1	\$189.2
Present value of total costs	\$32.8	\$29.0	\$8.7	\$8.3	\$41.6	\$37.3
BCR	6.2	5.1	6.0	4.9	6.2	5.1
IRR	24%	24%	26%	26%	25%	25%

Source: Tulipwood Economics estimates based on the Central Policy Case scenario relative to BAU.

⁷ See Chapters 4, 5, and 6 for a detailed sensitivity analysis. LPC – Low Policy Scenario; CPC – Central Policy Scenario; HPC – High Policy Scenario.

⁸ From a social welfare point of view, any BCR > 1, provides net benefits to society compared to the counter-factual scenario.

Part 1 Background

1. Introduction

1.1 Future Timber Hub research

The Future Timber Hub (the Hub), which is based at the School of Civil Engineering at University of Queensland (UQ) in Brisbane, is Australia's leading timber industry research hub dedicated to cutting-edge contemporary research and innovation. The Hub is also one of the leading timber research centres in the world and sits within the Centre for Future Timber Structures (CFTS) at the University of Queensland.⁹

The work of the Hub is funded from direct Australian Research Council (ARC) grants, as well as cash and in-kind support from The University of Queensland, partner universities, government agencies and industry partners. The Hub was established as an Industrial Transformation Research Hub (ITRH) that has broad industry, academic and government support, including from the Centre for Future Timber Structures (UQ), the Queensland Department of Agriculture and Fisheries (DAF), Queensland Fire and Emergency Services (QFES), Griffith University, the University of British Columbia and the University of Canterbury, Scion Research, as well as leading design, manufacturing and construction firms such as Arup, Hyne Timber and Lendlease.

1.2 Terms of reference

The Hub has commissioned the Australian Institute for Business and Economics (AIBE), based within the Faculty of Business, Economics and Law at the University of Queensland, to undertake an analysis of the potential economic, environmental and social impacts of four current marquee FTH research projects. AIBE has engaged Tulipwood Economics, a leading Australian economics consulting firm, to assist with the preparation of the report.¹⁰

The purpose of this report is to evaluate the investments in timber research relating to FTH projects PR002, PR014, PR015 and PR019 and, consequently, support the promotion of the Hub's work in stakeholder discussions and further funding applications. These economic impact assessments are important and represent a stocktake of work undertaken so far that can be used to demonstrate the Hub's benefits to industry as well as the ARC and government agencies that may support further research.

The terms of reference for this engagement require an economic impact assessment (EIA), in the form of a cost benefit analysis (CBA), to be undertaken of four selected CFTS/FTH investments, using the methodology outlined in the Council of Rural Research and Development Corporations (CRRDC) Impact Assessment Guidelines.¹¹

1.3 Structure of this report

This report is structured as follows:

- An Executive Summary sets out the main findings of the economic assessment.
- Part 1 of the report sets out the background to the study, including:

⁹ In 2015, the CFTS was formed as a collaboration between UQ and DAF. Later, Hyne Timber, Lendlease and Arup joined the Centre. This industry involvement assisted in the Centre applying for further funding through an ARC Industrial Transformation Research Hub Grant. An ARC grant of \$1.6mil was awarded at the end of 2016, however the Hub was not officially launched until November 2017. The Future Timber Hub technically falls within the purview of the CFTS as funds for the CFTS were directed to the Hub.

¹⁰ Further information about Tulipwood Economics can be found here: www.tulipwoodeconomics.com.au

¹¹ The current CRRDC impact assessment guidelines can be found at: https://www.ruralrdc.com.au/wp-content/uploads/2018/08/201804_RDC-IA-Guidelines-V.2.pdf

- An introduction setting out the background to the study, Terms of Reference and author credentials (Chapter 1).
- A description of engineered wood products (EWPs) (Chapter 2).
- An overview of the global and Australian market for timber and, in particular, engineered wood products in Australia (Chapter 3).
- Part 2 of the report sets out the methodology, assumptions, analysis and the results of the CBA, including:
 - Methodology and key assumptions of the economic evaluation (Chapter 4).
 - Results for the first CBA, which combines PR002 and PR015 (Chapter 5).
 - Results for the second CBA, which combines PR014 and PR019 (Chapter 6).
 - The aggregated results of the two CBAs and the results of the sensitivity analysis (Chapter 7).
- Part 3 of the report contains a number of appendixes providing additional and supporting information to the study, including:
 - A full description of each of the four research projects being evaluated including their cost (Appendix A).
 - A list of assumptions and the supporting evidence-base, by CBA (Appendix B).

1.4 About the authors

Professor John Mangan has over 40-years' experience as an academic, government bureaucrat and consultant economist. John is the Director of the Australian Institute for Business and Economics and a Professor of Economics within the UQ Business School.

John has expertise in undertaking complex CBA's and related economic evaluation techniques (such as regional IO modelling). John is an internationally respected economist who will oversee the project and provide methodological guidance and quality assurance.

John has instigated and completed numerous research projects, drawing on his experience of working with such iconic Australian brands and multinationals as BHPB, Rio Tinto, Energex, and the National Rugby League. He was the Business, Economics & Law Faculty's Associate Dean (Research) from 2008-2012.

John's extensive academic, consultancy, editorial and 'expert opinion' experience sees his economic modelling acumen regularly called upon for impact analyses and applied micro-economics relating to professional sports, wages and employment, and workplace health and safety.

Joe Branigan is a leading public policy economist in Australia with 25 years' experience working in government, academia and private sector consulting. Joe provides independent economic consulting services through his firm Tulipwood Advisory Pty Ltd. Joe is a well-known media commentator and author. For many years, Joe managed Professor Henry Ergas' consulting firm Green Square Associates, which provided economic policy analysis and advice (including complex economic evaluation) to central government agencies (such as the Department of Prime Minister & Cabinet and Commonwealth Treasury), corporations (such as BHPB and Google) and industry bodies (such as the Minerals Council of Australia and the Pharmacy Guild). Joe was (concurrently) a Senior Research Fellow at the SMART Infrastructure Facility UOW for 7 years and has been recently appointed an Industry Fellow with the University of Queensland.

Joe has been involved in numerous high-profile economic impact analyses and CBA's, including for agriculture, major network industry investments in telecommunications, water infrastructure, rail infrastructure and roads. Joe has also critiqued draft CBA guidelines for the Commonwealth, and the

NSW and Victorian Governments. In 2019, Joe completed two CBA's for the Queensland Alliance for Agriculture and Food Innovation (QAAFI UQ) in collaboration with AIBE UQ.

Joe is a former senior economic advisor to the American Ambassador to Australia. He has been a regulator at the Queensland Competition Authority (QCA) and Queensland Water Commission (QWC). Joe spent many years in Canberra working at the Productivity Commission and then Federal Treasury. Early in his career Joe was seconded to the Queensland Department of Agriculture and Fisheries (Forestry Division) from Queensland Treasury to manage issues related to the introduction of the National Competition Policy.

2. Engineered wood products

Engineered wood products (EWPs), also known as manufactured wood products or mass timber construction (MTC), are able to span larger distances than traditional sawn timber beams, act as sheets for walls or floors, have very consistent properties and performance and can be tailored for specific applications.¹²

2.1 Advantages of engineered wood products

The benefits of engineered wood products (EWPs) like Cross Laminated Timber (CLT) and Glue Laminated Timber (GLT) relative to its competitors – concrete and steel, or traditional timber frame construction – are numerous. EWPs tend to have one or more desirable characteristics, such as:

- comparable or greater strength;
- lighter weight providing greater manoeuvrability;
- the potential of using these materials in a prefabricated modular design;
- lower installation cost and faster installation;
- aesthetic properties; as well as
- environmental benefits such as reduced waste and a lower carbon footprint.

For commercial and residential buildings up to a height of about 35 metres, EWPs have enormous potential to substitute for the current dominance of concrete and steel construction. In addition, EWPs can be used more broadly in combination with concrete and steel construction in virtually any commercial or residential designs (

Box 2-1). Since its introduction in the 1990s, CLT has been the subject intensive research, which has enabled the development of product standards and design guidelines (Harte, 2016).

Box 2-1. What is CLT and GLT?

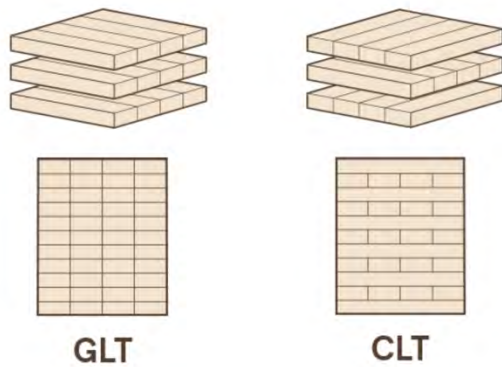
Timber is strong along the direction of the grain but weak in the cross direction. Cross Laminated Timber (CLT) is an engineered wood product (EWP) constructed by layering multiple strips of timber crosswise, with the perpendicular layers making it strong in two directions.

The cross-laminated configuration improves rigidity and stability, producing light but very strong panel products that are optimised for bearing loads. Structurally, CLT offers performance comparable to concrete or steel, with panels suitable for use as walls, floors, roofs and other applications. CLT panels are highly versatile and can be made off-site and erected quickly to form structural walls, ceilings and floors. CLT has many applications including in residential dwellings, multi-story residential and commercial buildings, public buildings and other types of speciality construction.

Glue Laminated Timber (GLT or Glulam) is an EWP similar to CLT except that the laying of multiple strips of timber are parallel not perpendicular (see graphic below). GLT is possibly the oldest EWP and has been used for more than a century in construction. GLT was first used in 1893 to construct an auditorium in Basel, Switzerland. Patented as the "Hetzer System," it used adhesives that by today's standards are not waterproof. As a consequence, its applications were limited to dry-use conditions (USDA, 1997).

Because GLT has a series of timber laminates bonded together along the grain, it allows for significantly stronger and longer pieces than would be otherwise possible. Additionally, the end product exhibits a very high strength-to-weight ratio.

¹² <https://www.woodsolutions.com.au/education/engineered-wood-products>



CLT walls and floors can be easier and cheaper to install.



GLT posts can be easier and cheaper to install.



The advantages of CLT and GLT are almost identical in terms of the strength to weight ratio, prefabrication, fire and seismic performance, as an insulator, its natural beauty, durability and carbon savings. GLT is often compared to steel, whereas CLT is often compared to concrete. In addition to the sustainability benefits, one of the primary benefits of CLT panels is the use of offsite prefabrication allowing for high-quality certified production, independent of the weather. As holes and notches in panels can be pre-cut prior to arrival to site and assembling methods are straightforward, construction and project delivery times are improved and costs reduced (Harte, 2016).

Source: <https://www.thinkwood.com/products-and-systems/mass-timber/cross-laminated-timber-clt-handbook>
<https://www.fpl.fs.fed.us/documnts/pdf1997/moody97a.pdf>

This study focuses on the two primary EWPs, being CLT and GLT. The long, clear spans afforded by GLT allow for more open floor plans unconstrained by columns. Because of their natural beauty, glued-laminated timbers are most often left exposed as a decorative element in residences, churches, shopping centers, and other public-use structures. By bending the timber during the manufacturing process, a variety of architectural effects, including arches and compound curves, can be created that are difficult or even impossible to achieve with unengineered timber.

Particular advantages include:

- the faster speed of construction using prefabricated CLT/GLT panels and beams;
- fewer highly skilled tradespeople on site (e.g. 1-2 crane operators and 2-4 workers to manipulate the panels in place);
- greater strength to weight ratios;
- better insulation;
- potentially better fire-resistance; and
- carbon storage.

Large Australian construction companies are recognising the benefits of EWPs. For instance, in recent years Lendlease Australia has committed to building 30 to 50 percent of its future projects with CLT. Lendlease has identified the benefits of CLT construction vis-à-vis substitutes as:

- improved safety standards particularly the elimination of manual handling and high-risk trades;
- reduced embodied CO2 emissions;
- reduced on-site worker needs, truck movements and OH&S issues;
- higher precision, design flexibility and customisation;
- reduced impact of construction on neighbouring communities; and
- significantly shortened construction times meaning a more cost-effective overall build.

In the 21st century, under the right conditions, many experts believe that EWPs such as CLT and GLT have the potential to be as important an innovation as concrete was in the 20th century. There is enormous potential for these aesthetically pleasing, strong, lightweight and low-cost products. This potential has been clearly articulated by recently by Alex de Rijke, a world renowned architect:

*Timber is the new concrete. The vast potential and versatility of engineered timber holds the key to construction for the 21st century, just as the 18th century was about brick, the 19th steel, and the 20th was concrete.” Alex de Rijke of London-based architecture firm de Rijke Marsh Morgan Architects.*¹³

Table 2-1 below reports the number of recently completed EWP or MTC buildings in Australia.¹⁴ The table identifies a total of 9 MTC buildings completed in Australia from 2011 to 2018. The list does not include recent building completions such as 25King Street in Brisbane. The height of the buildings range from the single storey Netball Central in Sydney, which boasts a 40 metre clear span to the Fortè Building in Melbourne and Aveo Norwest in Sydney (both 10 storeys). Of the nine buildings, five

¹³ Interview in the magazine Architecture and Design, 23 November 2015. Accessed: <https://www.architectureanddesign.com.au/features/comment/clt-will-be-considered-conventional-in-australia-b>

¹⁴ The table is taken from Envison et al (2018) and augmented.

are public buildings and four are private. Although, adding 25King Street makes for an even number of public and private buildings in the past decade.

Table 2-1. Recently completed Mass Timber Buildings in Australia, as at 2018

Building name	Completed	Location	Storys	Public building?	Timber features
The Good Shed	2011	Southbank, Melbourne	2	Y	LVL box truss system and I-joists
Forte	2012	Docklands, Melbourne	10	N	Full CLT design, honeycomb construction
The Green	2013	Parkville, Melbourne	6	N	TecBeam, LVL Cassette flooring system with light timber framing
Library at the Dock	2013	Docklands, Melbourne	2	Y	CLT and Glulam
Netball Central	2014	Sydney	1	Y	40 m clear span LVL portal
International House	2017	Barangaroo, Sydney	6	Y	CLT, Glulam and glass curtain wall system
Monash University Business School	2017	Caulfield, Melbourne	4	N	CLT vertical extension on top of an existing concrete structure.
Aveo Norwest	2018	Hills Shire, Sydney	10	Y	CLT structure comprising a multifunction center, library, restaurant and cafe, wellness center, and 449 independent living units over 10 buildings of varying heights (4-9 storys) and a 144 bed residential aged care facility
The Gardens, McAuthor	2018	Campbelltown, Sydney	6, 7, and 8	N	Full CLT design, honeycomb construction

CLT, cross-laminated timber; LVL, laminated veneer lumber.

Source: Envison et al (2018).

2.2 Perceived disadvantages of EWP

Despite the many demonstrated advantages of EWPs, there remains a generalised perception within the Australian construction industry that EWPs are:

- new and unknown;
- pose an increased professional risk for engineers and architects associated with specifying innovative materials or methods of construction;
- lack reliable production/import scale and supply-chains; and
- not compatible with the local building codes.

It is true that developing new markets requires surmounting many hurdles, such as developing local engineering expertise, designing or purchasing new capital equipment, building local supply chains, developing new sales and marketing programs and overcoming regulatory barriers.

There is some evidence that, perhaps, some of the larger tier one construction firms in the Australian market have adopted a 'wait and see' approach, waiting for some trigger to tip the balance in EWPs favour, perhaps the actions of a competitor, or a change in the way carbon is priced, or increased awareness of the market towards EWPs use and its advantages (Kremer, 2015).

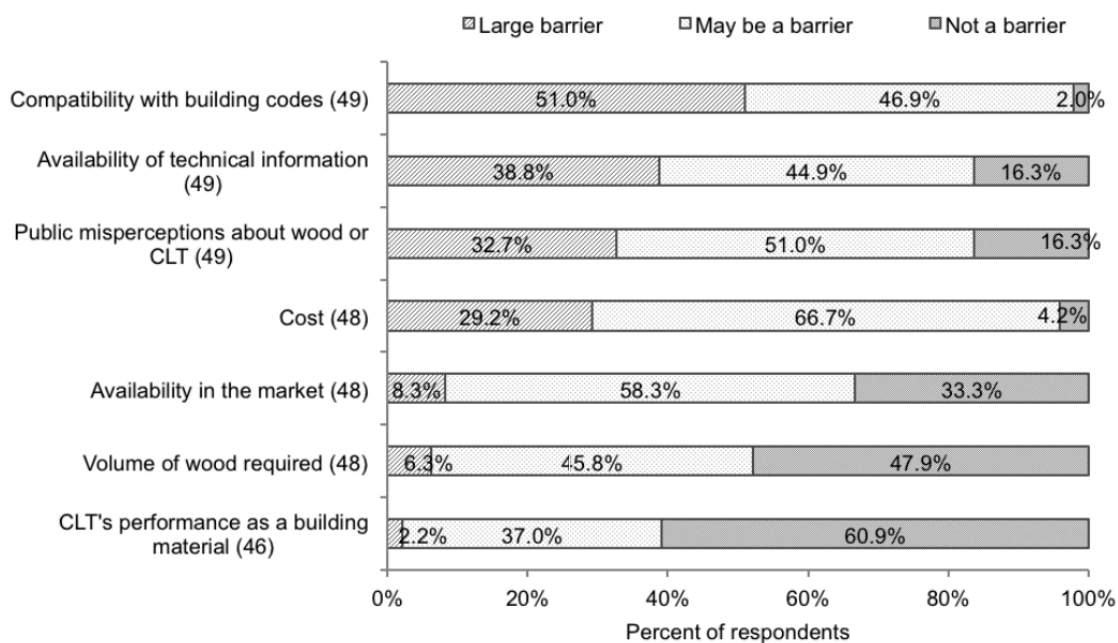
In a 2015 CLT study, European engineers were surveyed to learn about their current level of awareness of CLT, the major barriers to CLT adoption, and about the most pressing research needs to advance the use of CLT as a construction material. The results of the survey indicated that awareness of CLT was generally low across all professions surveyed (such as construction managers, architects, civil engineers). The major concerns were related to building code compatibility and the availability of technical information. The most pressing research needs for CLT development, according to respondents, are in the areas of structural performance and connections, moisture performance, and market research (Espinosa, 2015).

In particular, one question in the survey asked respondents to rate a list of potential barriers to the adoption of CLT in Europe. The results of shown in Figure 2-1 below. The largest barrier to CLT adoption was 'compatibility with building codes', where 98% of respondents believed that this was a large barrier or may be a barrier. 'Availability of technical information' (38.8%), 'Public misperceptions about wood or CLT (32.7%) and 'Cost' (29.2%) were also considered by a significant proportion of respondents as a large barrier to adoption.

What is interesting about the survey is that 61% of respondents did not consider 'CLT's performance as a building material' to be a barrier to CLT adoption. Indeed, only 2.2% of respondents indicated a concern in this regard.

A majority of respondents in the European survey considered raw material (52.1%) and product availability (66.6%) to be a large barrier or a potential barrier to adoption. These results were lower than a similar survey conducted in the United States (Laguarda-Mallo and Espinosa 2015, 2014) where 94% of U.S. architects considered the availability of CLT a large or potential barrier. This more pronounced concern for the availability of CLT in the U.S. is not surprising, as CLT is not yet readily available in the U.S. (Espinosa, 2016).

Figure 2-1. Perceived barriers to adoption of CLT, (number of respondents in parenthesis)



Source: Espinosa (2016, p.289).

2.3 Future Timber Hub projects

Set out below is a summary description of the four Future Timber Hub projects. Detailed descriptions of the four research projects, including their funding and timeframes, are provided at Appendix A. All of these research projects have commenced and remain ongoing, although are nearer to the end of their funding life than the beginning.

2.3.1 The optimisation of wood-based mass-panels for Australian building systems

This project (identified by FTH as PR002) has focussed on developing high performance panel construction designs suitable for local manufacture through comprehensive modelling, prototyping, semi-industrial and full-scale manufacturing. This project relates to both CLT and GLT.

This project aims to deliver technical tools, training and demonstration that will support Australian industry to supply the Australian residential and commercial building and construction sector with a versatile array of high-performance products from which to design and construct innovative timber

buildings. The research project includes a review of the latest developments in mass-panel products/systems and design, in order to identify priority products/systems that have immediate suitability for the Australian forest product and construction industries. Specific project outcomes include:

- provide the Australian building sector with high performance product solutions that can be sourced locally and which have been manufactured from sustainable low-embodied energy materials; and
- provide the design criteria and protocols for the manufacture of mass-panel products that will support and guide the Australian forest products industry towards being world-leading suppliers of high-performance panel systems;
- provide industry with the support tools for the design and manufacture of engineered wood products; and
- provide the Australian construction and forest product industries with confidence that locally produced wood-based building systems provide a viable and potentially superior alternative to imported products.¹⁵

2.3.2 Exploring the self-extinguishment mechanism of engineered timber in full-scale compartment fires

This project (PR014) investigates the self-extinguishment mechanism of engineered timber (such as CLT) at a full-scale in order to establish appropriate design criteria for the safe use of CLT and similar products in tall-timber buildings. The aim of the research project is to provide a methodology to establish criteria for self-extinguishment of EWPs at a full-scale, considering complexities such as delamination failure, encapsulation failure, and rate of exposure of timber surfaces.¹⁶ The focus of this project is on CLT.

Specific project objectives include:

- evaluate fundamental self-extinguishment criteria (critical external heat flux and pyrolysis rate) in various scales;
- determine conditions and time-scale of delamination that prevent self-extinguishment at full-scale;
- determine conditions and time-scale of encapsulation that prevent self-extinguishment at a full-scale;
- determine whether fully expose timber compartment may achieve self-extinguishment if delamination is controlled; and
- establish design guidelines for the fire-safe use of CLT, which enable self-extinguishment after burn out of the floor fuel load, including:
 - criteria for controlling delamination (fall-off) of charred lamellae;
 - criteria for controlling encapsulation failure; and
 - criteria for assessing the maximum number of exposed timber surfaces to be used.

¹⁵ For more information about the four FTH projects, see here: <https://futuretimberhub.org/projects/optimisation-wood-based-mass-panels-australian-building-systems>

¹⁶ See here: <https://futuretimberhub.org/projects/exploring-self-extinguishment-mechanism-engineered-timber-full-scale-compartment-fires>

2.3.3 Alternative uses for under-valued sawmill products in innovative timber structures

This project (PR015) investigates the design of innovative and alternative structure timber systems and technologies that adapt 'low value' timber products such as sawmill offcuts, centre of log, low structural grade, high structural grade but dimensionally undervalued, and end-of-log (butts less than 1.8m in length). The focus of this research is on both CLT and GLT.

