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# Review of End-of-life Options for Structural Timber Buildings in New Zealand and Australia.

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# 1.0 Executive summary

Deconstruction, at the end of the useful life of a building, produces a considerable amount of materials which must be disposed of, or be recycled / reused. At present, in New Zealand, most timber construction and demolition (C&D) material, particularly treated timber, is simply waste and is placed in landfills. For both technical and economic reasons (and despite the increasing cost of landfills), this position is unlikely to change in the next 10 – 15 years unless legislation dictates otherwise.

Careful deconstruction, as opposed to demolition, can provide some timber materials which can be immediately re-used (eg. doors and windows), or further processed into other components (eg. beams or walls) or recycled ('cascaded') into other timber or composite products (e.g. fibre-board). This reusing / recycling of materials is being driven slowly in NZ by legislation, the 'greening' of the construction industry and public pressure. However, the recovery of useful material can be expensive and uneconomic (as opposed to land-filling).

In NZ, there are few facilities which are able to sort and separate timber materials from other waste, although the soon-to-be commissioned Burwood Resource Recovery Park in Christchurch will attempt to deal with significant quantities of demolition waste from the recent earthquakes. The success (or otherwise) of this operation should provide good information as to how future C&D waste will be managed in NZ.

In NZ, there are only a few, small scale facilities which are able to burn waste wood for energy recovery (e.g. timber mills), and none are known to be able to handle large quantities of treated timber. Such facilities, with constantly improving technology, are being commissioned in Europe (often with Government subsidies) and this indicates that similar bio-energy (co)generation will be established in NZ in the future. However, at present, the NZ Government provides little assistance to the bio-energy industry and the emergence worldwide of shale-gas reserves is likely to push the economic viability of bio-energy further into the future.

The behaviour of timber materials placed in landfills is complex and poorly understood. Degrading timber in landfills has the potential to generate methane, a potent greenhouse gas, which can escape to the atmosphere and cancel out the significant benefits of carbon sequestration during tree growth. Improving security of landfills and more effective and efficient collection and utilisation of methane from landfills in NZ will significantly reduce the potential for leakage of methane to the atmosphere, acting as an offset to the continuing use of underground fossil fuels.

Life cycle assessment (LCA), an increasingly important methodology for quantifying the environmental impacts of building materials (particularly energy, and global warming potential (GWP)), will soon be incorporated into the NZ Green Building Council *Greenstar* rating tools. Such LCA studies must provide a *level playing field* for all building materials and consider the whole life cycle. Whilst the end-of-life treatment of timber by LCA may establish a present-day base scenario, any analysis must also present a realistic end-of-life scenario for the future deconstruction of any new building, as any building built today will be deconstructed many years in the future, when very different technologies will be available to deal with construction waste.

At present, LCA practitioners in NZ and Australia place much value on a single research document on the degradation of timber in landfills (Ximenes et al., 2008). This leads to an end-of-life base scenario for timber which many in the industry consider to be an overestimation of the potential negative effects of methane generation. In Europe, the base scenario for wood disposal is cascading timber products and then burning for energy recovery, which normally significantly reduces any negative effects of the end-of-life for timber. LCA studies in NZ should always provide a sensitivity analysis for the end-of-life of timber and strongly and confidently argue that alternative future scenarios are realistic disposal options for buildings deconstructed in the future.

Data-sets for environmental impacts (such as GWP) of building materials in NZ are limited and based on few research studies. The compilation of comprehensive data-sets with country-specific information for all building materials is considered a priority, preferably accounting for end-of-life options.

The NZ timber industry should continue to ‘champion’ the environmental credentials of timber, over and above those of the other major building materials (concrete and steel). End-of-life should not be considered the ‘Achilles heel’ of the timber story.

# 2.0 Introduction

This report reviews the current research and knowledge of what happens – and what may happen in the future - to the materials in a timber building in NZ or Australia when it reaches the end of its serviceable life and is deconstructed. The report also covers the environmental impacts, particularly global warming potential (GWP), that are associated with timber materials, through their full life cycle, including end-of-life. Where possible, comment is made from both an economic and a ‘practical’ perspective.

The way in which the environmental impacts of timber materials are normally measured is through life cycle assessment (LCA). To understand how LCA considers end-of-life for timber, it is necessary to have a general understanding of some of the issues around how LCA considers timber throughout all stages of the assessment process. An outline of some important LCA issues is given in this report.

## 2.1 Purpose of report

The report is a contractual deliverable from the University of Canterbury to the Structural Timber Innovation Company (STIC) to review and report on end-of-life options for structural timber in New Zealand.

## 2.2 Structure of the report

This report does not present any 'new' research – rather, it is a distillation of current understanding of end-of-life options for timber, drawing on the research of others working in the field (all reference material is cited and where appropriate, punctuation marks indicate direct quotations from reports, etc.).