A key research focus will be the consideration of timber members used at non-standard scales in comparison to conventional stud framing and roof truss construction. This approach seeks to innovate by combining non-standard sizes together in a novel way in order to achieve required overall physical and mechanical properties.

The final research objective will be to investigate the assembly of small member sizes that employ novel configurations to achieve large spans and stiffness through inherently stable geometric configurations.¹⁷

The current Australian softwood timber framing market is dominated by a narrow range of highly commoditised structural frame sizes. This approach is understandable to achieve economies of scale and high levels of productivity. However, resource losses in terms of unused timber (up to 55% of the log) is the consequence as only a certain volume of timber milled from each log can yield the required sizes of the commoditised products.

The outcomes of the project will include the identification of a shortlist of prototypical structural systems to be tested and developed further in ongoing research programs, including systems related to: (i) matrix (or bespoke) assemblies, and (ii) mass consolidations (i.e. mass panels).

2.3.4 Progressive collapse (robustness) resistance of tall frame timber buildings with CLT floors

This project (PR019) seeks to advance industry knowledge about the performance of available mass timber products such as CLT and Laminated Veneer Lumber (LVL) used in mid-rise to tall timber buildings. With increased building height and weight, the lateral performance of the buildings becomes more critical, and robust lateral load design must be achieved for safety and serviceability. The focus of this project is on CLT, GLT and LVL.

As design engineers work on larger force demand due to increased height and mass, they will face new challenges and problems that may fall out of current timber design codes. This project seeks to evaluate the performance of timber core-walls and provide technical information to guide core-wall design in tall timber buildings, with and without the incorporation of low-damage seismic design technology.¹⁸

The specific objectives of the project are to:

- investigate the progressive collapse mechanisms of tall frame mass timber buildings through experimental tests performed on scale substructures and edge column removal;
- to develop advanced numerical tools calibrated against the available experimental tests and use them to quantify the factors influencing the progressive collapse mechanisms of tall frame mass timber buildings through parametric studies;
- to develop and test new connectors to enhance the progressive collapse resistance of tall frame mass timber buildings; and

¹⁷ For more information, see here: <https://futuretimberhub.org/projects/alternative-uses-under-valued-sawmill-products-innovative-timber-structures>

¹⁸ For more information, see here: <https://futuretimberhub.org/projects/behaviour-critical-connections-and-core-wall-systems-tall-timber-buildings>

- to verify the accuracy of the current design and detailing guidelines to resist progressive collapse in current design specifications.

3. The market for engineered wood products

This chapter provides a brief overview of the Australian forestry and timber industry and then presents an analysis of the international and domestic EWP market. The research presented in this chapter supports the cost benefit analysis presented in subsequent chapters.

3.1 The Australian forest and timber industry

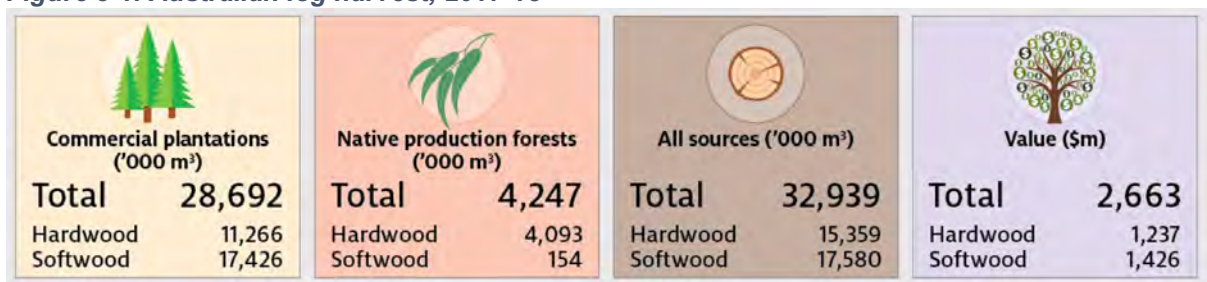
3.1.1 Forestry production

Australia’s timber industry harvests logs from native forests, hardwood plantations and softwood plantations as well as sourcing imported sawn wood, wood-based panels (including EWPs), paper and cardboard. Australia’s native forest estate, at 132 million hectares, is the sixth largest in the world, reflecting Australia’s position as the world’s sixth largest country by land area. Roughly 28 million hectares of native forest are suitable for commercial harvesting, although only a fraction of this area is harvested at any given time. The area of commercial timber plantations in Australia, at 1.9 million hectares in 2017-18, is much smaller than that of native forests. However, these plantations are managed more intensively than native forests and produce a much higher volume of wood per hectare per year (ABARES, 2019).

Based on the ABS National Accounts, total *Forestry and Fishing* industry gross value added (GVA) in 2018-19 was \$6.6 billion.¹⁹ In 2017-18, 32.9 million m³ of logs were harvested in Australia, generating \$2.7 billion in industry value-added and \$4.9 billion in sales and service income across the forestry and logging industries (ABARES 2020, see Figure 3-1 below). In the same year, downstream wood product manufacturing industries generated \$23.9 billion in sales and, according to the latest housing and population census, these industries supported over 52,000 jobs in 2016 (ABARES, 2019).

Accounting for the flow-on impacts of forestry, the forest and wood product manufacturing industries are estimated to have added \$9.2 billion (or 0.5% of GDP) to the national economy in 2017-18 (ABARES, 2019).

Figure 3-1. Australian log harvest, 2017-18



Source: ABARES (2020), Australian Forest and Wood Products Statistics. Accessed: <https://www.agriculture.gov.au/abares/forestsaustralia/australian-forest-and-wood-products-statistics>

3.1.2 Trade

In 2018-19, Australia’s main timber exports were woodchips (\$1.6 billion), paper and paperboard (\$1.0 billion) and round wood (\$0.7 billion).²⁰ In the same year, Australia’s main imports were paper and paperboard (\$2.2 billion), miscellaneous forest products (\$1.5 billion) and paper manufactures

¹⁹ Australian System of National Accounts 2018-19, ABS 5204.0, Table 5. Accessed: <https://www.abs.gov.au/AUSSTATS/abs@.nsf/DetailsPage/5204.02018-19?OpenDocument>

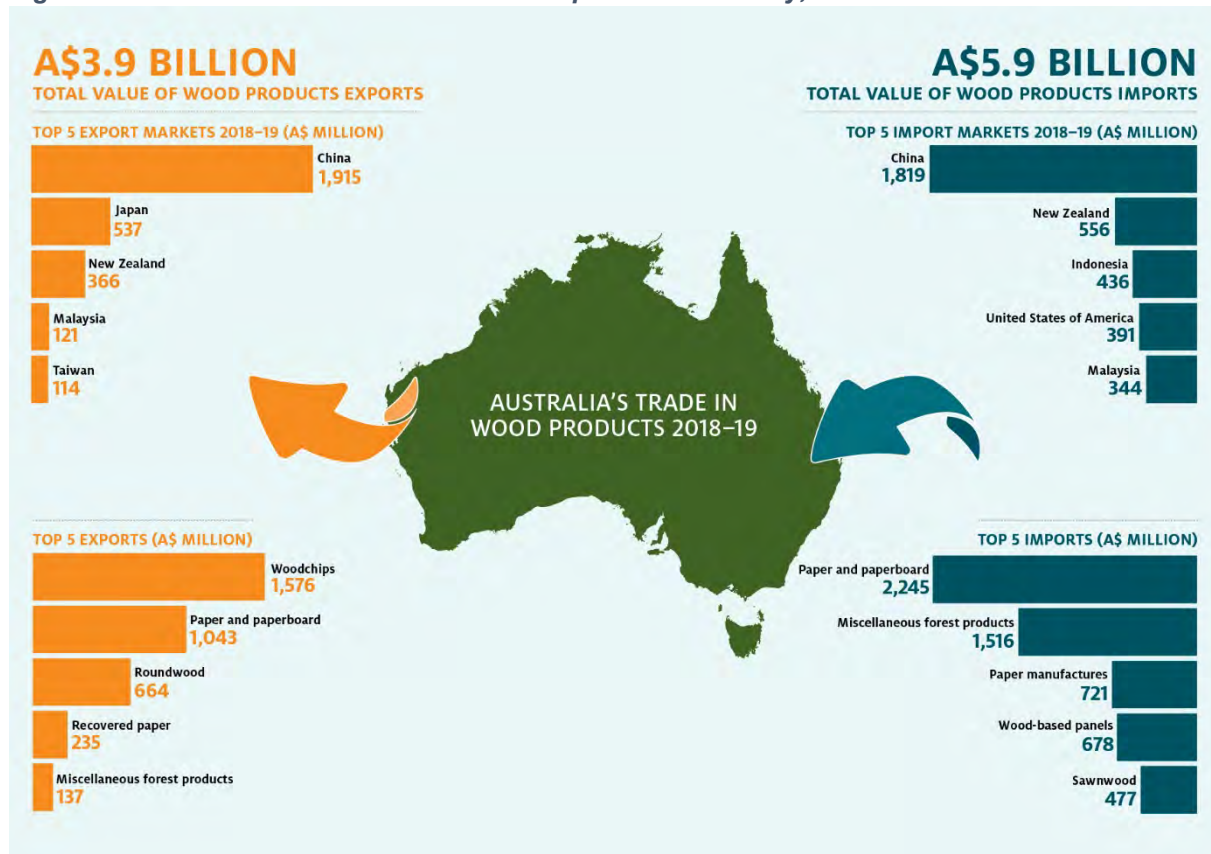
²⁰ Round wood is an equivalent term for logs.

(\$0.7 billion). China is Australia's largest trading partner in timber and wood products, followed by New Zealand, Japan and Indonesia (ABARES 2019, see

Figure 3-2 below).

Generally, Australian timber exports have contained a lower value-added than imported wood products. Australia's timber imports generally comprise more processed and higher value wood products to supplement domestic production and meet domestic demand, particularly for construction applications. In this regard, there appears to be ample scope for Australian production to move to higher value-added domestic production for both domestic and export markets.

Figure 3-2. Overview of the Australian wood products industry, 2018-19



Source: Australian Forests and Wood Products Statistics (ABARES, 2019).

3.1.3 Wood processing

Australia's wood processing industry is diverse, with mills of all types and sizes producing a wide range of wood products. In 2016-17 there were around 257 sawmills, 23 wood-based panel mills and a small number of pulp and paper facilities. Of the 257 sawmills in Australia, 182 processed hardwood sawlogs, 58 processed plantation softwood sawlogs, and 17 processed cypress pine (a softwood) from native forests (ABARES, 2019).

While there are more hardwood sawmills than softwood sawmills in Australia, hardwood sawmills tend to be much smaller in size and dispersed given the prohibitive economics of transporting hardwood logs over long distances. In 2016-17 only 4 percent of hardwood sawmills (compared to 52% of softwood sawmills) had an annual log input capacity greater than 45,000 m³, while all of the largest sawmills in Australia (capable of processing more than 400,000 m³ a year) were softwood sawmills (ABARES, 2019).

3.2 The international market for EWP

The use of EWPs such as CLT and GLT for mid-rise residential and commercial buildings has grown steadily around the world in recent years, particularly in Europe and in recent years in the United States and Canada. Sustainability and aesthetic factors have been key drivers of this trend, along with cost and time savings and flexibility.

EWPs have been promoted as a sustainable alternative to concrete and steel construction, particularly in mid-rise commercial and residential applications.

Canada has also recorded impressive growth in recent year, driven by some early success with prototype buildings. For example, in British Columbia, six-storey wood buildings were permitted in the early 2000s and the result has been 50 new timber structures with another 250 in the planning stage. Ontario has followed suit, altering its building code to allow for six-storey wood residential structures.

In 2015, Canada introduced a new National Building Code (NBC) and National Fire CODE (NFC). Thirty-four changes to the NBC and eight changes to the NFC permitted construction of six-storey buildings using 'combustible construction' materials. Consequently, additional protection measures were added to address the risk of injury due to fire and structural collapse in the finished building as well as during construction.

3.2.1 Global CLT market

Over the period 2008-2015, global production of CLT grew at an annual rate of 26 percent a year, with Europe accounting for most of this market. Major producers include Germany, Czech Republic, Italy, Spain and Switzerland.

By 2019, it has been estimated that there were ten CLT manufacturing plants in operation in North America (five in Canada and five in the US), with a combined annual production of about 400,000 m³. Further, two plants were under construction (both in Washington state), with a forecast production of roughly 185,000 m³ and three more plants had been announced (Timberbiz, 2020).

Globally, the residential market accounts for roughly one-half of CLT production, with the other half allocated to commercial construction. The 'sweet spot' for CLT is in mid-rise buildings after which the weight of CLT (as a load bearing structure) begins to work against it.

In the Asia Pacific, New Zealand, Australia, and Japan are major consumers of CLT. Earthquake-prone countries, such as Japan, New Zealand and India, have shown particular interest in using CLT. North America's CLT demand was valued around USD\$131 million in 2017, owing to the rising CLT use in residential and institutional applications. Increasing consumer demand for luxury and stylish apartments is anticipated to fuel this industry's growth. The growing CLT use in residential applications, including floors, ceilings, and walls, is also estimated to drive this market. This region is projected to be the second largest market in the future.

Based on a number of sources and applying conservative growth rates, this study estimates that global annual CLT production is around 1.2 million cubic metres in 2020. According to Plackner (2015), CLT production will potentially reach 3 million cubic metres by 2025, with most of the growth expected to occur outside Western Europe.

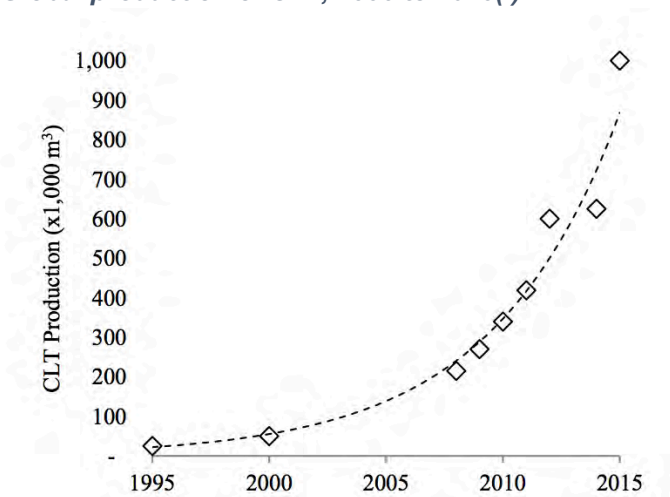
Figure 3-3 shows estimated production volumes for CLT based on industry newsletters, company contacts, conference presentations, and industry experts (Espinoza, 2016). The value of the global CLT market was estimated at USD\$603 million in 2017, and it is projected to reach USD\$1.6 billion in 2024 (Timberbiz, 2020). However, the iMarc Group estimated the global GLT market to be USD\$3.7 billion in 2019, with an annual growth rate of 3.6% over the period 2014 to 2019.²¹

²¹ <https://www.imarcgroup.com/glue-laminated-timber-market>

The global cross-laminated timber market reached a value of USD\$664 Million in 2018 with the market value expected to reach USD\$1.5 Billion by 2024 (“Crosslaminated timber market”, 2019). This is an expected doubling of growth within 5 years.

The market is expected to grow substantially, with a push towards larger market presence in the non-residential market currently dominated by steel and concrete structures. The rise in mass timber construction use is expected to increase the market for Cross-Laminated Timber, particularly outside of Central Europe which is just beginning to experience implementation and production within the past decade. Currently there are approximately seventy producers of Cross-Laminated Timber in the world. These manufacturers are heavily concentrated within Europe which represents three-quarters of the total global production of CLT. Just within Germany there are eleven manufacturers of Cross-Laminated Timber, while other major timber producing regions of the world including South America and Africa contain none. Other parts of the world are slowly emerging as players in CLT production including markets in North America and Japan.

Figure 3-3. Global production of CLT, 1995 to 2015(f)



Source: Espinoza et al (2016). The 2015 figure is a forecast by Esponzoa.

3.2.2 Global GLT market

The global GLT market is a complement to the global CLT market as GLT beams and posts are used in conjunction with CLT prefabricated walls and floors. In other words, the two markets tend to rise and fall together, along with other input materials into the construction industry. GLT beams have been available for many decades and are commonly used in both residential and non-residential construction. GLT often competes directly with steel, providing equivalent solutions for long span applications.

GLT is manufactured and used extensively in Europe, including in the United Kingdom, where the regulatory environment supports its use. Germany and Italy cumulatively accounted for around 60% of the Europe market revenue owing to the high acceptance and growing consumption of wood as a building material. Austria, being a rich source of softwood spruce and pine, is the largest production of glue laminated timber across the globe.

The GLT market is estimated to be around USD\$8 billion in 2020 based on a number of market industry reports and news articles. Most industry analysis estimate the CAGR at between 5-7% between 2015 and 2025. However, these forecasts do not account for the global recession induced by governments responses to COVID-19. Some market reports cite a tendency of GLT to absorb moisture from the atmosphere as a potential challenge to the market. However, Australian timber may be better at preventing moisture absorption.

Growing sustainability concerns across the globe and mounting awareness among consumers about wood as a building material are likely to be the major driving forces for the market in the coming years. Shifting consumer preference for wood-based construction owing to its durability, high thermal performance, and light weight is expected to propel market growth over the forecast period.

The growth potential for GLT is in the Asia-Pacific region, including Australia and New Zealand. GLT is already widely used in Europe and increasingly used in North America. It is expected that there will be an increased GLT manufacturing presence in China and Australia in particular in coming years. At present, the bulk of GLT manufacturing is in Europe with some of the key players being: Mayr-Melnhof Holz Gaisorn GmbH, Boise Cascade, Structural Wood Systems, Forest Timber Engineering Ltd., Ecocurves, Pfeifer Holz GmbH, Canfor Corporation, Setra Group AB, Meiken Lamwood Corp., B & K Structures, Schilliger Holz AG, Eugen Decker Holzindustrie KG and Binderholz GmbH. In Australia, Hyne Timber is the key player in the local GLT market.

Manufacturers of GLT continue to focus on technological advancements in the product. Such developments, coupled with competitive pricing, are likely to assist them in increasing their market share over the forecast period.

3.3 Domestic market and competitive analysis

3.3.1 Overview of the domestic market

Domestic production

EWPs have a small foothold in the Australian residential and commercial construction market compared to the overall size of the building construction market, at \$32.1 billion in 2018-19.²² That said, this foothold is growing steadily and there is potential for EWPs to account for an increasingly sizable share of the materials used in both residential and commercial construction over the next two decades. The development of the EWP market in Australia has been slower than in a number of other countries, notably in central Europe and North America.

Currently the Australian EWP manufacturing industry is in its infancy. However, this is changing. In 2018 XLam began manufacturing Cross Laminated Timber (CLT) panels at its Wodonga site in Victoria. In 2019, Hyne Timber opened its Glue Laminated Timber (GLT) Plant, which is located in Maryborough, Queensland. And in February 2020 Timberlink Australia announced that it would invest in a state-of-the-art Cross Laminated Timber (CLT) and Glue Laminated Timber (Glulam or GLT) facility in the Green Triangle (South Australia and Victoria) which indicates the growing market for engineered wood products.²³

Based on a review of trade reports and interviews with ARC FTH industry collaborators, it is estimated that the domestic production of EWP's, in 2020, is as follows:

- CLT domestic production is around 20,000 cubic metres per year.
- GLT domestic production is also around 20,000 cubic metres year.
- LVL domestic production is around 150,000 to 200,000 cubic metres per year.²⁴

Imports

It has been difficult to determine the exact size of the CLT-GLT import share in Australia and there are no publicly available estimates of annual CLT-GLT imports (or EWP imports more broadly). Interviews with industry as well as an analysis of trade reports indicates that imports most likely account for around 60 percent of the EWP market in Australia, with most imported material made in Germany, Austria and Italy.

There are presently three primary importers of CLT (KLH, Binderholz and Stora-Enso). For example, the Australian construction firm Strongbuild imported prefabricated CLT from the Australian company

²² ABS National Accounts 5204.0 Table 6. The residential and commercial construction market is defined in the National Accounts under the ANZSIC Classification System as Division E (301,302).

²³ <https://industryedge.com.au/new-cross-laminated-timber-facility-in-australia/>

²⁴ LVL manufacturing is not a key focus in this study.

Binderholz. Current estimates regarding the volume of imported CLT range between 25,000 and 40,000 cubic metres per year. GLT imports are estimated to be significantly lower.

This study has estimated total EWP imports at:

- CLT imports total 30,000 cubic metres per year.
- GLT imports total 5,000 cubic metres per year.
- Imports of other EWPs is significantly lower than CLT-GLT imports.²⁵

3.3.2 Competitive analysis

Relative cost of substitutes

Generally, European suppliers of CLT-GLT manufacture at a much larger scale and, hence, set the wholesale price in the Australian domestic market. It is likely that EU supplied CLT-GLT will be a permanent competitor in the local markets, based on price and cost, without further research and development in Australia to lower the cost of domestic manufacturing.

Data on precise cost savings from the use of EWPs (specifically CLT) relative to substitute materials are patchy at best. Data vary greatly on cost and time savings for CLT use in buildings due to the relatively small dataset and difficulty in making like-for-like comparisons. The primary substitutes for EWPs are: (i) concrete and steel, particularly in commercial construction, and (ii) traditional timber frames, posts and beams, particularly in residential construction.

Relative to traditional concrete and steel construction, estimated CLT costs savings range from very small (around 1-3% in terms of overall costs) to quite significant (around 15-30% solely in terms of labour and time savings). Yet other studies indicate that concrete and steel maintain an advantage of up to 10 percent, particularly for larger mid-rise buildings.

Generally, most studies provide evidence that CLT is a lower cost building material (as installed) and, in our view, this claim is correct within a limited set of criteria. One issue in Australia is that, because CLT is not widely used, there are higher costs involved with bespoke production and little experience with installation. A second issue is that CLT, at this stage, is only proven to be a safe and structurally sound material up to the height of mid-rise buildings (say 30-35 metres).

One of the first commercial relative cost studies was conducted by Mahlum, Walsh Construction and Coughlin Porter Lundeen Engineering to determine the feasibility of CLT construction in the Pacific Northwest, mainly focusing on Seattle (Mahlum, 2014). The study found a number of benefits from using CLT, including:

- fewer skilled labourers are required;
- construction times are shorter;
- better tolerances and quality;
- safer work (for instance less workers means a safer workplace all things being equal);
- utilization of local and sustainable materials; and
- lower overall carbon footprint, given timber embodies much of the overall carbon cost of the product.

²⁵ This analysis abstracts from the impact of COVID-19 in 2020.

Overall the study identified a four percent cost saving when directly comparing a 10-storey concrete building with a CLT design. While four per cent is not significantly cheaper, and different building configurations would change the relativities, this study showed that, in certain circumstances CLT is a very competitive option. Moreover, even a cost saving of this magnitude would allow CLT to absorb at least a portion of the market share held of the dominant concrete and steel alternative.

A study by Mallo and Espinosa (2016) produced detailed cost comparisons between CLT and concrete/steel across a range of buildings.²⁶ The rationale of the authors was to examine why, despite its known advantages, CLT still suffered a market disadvantage in the United States from an architecture firm's point of view and to compare the economic performance of CLT with that of traditional construction systems, namely concrete and steel (Mallo and Espinosa, p.1).

The authors first established the primary structural materials used by building type. The findings are similar to the experience in Australia where wood frames are still the most common building material in residential construction, and larger commercial buildings use various combinations of concrete and steel, as well as wood (often for aesthetic rather than structural purposes).

To examine cost comparisons between the traditional building material combination and one built with increased use of CLT the authors chose a performing arts centre built in 2008 near Napa in California as a case study.²⁷ Their overall conclusion was (Mallo and Espinosa, P.6):

"The cost evaluation for the performing arts centre showed that CLT would signify a cost reduction of up to 21.7% in the cost of structure, depending on the extent to which CLT is used in the building and the manufacturer selected. Moreover, compared to prefabricated materials such as pre-cast concrete, CLT would allow savings in construction time and have lower material costs."

Specifically, the study found that:

- CLT panels were potentially up to 21.9% lower cost than the full concrete and steel building option;
- Savings using the 'green' option where no concrete or steel was used apart from the foundations, ranged between 6.3 and 21.9%;
- Where steel was used for the beams and frames, savings ranged from 0% (high cost) to 14.1% under the low-cost option;
- Interview with building practitioners confirmed a number of advantages of CLT over concrete and steel, such as: lighter weight, smaller and shallower (and cheaper) foundations, and cheaper roofing systems (Table 3-1).

Table 3-1. Cost Comparisons CLT versus Concrete and Steel in Construction of Art Centre

Building material	CONCRETE/ST EEL	CLT-1a (High Cost)	CLT-2 (Low Cost)	CLT-3 (GREEN) (High Cost)	CLT-4 (GREEN) (Low Cost)
	Concrete/Steel (walls, roofs, beams, frame)		CLT (walls, roof); Steel (beams, frame)	CLT (walls, roof); Glulam beams; Wood frames	
Cost per SQFT (USD, 2016)	\$64	\$64	\$55	\$60	\$50
Cost per SQM (USD, 2016) ^b	\$689	\$689	\$592	\$646	\$538

²⁶ Mallo, L. and Espinosa, O. (2016) "Cross Laminated Timber versus Concrete/Steel cost comparison using a Case Study" Paper presented to the World Conference on Timber Engineering" Vienna, August.

²⁷ Mallo and Espinosa (2016); see discussion at section 3.2.1 in the paper.

Cost per SQM (AUD, 2020) ^c	\$1,021	\$1,021	\$877	\$957	\$797
Cost savings compared to C/S (%) ^d	-	0.0%	14.1%	6.3%	21.9%

Source: Mallo and Spinoza (2016, p.3). **a** The descriptions CLT-1 to CLT-4 refer to the four CLT scenarios that utilise a combination of building materials (as described in the table) **b** Conversion from SQFT to SQM used a multiple of 10.764. **c** Conversion from USD to AUD used a 2016-2020 average AUD-USD exchange rate of 0.7304 US dollars.²⁸ An annual Australian inflation rate of 2% has been assumed over the period 2016 to 2020. **d** 'C/S' = concrete and steel.

A significant problem with the Mallo and Espinoza study is that, while detailed, it is based on only a single case study. Therefore, it would be problematic to generalise these results, particularly to the 2020 Australian context. Nonetheless, these results are positive for CLT and have been absorbed into this CBA along with the other studies and industry feedback to develop a picture of the relative cost competitiveness of CLT.

A 2015 study compared the costs of construction between mass timber construction (MTC) and traditional forms of construction (Dunn, 2015). The study compared four commercial buildings and assessed the differences in costs associated with using timber compared with concrete and steel. Specifically, the study assessed a seven-story office building, an eight-story apartment building, a two-story aged care facility, and an industrial shed. Each of the projects was designed and independently assessed (costs and other input factors) using timber as the primary construction material with a comparison material/s (conventional concrete-framed or steel-framed building) in an urban location—Sydney, Australia.

The results of the study revealed that MTC construction was lower cost than the non-timber solution. For example, the cost advantage for the eight-storey apartment building was 2.2%, the single-story industrial shed (9.4%), the seven-story office building (12.4%), and the two-story aged care facility (13.9%). The study also found that the costs savings would have been greater had it not been for the additional fire protection required for exposed timber structures, additional fire engineering costs and the costs of termite protection (Dunn, 2015).

A recent paper (Smith, 2018) that undertook a comparative analysis of a number of similar traditional and prefabricated timber structures using a case study approach found that modular construction cuts costs by 4.2 percent and reduces construction time by 20 percent compared with traditionally-built projects (Smith, 2018).²⁹

Figure 3-4 (below), which is taken from the paper, illustrates the cost advantage of mass timber construction (MTC) in six out of seven case studies. The study also found that MTC projects that were considered 'pilot projects' (and hence not included in the core analysis) tended to be more expensive than traditional building materials and methods. This indicates a 'learning-by-doing' productivity factor that needs to be considered with EWPs given their relative novelty in the construction market.

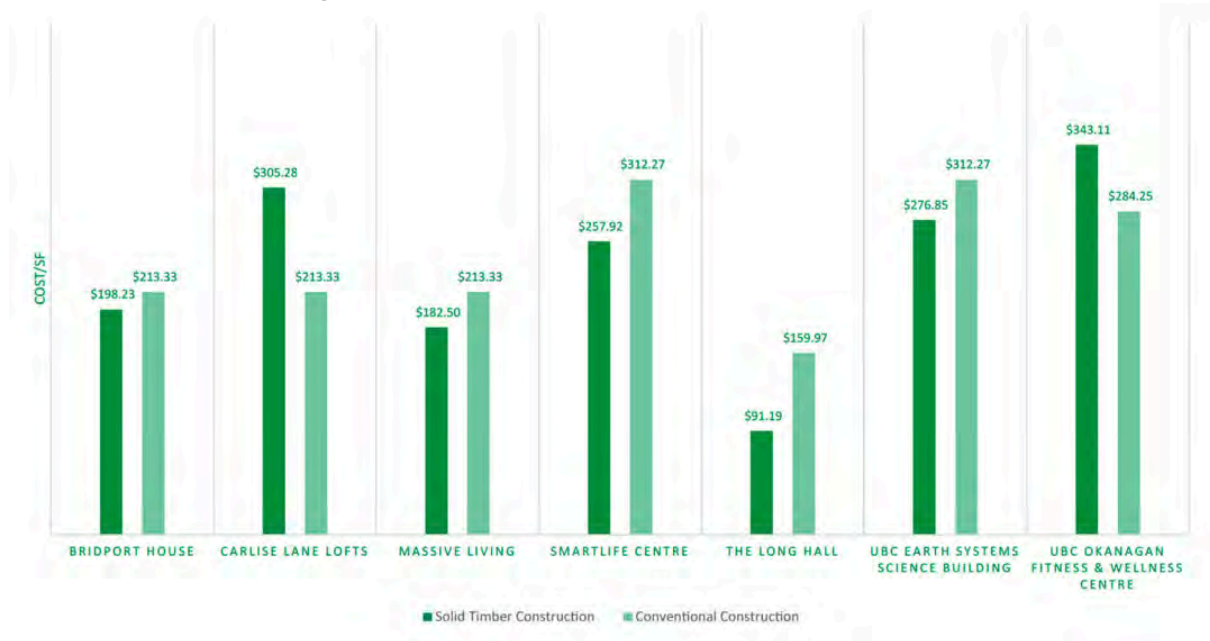
The case studies also drew out qualitative lessons learned from stakeholders and indicated that the advantages of mass panel constructions included: speed of construction; weather versatility; material, carbon saving; foundation reduction; ability to build in remote locations; a reduction of labour hours; precision of construction; and increased safety. The disadvantages reported by stakeholders' respondents included a lack of knowledge and skills with prefabricated mass panels; handling and logistics are more challenging due to the (at times) massive nature of panels and especially with wind exposure; requirement for upfront planning; additional sound attenuation costs; authorities having

²⁸ See RBA Table F11 Exchange Rates – Monthly – January 2010 to latest complete month of current year. Accessed here: <https://www.rba.gov.au/statistics/historical-data.html#exchange-rates>

²⁹ The study identified 18 possible case studies before settling on 7 case studies that were highly amenable to comparison.

jurisdiction not being familiar with mass panels; and the potential of job displacement due to labour efficiencies (Smith 2018).

Figure 3-4. Cost per square foot comparison between MTC case studies and traditional site-built counterparts



Source: Smith (2018, p.131).

Notwithstanding the very real issue of the lack of economies of scale in Australia, the overall picture is that, in a narrow set of building designs (generally being mid-rise, medium sized buildings) CLT is likely to maintain (and over time improve upon) a current small cost advantage over concrete and steel. In addition, using CLT and exposed CLT as part of an overall design that still uses concrete and steel for structural support can be cheaper as well as provide a higher value-added to builders and building owners.

CLT-GLT Prices

In terms of CLT, a summary of the available data from a range of the top European producers show that while market prices vary according to the dimensions of the product, an average price of €500 to €600 per m³ is set by the larger producers for benchmark products.³⁰ This translates to AUD\$800 to AUD\$1,000 per cubic metre in 2020 depending on the exchange rate applied. Other sources on total global supply and sales suggest prices per cubic metre of CLT somewhat lower at around \$US520 or around \$AUD750 per m³ at current exchange rates.³¹ Taking all of the evidence together, the most reliable indicator of the benchmark (or competitive) price of CLT in Australia, is the landed price of imports being AUD\$1,000 per cubic metre.

In terms of GLT, the available data suggests that this product is more expensive than CLT in both the European and North American markets. Generally, in Australia wholesale prices delivered to the

³⁰ <https://www.cbi.eu/market-information/timber-products/cross-laminated-timber/europe/>

³¹ <http://www.unece.org/fileadmin/DAM/timber/publications/SP48.pdf> Food and Agricultural Organization of the United Nations 2019 Forest Products Annual Market Review 2018-19

building site range between \$2,000 and \$3,000 per cubic metre. A median Australian GLT wholesale price has been used in this analysis.

As comprehensive Australian data on CLT and GLT costs/prices used in residential and commercial construction are unavailable the starting point for this analysis is the 'market-setting' landed import price of:

- CLT, which industry feedback suggests is around AUD\$1,100 per m³ in 2020; and
- GLT, which industry feedback suggests is around AUD\$2,200 per m³ in 2020.

From these initial 'market setting' wholesale import prices, domestic transport costs are added to determine a 'delivered wholesale' median price of:

- \$1,250 per cubic metre for CLT; and
- \$2,500 per cubic metre for GLT.

The study also utilises several other data sources to cross-check and validate this key price assumption. Forecasts of prices are provided for CBA-1 and CBA-2 in chapters 3 and 4.

Part 2 Cost benefit appraisal of four FTH research projects

4. Methodology

This chapter sets out the CBA methodology used for this Study in general terms. Readers familiar with the CBA method can move straight to the two CBA chapters, being chapters 4 and 5, which provide their own detailed descriptions of the methodology, process and results.

4.1 What we've been asked to do

The ARC Future Timber Hub (FTH), which is based at the School of Civil Engineering at the University of Queensland has commissioned the Australian Institute for Business and Economics (AIBE), based within the Faculty of Business, Economics and Law at the University of Queensland, to undertake an analysis of the potential economic, environmental and social impacts of four current marquee FTH research projects. AIBE has engaged Tulipwood Economics, a leading Australian economics consulting firm, to assist with the preparation of the report.

The work of the FTH is funded from direct Australian Research Council (ARC) grants, as well as cash and in-kind support from The University of Queensland, partner universities, government agencies and industry partners. The core objective of the Hub is to transform the timber construction industry in Australia by generating the skills, knowledge and resources that will overcome current technological and social barriers limiting the application of timber to mid-rise and tall residential and commercial buildings, particularly new engineered wood products (EWPs).

The purpose of this report is to evaluate four discrete FTH research projects and, consequently, support the promotion of the Hub's mission. These impact assessments are important and represent a stocktake of work undertaken so far that can be used to demonstrate the Hub's benefits to industry, the ARC and government agencies that may support further research and the broader Australian community.

4.2 What is a Cost Benefit Appraisal?

"Cost-benefit analysis is a process of identifying, measuring and comparing the benefits and costs of an investment project or program." (Campbell and Brown 2016, p.1).

A cost benefit appraisal (CBA), which applies the techniques of cost benefit analysis, is an applied analytical tool used to account for the benefits and costs of particular proposals or decisions on a common basis in terms of currency and time, such that the comparison can be easily understood. A CBA can be forward-looking assessing the merits of a proposal, or backwards-looking considering whether a particular project was worthwhile. CBAs are often used to assess proposed regulations under the Regulation Impact Assessment (RIA) process or to review the impact of regulations under the Post-Implementation Review (PIR) process.³²

Additionally, a CBA can be used as a transparent, open or public analysis whereby assumptions, data sources and methodologies are clearly stated and can be challenged and replicated. The CBA approach, therefore, provides a basis on which the Future Timber Hub and its investors might assess the net public benefits of ongoing research.

The CBA framework is focused on the social welfare of the community as a whole rather than a single (or multiple) private entity. In other words, a CBA is broader than a financial analysis where the benefits or costs of a project might be solely captured by the project proponent and its investors.

³² For a description of the RIA and PIR processes followed in Australia, see here: <https://www.pmc.gov.au/regulation>

Accordingly, as an analytical tool, a CBA is capable of considering a wide range of costs and benefits, including financial, social, cultural, environmental, strategic and military. A well-designed CBA places each of these types of impacts on a common basis (eg. in 2020 Australian dollars) so that they can be compared and understood. In this way, a CBA framework also considers the timing of each of the impacts because future impacts are 'converted' into today's terms so that they can be meaningfully compared. A CBA can therefore enable an evaluation of policies that deliver different streams of benefits and costs over time.

Finally, a CBA can help project proponents or managers better understand their own project and, especially, the risks and uncertainties inherent in their project. And by varying key assumptions, it is possible to test whether the outcomes, including the ranking of alternatives, are sensitive to the assumptions on which the analysis is based. That helps highlight the risks the project involves, and can inform the management of those risks.

4.3 Types of impacts – General Overview

Figure 4-1 (below) sets out the core characteristics of the CBA framework, in terms of types of impacts, types of stakeholders and the nature of the impacts. The first column categorises the types of impacts into three broad themes, namely: (i) economic (including financial) impacts, (ii) environmental impacts, and (iii) social impacts:

- Economics impacts can be defined as those impacts that can be captured by individuals or private firms. Economic impacts also include what are generally referred to as financial impacts. For example, if an infrastructure investment increases a firm’s revenue, the value-added (i.e. additional profit and wages) can be estimated as an economic benefit.
- Environmental impacts relate to the production and consumption of environmental goods and services, such as trees, biodiversity, noise, pollution or visual amenity. Environmental goods can be ‘consumed’ and ‘earned’ in the same way as economic goods and services.
- Social impacts relate to those impacts that cannot be fully captured by individuals or private firms, (such as is captured in the price paid or received for a good or service). For instance, if the academic research undertaken by FTH leads to new knowledge or processes that benefit broader society as well as the FTH, then these impacts are defined as social impacts.

Generally, a CBA evaluation framework identifies four types of stakeholders, namely: (i) households, (ii) businesses, (iii) government, and (iv) society. Households (including individuals) and businesses capture so-called ‘private’ benefits and bear ‘private’ costs. Benefits and costs accruing to governments are, generally, simply transfers between groups of taxpayers. Society is defined as the sum of all households and businesses, and captures the broader social costs and benefits that are not solely captured by individuals or businesses. For example, if a generous individual were to build a park bench in a public park that could be used by any citizen, the costs of the park bench would be borne by the generous individual but the benefits would accrue to every citizen that used the seat.

Finally, the nature of impacts can be categorised as: (i) benefits, (ii) costs, and (iii) transfers. Initial seed funding for these projects is derived from the Australian taxpayer via the ARC grant process as well as university, industry and government in-kind contributions.

Figure 4-1. Overview of the CBA evaluation framework



Source: Tulipwood Economics.

4.4 Approach to the study

4.4.1 Overview

The FTH projects are classified as academic research with industry support and input. Industry partners will jointly own the IP produced during the research program and this makes it more probable that the innovation produced through the academic research is commercialised in a timely manner. At the same time, several other academic institutions around the world are undertaking similar research with similar aims. Published academic work is either freely available (to academics) or available at negligible cost to industry. Indeed, current academic practice is to collaborate across institutions and share work as much as feasible. Further, it is assumed that industry allocates a small proportion of its revenue (at 1%) to R&D investment to achieve similar goals, such as reducing the resources costs of products and understanding the capabilities of the products.³³

The four projects under review are quite similar in aims, which is to expand the use of CLT in Australia. Projects PR002 and PR015 have more of a pure market focus, and projects PR014 and PR019 relate more to the regulatory and standards environment that supports the market (Table 4-1). Accordingly, the study undertakes two separate CBA's, as follows:

- CBA-1 comprises PR002 and PR015; and
- CBA-2 comprises PR014 and PR019.

Table 4-1. Approach and data requirements, by FTH project

Project	Approach	Data requirements
PR002 – Optimisation of wood-based mass-panels; and PR015 – Alternative uses for under-valued sawmill products	CBA framework Market analysis	Current international and Australian market demand and supply; resources costs and prices
PR014 – EWP self-extinguishment in compartment fires; and PR019 – Collapse resistance in tall-frame timber buildings	CBA framework RIA framework Market analysis	National Construction Code specifications Current international and Australian market demand and supply; resources costs and prices

Source: ARC funding applications by project and Tulipwood Economics analysis.

4.4.2 Impact of COVID-19

There is little doubt that the unprecedented economic shock caused by Australian Government's response to COVID-19 will be enduring and affect Australia's economy for at least the first half of this decade. Australia's GDP declined by 0.3 percent in the March quarter 2020 and the consensus of the recent economic modelling points to a dramatic decline in June quarter Australian GDP of up to 25 percent (or 6.25% in annual terms), even accounting for government measures such as the JobSeeker and JobKeeper payments and cash boosts for small and medium businesses.³⁴

Employment decreased by almost 600,000 workers in April and a further 228,000 in May as thousands of businesses were forced to shut down as a result of the social distancing measures introduced. Australia's unemployment rate stands at 7.1 percent in May 2020; however, measured including all forms of underemployment, the rate is almost double that at 13.1 percent.³⁵

³³ Across the OECD, firms on average spend 1-5% of their revenues on R&D, depending on the industry and how the investment is measured. For a discussion, see here: https://stats.oecd.org/Index.aspx?DataSetCode=BERD_STIO

³⁴ ABS 5206.0 Australian National Account: National Income, Expenditure and Product, March 2020. Accessed: <https://www.abs.gov.au/ausstats/abs@.nsf/mf/5206.0?opendocument&ref=HPKI>

³⁵ ABS 6202.0 Labour Force Australia, May 2020. Accessed: <https://www.abs.gov.au/ausstats/abs@.nsf/mf/6202.0?opendocument&ref=HPKI>

In the March quarter 2020, residential construction declined by 2.9 percent (quarterly) and by 12.3 percent through-the-year. Non-residential construction increased slightly by 0.7 percent in the March quarter to be 3.9 percent higher over the year.³⁶ The Australian Government has introduced a number of measures to support the residential construction sector in 2020, including early access to superannuation and cash grants for renovation projects valued at \$150,000 or greater. Nonetheless, it is expected that the construction sector will take time to rebound, particularly given the impact of the closed international border on Australia's population growth rate.

That said, this analysis 'looks through' the impacts of COVID-19 and assumes that the Australian construction sector continues to grow at its long-term trend rate over the time period of the modelling. The reasons are twofold, as follows:

- First, although the economic impact of the COVID-19 response is large, it is nonetheless temporary. There is a high degree of confidence that a vaccine will be developed before the end of 2021 and this will allow the international border to open and Australia's population growth rate to return to its long-run trend.
- Second, the aim of this project is to determine the impact of specific academic research related to EWP's on the economy, and in order to measure this as accurately as possible, other impacts (or noise) should be set aside.

4.4.3 Measuring incremental changes

The measurement approach used for this analysis is incremental or what is called 'marginal' in the language of economics. In other words, the net benefits of the four FTH research projects are calculated as the incremental change in the so-called Policy Case vis-à-vis the incremental change in the BAU scenario. For example, if the research projects increase value-added by 20 percent over a 20-year period compared to the base year, but the BAU pathway would have achieved a 10 percent increase in any case, then the actual incremental impact is (20% less 10%) 10 percent as a result of the projects.

³⁶ ABS 7755.0 Construction Work Done, Australia, Preliminary March 2020. Accessed: <https://www.abs.gov.au/ausstats/abs@.nsf/mf/8755.0>

Table 4-2 explains the intellectual framework behind a marginal CBA analysis. Another way to explain the measurement approach is that the net benefit of a project is the area between the two growth lines (BAU and Policy Case) over a fixed time period (as opposed to the whole area underneath the Policy Case growth line).