The report is structured to 'develop-a-story' from why it is important to consider the full life cycle environmental impacts of timber building materials, to the tools used to measure these impacts, the various options for what happens to timber after the deconstruction of a building - both now and what may be available in the future – and, finally, makes recommendations as to how and why all of this is important to the timber industry in New Zealand and Australia.

## 2.3 Scope

The report covers knowledge gathered from sources all around the globe, then focuses this understanding on end-of-life options principally for structural timber components presently being incorporated into large-scale commercial buildings in New Zealand, such as those which employ *Expan*[1] technology (large, glued laminated veneer lumber [LVL] beams and columns [normally untreated]). It is anticipated that end-of-life options for timber are not (and will not be) substantially different in Australia.

The review is written primarily for the Structural Timber Innovation Company but may suit a wider audience interested in sustainability issues of building materials, *Green* buildings, LCA practitioners and timber users and advocates.

# 3.0 End-of-life: definition and associated processes.

In this report, and generally within the life cycle assessment (LCA) community considering buildings and building materials, end-of-life covers that period of time and those processes which happen to a building's materials, such as timber, concrete and steel, when the building is deconstructed or demolished at the end of it useful, occupied life.

Deconstruction implies a controlled 'reversal' of the construction process whereby building components and systems are removed, at least partially intact for re-use in their current manufactured form. Demolition implies a forceful 'breaking-down' of a building, to produce largely rubble, where various materials may be randomly mixed together and where any previously useful

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[1] *Expan* is a range of pre-stressed, pre-fabricated timber products offering designers and developers all the aesthetic and structural advantages of wood – with the strength and endurance of concrete and steel. At the core of the *Expan* system is a range of building technologies based on the latest LVL and glulam products. Multi-storey *Expan* buildings incorporating *Pres-Lam* technology use post-tensioned tendons, embedded in the timber, to lock the system together. The system allows the creation of very open-plan, very flexible building lay-outs without the need for closely spaced columns and walls (see http://www.expan.co.nz and http://www.stic.co.nz/products).

components have been subdivided to the extent that re-manufacture would be necessary, if they are able to be used at all.

A real-life situation normally involves varying degrees of both deconstruction and demolition so that there is the potential for 'recovery' of at least some useful materials / components / building systems.

End-of-life is a distinct phase of the life cycle assessment process which is largely considered to '*complete the circle'* of a building's material's life cycle which most usually begins with extraction / sourcing of the raw material [but could be from re-cycling], followed by its processing, usage, maintenance and finally end-of-life.

Careful deconstruction, often a costly process, is most likely to lead to the possibility for the recovery of useful / re-useable materials, or at least partially intact components / building systems which can be re-used or re-cycled, for example, directly in the construction of other buildings.

Demolition is most likely to lead to a situation where some limited material may be recovered intact but much material / components will be damaged and broken. At this point, the base material may be recovered, through (further break-down and) sorting, to produce useable amounts of wood waste, such as wood pellets, steel for recycling or concrete for aggregate. Alternatively, rubble from the demolition process may be removed wholesale and placed in landfill.

# 4.0 The role of wood in the carbon cycle and climate change.

Timber as a material has been an integral part of the construction of buildings throughout the history of mankind. In the last 20 years or so, the world has focused increasing attention on environmental matters, climate change and in particular the importance of buildings in consuming a considerable proportion of the world's energy and being responsible for producing a considerable proportion of the world's waste, together with similar proportions of the world's greenhouse gas emissions.

Of great interest is the role of wood in removing carbon dioxide ($CO_2$) from the atmosphere during the growth phase of a tree (a forest), incorporating and embedding carbon (C) into the very structure of wood and timber materials and thus buildings which use timber, storing this C during the continued existence of the intact material and then the potential release of C back into the atmosphere at the end of the useful life of the timber and its possible decay.

Sathre and O'Connor (2008 and 2009) have produced an extensive synthesis of existing scientific literature about the role of wood and timber products in relation to greenhouse gas (GHG) impacts (carbon balances) summarising consensus findings, or range of findings, addressing the net life cycle greenhouse gas footprint of wood construction products (their 2008 technical report is highly recommended).

The following is from Sathre and O'Connor:

> ……. *studies indicated several mechanisms by which wood product substitution* [that is using wood products as an alternative to conventional concrete and steel products] *affects GHG balances. These include the fossil energy used to manufacture wood products compared with alternative materials; the avoidance of industrial process carbon emissions such as from cement manufacturing; the physical storage of carbon in forests and wood materials; the use of wood by-products as biofuel to replace fossil fuels; and the possible carbon sequestration in, and methane emissions from, wood products deposited in landfills*

This report on end-of-life of timber will consider the last two points noted by Sathre and O'Connor.