Table 4-2. Measuring the incremental benefits and costs in CBA

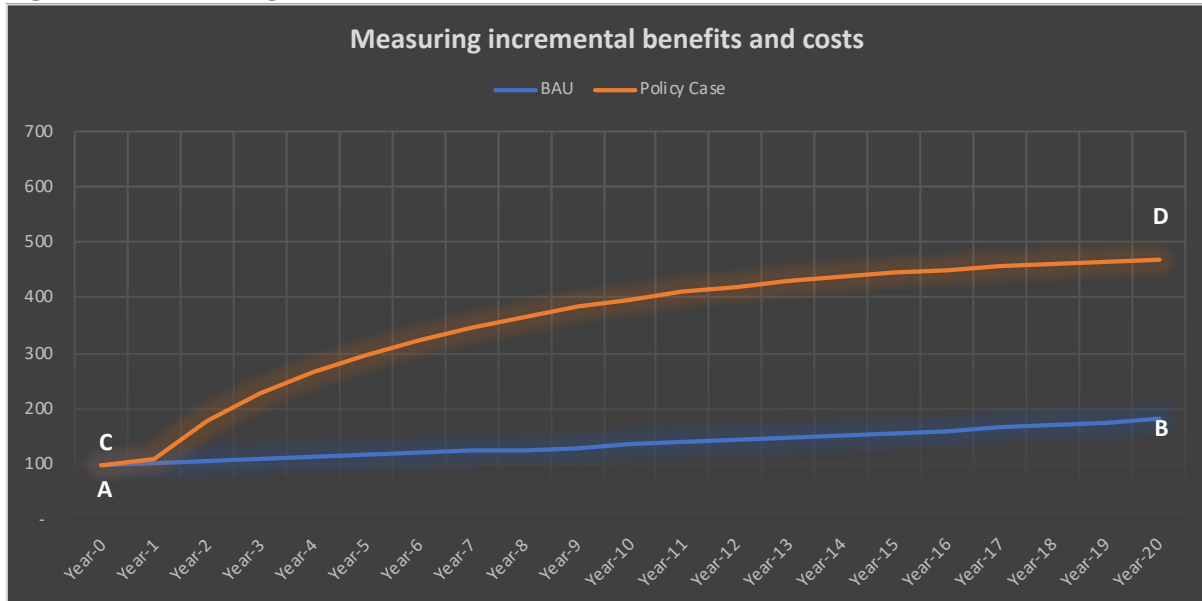
Parameter	Notation
BAU Year-1	A
BAU Year-20	B
Policy Case Year-1	C
Policy Case Year-20	D
CBA formula =	$[D-C] - [B-A]$

Source: Tulipwood Economics.

Figure 4-2 (below) illustrates the formula set out in

Table 4-2 (above).

Figure 4-2. Measuring the incremental benefits and costs in CBA



Source: Tulipwood Economics.

4.5 Steps involved in undertaking the CBAs

Table 4-3. Steps involved in undertaking the CBAs

No.	Definition	Explanation
1	Articulate the decision to be made	Whether the four research projects: PR002, PR014, PR015, PR019, are a good use of taxpayer funds
2	Methodology	Develop a conceptual framework to undertake the analysis
3	Establish the BAU Case	The four research projects (and related international research) and industry investment did not take place. The global and Australian CLT markets grew at their long-run growth rate (proxied by the long-run growth rate of the Australian residential and commercial construction sector).
4	Establish the 'Policy Case' (PC)	The four FTH research projects (and related international research) and industry investment took place. This research had a positive impact on the Australian CLT market.
5	Identify all possible costs for BAU and Policy Case	Private and Social Costs (including environmental costs) Capital, Operating, Avoided, Environmental, Social, Third Parties, DWL of taxation
6	Identify all possible benefits for BAU and Policy Case	Private benefits: increased wages and profits (value-added) Social benefits: more resilient domestic EWP industry, wider variety of jobs, environmental benefits from lower carbon content and embedded carbon in CLT Residual value of assets
7	Calculate incremental changes between Base Case and Project Case	Financial and economic model (see Table 4.2 above).
8	Apply an NPV methodology and calculate net benefits/costs.	Compare costs and benefits over time. Calculate a single value of net benefits using an appropriate discount rate.
10	Make investment decision or, in this case, justify/or not (ex post) project investment.	Result of the analysis either justifies (or does not) the arguments made in the ARC grant application.

Source: Tulipwood Economics.

(below) sets out the main steps, in general terms, in the CBA process for this study.

Table 4-3. Steps involved in undertaking the CBAs

No.	Definition	Explanation
1	Articulate the decision to be made	Whether the four research projects: PR002, PR014, PR015, PR019, are a good use of taxpayer funds
2	Methodology	Develop a conceptual framework to undertake the analysis
3	Establish the BAU Case	The four research projects (and related international research) and industry investment did not take place. The global and Australian CLT markets grew at their long-run growth rate (proxied by the long-run growth rate of the Australian residential and commercial construction sector).

4	Establish the 'Policy Case' (PC)	The four FTH research projects (and related international research) and industry investment took place. This research had a positive impact on the Australian CLT market.
5	Identify all possible costs for BAU and Policy Case	Private and Social Costs (including environmental costs) Capital, Operating, Avoided, Environmental, Social, Third Parties, DWL of taxation
6	Identify all possible benefits for BAU and Policy Case	Private benefits: increased wages and profits (value-added) Social benefits: more resilient domestic EWP industry, wider variety of jobs, environmental benefits from lower carbon content and embedded carbon in CLT Residual value of assets
7	Calculate incremental changes between Base Case and Project Case	Financial and economic model (see Table 4.2 above).
8	Apply an NPV methodology and calculate net benefits/costs.	Compare costs and benefits over time. Calculate a single value of net benefits using an appropriate discount rate.
10	Make investment decision or, in this case, justify/or not (ex post) project investment.	Result of the analysis either justifies (or does not) the arguments made in the ARC grant application.

Source: Tulipwood Economics.

4.5.1 The decision framework

A decision will be made, in part based on the results presented in this CBA report. We use three summary measures to explain the results, being an NPV measure to present the results in dollar values in a single time period, a benefit-cost ratio (BCR) which must be greater than one, and an Internal Rate of Return measure which must be positive (**Error! Reference source not found.**).

Table 4-4. Summary measures generally included in a CBA evaluation

Parameter	Definition	Advantages	Decision
Net Present Value (NPV)	Sum of discounted annual net benefits over the evaluation timeframe.	Can compare options, with the largest value providing the greatest economic return.	NPV > 0
Benefit Cost Ratio (BCR)	Ratio of the present value of total benefits to the present value of total costs.	Can compare options, where the largest BCR should be favoured.	BCR > 1
Internal Rate of Return	The discount rate that makes the net present value (NPV) of all cash	Can compare to other potential projects, selecting the highest IRR.	IRR (a) > IRR (b)

flows from a particular project equal to zero.

Source: Tulipwood Economics.

4.5.2 Scenarios modelled

For this analysis, we have modelled a single BAU scenario and three policy scenarios, being: (i) Low Policy Case, (ii) Central Policy Case, and (iii) High Policy Case.

4.6 General CBA parameters

4.6.1 Unit of measurement

This economic analysis, and the supporting financial models, is undertaken in **2020 Australian dollars**. To the greatest extent possible, the study has converted all costs and benefits into 2020 Australian dollars. Accordingly, this study is framed in real, as opposed to nominal dollar terms.

In terms of building materials, the standard unit of measurement applied in this analysis is **cubic metres**, which is generally denoted m³.

4.6.2 Discount rate

The discount rate determines the weight placed on future benefits and costs relative to more immediate benefits and costs. There is an extensive academic literature on determining the social discount rate and often project-specific discount rates are developed, for example in network industries such as water, telecommunications or airport facilities.³⁷ In recent years there has been increased debate about what the appropriate social discount rate should be. In the current low interest rate environment, some have argued for a lower benchmark social discount rate.³⁸

That said, it is important to keep in mind that the current post-GFC/COVID interest rate environment is a result of policy decisions made by central banks to stimulate economic activity, rather than a reflection of the supply-demand balance between the global stock of savings and investment opportunities. Moreover, the actions taken by central banks are in part a response to the increased risk premium that governments and firms will likely place on potential public and private investments in a post-COVID world. In other words, often when the risk free rate falls the risk premia rises and the post-COVID world is likely to be no different to the post-GFC world in terms of evaluating economic risk. Central banks attempt to offset that risk by increasing the supply of money in the economy to lower the risk free rate. But these actions do not, and can not, eliminate all investment risk. Social discount rates should incorporate a risk premium that reflects the risks involved with the particular project under consideration. In this instance, academic research is inherently risky in terms of whether that research ultimately leads to commercial and broader economic returns for society.

Accordingly, for this study, we have applied three discount rates in the analysis, being 5%, 7% and 9%. The central discount rate (being **7 per cent**) is the commonly accepted 'central point' social discount rate used in Australia and recommended by most government agencies (such as the Commonwealth Treasury Department, Infrastructure Australia and NSW Treasury). Our headline estimates and NPV and BCR calculations are based on a discount rate of 7 per cent.

This Study notes the recommendation in the RRDC Cross-RDC Impact Assessment Program Guidelines (April 2018), which recommend that a 5% discount rate be used in CBAs undertaken in relation to the 15 partner Rural R&D corporations in the RRDC. While this Study provides all results at a 5% discount rate, we recommend that the results of the study be interpreted using the 7% social discount rate as the central rate because of: (i) the inherent risk in translating academic research into commercially successful outcomes and (ii) the inherent uncertainty around the post-COVID economic recovery, both globally and in Australia.

³⁷ See, for example, Harrison (2010).

³⁸ See, for example, Terrill et al (2018).

4.6.3 Time period

Generally, the time period for a financial or economic analysis matches the whole-of-life span of the asset being analysed. In this case, the intellectual property being developed by the FTH is permanent and, indeed, is improved upon over time. That said, with any positive non-zero discount rate, benefits and costs in the far-off future have little impact on the overall results of the analysis.

The analysis is undertaken over a **20-year timeframe**.

There are a number of reasons for choosing a 20-year timeframe. First, the period of initial research is three years. Second, it is assumed that there is a further industry development period of 2 years required to produce the CLT mass panels such that the first lower cost CLT panels do not enter the market until Year-6. Third, it is assumed that it will take a number of years for CLT panels to build up market share as further productivity gains reduce the relative price of CLT compared to substitutes. Fourth, as a result the whole process of market disruption does not settle back into equilibrium until between Year 10 to Year-20.

4.6.4 Residual value of assets

There are two approaches available for estimating the residual value of the assets at the end of the evaluation period. The first approach is cost based, which considers the depreciated value of assets at the end of the CBA period. The second approach is benefit based, which considers the future value of benefits extending beyond the evaluation period.

For this study, a **residual value has not been applied** as it would not influence the findings of the study.

4.6.5 Deadweight loss of taxation

The deadweight loss (DWL) of taxation parameter captures the costs of raising government revenue to fund the four FTH research projects. For CBAs of very large projects, a DWL estimate is generally included as a cost parameter.

All things being equal, tax levels need to be higher than would otherwise be the case in order to fund any government contribution to the delivery of the ARC research program in general and the four FTH projects in particular. Taxes impose economic costs because they induce individuals to behave differently and make decisions they would not have made in the absence of the tax. For example, taxes reduce real incomes and the quantity of goods and services people can purchase with their after-tax income. The result is what economists call a social cost or 'excess burden'.³⁹

The losses associated with these excess burdens should be included where there is a substantial net government contribution. These costs of taxation are typically reported as the dollar social cost per dollar of revenue raised from taxation.

For these CBAs, **we do not apply a DWL factor**, for the following reasons:

- The funding for the four FTH research projects is negligible relative to the size of the total ARC program;
- Funding for ARC programs is limited and based on a competitive application process; and
- The DWL parameter is not required as a component of the recommended CRRDC Impact Assessment Guidelines (CRRDC, 2018).

³⁹ The excess burden from a tax is the difference between the cost to taxpayers from having a tax imposed and the amount of tax collected. The more the tax changes behaviour, the greater the excess burden.

5. CBA-1: Lowering the resources cost of engineered wood products (PR002 and PR015)

5.1 General approach to CBA-1

This chapter describes the analytical framework and reports the combined CBA results of the two ARC FTH research projects PR002 and PR015. These two research streams are focussed on lowering the resources costs of EWPs, specifically CLT and GLT. The objectives of PR002 (Optimisation of wood-based mass-panels for Australian buildings systems) and PR015 (Alternative uses for under-valued sawmill products in innovative timber structures) are closely aligned and, accordingly, a combined CBA has been undertaken. PR002 is the major partner of the two projects in terms of ARC and in-kind funding, accounting for 90 percent of the combined funding pool in CBA-1.

5.2 Scenarios modelled

To assess the potential costs and benefits of the two ARC FTH UQ research projects PR002 and PR015 two scenarios were specified and compared:

- A business as usual (BAU) case, in which we assume that the academic research (and related industry collaboration and investment) did not take place and, consequently, the Australian CLT-GLT sector grows at its expected rate, which includes a ramp-up in demand in the short-term as advised by industry.⁴⁰ The CLT-GLT import share declines over time as the ramp-up in demand is sourced primarily from an expansion in domestic manufacturing capacity.
- A Central Policy Case (CPC) scenario, in which the academic research (and related industry collaboration and investment) successfully reduces the cost of domestically manufacturing EWPs (specifically CLT and GLT) over time such that CLT-GLT becomes even more competitive against imports.
- Two alternative policy case scenarios whereby the main input parameters are adjusted to test the robustness of the CPC result.
 - In the ‘High Policy Case’ scenario, CLT-GLT successfully competes against, and take market share from, domestically produced substitutes concrete and steel, and timber framing.
 - In the ‘Low Policy Case’ scenario, the take-up of CLT-GLT is slower and the market takes more time to adjust to the new technology and construction processes.

The costs and benefits of these two scenarios (BAU and CPC) were compared over a 20-year time frame using the standard social discount rate of 7 percent as well as a lower (5%) and higher (9%) discount rate. The analysis has been based on a set of input assumptions and data drawing on the best available information on the commercial potential of CLT-GLT and broader commercial construction industry trends in Australia.⁴¹

There are a number of reasons for choosing a 20-year timeframe. First, the period of research, before any commercial value could be realised, is three years. It is then assumed that further industry development and capital investment is required over two years to produce lower cost EWPs such that the first lower cost mass timber CLT-GLT panels, posts and beams do not enter the market until Year-6. Third, it is assumed that it will take a number of years for these products to gain market share as further productivity gains reduce the relative price of CLT-GLT. Fourth, as a result the total market

⁴⁰ Both CBA-1 and CBA-2 abstract from the economic impact of the Australian Government’s response to COVID-19 (see discussion at section 3.4.2). The industry has advised that it expects strong growth in market demand for CLT and GLT products over the next 5 years. The high growth rates specified by industry before the academic research is commercialised impacts indirectly on the final results of the study because the size of the industry (and hence net benefits) is significantly larger.

⁴¹ General assumptions around CBA timeframes and discount rates are discussed in Chapter 3.

adjustment process does not settle back into equilibrium until towards Year-20. Fifth, the benefits of the research and the new products are long-lived. For example, it is assumed that the research is continually augmented and built on, like most academic research. Further, the residential and commercial buildings produced generally have lives of at least 20 years, thus provided a stream of benefits lasting at least two decades.

5.3 Incremental costs of PR002 and PR015

This section sets out the incremental costs of the two research projects. There are two categories of incremental costs, being: (i) the initial project investment, capital costs and ongoing R&D costs, and (ii) the resources costs involved in manufacturing and installing CLT-GLT mass panels.

5.3.1 Initial project investment and ongoing R&D costs

In the CPC scenario, the incremental costs associated with PR002 and PR015 are equal to:

- The sum of the project investment over the life of the two research projects (being 3-years), being \$1.4 million;
- The costs of additional academic research undertaken globally with the same (or very similar) project goals to PR002 and PR015 where it is assumed that FTH contributes 15 percent of the global research effort towards achieving the project goals, being \$7.7 million;
- Additional up-front capital costs in Year-4 and Year-5 of \$11.2 million; and
- Ongoing industry R&D investment (at 1 percent of annual industry value-added) directed towards the same (or very similar) goals in relation to lowering the delivered cost of CLT-GLT, being \$6.3 million.⁴²

In order to appropriately attribute the economic benefits of the research to the ARC FTH program, the international research in the same field over the same period is counted since academic research is widely shared, utilised and freely available among academics. Therefore, from an economic point of view, the global academic research effort must be set against the potential benefits of the research.

The total costs of the research project (PR002 and PR015), except for the resources costs involved in production, is \$26.6 million (see Table 5-1 below).

Table 5-1. Initial ARC and in-kind funding, and ongoing R&D, PR002 and PR015

	Category	Amount (\$2020)
	PR002 FTH investment (Years 1,2,3)	\$1,218,625
	PR015 FTH investment (Years 1,2,3)	\$140,443
	Other similar academic research (globally) (Years 1,2,3) ^a	\$7,701,385
	Additional capital investment (Years 4,5)	\$11,239,033
	Additional Australian industry R&D (Years 4 to 25) ^b	\$6,262,098
	Total investment (25-years)	\$26,562,585

Source: ARC grant applications and Tulipwood Economics analysis. Notes: **a** It is assumed that the effort to reduce the relative cost of CLT is global and hence an estimate of similar research undertaken elsewhere is included, such that FTH research represents 15% of all research globally. This is considered a conservative assumption **b** Industry research is assumed to be ongoing at 1% of industry value-added per year. This is considered a reasonable, or mid-point, assumption.

⁴² These figures are in real terms and undiscounted.

5.3.2 Resources costs in manufacturing and installation

The resources costs involved in manufacturing and installing CLT-GLT panels are not accounted for in this cost section. These costs are 'netted out' in the estimation of incremental benefits. That is, the difference in manufacturing and installation costs between the BAU and Policy Case scenarios is identified as an incremental benefit (see section 4.2 below).

5.4 Incremental benefits assumptions

This section provides more supporting evidence to the major assumptions made in relation to a declining price (cost) and increased domestic production that have been set out above.

5.4.1 Time saved due to prefabrication of EWP

Time-saving estimates for the prefabrication of EWPs relative to alternatives vary. That said, the evidence that prefabrication of EWP panels can result in significant time (labour) savings is strong.

Whereas traditional concrete multi-storey buildings are assembled fully on site, with engineered wood timber systems most of the construction is undertaken in the factory with only the assembly of modules completed on the building site (see picture below). Time spent at the building site can be up to half (in person-hours) compared to the counter-factual in multi-storey construction, generating substantial cost savings and improving competitiveness.⁴³

There are additional cost benefits with EWPs related to the materials relatively light weight, which can result in time save, lower costs of transportation, lighter foundations and smaller cranes and other equipment.⁴⁴



5.4.2 Learning-by-doing productivity gains

Given the construction of buildings using CLT and EWPs is in its relative infancy improvements to on-site productivity, CLT supply chains, skill levels of construction industry workforce will be expected to rise with increasing familiarity – as is the case with all new technologies. Arguably, learning and adapting to off-site prefabrication methods will take time, including issues related to regulation, transportation logistics, coordination with designers, and industry knowledge about installation. To

⁴³ https://www.efi.int/sites/default/files/files/publication-bank/2018/tr_91.pdf See Lehman 2012 and Mahapatra & Gustavsson 2009

⁴⁴ (Mahapatra & Gustavsson 2009a). (FPAC & FPInnovations 2013).

account for this in the analysis, the cost reductions associated with CLT are assumed to increase gradually over time (see section 4.3.1 above).

Attempting to disaggregate and separately quantify impacts beyond the assumptions made in section 4.3.1 would imply a false precision given the extent of unknown variables. That said, this analysis has estimated labour cost savings (of eventually 10 percent) due to shorter construction times to support the productivity assumptions. This assumption alone is sufficient to account for the overall assumed productivity gains over time.

5.4.3 Environmental benefits

There is clear evidence that the increased use of CLT relative to concrete and steel provides an environmental benefit of lower carbon use. While it is true that CLT manufacturing is carbon intensive, concrete and steel making is more carbon intensive. Further, the installation of concrete and structure structures is more carbon intensive than CLT installation because of the heavier equipment (and more fuel) required. Finally, the embedded carbon in timber is permanently captured (or sequestered). In other words, the removal of a tree for use as CLT does not add to carbon emissions in a carbon accounting framework.

In summary, it is assumed that:

- Carbon emissions in the construction industry is lowered due to the switch away from high embodied carbon products like steel, concrete and plasterboard;
- There is a greater use of renewable timber with associated carbon sequestration and sustainability benefits;
- Increased recyclability of building materials in construction industry and reduced timber waste; and
- Lower embodied CO₂ - as CLT is renewable resource which requires substantially lower energy use relative to construction materials such as steel, concrete and plasterboard.

The total reduction in construction costs due to the project is estimated by first calculating the cost savings and other benefits of using additional CLT in construction at the unit level. This comprises the sum of reduced materials costs, times saved and efficiency benefits and other cost savings from the use of CLT. For this calculation the base unit used is a cubic metre (m³) of CLT. Economy-wide benefits are then calculated by multiplying these unit level benefit estimates by the expected total CLT usage in the construction sector.

In the Central Policy Case, it is assumed that the growth in local CLT production offsets CLT imports with no overall growth in the market. Accordingly, these environmental benefits are not included in the Central Policy Case estimates, but rather in the sensitivity analysis (see Appendix B).

5.4.4 Broader macroeconomic and social impacts

This analysis does not explicitly model and quantify the potential economy-wide impacts from a more rapid development of an Australian CLT industry identified above other than in relation to achieving economies of scale and related gains in productivity and value-added. Similarly, broader social impacts are not measured in this study.

5.4.5 Direct cost comparisons

There have been a number of studies comparing the installed cost of CLT relative to concrete and steel, and more traditional timber frames. Generally, the evidence is strong for slight cost advantages for CLT vis-à-vis concrete and steel for specific building designs such as mid-rise residential and commercial buildings. For buildings higher than about 35 metres, CLT becomes prohibitively expensive for reasons related to weight and lateral strength.

It has been estimated that the overall cost of constructing buildings in North America in recent years appears to be broadly similar for CLT vis-à-vis concrete and steel.⁴⁵ For example, a 2017 study found CLT to be slightly cheaper by between 0.6 and 1.4 percent (Oregon Best, 2017).⁴⁶ Others claim time savings of as much as 30 per cent, however little evidence is available to support these claims of significant cost differences.⁴⁷ And some studies put the cost of CLT construction higher than conventional concrete and steel.⁴⁸

5.5 Incremental benefits estimates

There are a number of incremental benefits that have been identified in relation to the increased use of CLT-GLT for residential and commercial construction. These benefits relate to the unique characteristics of CLT-GLT vis-à-vis the main building material substitutes, such as concrete and steel, and traditional timber frames.

5.5.1 Declining variable costs lead to greater per unit value-added

Relative to the BAU scenario, in the Central Policy Case scenario it is assumed that the ARC FTH research (and related global research) leads to a reduction in the delivered cost of CLT mass panels and GLT posts and beams.⁴⁹ Further, it is assumed that ongoing industry R&D supports continual productivity improvements over the 20-year project period.

In the CPC scenario, it is assumed that the ARC FTH research meets its stated objectives and is successful in leading to the following impacts:

- Lower materials cost of manufactured CLT-GLT panels and beams;
- Lower total labour costs due to shorter building times and increased productivity resulting from greater use of prefabricated CLT-GLT, which is also easier to handle and work relative to heavier products such as steel and concrete and less time spent installing plasterboard, taping and jointing/finishing etc;
- Lower capital costs through the need for less heavy equipment for construction due to lighter weight building materials;
- Greater flexibility in building design due to the smaller and lighter foundations;
- Greater competition among building material supply businesses due to the increase in choice of construction materials; and
- Consequently, an increase in the market share of domestically manufactured CLT-GLT whereby a portion of the reduction in resource costs is 'clawed back' in the form of higher wages and profits.

The last dot point is supported by economic theory and empirical experience. In markets which are not perfectly competitive, suppliers are able to claw back some of their cost advantage in higher returns to the factors of production, being labour (wages) and capital (profits). For example, in an imperfectly competitive market, a supplier whose costs of production are 10% lower than the next cheapest supplier, can set their own price, say, 5% below the next cheapest supplier and retain the other 5% in higher wages and profits and still be the lowest cost supplier and gain the greatest market share.

⁴⁵ In this study, we assume a very small cost advantage to CLT over concrete and steel in the second half of the project period.

⁴⁶ Oregon Best. 2017. Advanced wood product manufacturing study for cross-laminated timber acceleration in Oregon and SW Washington. Available at: https://www.oregon4biz.com/assets/docs/CLT_Mfg_2017OregonBEST.pdf

⁴⁷ <https://www.xlam.co.nz/Why-XLam.html#economic-benefits>

⁴⁸ <https://buildingresiliencoalition.org/comparing-the-costs-of-cross-laminated-timber-clt-and-cast-in-place-reinforced-concrete-structures/>

⁴⁹ Evidence of cost relativities is provided in Chapter 2.

5.5.2 Price estimates

In order to account for the combined effects of a reduction in the CLT and GLT price over time, the analysis constructs a blended or composite CLT-GLT price, which accounts for their respective wholesale prices (delivered to the building site) based on their average market share in residential and commercial construction (being 80:20 in CLT's favour).

Taken together, we have conservatively modelled a number of scenarios whereby the real resources costs of manufacturing and installing a composite CLT-GLT product decline over time relative to the real price of installed concrete and steel. The composite CLT-GLT product takes the median wholesale price of delivered CLT (at \$1,250) and the median wholesale price of delivered GLT (at \$2,500) to arrive at a blended price of \$1,500 per cubic metre. This figure represents an 80:20 split in resource use in CLTs favour. Installation costs are then added, including resources costs, and a labour and profit component to arrive at a final composite CLT-GLT installed price, as follows:

- In the BAU scenario, in Year-1 the CLT-GLT composite installed price is \$2,667 per m³, which includes the additional resources costs of installation (i.e. plasterboard and other fittings) and returns to labour (wages) and capital (profit). This price remains constant in real terms over the 20-year project period.
- In the CPC scenario, the Year-1 CLT-GLT composite installation price is \$2,667 per m³, which includes the additional resources costs of installation (i.e. plasterboard and other fittings) and returns to labour (wages) and capital (profit). This initial price then declines over time.
- In the CPC scenario, over a 14-year period (from Year-6 to Year-20), the installed cost/price of 1 cubic metre of the CLT-GLT composite product declines by 12.3 percent in real terms. This reduction is caused by an initial 10.0% reduction in the delivered wholesale price of the CLT-GLT composite in Year-6 (reflecting the immediate benefit of the academic research and industry R&D), followed by an annual 'learning-by-doing' productivity reduction of 1.0% per year from Year-7 to Year-20.
- In order to evaluate the isolated impact of the reduction in the price of the CLT-GLT composite, the cost of related installation materials remains unchanged in real terms (i.e. 2020 dollars).
- Returns to labour (i.e. wages) remain unchanged (although its share rises as a percentage of the total price, reflecting an increase in labour value-added).
- Returns to capital (i.e. profit) remain unchanged (although its share rises as a percentage of the total price, reflecting an increase in capital value-added).
- Overall, the value-added share (wages plus profits inclusive of taxes paid) of the total price rises by 3.5 percentage points from 25.0% to 28.5%.
- Overall, in the Central Policy Case scenario over the 20-year period, the installed price of the CLT-GLT composite product per cubic metre (in real terms) declines by 12.3 percent relative to the BAU (Table 6-3 and Figure 5-1 below).

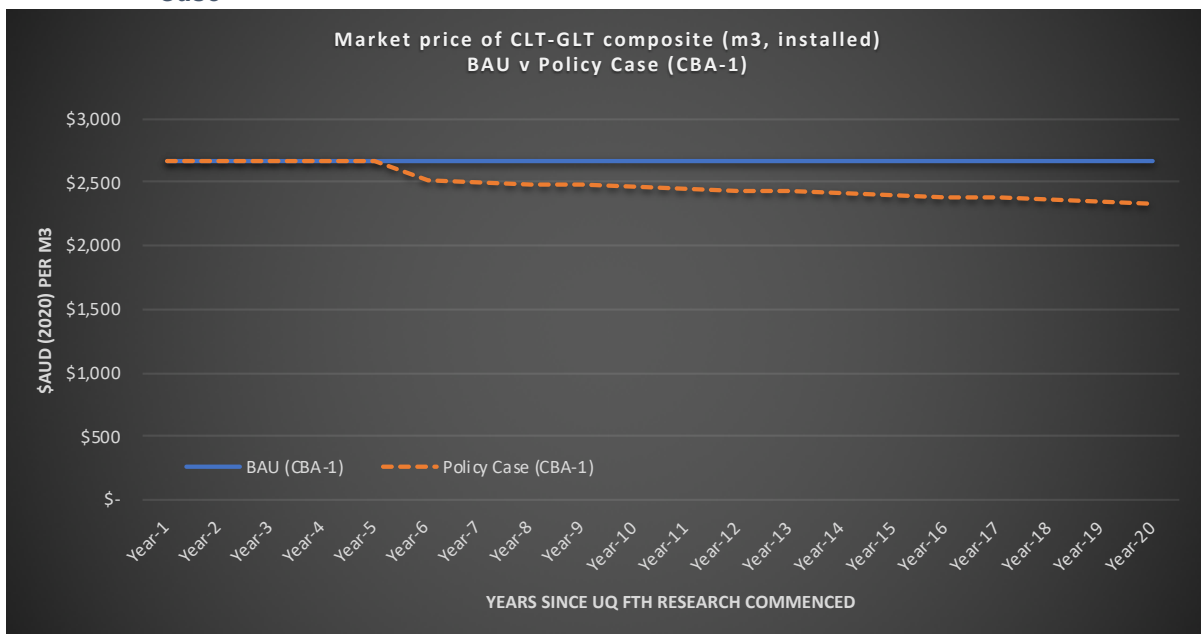
Table 5-2. Change in installed price of CLT-GLT composite, BAU v Central Policy Case (Year-1 v Year-20), CBA-1

Description (CLT-GLT) (\$AUD, 2020)	Cost per m ³		Change (%)
	BAU (Year-1 to Year-20)	Policy Case (Year-20)	
Delivered to building site (per m ³)	\$1,500	\$1,173	-21.8%
Additional costs of installation (per m ³)	\$500	\$500	-
Labour costs of installation (per m ³)	\$467	\$467	-
Profit (per m ³)	\$200	\$200	-
Price (installed, per m ³)	\$2,667	\$2,339	-12.3%
Value-Added share (%)	25.0%	27.5%	+3.5pp

Source: Tulipwood Economics. pp = percentage points.

Figure 5-1 (below) illustrates the assumed decline in the installed wholesale price of the CLT-GLT composite product relative to the BAU scenario, from \$2,667 per cubic metre in Year-1 to \$2,339 per cubic metre in Year-20. As a result of this decline in price, CLT-GLT's market share increases (see section 4.3.2 below) and the value-added proportion in the total price increases by 3.5 percentage points.

Figure 5-1 Market price of installed CLT-GLT composite (covered, m³), BAU v Central Policy Case



Source: Tulipwood Economics estimates.

5.5.3 Market demand estimates

Increased use of CLT-GLT in the Australian construction sector relative to a BAU scenario would be expected to drive higher rates of growth and profitability in the Australian timber industry due to:

- Less resources are used to make the same thing. As a result, the share of value-added in the final price of the CLT-GLT composite is higher.

- Increased domestic production for CLT-GLT at the import competing price (or lower) reduces imports and, as a result (all things being equal) increases GDP.
- In the high-growth scenario, switching from concrete and steel to CLT-GLT has a positive impact on industry value-added.
- Development of a stronger domestic CLT industry would be expected to result in some firms also looking to also grow export markets for new CLT products using Australian timber (thus increasing GDP); and
- Lowering Australia's carbon emissions and helping Australia meet its domestic and international carbon emissions targets.⁵⁰

Estimates about the potential for CLT-GLT growth in Australia vary widely (see discussion at Chapter 2). In this analysis we have taken a conservative approach where data is difficult to obtain or interpret.

In Year-1 it is assumed that the total market demand for CLT-GLT in Australia is 75,000 cubic metres, comprising 40,000 cubic metres produced domestically and 35,000 cubic metres imported.⁵¹ These Year-1 figures relate to current (2020) estimates of domestic market demand for CLT-GLT (i.e. with plasterboard).

Of this total, a small proportion is subtracted to represent the 'exposed CLT-GLT' segment of the market, which is the subject of the CBA-2 analysis. Accordingly, 3,750 cubic metres of CLT-GLT is taken from this analysis, leaving only the 'covered CLT-GLT' market at 71,250 cubic metres.

Figure 5-2 (below) illustrates the growth in total Australian market demand (domestic production plus imports) for CLT and GLT (combining CBA-1 and CBA-2). Growth in the initial years (before FTH research is commercialised in Year-6) is already strong, reflecting current industry growth estimates in the short-term.⁵²

In the BAU scenario, growth in domestic production averages 12.3 percent per year over the 20-year period. Import growth remains fixed at 3 percent per year in the BAU scenario. Overall, growth averages 9.1 percent per year in the BAU. Initially, growth is strong reflecting current industry prospects before levelling off at more sustainable levels. The domestic production growth rate in Year-19 is 3.0 percent, reflecting the long-run growth rate of the Australian residential and commercial construction industry.⁵³

In the three policy case scenarios, domestic production matches the BAU scenario in Years 1-6, after which growth is stronger, reflecting the successful commercialisation of FTH research. Supporting this, there is also additional capital investment in plant and equipment in Years 5 and 6 (Figure 5-2).

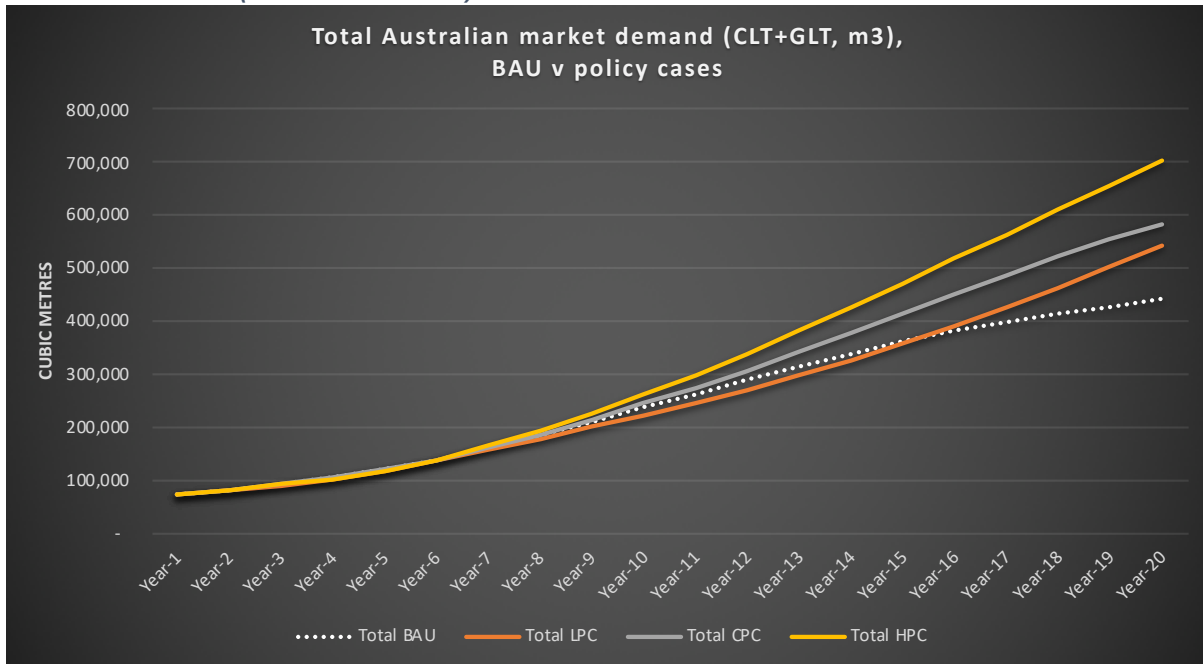
⁵⁰ The last two impacts (dot points) identified have not been modelled at this stage due to either the small size of the impact or the difficulty in measuring the effects.

⁵¹ These assumptions are based on industry feedback during interviews and various market reports. A full discussion can be found in Chapter 2. Note that the analysis in CBA-1 relates to 'covered CLT-GLT' (i.e. with plasterboard) whereas the analysis in CBA-2 relates to 'exposed CLT-GLT' (i.e. without plasterboard). Total domestic production for covered and exposed CLT-GLT in Australia is assumed to be 40,000 cubic metres in Year-1.

⁵² These estimates abstract from the impact of COVID-19 on the global and Australian economies.

⁵³ See ABS 5204.0 Australian System of National Accounts (2018-19), Table 6 (column V).

Figure 5-2. Total market demand (production plus imports) for CLT plus GLT, BAU v policy cases (Year-1 to Year-20)



Source: Tulipwood Economics analysis. Note Figure 5.2 illustrates total market demand for the combined CBA-1 and CBA-2 scenarios. Because the growth in imports is assumed to be constant, the slope of the lines reflect growth in domestic production.

Table 5-3 (below) reports the Year-1 and Year-20 market for CLT-GLT by source of production in the CBA-1 case. Domestic production rises from 38,000 cubic metres to 343,748 cubic metres in Year-20. Imports rise by 3.0 percent per year from 33,250 cubic metres to 58,304 cubic metres per year. The growth in the market is absorbed by an increase in domestic production in the BAU scenario. In the Central Policy Case (CPC) scenario, domestic production increases from 38,000 cubic metres in Year-1 to be 484,184 cubic metres in Year-20. Imports are assumed to increase at the same rate as under the BAU scenatium. Overall, the difference in growth between the BAU and CPC scenarios is 2.2 per cent (being 11.3% less 9.1%).

Table 5-3. CBA-1 growth in CLT-GLT production, CPC domestic manufacturing v imports (Year-1, Year-20)

Scenario	BAU (cubic metres produced)			CPC (cubic metres produced)		
Source of production	Domestic	Imports	Total	Domestic	Imports	Total
Year-1	38,000	33,250	71,250	38,000	33,250	71,250
Year-20	343,748	58,304	402,052	484,184	58,304	542,488
CAGR (%)	12.3%	3.0%	9.1%	14.3%	3.0%	11.3%

Source: Tulipwood Economics analysis. CAGR = Compound Annual Growth Rate (%).

5.6 Results of CBA-1

The results of CBA-1 are set out below. In the Central Policy Case scenario, we found that:

- The present value of the **net benefits** of the two projects PR002 and PR015 (CBA-1) over the 20-year timeframe is **\$119.9 million** (at the 7% social discount rate);
- The present value of the total benefits amounts to \$148.9 million and the present value of total costs amount to \$29.0 million;

- Accordingly, the **benefit-cost ratio (BCR)** is calculated to be **5.1 times** (at the 7% social discount rate). The BCR is calculated to be 6.2 times at the 5% social discount rate; and
- The internal rate of return (IRR) of the research investment is calculated to be **24%** (

Table 5-4 (below) reports the results of CBA-1 under the three key social discount rates.

- Table 5-4).⁵⁴

Table 5-4 (below) reports the results of CBA-1 under the three key social discount rates.

Table 5-4. Results of CBA-1, PR002 and PR015

Parameter	\$m (NPV, 5%)	\$m (NPV, 7%)	\$m (NPV, 9%)
Net benefits (NPV)	\$171.1	\$119.9	\$83.7
Present value of total benefits	\$203.9	\$148.9	\$109.7
Present value of total costs	\$32.8	\$29.0	\$25.9
BCR	6.2	5.1	4.2
IRR	24%	24%	24%

Source: Tulipwood Economics analysis. Central Policy Case under various discount rates.

5.7 Sensitivity analysis

5.7.1 Input parameters varied

A sensitivity analysis was undertaken to determine the robustness of the assumptions made in this study. These assumptions can be categorised in terms of costs and benefits. In terms of costs, the three main input parameters are:

- The initial project investment of PR002 and PR015;
- The global academic research investment in objectives very similar to PR002 and PR015; and
- Ongoing industry investment to support continual productivity improvements in CLT-GLT manufacturing and installation.

In terms of benefits, there are five primary inputs parameters, as follows:

- The rate of ramp-up in domestic production in Year-6 (i.e. the 'shape' of the ramp-up curve);
- The rate of growth in demand post ramp-up (from Year-7 to Year-20);
- The share of value-added (being wages and profits) in the installed price of CLT-GLT, and the rate of change in the share of value-added over time; and
- The trajectory of the relative price of CLT-GLT vis-à-vis concrete and steel (HPC only); and

The environmental benefits of switching from concrete and steel to CLT-GLT (HPC only), (

⁵⁴ The calculated IRR is the same regardless of the discount rate.

Table 5-5 (below) illustrates the variation in input parameters in the LPC, CPC and HPC scenarios. In terms of costs, industry R&D investment is varied by 0.25 percentage points across the three scenarios whereby a lower level of industry investment would result in a higher level of net benefits all else being equal. Additional capital costs are varied by 2.5 percentage points, ranging from a low of 17.5 percent to a high of 22.5 percent. These fixed costs rise as demand rises such that a higher amount of capital investment is required to meet a higher demand of mass timber panels. Finally, in the LPC it is assumed that FTH research accounts for a lower share of global research (thus raising overall research costs), and in the HPC it is assumed that FTH research accounts for a higher share of global research costs (thus lowering overall research costs).

- Table 5-5).

Table 5-5 (below) illustrates the variation in input parameters in the LPC, CPC and HPC scenarios. In terms of costs, industry R&D investment is varied by 0.25 percentage points across the three scenarios whereby a lower level of industry investment would result in a higher level of net benefits all else being equal. Additional capital costs are varied by 2.5 percentage points, ranging from a low of 17.5 percent to a high of 22.5 percent. These fixed costs rise as demand rises such that a higher amount of capital investment is required to meet a higher demand of mass timber panels. Finally, in the LPC it is assumed that FTH research accounts for a lower share of global research (thus raising overall research costs), and in the HPC it is assumed that FTH research accounts for a higher share of global research costs (thus lowering overall research costs).

Table 5-5. CBA-1 sensitivity analysis, variation in input parameters

Parameter	LPC	CPC	HPC
Costs			
Industry R&D investment (Years 4-20), (% of industry value-added)	1.25%	1.00%	0.75%
Additional capital costs (Year 4 and Year 5), (% additional industry value-add)	22.5%	20.0%	17.5%
FTH share of global academic EWP research	12.5%	15.0%	17.5%
Benefits			
Domestic production CLT+GLT (Year-20), (m ³)	455,445	484,184	593,155
Annual Import growth (CPC)	3.00%	3.00%	3.00%
Value-added share of CLT-GLT total revenue (Wages + Profits + Taxes), (Year-20)	27.5%	28.5%	30.5%
Price of CLT-GLT relative to concrete and steel (Year-20)	n/a	n/a	-5.0%
Environmental benefits of switching from concrete and steel to CLT-GLT (\$ per tonne carbon emissions saved, concrete & steel)	n/a	n/a	\$16

Source: Tulipwood Economics analysis.

5.7.2 Results

Varying the input parameters as described above has had a significant effect on the estimated results. The net present value of net benefits of PR002 and PR015 (CBA-1) ranges between \$6.0 million (LPC) to 279.0 million (HPC) over the 20-year period at a social discount rate of 7 percent. The corresponding BCR's are: 1.2 (LPC), 5.1 (CPC) and 9.8 (HPC). The corresponding IRR's are: 8% (LPC), 24% (CPC) and 35% (HPC) (Table 5-6).

The conclusions of the Central Policy Case scenario analysis remain robust to adjustments in input parameters (

Table 5-6).

Table 5-6. CBA-1 Sensitivity analysis, (NPV, 7%)

Parameter	LOW POLICY CASE	CENTRAL POLICY CASE	HIGH POLICY CASE
Net benefits (NPV)	\$6.0	\$119.9	\$279.0
Present value of total benefits	\$35.9	\$148.9	\$310.6
Present value of total costs	\$29.9	\$29.0	\$31.6
BCR	1.2	5.1	9.8
IRR	8%	24%	35%

Source: Tulipwood Economics estimates.

5.8 Conclusion

This chapter set out the analysis and results of CBA-1. The analysis undertaken here suggests that, based on a reasonable set of assumptions, the expected net benefits of CBA-1 (PR002 and PR015) are likely to be positive and provide benefits to the Australian community. As part of this, the domestic CLT-GLT manufacturing sector is expected to expand providing higher value-added returns to workers and owners of capital than in the BAU scenario.

In the Central Case scenario, at a social discount rate of **7 per cent**, the present value of the net benefits of CBA-1 (PR002 and PR015) is **\$119.9 million**, the **BCR is 5.1 times** and the **IRR is 24 percent**.

In the Central Case scenario, at a social discount rate of **5 per cent**, the present value of the net benefits of CBA-1 (PR002 and PR015) is **\$171.1 million**, the **BCR is 6.2 times** and the **IRR is 24 percent**.

6. CBA-2: Providing greater industry confidence in exposed EWPs (PR014 and PR019)

6.1 Introduction

A number of the most beautifully designed and aesthetically pleasing buildings constructed in this century have been built using exposed EWPs such as CLT and GLT. Timber framed buildings such as the eight-story Wood Innovation and Design Centre in Prince George Canada and “The Tree”, a fourteen-story residential apartment building in Bergen Norway, are highly celebrated as examples of all-timber construction.^{55,56}

In Australia, using EWPs as the core structure of mid-rise residential and commercial buildings has yet to really ‘take off’ relative to the growth in Europe and North America, arguably constrained by a lack of industry knowledge and confidence in new EWP materials and techniques, little information about cost advantages, and associated real and perceived regulatory barriers.

That said, there are a few notable mid-rise timber buildings that have been successfully completed, such as 25King Street in Brisbane (a commercial office building), the Forté mid-rise luxury apartment tower in the Docklands of Melbourne and the ‘Library at the Dock’, built on the waterfront of Victoria Harbour in 2014 and Australia’s very first CLT public building.⁵⁷ Nevertheless, it is early days in Australia for EWP buildings.