It is the unique ability of wood to firstly harness renewable ('*endless'*) solar energy, and in the process sequester and store C in timber building materials, that significantly differentiates this renewable, raw material from the other more conventional structural materials, concrete and steel. Furthermore, timber offers the potential to 'recover' at least some of the stored solar energy in other useable forms at the end-of-life.

# 5.0 LCA and the conundrum of end-of-life?

How to? – indeed, whether to? – include the end-of-life phase for building materials in LCA studies has posed a considerable problem for both the proponents of different building materials and the LCA practitioners tasked with providing the science to support various 'claims', such as '*this* material is more sustainable than *that* material'.

At the heart of the problem are issues such as what are the boundaries for the system under consideration, the timeframe and a process of system expansion or 'allocation' used in LCA which 'attributes' various impacts (benefits and 'penalties') to the various outputs. Whilst an in-depth review of these 'complications' in the LCA process is beyond the scope of this report, it is necessary to briefly explain the importance of and understand a number of points and some fundamentals of LCA, and thus understand the importance of end-of-life.

It is always considered absolutely essential that in any LCA study for determination or comparisons of impacts, all assumptions must be clearly stated, so that the reader has full knowledge of how data has been collated and analysis performed (in the real world, *assumptions* are sometimes poorly stated, if at all).

## 5.1 System boundaries

LCA integrates consumption and production strategies over a whole life cycle, so preventing a piece-meal approach to systems analysis. Life cycle approaches should avoid problem-shifting from one life cycle stage to another, from one geographic area to another and from one environmental medium to another. LCA is most often conducted under the ISO 14040 and ISO 14044 guidelines (ISO, 2006).

Thus by its very definition, LCA must consider the whole life cycle, with end-of-life an integral part - this is termed ‘cradle-to-grave’.

Yet many LCA studies, often (and, often without comment) ‘choose’ to include only certain parts of a product’s life cycle. The use of the word ‘choose’ is carefully considered – it implies that the practitioner is deliberately selecting only parts of a full life cycle – undoubtedly, often because a full life cycle study is likely to be much more complicated and expensive to undertake but also because, analysing only certain parts of a life cycle will produce results which are more ‘desirable’ – thereby, enhancing the credentials of a particular product[2]. The most common misuse – perhaps misunderstanding – of LCA ‘results’ applied to building materials is where only the first parts of the life cycle are analysed – the extraction / sourcing of the raw material followed by its further processing and/or manufacturing into building components and systems; this is known as ‘cradle-to-gate’ (the factory gate) and really is a measure of ‘embodied’ impacts (embodied energy and GWP) ‘*within’* the material.

There are a number of extensively populated and well-known datasets for cradle-to-gate coefficients which include building materials, such as the international EcoInvent (http://www.ecoinvent.org/database/), and in New Zealand, Nebel, Alcorn and Wittsock (2008) have developed datasets for New Zealand building materials (see also Love (2010) for NZ-manufactured laminated veneer lumber).

These embodied or cradle-to-gate datasets do not consider what happens to the materials at end-of-life.

## 5.2 Timeframe

Consideration of ‘the timeframe’ should be clear in any discussion – so, for instance above, the timeframe for embodied values is ‘shortened’ compared to the timeframe – which must be longer – when considering the whole life cycle.

It is also very important to note the time period over which environmental impacts, such as GWP (carbon foot-printing), are calculated for any study – typically for studies involving building products this is 100 years, in line with PAS 2050:2008 (BSI, 2008) and studies carried out by ScionResearch in NZ (Sandilands and Nebel, 2009). So, for instance, for timber products this 100 year time period begins with tree growth (around 30 years for *P. radiata*), followed by production and 50 years of use and finally disposal, which cover only 20 years in landfill (while of course, the materials continue to exist, albeit underground, well beyond this time).

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[2] For example, in a recent discussion with a senior employee of the Canadian Wood Council, in a marketing role, the lead author was told, in so many words, that end-of-life for timber products was not worth considering because the consequences of any end-of-life impacts were likely to be negligible (and on the ‘*wrong side of the ledger*’) because they occurred so far off in the future – and who knows what the world may look like then!

Thus the environmental impact $GWP_{100}$, the global warming impact potential over 100 years is a measure of how much a given mass of greenhouse gas is estimated to contribute to global warming, calculated over a specific time interval (100 years). The time interval must be stated whenever a GWP is quoted or else the value is meaningless[3].

Yet how often then has the reader seen a GWP figure for a product but has been given no indication of the time period applicable?