This chapter describes the analysis and results of CBA-2 (PR014 and PR019), which is related to the commercial potential of exposed CLT-GLT. The chapter considers the growth potential for the use of CLT-GLT that is not covered with plasterboard (aka Gyprock) in residential and commercial mid-rise buildings following the successful completion of research that better clarifies the fire safety and strength (connection) properties of CLT-GLT in mid-rise timber framed buildings. In this regard, PR014 (fire properties) is focussed on CLT, and PR019 (connector strength) is focussed on GLT.

6.2 Regulatory background

In Australia, the use of EWPs in tall residential buildings was effectively prohibited prior to 2016 under the National Construction Code (NCC), which was first adopted by the Australian States and Territories as a national code in 2011. Moreover, highly restrictive legislation was in place throughout the second half of the 20th century to reduce the incidence of fires in residential and commercial buildings. In 2016, changes to the NCC (via COAG agreement) were made which allowed their use as an exposed material for the first time.^{58, 59}

The 2016 NCC changes created a voluntary prescriptive performance (previously known as a ‘deemed-to-satisfy’ solution) for the use of timber building systems in Class 2 (apartments), Class 3 (hotels) and Class 5 (office) buildings up to 25 metres in effective height. Covering both traditional timber framing and innovative massive timber systems such as CLT and GLT, the 2016 provisions required the use of appropriate layers of fire-resistant materials and sprinkler systems. A key provision of the 2016 changes was that all fire-protected timber building systems must be encapsulated in a non-combustible fire-protective covering of at least two layers of fire-protective grade plasterboard. Under the pre-2016 Code, timber building systems had been restricted to three storeys under the NCC’s deemed-to-satisfy provisions, with taller buildings requiring an ‘alternative solution’ to be designed and documented to gain approval. While practical on larger projects, alternative solutions were generally considered too costly for smaller jobs.

In 2019, further changes were made to the NCC to move away from prescriptive measures and towards a performance-based code. This change has increased the range of buildings, up to an

⁵⁵ <https://www.archdaily.com/630264/wood-innovation-design-centre-michael-green-architecture>

⁵⁶ <https://www.buildup.eu/en/practices/cases/treet-wooden-high-rise-building-excellent-energy-performance>

⁵⁷ <https://www.aurecongroup.com/projects/property/25-king>

⁵⁸ <https://ncc.abcb.gov.au/ncc-online/About>

⁵⁹ <https://ncc.abcb.gov.au/ncc-online/NCC>

effective height of 25m, typically eight stories, in which fire-protected timber construction systems can be used. The new classifications potentially add schools, retail premises, hospitals and aged care facilities to the previously approved multi-residential, hospitality accommodation and office buildings (see Box 2 below).

State bodies responsible for fire safety, such as QFES in Queensland, seem ready to assess these new EWP buildings on their merits in terms of safety. For example, in the case of 25King Street in Brisbane, at the project inception there were approximately thirteen variations from prescriptive building compliance clauses being proposed. However, as the building was predominantly timber, laminated and considered significantly different from the prescriptive code basis, the fire safety design needed to be demonstrated against fire performance targets, rather than assessed and being comparative equivalent to a standard code-approved building. This has been an important change to the regulations, because it allows building designers to demonstrate that an EWP building meets a safety standard rather than meets a list of prescriptive requirements.⁶⁰

6.3 General approach to CBA-2

The objectives of PR014 (self-extinguishment mechanism of EWPs) and PR019 (progressive collapse resistance of tall-frame timber buildings) are to increase the knowledge base of EWPs (in particular, CLT and GLT) in Australia and consequently provide greater industry confidence to the domestic market.

The analysis presented in this chapter is organised in a format broadly in line with the accepted approach for Regulatory Impact Analysis agreed to by the Australian Government's Office of Best Practice Regulation (OBPR) best practice regulation framework and principles.⁶¹ This approach reflects the fact that the National Construction Code has been developed consistent with the principles of best practice regulation, and any future amendments to the Code developed as new information and understanding of the properties and safe usage of CLT and GLT emerges through research projects such as PR014 and PR019 would need to be subject to detailed Regulation Impact Assessment (RIA) before adoption. Given that the two ARC FTH projects to which this CBA-2 relates are already underway, the analysis presented in this chapter is also partly reflective of the Post-Implementation Review (PIR) approach developed by the OBPR.

6.3.1 Self-extinguishment mechanism of engineered timber (PR014)

During 2019, the research project PR014 – Exploring the self-extinguishment mechanism of engineered timber in full-scale compartment fires commenced testing to explore the extent to which engineered timber (like CLT) is fire resistant. The work is being undertaken by ARC Future Timber Hub researchers assisted by researchers from The University of Queensland (UQ) Fire Safety Engineering Research Group. To date four full scale tests have been undertaken with further tests due in 2020.

The objective of this ARC FTH project is to establish design criteria for the fire-safe use of CLT in tall-timber buildings by investigation of the self-extinguishment mechanism of CLT.

The aim is to provide a methodology to establish criteria for self-extinguishment of CLT at a full-scale, considering complexities such as delamination failure, encapsulation failure, and rate of exposure of timber surfaces. The framework is intended to be validated using an experimental approach based on large-scale compartment tests where the different failure modes can be isolated.

Specific objectives include:

- Evaluate fundamental self-extinguishment criteria (critical external heat flux and pyrolysis rate) in various scales.

⁶⁰ <https://www.aurecongroup.com/projects/property/25-king>

⁶¹ <https://www.pmc.gov.au/regulation>

- Determine conditions and time-scale of delamination that prevent self-extinguishment at a full-scale.
- Determine conditions and time-scale of encapsulation that prevent self-extinguishment at a full-scale.
- Determine whether fully exposed timber compartments may achieve self-extinguishment if delamination is controlled.

Box 6-1. NCC requirements for timber construction systems (2016 vis-à-vis 2019)

In 2016, a Deemed-to-Satisfy solution was introduced to the NCC permitting, for the first time, construction in fire-protected timber building systems (including both traditional lightweight timber framing as well as EWP's such as CLT) to an effective height of 25 metres (typically 8 storeys) for class 2 (apartment), 3 (hotel) and 5 (office) buildings. These provisions were extended in 2019 to include all classes of building, which allowed the use of timber building systems in aged accommodation, schools, retail and hospitals.

NCC 2019 Volume Three Amendment 1 Specification C1.13a Fire-protected timber, 2.1 General requirements states:

“Fire-protected timber must utilise a non-combustible fire-protective covering fixed in accordance with the system requirements to achieve an FRL not less than that required for the building element; and have a non-combustible fire-protective covering fixed in accordance with system requirements ... which consists of not less than 2 layers of 13 mm thick, fire-protective grade plasterboard.”⁶²

NCC 2019 Amendment 1 is expected to be adopted by States and Territories from 1 July 2020.

Deemed to satisfy solutions such as this mean that builders and developers who want to work with timber face a less time-consuming and expensive process to gain building approval than is required for performance-based solutions. The changes provide the opportunity for designers to make greater use of CLT in Australian buildings in a wide range of different ways, including, for example, mixed use mid-rise timber buildings, with residential upper levels and lower levels used for office space or retail. An important related change introduced to the NCC last year means that all Class 2 and 3 buildings four stories or above in height, must now be sprinkler protected. It is expected that the cost of this will be significantly offset by greater flexibility provided by new concessions for sprinkler protected Class 2 and 3 buildings. These new concessions include some reductions in fire resistance levels and extended travel distances which may translate to potentially improving lettable space within buildings.⁶³

Source: <https://ncc.abcb.gov.au/ncc-online/About>

6.3.2 Progressive collapse resistance of tall-frame timber buildings (PR019)

There is a need to better understand the structural performance characteristics of tall timber-framed buildings that utilise EWP's. This particular ARC FTH project is a vital part of that attempt to increase the understanding of what GLT is capable of and under what circumstances. For instance, under what conditions (such as building height and overall size) are GLT structural buildings just as safe, or able to bear similar loads to concrete and steel frames. What width can GLT beams handle relative to concrete and steel. And what is the cost differential between the two approaches, accounting for an equivalent minimum safety level and environmental costs?

One obvious benefit from this increase in knowledge is that:

“If you know your design is safe, you won't need to over-specify the use of materials in construction, which leads to capital cost savings.”⁶⁴

⁶² <https://ncc.abcb.gov.au/ncc-online/NCC/2019-A1/NCC-2019-Volume-One-Amendment-1/Section-C-Fire-Resistance/Specification-C113A-FireProtected-Timber>

⁶³ <https://www.woodsolutions.com.au/blog/2019-changes-national-construction-code-ncc>

⁶⁴ Feedback from industry interviews held in April-May 2020.

Despite the steady increase in tall timber buildings globally, arguably there is insufficient understanding of the design performance of the connectors that hold together GLT posts and beams. This lack of understanding (and consequently regulatory clarity) impacts on the commercial potential of mid-rise timber framed buildings. The core project objective of PR019 is to provide 'design guidance' for a more robust connector that assists industry by providing a much clearer picture of the connector's capabilities.

6.4 Scenarios modelled

To assess the potential costs and benefits of the two ARC FTH UQ research projects PR014 and PR019 two scenarios were specified and compared:

- A Business as Usual (BAU) case, in which the research did not take place and, consequently, the existing specifications in the National Construction Code and level of industry understanding (and, relatedly, level of risk aversion) about the performance properties of CLT-GLT remain the same. Nonetheless, the Australian EWP timber market grows strongly in the first few years (before the academic research is produced) as advised by industry.⁶⁵ Towards Year-20, the industry returns to a long-run sustainable growth rate of 3 percent per year (the long-term industry growth rate) with no change in the import share.
- A Central Policy Case (CPC) scenario, in which the research successfully:
 - defines the fire-resistant properties of CLT to a degree that increases industry acceptance of CLT as a safe building material and paves the way for eventual amendments to the NCC allowing for the use of uncovered CLT (and GLT) in tall timber buildings – including buildings above 25 metres in height – resulting in increased CLT and GLT use and more rapid growth in domestic production; and
 - Identifies and classifies the progressive collapse properties of GLT and associated joinery in tall-frame timber buildings consequently leading to its increased use as a building material.⁶⁶

These two scenarios (BAU and CPC) were compared using cost and benefit projections over a 20-year time frame and standard discount rates based on a set of assumptions and data drawing on the best available information on the CLT-GLT and broader residential and commercial construction industry in Australia.⁶⁷

Productivity, environmental and social benefits are detailed below, along with a discussion of potential spill-over benefits to other industries, consumers and overseas.

6.5 Incremental costs of PR014 and PR019

This section sets out the incremental costs of the two projects (PR014 and PR019). There are two categories of incremental costs, being: (i) the initial project investment and ongoing R&D costs, and (ii) the resources costs involved in manufacturing and installing CLT mass panels and GLT posts and beams.

6.5.1 Initial project investment and ongoing R&D costs

In the Central Policy Case scenario, the incremental costs associated with PR014 and PR019 are equal to:

- The sum of the project investment over the life of the two research projects (being 3-years);

⁶⁵ The high growth rates specified by industry before the academic research is commercialised impacts indirectly on the final results of the study because the size of the industry (and hence net benefits) is significantly larger.

⁶⁶ A full description of the CBA methodology is provided in Chapter 3.

⁶⁷ General assumptions around CBA timeframes and discount rates are discussed in Chapter 3.

- The costs of additional academic research undertaken globally with the same (or very similar) project goals to PR014 and PR019 where it is assumed that FTH contributes 20 percent of the global research effort towards achieving the project goals;
- Additional capital investment (in Year-4 and Year-5) at 20 percent of total 'exposed-EWP' industry value-added to allow for new production processes; and
- Ongoing industry R&D (at 1 percent of annual industry value-added) directed towards the same (or very similar) goals in relation to better understanding the performance properties of CLT-GLT.

The reason that the total costs of the research project are counted is because we assume that in the counter-factual BAU case, the research did not take place. Similarly, in order to appropriately attribute the economic benefits of the research to the ARC FTH projects, the international research over the same period is counted since academic research is widely shared, utilised and freely available among academics (Table 6-1).

The total initial investment is described in the table below. The total investment, in real terms over the 20-year investment period is \$37.5 million. The initial ARC FTH investment can be seen as a catalysing investment to promote further industry investment through the investment period (at 1 percent of annual industry value-added).

Table 6-1. Initial ARC and in-kind funding, and ongoing R&D, PR014 and PR019

Category	Amount (\$AUD2020)
PR014 FTH investment (Years 1,2,3)	\$885,198
PR019 FTH investment (Years 1,2,3)	\$663,555
Other similar academic research (globally) (Years 1,2,3) ^a	\$6,195,012
Additional capital investment	\$539,426
Additional Australian industry R&D (Years 4 to 25) ^b	\$604,987
Total investment (25-years)	\$8,888,178

Source: ARC FTH grant applications and Tulipwood Economics analysis. Notes: **a** It is assumed that the effort to better understand the fire and strength properties of CLT-GLT is undertaken in a number of other academic institutes such that FTH research represents 20% of all research globally. **b** Industry research is assumed to be ongoing at 1% of industry revenue per year. This is considered to be a reasonable, or mid-point, assumption.

6.5.2 Resources costs in manufacturing and installation

The resources costs involved in manufacturing and installing CLT-GLT panels and posts and beams are not accounted for in this cost section. These costs are 'netted out' in the estimation of incremental benefits. That is, the difference in manufacturing and installation costs between the BAU and Policy Case scenarios is identified as an incremental benefit (see section 6.6 below).

6.6 Incremental benefits assumptions

6.6.1 Project outcomes, PR014 and PR019

To assess potential benefits from PR014 it is assumed that the research outputs produced by PR014 successfully define the fire-resistant properties of CLT and that appropriate fire safety levels can be achieved with the use of CLT used in multi-story buildings using solutions with lower (up to 50

percent) requirements for encapsulation with plasterboard.⁶⁸ It is further assumed that this research makes a material contribution to the development of either an acceptable performance solution which demonstrates compliance with the NCC performance requirements or, alternatively, drives a change in the deemed-to-satisfy requirements in the NCC for CLT use in timber construction systems which allows their use without encapsulation in plasterboard.

Similarly, to assess the benefits of PR019 it is assumed that the research outputs produced by PR019 successfully define the structural characteristics of connectors joining GLT posts and beams in mid-rise residential and commercial buildings. It is further assumed that this research makes a material contribution to the development of either an acceptable performance solution which demonstrates compliance with the NCC performance requirements or, alternatively, drives a change in the deemed-to-satisfy requirements in the NCC for GLT use in timber construction systems which allows greater use of GLT posts and beams.

6.6.2 Contribution of international research CLT-GLT construction

The strong growth in the use of CLT-GLT and other EWP's internationally has encouraged a growing number of research projects into aspects of CLT-GLT performance as a building material in residential and commercial buildings including related to fire-safety and the strength of connectors joining structural beams and posts.⁶⁹

It is assumed for the purposes of this study that current and future international research into fire resistance of CLT and the structural characteristics of connectors contribute to future changes to Australian specifications relating EWP's in the NCC. While Australia has its own residential and commercial building code designed for Australian industry and standards, the research that contributes to the development of the code is international in scope and freely available via academic publication protocols. Given this, it is reasonable to assume that international research would provide valuable input into the work of the FTH and, consequently, any future refinements to the NCC.

6.6.3 Building safety

The cost-benefit analysis assumes that the structural and fire safety of buildings under the new regulations remains unchanged in aggregate, in terms of risk of collapse, loss of life as well as general property damage. The requirement introduced in the 2019 changes to make sprinklers mandatory for all Class 2 and 3 buildings four stories or above in height, is assumed to keep the expected fatality rate the same under the BAU and the policy scenarios. In addition, it is assumed that revisions to building regulations liberalising the use of CLT in tall timber buildings are accompanied with requirements to ensure an equivalent level of safety, such as better access to fire exits, improved sprinkler systems.

6.6.4 Avoided costs

The research undertaken by the FTH (PR014, PR019) and others is assumed to provide greater confidence and associated regulatory changes such that there is an increase in the use of locally-manufactured exposed CLT in Australian building construction. The increased use of exposed CLT-GLT can reduce building constructions costs due to:

- Increased confidence in the structural characteristics of GLT posts and beams;
- lower materials cost resulting from a (up to 50%) reduction in use of plasterboard in buildings;
- lower labour costs due to shorter building times and increased productivity resulting from greater use of prefabricated CLT-GLT – which is also easier to handle and work relative to

⁶⁸ That is, the analysis conservatively assumes that no more than 50% less plasterboard is used in construction.

⁶⁹ For example, the University of Edinburgh is regarded as a leading academic centre of excellence researching the fire-safety characteristics of CLT. See for example Weisner, F. and Bisby, L. (2018), "The structural capacity of laminated timber compression elements in fire: A meta-analysis", in *Fire Safety Journal* 107, (2019), pp114-125, <https://reader.elsevier.com/reader/sd/pii/S0379711218301759?token=583DC3521EFA0560A0B076D71E522750DA59DFB60F48E7CF0FC9B958B73C12AC6647B5E132EC252727F5EB3B86DB5A9D>

heavier products such as steel and concrete and less time spent installing plasterboard, taping and jointing/finishing etc;

- lower capital costs through the need for less heavy equipment for construction due to lighter weight building materials;
- greater flexibility in building design due to the smaller and lighter foundations; and
- greater competition among building material supply businesses due to the increase in choice of construction materials.

6.6.5 Consumer satisfaction and amenity

There is widespread industry support for the view that exposed CLT provides for greater consumer satisfaction and amenity compared with covered plasterboard designs. Specifically, exposed CLT provides for:

- Increased consumer satisfaction due to greater choice of building construction and finish.
- Opportunity for use of exposed timber in buildings can increase the perceived beauty/warmth of rooms and buildings.

6.6.6 Environmental benefits

There are a number of environmental benefits from using exposed CLT-GLT relative to traditional methods, as follows:

- reduced carbon content of construction industry due to lower use of high embodied carbon products like steel, concrete and plasterboard;
- greater use of renewable timber with associated carbon sequestration and sustainability benefits;
- increased recyclability of building materials in construction industry and reduced timber waste; and
- lower embodied CO₂ - as CLT-GLT is renewable resource which requires substantially lower energy use relative to construction materials such as steel, concrete and plasterboard.

The total reduction in construction costs due to the project is estimated by first calculating the cost savings and other benefits of using additional CLT-GLT in construction at the unit level. This comprises the sum of reduced materials costs, times saved and efficiency benefits and other cost savings from the use of CLT. For this calculation the base unit used is a cubic metre (m³) of CLT-GLT. Economy-wide benefits are then calculated by multiplying these unit level benefit estimates by the expected total CLT-GLT usage in the construction sector.

To calculate the environmental benefit each cubic metre of CLT-GLT used in construction it is assumed to sequester 1 tonne of CO₂ equivalent.⁷⁰ This is multiplied by a carbon price assumed to be \$16.14 – which is based on the most recent ERF auction price.⁷¹

Given the ERF auction prices are the lowest marginal price bids, and as others have pointed out once the lowest cost options for carbon reduction are exhausted the expected price of carbon abatement will rise this price can be treated as a conservative estimate.

⁷⁰ 250 kg of carbon creates 917 kg of CO₂, which is about 1 tonne of CO₂ per cubic metre of wood (Arno Frühwald, University of Hamburg) <https://www.wooddays.eu/en/woodclimate/>

⁷¹

<http://www.cleanenergyregulator.gov.au/Infohub/Markets/Pages/Buying%20ACCUs/ACCU%20market%20updates/Australian-Carbon-Credit-Units-Market-Update-%E2%80%93-October-2019.aspx>

Other environmental benefits including recyclability and sustainability advantages of timber and the lower embodied energy (and CO₂) of timber relative to steel and concrete are not quantified in the analysis.

6.6.7 Reduced plasterboard usage

To estimate the reduction in plasterboard usage current Australian industry data and benchmarks have been used.

Gypsum-based plaster products are principally used for internal cladding of building walls and ceilings and are a key input to residential and commercial buildings. Total production for this industry in Australia is valued at around \$1 billion a year.⁷² Total production for Australasia in volume terms is around 170 million square metres per year – of which around 150 million square metres are used in Australia.⁷³

The current ATO input benchmark installation cost for plasterboard installation (excluding the cost of material) indicate costs ranged from \$8-16 per square metre. Total benchmark costs for both supply and install (mid-range) standard plasterboards is \$15-20.⁷⁴ This implies a benchmark price per square metre of plasterboard of \$4-8 per square metre. However, for the thicker 13mm plasterboard required for tall building fire encapsulation of CLT prices are higher at around \$13 per square metre.

The reduction in plasterboard usage per m³ of CLT for the purposes of this analysis was approximated based on the following assumptions. Assuming an average CLT panel thickness of 150mm (noting CLT panels can vary from 57mm to 300mm) a cubic metre of CLT would translate into 6.7 square metres of panel. To fully encapsulate this would require 13.3 square metres of plasterboard if double encapsulated. Based on the benchmark prices above this would translate into a labour cost of \$160 for installation and finishing (excluding painting) and \$173 for materials per m³ of CLT.

For this analysis the more conservative assumption that only half of the CLT used in construction is used for uncovered panels, and the remainder is used for other covered structural purposes. In addition, it is assumed that the revised NCC requirements around CLT do not eliminate the need for encapsulation entirely in all uses, but rather reduce the requirement by up to half relative to BAU. Based on the above assumptions and analysis, the resources saving has been estimated at \$84 per cubic metre of CLT-GLT composite (in \$2020).

6.6.8 Time saved due to prefabrication

Time-saving estimates for the prefabrication of EWP's relative to alternatives vary. That said, the evidence that prefabrication of EWP panels can result in significant time (labour) savings is strong.

Whereas traditional concrete multi-story buildings are assembled fully on site, with engineered wood timber systems most of the construction is undertaken in the factory with only the assembly of modules completed on the building site. Time spent at the building site can be up to half (in person-hours) compared to the counter-factual in multi-storey construction, generating substantial cost savings and improving competitiveness.

There are additional cost benefits with EWP's related to the materials relatively light weight, which can result in time save, lower costs of transportation, lighter foundations and smaller cranes and other equipment. Based on the information available, the estimated reduction in labour savings from the lower use of plasterboard is \$92 per cubic metre of CLT-GLT composite.

6.7 Incremental benefits estimates

⁷² <https://www.ibisworld.com/au/industry/plaster-product-manufacturing/214/>

⁷³ <https://knauf.solutions/wp-content/uploads/2019/03/The-life-cycle-of-plasterboard-in-Australia.pdf>.

⁷⁴ All prices include GST and relate to 2016-17 FY the most current available data and do not include the cost of painting the plasterboard. https://www.ato.gov.au/Business/Small-business-benchmarks/In-detail/Benchmarks-by-industry/Building-and-construction-trade-services/Plastering-and-ceiling-services/?page=4#input_benchmark_plasterboard_installation

6.7.1 Market demand and production volumes

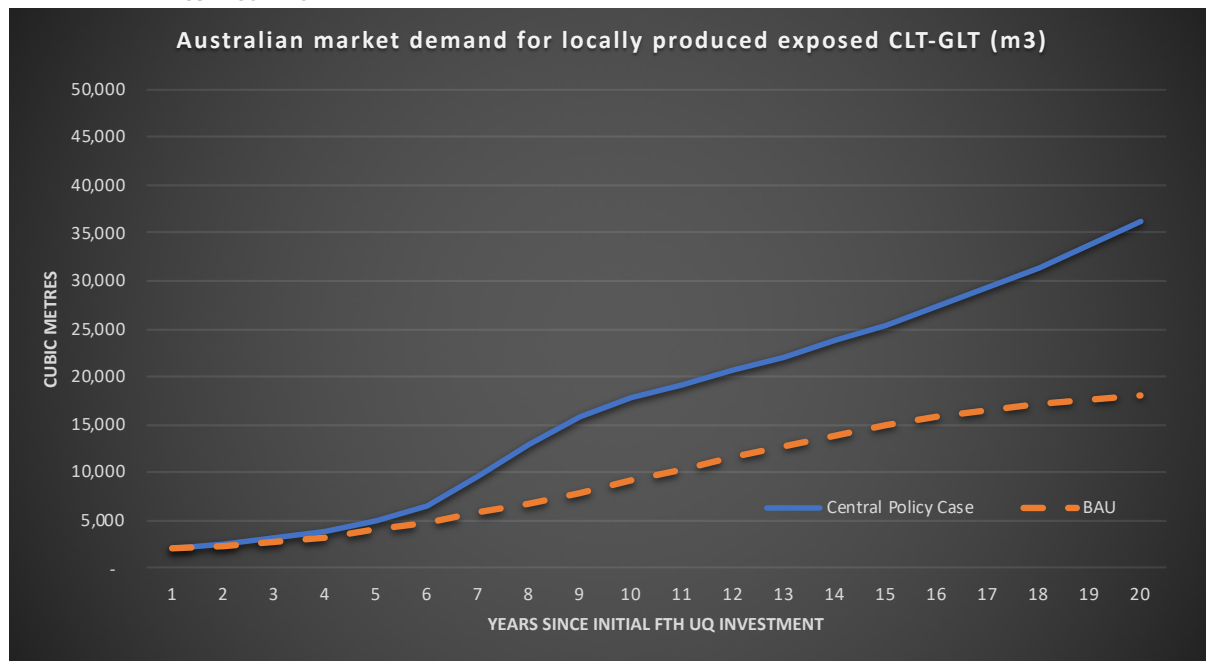
CBA-2 is specifically related to the use of exposed CLT and GLT. Accordingly, in terms of production volumes, an estimate of the initial level of CLT-GLT used as an exposed product and an annual growth rate is required. There is very little information available about the size of the exposed CLT-GLT market and, hence, a very conservative assumption about the current market size has been made, which is 2,000 m³ per year. This represents 5 percent of the current size of domestic production of CLT-GLT in Australia (of 40,000 m³). A simplifying assumption in this analysis is that 100 percent of the exposed CLT-GLT used in the Australian market is produced in Australia. In other words, the growth in market demand is met by domestic production.

In the BAU and CPC scenarios, exposed CLT-GLT domestic production is assumed to grow strongly in Years 1-5, as advised by industry, from 2,000 m³ in Year-1 to 3,973 m³ in Year-5. In the BAU scenario, domestic production reaches 18,092 m³ in Year-20. The CAGR in the BAU scenario over the 20-year period is 12.3 percent per year.

In the Central Policy Case scenario, growth in the exposed CLT-GLT domestic production market is assumed to take the following shape:

- the starting level is 2,000 m³ in Year-1;
- demand grows strongly in the first five years (as advised by industry);
- then a quick ramp-up in demand begins in Year-6; after which;⁷⁵
- growth slows and eventually returns to the long-run trend rate 3.0% from Year-18 until Year-20; such that
- in Year-20, the level of market demand for exposed CLT-GLT is 36,184 m³ (Figure 6-1). The CAGR in the CPC scenario over the 20-year period is 16.5 percent per year.

Figure 6-1. Australian market demand for domestically produced exposed CLT-GLT (m³), Year-1 to Year-20



Source: Tulipwood Economics estimates based on Central Policy Case assumptions.

⁷⁵ The maximum growth rate in the ramp-up is in Year-7 (50%), followed by declining growth rates in Year-8 (34%), Year-9 (22%), Year-10 (13%) and so on until returning to long-run trend growth (of 3%) in Year-18.

6.7.2 Prices

In order to account for the combined effects of a reduction in the CLT and GLT price over time, the analysis constructs a blended or composite CLT-GLT price, which accounts for their respective wholesale prices (delivered to the building site) and their average market share in residential and commercial construction (being 80:20 in CLT's favour).

Taken together, we have conservatively modelled a number of scenarios whereby the real resources costs of manufacturing and installing a composite CLT-GLT product decline over time relative to the real price of installed concrete and steel. The composite CLT-GLT product takes the median wholesale price of delivered CLT (at \$1,250) and the median wholesale price of delivered GLT (at \$2,500) to arrive at a blended price of \$1,500 per cubic metre. This figure represents an 80:20 split in resource use in CLTs favour. Installation costs are then added, including resources costs, and a labour and profit component to arrive at a final composite CLT-GLT installed price.

In CBA-2, for exposed CLT-GLT, the resources costs are lower as is the labour installation component given that up to 50% less plasterboard is installed.

In summary:

- The Year-1 total installation price (in AUD\$2020) of the CLT-GLT is \$2,432 per m³, which includes the additional resources costs of installation (e.g. a lower amount of plasterboard and other fittings) and returns to labour (wages) and capital (profit) (in both the BAU and Central Policy Case).
- Over a 14-year period (from Year-6 to Year-20), the installed cost/price of 1 cubic metre of the CLT-GLT composite product declines by 12.0 percent in real terms. This reduction is caused by an initial 10.0% reduction in the delivered wholesale price of the CLT-GLT composite in Year-6 (reflecting the immediate benefit of the academic research and industry R&D), followed by an annual 'learning-by-doing' productivity reduction of 1.0% per year from Year-7 to Year-20.
- In order to evaluate the isolated impact of the reduction in the price of the CLT-GLT composite, the cost of related installation materials remains unchanged in real terms (i.e. 2020 dollars).
- Similarly, returns to labour (i.e. wages) remain unchanged (although its share rises as a percentage of the total price, reflecting an increase in labour value-added).
- In CBA-2, returns to capital (i.e. profit) increase in absolute terms over the 14-year period (from Year-6) because it is assumed that consumers are willing to pay a price premium of 1.5 percent (applied in Year-6) for the aesthetic qualities of exposed CLT and GLT. This 1.5 percent price premium is equivalent to a 20 percent profit premium. As a result of this, as well as the declining resources costs, profit as a share of the final price increases over time.
- Accordingly, in the Central Policy Case scenario over the 20-year period, the installed price of the CLT-GLT composite product per cubic metre (in real terms) declines by 12.0 percent relative to the BAU (Table 4.2 and Figure 4.1 below).

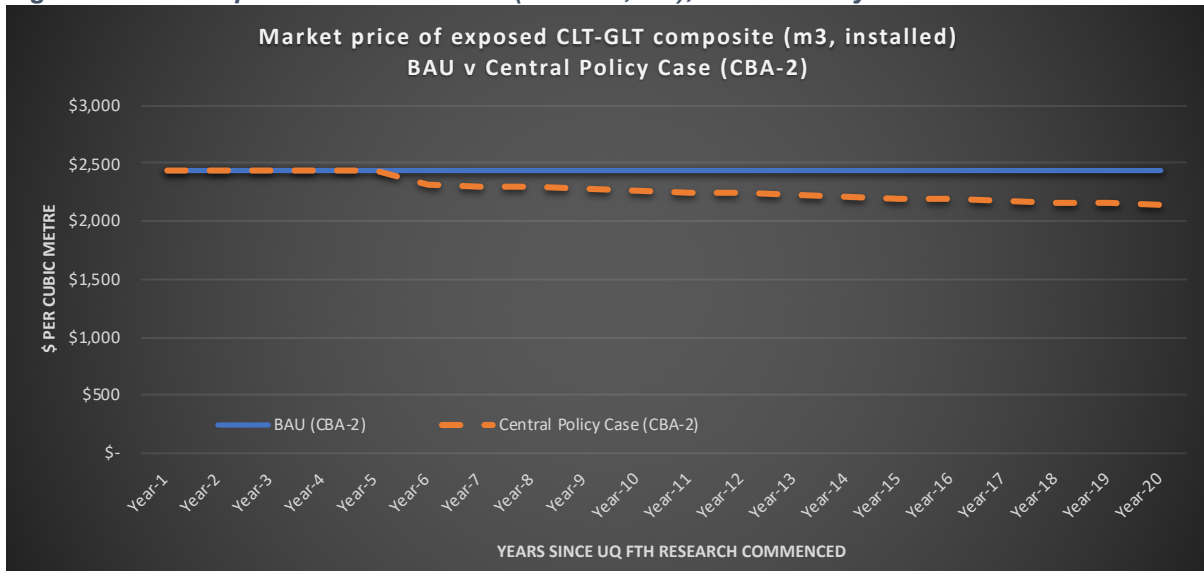
Table 6-2. Change in installed price of CLT-GLT composite, BAU v Central Policy Case (Year-1 v Year-20)

Description (CLT-GLT) (\$AUD, 2020)	Cost per m ³		Change (%)
	BAU (Year-1 to Year-20)	CPC (Year-20)	
Delivered to building site (per m ³)	\$1,500	\$1,173	-28.1%
Additional costs of installation (per m ³)	\$324	\$324	-
Labour costs of installation (per m ³)	\$426	\$426	-
Profit (per m ³)	\$182	\$219	+20%
Price (installed, per m ³)	\$2,432	\$2,141	-12.0%
Value-Added share (Year-20) (%)	25.0%	30.1%	+5.1pp

Source: Tulipwood Economics. pp = percentage points.

Figure 6-2 (below) illustrates the assumption of a decline in the installed wholesale price of the CLT-GLT composite product, from \$2,432 per cubic metre in Year-1 to \$2,141 per cubic metre in Year-20. As a result of this decline in price, CLT-GLT’s market share increases (see section 4.3.2 below) and the value-added proportion in the total price increases 25.0 percent to 30.1 percent.

Figure 6-2 Market price of installed CLT (covered, m3), BAU v Policy Case



Source: Tulipwood Economics estimates.

6.8 Results of CBA-2

The results of CBA-2 are set out below. In the Central Policy Case (CPC) scenario, we found that:

- The present value of the net benefits of the two projects PR014 and PR019 over the 20-year timeframe at the **7 percent social discount rate is \$32.1 million;**
 - The present value of the total benefits amounts to \$40.3 million and the present value of total costs amount to \$8.3 million;
 - Accordingly, the **benefit-cost ratio** is calculated to be **4.9 times;**

- The present value of the net benefits of the two projects PR014 and PR019 over the 20-year timeframe at the **5 percent social discount rate is \$43.3 million**;
 - The present value of the total benefits amounts to \$52.1 million set against the present value of total costs, which amount to \$8.7 million;
 - Accordingly, the **benefit-cost ratio** is calculated to be **6.0 times**; and

The **internal rate of return (IRR)** of the research investment is calculated to be **26%** irrespective of the social discount rate applied (Table 6-3), which indicates that the two projects PR014 and PR019 are very likely to prove to be beneficial from society's (i.e. the taxpayers) point of view.

Table 6-3 (below) presents the results of CBA-2 at the 5%, 7% and 9% social discount rates. Under all discount rates the net present value of net benefits remains positive and the BCR is at least 4.0 times in all cases, which indicates that the two projects PR014 and PR019 are very likely to prove to be beneficial from society's (i.e. the taxpayers) point of view.

Table 6-3. Results of CBA-2, PR014 and PR019, CPC (NPV 5%, 7%, 9%)

Parameter	\$m (NPV, 5%)	\$m (NPV, 7%)	\$m (NPV, 9%)
Net benefits (NPV)	\$43.3	\$32.1	\$23.7
Present value of total benefits	\$52.1	\$40.3	\$31.6
Present value of total costs	\$8.7	\$8.3	\$7.9
BCR	6.0	4.9	4.0
IRR	26%	26%	26%

Source: Tulipwood Economics analysis.

6.9 Sensitivity analysis

A sensitivity analysis was undertaken to determine the robustness of the assumptions made in this study. These assumptions can be categorised in terms of costs and benefits.

In terms of costs, the three main input parameters that are varied are:

- The initial project investment of PR014 and PR019;
- The global academic research investment in objectives very similar to PR014 and PR019; and
- Ongoing industry capital investment to support continual productivity improvements in exposed CLT-GLT manufacturing and installation.

In terms of benefits, there are five primary inputs parameters that are varied are:

- The rate of ramp-up in domestic production in Year-6 (i.e. the 'shape' of the ramp-up curve);
- The rate of growth in demand post ramp-up (from Year-7 to Year-20);
- The share of value-added (being wages and profits) in the installed price of the CLT-GLT composite product, and the rate of change in the share of value-added over time; and
- The trajectory of the relative price of CLT-GLT composite product vis-à-vis concrete and steel; and
- The environmental benefits of switching from concrete and steel to CLT (
- Table 6-4).

Table 6-4. CBA-2 sensitivity analysis, variation in input parameters

Parameter	LPC	CPC	HPC
Costs			
Industry R&D investment (Years 4-25), (% of industry value-added)	1.25%	1.00%	0.75%
Additional capital costs (Year 4 and Year 5), (% additional industry value-added)	22.5%	20.0%	17.5%
FTH share of global academic EWP research	17.5%	20.0%	22.5%
Benefits			
Domestic production CLT+GLT (Year-20 target), (m ³) [BAU = 18,092 m ³]	27,607	36,184	47,393
Demand growth for CLT-GLT products post ramp-up phase, (Year-20, % annual)	6.50%	7.29%	13.00%
Annual Import growth (CPC)	3.00%	3.00%	3.00%
CLT-GLT domestic production growth rate, CAGR (Year-1 to Year-20)	14.8%	16.46%	18.13%
Value-added share of CLT-GLT total revenue (Wages + Profits + Taxes), (Year-20)	28.5%	30.1%	33.1%
Price of CLT-GLT relative to concrete and steel (Year-20)	n/a	n/a	-5.0%
Environmental benefits of switching from concrete and steel to CLT-GLT (\$ per tonne carbon emissions saved, concrete & steel)	n/a	n/a	\$16

Source: Tulipwood Economics analysis.

6.10 Conclusion

This chapter set out the analysis and results of CBA-2 (PR014 and PR019). The analysis undertaken here suggests that, based on a reasonable set of assumptions, the expected net benefits of CBA-2 are likely to be positive and provide benefits to the Australian community. As part of this, the domestic CLT-GLT manufacturing sector is expected to expand providing higher value-added returns to workers and owners of capital than in the BAU scenario. This would add to Australian GDP and GDP per capita.

In the Central Policy Case scenario, at a **social discount rate of 7%**, the present value of the net benefits of PR014 and PR019 is **\$32.1 million**, the BCR is **4.9 times** and the IRR is **26 percent**.

In the Central Policy Case scenario, at a **social discount rate of 5%**, the present value of the net benefits of PR014 and PR019 is **\$43.3 million**, the BCR is **6.0 times** and the IRR is **26 percent**.

These results, and the sensitivity analysis, suggests that the two ARC FTH projects related to CBA-2 represent a responsible use of taxpayer resources from society's point of view.

7. Combined CBA results and sensitivity analysis

7.1 Summary

This chapter reports the results of the combined CBA, being CBA-1 plus CBA-2. The two sets of analyses are additive. In other words, the results of each CBA are not influenced by the other. This is a simplifying assumption. It is conceivable for example, that the research projects relating to increasing industry confidence in EWPs (PR014 and PR019) could have a multiplicative impact on the research related to lowering the cost of EWPs (PR002 and PR015). In this regard, the estimates when taken together are conservative, just as they are when taken separately.

To summarise here:

- CBA-1 is related to lowering the cost of producing and installing covered CLT-GLT whereby plasterboard is still used as a protective covering material; and
- CBA-2 is related to expanding the use of exposed CLT-GLT where plasterboard is not used as a covering material.

It is assumed that covered CLT-GLT gains market share at the expense of imports such that the overall growth in market demand over the 20-year period is constant. The exposed CLT-GLT market is, essentially, assumed to be a new market in the sense that its growth does not significantly crowd out substitutes such as covered CLT-GLT, concrete and steel, or traditional timber frame materials. In the HPC, exposed CLT-GLT begins to take market share away from concrete and steel.

7.2 Combined results, CBA-1 plus CBA-2

The combined results of the two CBAs are presented in Table 7-1 below. The results are additive and presented in real net present value terms (in \$2020).

At a **social discount rate of 7 percent**, the net benefits of undertaking the four ARC FTH research projects is estimated to be **\$152.0 million**.⁷⁶ This figure represents the difference between the present value of total benefits (of \$189.2 million) and the present value of total costs (of \$37.3 million). The **benefit-cost ratio (BCR)**, which divides benefits by costs, is calculated to be **5.1 times**. The **internal rate of return (IRR)** is calculated to be **25%**. Taken together, these estimates of the net benefits of the four FTH projects are strong. Based on these estimates, the projects represent a responsible use of taxpayer resources from society's point of view (Table 7-1).

At a **social discount rate of 5 percent**, the net benefits of undertaking the four ARC FTH research projects is estimated to be **\$214.5 million**.⁷⁷ This figure represents the difference between the present value of total benefits (of \$256.1 million) and the present value of total costs (of \$41.6 million). The **benefit-cost ratio (BCR)**, which divides benefits by costs, is calculated to be **6.2 times**. The **internal rate of return (IRR)** is calculated to be **25%**. Taken together, these estimates of the net benefits of the four FTH projects are strong. Based on these estimates, the projects represent a responsible use of taxpayer resources from society's point of view.

⁷⁶ All figures reported are in real \$2020 dollars. A detailed discussion about the appropriate choice of a social discount rate is provided in Chapter 3.

⁷⁷ All figures reported are in real \$2020 dollars. A detailed discussion about the appropriate choice of a social discount rate is provided in Chapter 3.

Table 7-1. Combined results of CBA-1 and CBA-2, (at NPV of 7%)

Parameter	CBA-1	CBA-2	Total CBA-1,2
	\$m (NPV, 7%)	\$m (NPV, 7%)	\$m (NPV, 7%)
Net benefits (NPV)	\$119.9	\$32.1	\$152.0
Present value of total benefits	\$148.9	\$40.3	\$189.2
Present value of total costs	\$29.0	\$8.3	\$37.3
BCR	5.1	4.9	5.1
IRR	24%	26%	25%

Source: Tulipwood Economics analysis.

7.3 Combined sensitivity analysis, CBA-1 plus CBA-2

7.3.1 Social discount rate

Sensitivity analysis has been undertaken to test the robustness of the key input assumptions in the analysis. First, the results were tested against changes to the social discount rate. A higher (9%) and lower (5%) rate was applied to the stream of benefits and costs over the 20-year period.

Given that a significant share of the costs are 'up-front' and the benefits rise over time, the higher discount rate produces lower net benefits. That said, in the Central Policy Case scenario, at a social discount rate of 9 percent, the net present value of net benefits of CBA-1,2 is estimated to be \$107.5 million and the BCR is 4.2 times (Table 7-2). These results are still strong and reflect the catalytic effect of the academic research on the building construction industry.

At a lower social discount rate of 5 percent, the net present value of the net benefits is estimated to be roughly double at \$214.5 million and the BCR consequently higher at 6.2 times. Given the distribution over time of the costs (up-front) and benefits (delayed), a lower discount rate increases the calculated benefits in later years relative to costs. Overall, the social discount rate sensitivity analysis demonstrates that the conclusion – that the four ARC FTH projects represent a responsible use of taxpayer resources from society's point of view – remains robust (Table 7-2).

Table 7-2. Combined results of CBA-1 and CBA-2, (CPC at NPV of 5%, 7%, 9%)

Parameter	Total CBA-1,2	Total CBA-1,2	Total CBA-1,2
	\$m (NPV, 5%)	\$m (NPV, 7%)	\$m (NPV, 9%)
Net benefits (NPV)	\$214.5	\$152.0	\$107.5
Present value of total benefits	\$256.1	\$189.2	\$141.2
Present value of total costs	\$41.6	\$37.3	\$33.8
BCR	6.2	5.1	4.2
IRR	25%	25%	25%

Source: Tulipwood Economics estimates.

7.3.2 Key input parameters

A number of key input parameters were varied to test the robustness of the analysis under the Central Policy Case scenario. These are discussed in the chapter 5 (CBA-1) and chapter 6 (CBA-2).⁷⁸

7.3.3 Sensitivity analysis results (LPC, CPC, HPC)

Varying the input parameters as described in previous chapters has had a significant effect on the estimated results. The net present value of net benefits ranges between \$24.1 million and \$347.2 million over the 20-year period at a social discount rate of 7 percent. The calculated BCR ranges between 1.6 and 10.8 times. The IRR ranges between 11 percent and 36 percent, indicating a positive internal rate of return over the range of scenarios. Overall, the sensitivity analysis supports the conclusion that the four ARC FTH projects represents a worthwhile investment from society's point of view under the most reasonable assumptions. (Table 7-3).

Table 7-3. Combined results of CBA-1 and CBA-2, by policy scenario (at 7% discount rate)

Parameter	Total CBA-1,2	Total CBA-1,2	Total CBA-1,2
	LPC	CPC	HPC
Net benefits (NPV)	\$24.1	\$152.0	\$347.2
Present value of total benefits	\$66.3	\$189.2	\$382.5
Present value of total costs	\$42.3	\$37.3	\$35.3
BCR	1.6	5.1	10.8
IRR	11%	25%	36%

Source: Tulipwood Economics estimates.

7.4 Conclusion

The concept of EWPs is simple, yet offers a tremendous opportunity for Australian industry and society, both from an economic and environmental viewpoint. Ongoing research by FTH and other academic institutions globally as well as industry has the potential to lower the cost of manufacturing prefabricated mass panels and posts and beams, as well as expand domestic manufacturing and increase overall market demand for these lower cost and environmentally friendly building products. Because of its lower overall cost compared with substitutes, CLT-GLT has the potential to increase value-added, which would boost GDP and raise incomes in the industry.

The benefits of EWPs like CLT and GLT relative to its competitors concrete and steel or traditional timber frame construction are numerous and relate to a combination of factors, such as: comparable or greater strength, lighter weight providing greater manoeuvrability, modular design, lower installation cost, faster installation, aesthetic properties as well as environmental benefits such as reduced waste and a lower carbon footprint. For commercial and residential buildings up to a height of about 35 metres, EWPs have enormous potential to substitute for the current dominance of concrete and steel construction. In addition, EWPs can be used more broadly in combination with concrete and steel construction in virtually any commercial or residential designs.

The net benefits of undertaking the four ARC FTH research projects based on the best information available on the likely costs and benefits of industry expansion is estimated to be **\$152.0 million at the 7 percent social discount rate**. This figure represents the difference between the present value of total benefits (of \$189.2 million) and the present value of total costs (of \$37.3 million). The benefit-cost ratio (BCR), which divides benefits by costs, is calculated to be **5.1 times**. The internal rate of return (IRR) is calculated to be **25%**. Taken together, these estimates of the net benefits of the four ARC FTH projects indicate that the projects represent a good use of taxpayer resources from society's point of view.

⁷⁸ See Table 5.5 and Table 6.4.

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Part 3 Appendices

Appendix A

ARC FTH Project descriptions

A-1 Lowering the resources costs of EWP

A-1-1 The optimisation of wood-based mass-panels for Australian building systems (PR002)

This project (identified by FTH as PR002) has focussed on developing high performance panel construction designs suitable for local manufacture through comprehensive modelling, prototyping, semi-industrial and full-scale manufacturing.

This project aims to deliver technical tools, training and demonstration that will support Australian industry to supply the Australian residential and commercial building and construction sector with a versatile array of high-performance products from which to design and construct innovative timber buildings. The research project includes a review of the latest developments in mass-panel products/systems and design, in order to identify priority products/systems that have immediate suitability for the Australian forest product and construction industries. Specific project outcomes include:

- provide the Australian building sector with high performance product solutions that can be sourced locally and which have been manufactured from sustainable low-embodied energy materials; and
- provide the design criteria and protocols for the manufacture of mass-panel products that will support and guide the Australian forest products industry towards being world-leading suppliers of high-performance panel systems;
- provide industry with the support tools for the design and manufacture of engineered wood products; and
- provide the Australian construction and forest product industries with confidence that locally produced wood-based building systems provide a viable and potentially superior alternative to imported products.⁷⁹

A-1-2 Alternative uses for under-valued sawmill products in innovative timber structures (PR015)

This project (PR015) investigates the design of innovative and alternative structure timber systems and technologies that adapt 'low value' timber products such as sawmill offcuts, centre of log, low structural grade, high structural grade but dimensionally undervalued, and end-of-log (butts less than 1.8m in length).

A key research focus will be the consideration of timber members used at non-standard scales in comparison to conventional stud framing and roof truss construction. This approach seeks to innovate

⁷⁹ For more information about the four FTH projects, see here: <https://futuretimberhub.org/projects/optimisation-wood-based-mass-panels-australian-building-systems>

by combining non-standard sizes together in a novel way in order to achieve required overall physical and mechanical properties.

The final research objective will be to investigate the assembly of small member sizes that employ novel configurations to achieve large spans and stiffness through inherently stable geometric configurations.⁸⁰

The current Australian softwood timber framing market is dominated by a narrow range of highly commoditised structural frame sizes. This approach is understandable to achieve economies of scale and high levels of productivity. However, resource losses in terms of unused timber (up to 55% of the log) is the consequence as only a certain volume of timber milled from each log can yield the required sizes of the commoditised products.

The outcomes of the project will include the identification of a shortlist of prototypical structural systems to be tested and developed further in ongoing research programs, including systems related to: (i) matrix (or be-spoke) assemblies, and (ii) mass consolidations (i.e. mass panels).

A-1-3 Total Cost of seed funding CBA-1

The total cost of the CBA-1 projects, by funder by year, is set out in the table below. The total seed budget for the two projects (PR002 and PR015) related to CBA-1 is **\$1,359,068** in nominal terms (\$2020).

Table A-1 FTH seed funding for PR002 and PR015

Contributor	PR002 – Optimisation of wood-FTH Project based mass-panels for Australian buildings systems			PR015 – Alternative uses for undervalued sawmill products in innovative timber structures		
	Year 1	Year 2	Year 3	Year 1	Year 2	Year 3
ARC cash grant	\$134,898	\$153,069	\$138,676	\$8,250	\$8,250	\$36,250
UQ (in-kind)	\$75,000	\$75,000	\$75,000	\$18,641	\$18,641	\$35,411
DAF (in-kind)	\$160,886	\$185,637	\$190,462	\$0	\$0	\$0
Hyne Timber (in-kind)	\$3,333	\$3,333	\$3,333	\$5,000	\$5,000	\$5,000
Lend Lease (in-kind)	\$3,333	\$3,333	\$3,333	\$0	\$0	\$0
Arup (in-kind)	\$3,333	\$3,333	\$3,333	\$0	\$0	\$0
Total	\$380,783	\$423,705	\$414,137	\$31,891	\$31,891	\$76,661

Source: ARC grant application (FTH).

A-2 Increasing industry confidence in EWP

A-2-1 Exploring the self-extinguishment mechanism of engineered timber in full-scale compartment fires (PR014)

⁸⁰ For more information, see here: <https://futuretimberhub.org/projects/alternative-uses-under-valued-sawmill-products-innovative-timber-structures>

This project (PR014) investigates the self-extinguishment mechanism of engineered timber (such as CLT) at a full-scale in order to establish appropriate design criteria for the safe use of CLT and similar products in tall-timber buildings. The aim of the research project is to provide a methodology to establish criteria for self-extinguishment of EWPs at a full-scale, considering complexities such as delamination failure, encapsulation failure, and rate of exposure of timber surfaces.⁸¹

Specific project objectives include:

- evaluate fundamental self-extinguishment criteria (critical external heat flux and pyrolysis rate) in various scales;
- determine conditions and time-scale of delamination that prevent self-extinguishment at full-scale;
- determine conditions and time-scale of encapsulation that prevent self-extinguishment at a full-scale;
- determine whether fully expose timber compartment may achieve self-extinguishment if delamination is controlled; and
- establish design guidelines for the fire-safe use of CLT, which enable self-extinguishment after burn out of the floor fuel load, including:
 - criteria for controlling delamination (fall-off) of charred lamellae;
 - criteria for controlling encapsulation failure; and
 - criteria for assessing the maximum number of exposed timber surfaces to be used.

A-2-2 Progressive collapse (robustness) resistance of tall frame timber buildings with CLT floors (PR019)

This project (PR019) seeks to advance industry knowledge about the performance of available mass timber products such as CLT and Laminated Veneer Lumber (LVL) used in mid-rise to tall timber buildings. With increased building height and weight, the lateral performance of the buildings becomes more critical, and robust lateral load design must be achieved for safety and serviceability.

As design engineers work on larger force demand due to increased height and mass, they will face new challenges and problems that may fall out of current timber design codes. This project seeks to evaluate the performance of timber core-walls and provide technical information to guide core-wall design in tall timber buildings, with and without the incorporation of low-damage seismic design technology.⁸²

The specific objectives of the project are to:

- investigate the progressive collapse mechanisms of tall frame mass timber buildings through experimental tests performed on scale substructures and edge column removal;
- to develop advanced numerical tools calibrated against the available experimental tests and use them to quantify the factors influencing the progressive collapse mechanisms of tall frame mass timber buildings through parametric studies;

⁸¹ See here: <https://futuretimberhub.org/projects/exploring-self-extinguishment-mechanism-engineered-timber-full-scale-compartment-fires>

⁸² For more information, see here: <https://futuretimberhub.org/projects/behaviour-critical-connections-and-core-wall-systems-tall-timber-buildings>

- to develop and test new connectors to enhance the progressive collapse resistance of tall frame mass timber buildings; and
- to verify the accuracy of the current design and detailing guidelines to resist progressive collapse in current design specifications.

A-2-3 Total Cost of seed funding CBA-2

The total cost of the CBA-1 projects, by funder by year, is set out in the table below. The total seed budget for the two projects (PR014 and PR019) related to CBA-2 is **\$1,548,753** in nominal terms (\$2020).

Table A-2 FTH seed funding for PR014 and PR019

FTH Project	PR014 – Self-extinguishment properties of EWP			PR019 – Progressive collapse resistance of tall frame timber buildings		
	Year 1	Year 2	Year 3	Year 1	Year 2	Year 3
ARC cash grant	\$155,435	\$118,581	\$38,998	\$90,430	\$48,390	\$15,000
UQ (in-kind)	\$192,195	\$212,151	\$65,138	\$0	\$0	\$0
DAF (in-kind)	\$0	\$0	\$0	\$3,000	\$3,000	\$3,000
Hyne Timber (in-kind)	\$19,067	\$6,667	\$6,667	\$0	\$0	\$0
QFES (in-kind)	\$21,500	\$21,500	\$17,300	\$0	\$0	\$0
Lend Lease (in-kind)	\$3,333	\$3,333	\$3,333	\$0	\$0	\$0
Arup (in-kind)	\$0	\$0	\$0	\$3,000	\$3,000	\$3,000
Griffith Uni cash grant	\$0	\$0	\$0	\$186,385	\$166,245	\$139,105
Total	\$391,530	\$362,232	\$131,436	\$282,815	\$220,635	\$160,105

Source: ARC FTH grant application.

Appendix B and evidence-base

CBA assumptions

B1 CBA-1

Table B.1 Summary of assumptions and evidence-base (CBA-1), page 1

Parameter	Value	Assumptions and evidence-base
Wholesale delivered price of a composite CLT-GLT product per cubic metre. The composite product reflects an 80:20 resource split in CLTs favour. The assumed price of CLT is \$1,250 per cubic metre. The assumed price of GLT is \$2,500 per cubic metre.	\$1,500	The estimate based on a range of available market data from the past five years and discussions with Australian CLT and GLT manufacturers. It is assumed that the landed price of imported CLT per cubic metre sets the market price. It is assumed that the competitive domestic price of GLT sets the market price. These wholesale prices are roughly half the published retail prices across various capital city markets. ^{83, 84}
Additional installation cost of CLT-GLT composite product per cubic metre in terms of resources such as fittings and plasterboard covering.	\$500	Discussions with Australian CLT and GLT manufacturers; Rawlinsons Construction Cost database (2020).
Return to Labour (Wages), (\$AUD 2020, per m ³).	\$467	Derived based on the assumption that, in the construction industry, the share of resources costs and return to the factors of production are as follows: Resources costs (overheads) = 75%; Returns to Labour (wages) = 17.5%; Returns to Capital (profit) = 7.5%. In the Construction sector, resources costs as a share of market price are significantly higher than in other industries. ABS System of 5204.0 (2018-19), and Australian National Accounts: Input-Output Tables 5209.0.55.001 (2017-19).
Return to Capital (Profit)	\$200	As above.
Total installed price of CLT-GLT composite product per cubic metre in a mid-rise commercial building.	\$2,667	Calculated figure as the sum of the above components (overheads + wages + profit). Note that these components are inclusive of taxes. These figures (on this page) represent the BAU scenario and the Year-1 starting point for the three policy cases (LPC, CPC, HPC).

⁸³ <http://www.unece.org/fileadmin/DAM/timber/publications/SP48.pdf>

⁸⁴ <https://www.cbi.eu/market-information/timber-products/cross-laminated-timber/europe/>

Parameter	Value	Assumptions and evidence-base
Total Australian domestic CLT demand (2020, m3)	50,000	Estimate based on a/v market data, including IndustryEdge calculations based on import data. Discussions with industry. ⁸⁵ Note the CLT is used in the study as a proxy for CLT-substitutes (such as NLT, GLT, LVL etc). In other words the whole EWP market is proxied by CLT.
Of which...		
Total domestic production of CLT (covered and exposed), (2020, m3)	20,000	As above. Figure confirmed by discussions with an industry manufacturer.
Total CLT imports (2020, m3)	30,000	Derived from the estimate of total market demand and total domestic production
Size of CLT market (delivered to building site and installed), (\$m, 2020)	\$100 m	Calculation based on installed price per cubic metre (\$2,000) multiplied by total domestic demand (50,000 m3).
Total Australian domestic GLT demand (2020, m3)	25,000	Estimate based on discussions with industry.
Of which...		
Total domestic production of GLT (covered and exposed), (2020, m3)	20,000	Estimate based on discussions with industry.
Total GLT imports (2020, m3)	5,000	Estimate based on discussion with industry.
Size of GLT market (delivered to building site and installed), (\$m, 2020)	\$50 m	Derived from above estimates.

⁸⁵ <https://industryedge.com.au/new-cross-laminated-timber-facility-in-australia/>

Parameter	Value	Assumptions and evidence-base
Total domestic market production for 'covered' CLT38,000 and GLT		Discussion with industry (see above). We have subtracted 2,000 m3 from the total estimated domestic production figure of 20,000 m3, as the starting level of 'exposed CLT-GLT' (see CBA-2 analysis). This is because the analysis of covered and exposed CLT is undertaken in separate CBAs (being CBA-1 and CBA-2).
CAGR in market demand: BAU Year-1 to Year-20	12.29%	Long-run growth rate in the residential and commercial construction sector is 3.14% (whole series of 24 years, 1994-95 to 2018-19). ⁸⁶ However, industry has advised that it expects strong growth over the next five years. This growth is then followed by as assumed ramp-up in growth as a result of the commercialisation of the academic research. Domestic production in Year-20 is 343,748 cubic metres.
Growth rate in domestic production: Low Policy Case (LPC) Year-1 to Year-20 CAGR	13.96%	In the LPC scenario, market demand tracks the BAU scenario until Year-10, where BAU growth begins to fall to long-run sustainable levels. In the LPC scenario, the growth rate begins to decline, but at the slower rate than in the BAU scenario. Domestic production in Year-20 is 455,445 cubic metres. Imports in Year-20 are 58,304 cubic metres.
Growth rate in market demand: Central Policy Case (CPC) Year-1 to Year-20 CAGR	14.33%	In the CPC scenario, growth follows the BAU scenario until Year-6, when the commercialisation of the FTH academic research leads to a higher growth trajectory, driven by a lower cost structure, greater manufacturing capability and more awareness of the environmental benefits. Domestic production (Year-20): 484,184 cubic metres. Imports (Year-20): 58,304 cubic metres.
Growth rate in market demand: High Policy Case (HPC) Year-1 to Year-20 CAGR	15.56%	In the HPC scenario, growth follows the BAU scenario until Year-6, when the commercialisation of the FTH academic research leads to a higher growth trajectory, driven by faster productivity growth (compared to the CPC scenario), a lower cost structure, greater manufacturing capability and more awareness of the environmental benefits. Domestic production (Year-20): 593,155 cubic metres. Imports (Year-20): 58,304 cubic metres.

⁸⁶ See Australian System of National Accounts 5204.0, Table 5 (Construction E, Building Construction), (2018-19). <https://www.abs.gov.au/AUSSTATS/abs@.nsf/DetailsPage/5204.02018-19?OpenDocument>

Parameter	Value	Assumptions and evidence-base
Labour savings due to shorter construction time, lighter weight, flexibility, ease of assembly etc (\$/m3)	\$75.98	Calculation based on applying estimated 10 per cent time saving premium to the labour component based on Australia wide input cost shares wages and entitlements. ⁸⁷ Labour saving estimates vary considerably. We have taken a conservative approach, in line with all assumptions in this study.
Carbon price (\$AUD2020, tonne of CO2 equivalent)	\$16.00	2019 ERF auction ⁸⁸
Sequestered CO2 in m3 of CLT (tonnes)	1	Carbon accounting standard ⁸⁹

⁸⁷ <https://macromonitor.com.au/wp-content/uploads/2019/05/EXTRACT-Construction-Cost-Trends-October-2018.pdf>

⁸⁸ <http://www.cleanenergyregulator.gov.au/ERF/Auctions-results/march-2020>

⁸⁹ <https://www.wooddays.eu/en/woodclimate/>

B2 CBA-2

Table B.2 Summary of assumptions and evidence-base (CBA-2), page 1

Parameter	Value	Assumptions and evidence-base
Wholesale delivered price of a composite CLT-GLT product per cubic metre. The composite product reflects an 80:20 resource split in CLTs favour. The assumed price of CLT is \$1,250 per cubic metre. The assumed price of GLT is \$2,500 per cubic metre.	\$1,500	The estimate based on a range of available market data from the past five years and discussions with Australian CLT and GLT manufacturers. It is assumed that the landed price of imported CLT per cubic metre sets the market price. It is assumed that the competitive domestic price of GLT sets the market price. ^{90, 91}
Additional installation cost of CLT-GLT composite product per cubic metre in terms of resources such as fittings and plasterboard covering.	\$324	Based on CBA-1, and then savings are applied due to easier installation.
Return to Labour (Wages), (\$AUD 2020, per m3).	\$426	Based on CBA-1, and then savings are applied to to less labour required.
Return to Capital (Profit)	\$182	Based on CBA-1, but at a lower value due to the lower overall value of the product.
Total installed price of CLT-GLT composite product per cubic metre in a mid-rise commercial building.	\$2,432	Calculated figure as the sum of the above components (overheads + wages + profit). Note that these components are inclusive of taxes.
Total Australian domestic CLT-GLT demand (2020, m3) in Year-1	3,750	Based on CBA-1. A proportion (being 5%) of total domestic production is allocated to the “exposed CLT-GLT” market.
Total domestic production of CLT (covered and exposed), (2020, m3)	2,000	As above.
Total imports (Year-1, m3)	1,750	Derived from the estimate of total market demand and total domestic production.
Total imports (Year-20, m3)	3,069	Reflecting a constant 3% annual growth rate in imports per year (under all three policy scenarios and the BAU scenario).

⁹⁰ <http://www.unece.org/fileadmin/DAM/timber/publications/SP48.pdf>

⁹¹ <https://www.cbi.eu/market-information/timber-products/cross-laminated-timber/europe/>

Table B.2 Summary of assumptions and evidence-base (CBA-2), page 2

Parameter	Value	Assumptions and evidence-base
Growth rate in market demand: BAU scenario	12.29%	<p>Long-run growth rate in the residential and commercial construction sector is 3.14% (whole series of 24 years, 1994-95 to 2018-19). See Australian System of National Accounts 5204.0, Table 5 (Construction E, Building Construction), (2018-19).⁹² However, industry has advised that it expects strong growth in the next 5 years, and this growth is followed by a further ramp-up in growth as a result of the commercialisation of the ARC FTH academic research.</p> <p>In the BAU scenario, domestic production in Year-20 is 18,092 cubic metres. Imports in Year-20 are 3,069 cubic metres.</p>
Year-1 to Year-20 CAGR		
Growth rate in market demand: Low Policy Case (LPC)	14.51%	<p>Following strong industry growth in the first 5 years (unrelated to the ARC FTH academic research), there is a further ramp-up in growth in Year-6 is distributed to follow an 's-curve'. The 'market absorption' literature provides evidence of s-curve growth rates for new products superseding old products. In the LPC scenario, the ramp-up trajectory is flatter reflecting a slower uptake of the new product.</p> <p>Domestic production in Year-20 is 26,226 cubic metres. Imports in Year-20 are 3,069 cubic metres.</p>
Year-1 to Year-20 CAGR		
Growth rate in market demand: Central Policy Case (CPC)	16.46%	<p>Following strong industry growth in the first 5 years (unrelated to the ARC FTH academic research), there is a further ramp-up in growth in Year-6 is distributed to follow an 's-curve'. The 'market absorption' literature provides evidence of s-curve growth rates for new products superseding old products.</p> <p>Domestic production in Year-20 is 36,184 cubic metres. Imports in Year-20 are 3,069 cubic metres.</p>
Year-1 to Year-20 CAGR		
Growth rate in market demand: High Policy Case (HPC)	18.13%	<p>Following strong industry growth in the first 5 years (unrelated to the ARC FTH academic research), there is a further ramp-up in growth in Year-6 is distributed to follow an 's-curve'. The 'market absorption' literature provides evidence of s-curve growth rates for new products superseding old products. In the HPC scenario, the ramp-up trajectory is steeper reflecting a faster uptake of the new product.</p> <p>Domestic production in Year-20 is 47,393 cubic metres. Imports in Year-20 are 3,069 cubic metres.</p>
Year-1 to Year-20 CAGR		

⁹² <https://www.abs.gov.au/AUSSTATS/abs@.nsf/DetailsPage/5204.02018-19?OpenDocument>

Parameter	Value	Assumptions and evidence-base
Labour savings due to shorter construction time, lighter weight, flexibility, ease of assembly etc (\$/m3)	\$75.98	Calculation based on applying estimated 10 percent time saving premium to the labour component based on Australia wide input cost shares wages and entitlements. ⁹³ Labour saving estimates vary considerably. We have taken a conservative approach, in line with all assumptions in this study.
Carbon price (\$AUD2020, tonne of CO2 equivalent)	\$16.00	2019 ERF auction ⁹⁴
Sequestered CO2 in m3 of CLT (tonnes)	1	Carbon accounting standard ⁹⁵
Carbon price (tonne of CO2 equivalent)	16	2019 ERF auction ⁹⁶
Sequestered CO2 in m3 of CLT (tonnes)	1	Carbon accounting standard ⁹⁷
Additional value-added - aesthetic value (\$A)	\$24.32	By assumption, based on a 20% premium attributed to the profit share of the total price of the composite CLT-GLT product. The assumed premium represents 1.5% of the total price.
Resource saving from using up to 50% less plasterboard in the installation of the composite CLT-GLT product (\$AUD per m3)	\$84.37	Based on ATO input benchmark costs for plasterboard.
Additional labour saving from not using plasterboard (\$AUD, per cubic metre)	\$91.79	Based on ATO input benchmark costs for plasterboard installation. Calculation based on applying estimated 10 per cent time saving premium to the labour component based on Australia wide input cost shares wages and entitlements ⁹⁸
Cost of additional fire safety measures to ensure exposed CLT-GLT is safe (\$AUD per m3)	\$48.64	By assumption, being 2% of the installed price of the composite CLT-GLT product. Based on discussion with industry, whose experience suggests increased fire safety measures will not be a significant component of overall cost.

⁹³ <https://macromonitor.com.au/wp-content/uploads/2019/05/EXTRACT-Construction-Cost-Trends-October-2018.pdf>

⁹⁴ <http://www.cleanenergyregulator.gov.au/ERF/Auctions-results/march-2020>

⁹⁵ <https://www.wooddays.eu/en/woodclimate/>

⁹⁶ <http://www.cleanenergyregulator.gov.au/ERF/Auctions-results/march-2020>

⁹⁷ <https://www.wooddays.eu/en/woodclimate/>

⁹⁸ <https://macromonitor.com.au/wp-content/uploads/2019/05/EXTRACT-Construction-Cost-Trends-October-2018.pdf>

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CRICOS Provider Number 00025B