The PAS 2050 GHG foot-printing methodology (PAS, 2050) limits impacts to what happens inside the 100 year period – if a building product exists beyond 100 years does this imply that end-of-life consideration are beyond the 100 time period for considering impacts and thus, not applicable? Similarly, if the effect of placing products in landfills only extends to 20 years (of the total 100 year timeframe), what happens beyond this 100 year time period – products will continue to have (mostly) negative impacts, which should surely be considered.

Thus the argument is easily made then that a true LCA should consider all the potential impacts with no timeframe attached. This could be considered impractical but definitely for timber products placed in landfill, extension of the decomposition period beyond 20 years should be investigated, at least in a sensitivity analysis (an example of this will appear later when considering the carbon footprint of NZ LVL).

## 5.3 System expansion or allocation

Any LCA must state clearly whether and how system expansion or allocation have been used – results from the two methodologies can vary greatly[4].

Further important ‘complications’ apply particularly when considering timber and timber products.

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[3] Noting that a substance’s GWP depends on the time horizon over which the potential is calculated, a gas which is quickly removed from the atmosphere may initially have a large effect but for longer time periods, as it is has been removed, becomes less important.

[4] ***Attributional*** LCA is an inventory of the emissions and removals from the processes used in the life cycle of a product (this can be distinguished from ***consequential*** LCA which measures the total change in emissions which result from a change in the level of demand for a product).

In many processes, more than one product is produced (joint production) and in such cases it is necessary to divide the environmental impacts from the process between the products. It is not straightforward to divide environmental impacts between the product and the co-product, but with help from allocation or system expansion it can be done. The choice between the two methods can have huge impacts on the result of the LCA. The ISO 14040 –series suggest using system expansion whenever possible and where it is not possible to use system expansion, allocation, for instance by cost or weight, can be used instead.

Allocation is part of the traditional attributional LCA method which seeks only to cut the piece of the global environmental impact related to the product. The goal is to describe the environmentally relevant physical flow/s. Average supplier’s data are used. System expansion is part of the consequential LCA method that seeks to capture changes in environmental impacts as a consequence of a certain activity and there by generate information on consequences of actions. Marginal data is used.

## 5.4 Carbon storage in products

Timber and timber products are the only common structural building materials to sequester and potentially store large amounts of carbon, as wood material is composed of about 50% carbon by dry weight. Steel incorporates and stores small amounts of carbon (typically < 0.4%).

Wood products thus provide a physical store of carbon that was previously in the atmosphere as a greenhouse gas. The climatic significance of carbon storage in wood products depends on the dynamics of the products pool as a whole, i.e., whether the total quantity of stored carbon is increasing, decreasing, or is stable. Atmospheric carbon concentration is affected by changes in the size of the wood product pool, rather than by the size of the pool itself. In the short to medium term, climate benefits can result from increasing the total stock of carbon in wood products, by using more wood products or using longer-lived wood products. In the long term as the stock of products stabilizes at a higher level, wood products provide a stable pool of carbon as new wood entering the pool is balanced by old wood leaving the pool.

The timber industry has long advocated that carbon sequestration and storage must be included when considering the environmental impacts of using different building materials – clearly because the industry believes that the 'positive' removal of carbon from the atmosphere and long-term storage in timber products is a benefit to the 'environmental credentials' of timber. LCA practitioners have largely accepted these rational arguments (if indeed, proponents of the concrete and steel industry have not!).

Studies and calculations of embodied GWP of building materials will often make allowance for this carbon sequestration. Thus, for instance, Nebel (2009) offers GWP coefficients (kg $CO_{2\ eq.}$ / kg) for timber products both with and without carbon sequestration.

However – and this is absolutely essential to the consideration of end-of-life – all the carbon sequestered during the growth of a tree has the potential to be released back into the atmosphere at end-of-life.

To paraphrase a very popular epithet '*You can't have your cake and eat it'*. It is disingenuous to emphasis the 'benefits' of carbon sequestration by timber without also accepting the 'down-side/s' which can occur at end-of-life. This is discussed further in Sections 6, 8 and 9.

## 5.5 Carbon storage in the forest

Many argue that beyond carbon storage in timber products, it is necessary to consider – indeed, it is incomplete without – carbon storage in the forest. Some would argue that it is all a matter of where the system boundaries are established. Sathre and O'Connor (2009) review international studies that include the forest within the system boundaries and the reader is referred here for further reading[5]. In NZ, this matter has largely not been raised, either by the

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[5] Leif Gustavsson the ('father' of timber construction LCA studies in Europe) has argued very persuasively that a full life-time LCA should encompass more than just the 'operations' within the forest that provide the raw timber material. His studies consider

forest industry or the competing concrete and steel industries – perhaps because the science is complicated and not so well understood, and it is not easy to define the system boundaries.

## 5.6 Substitution

The substitution method in LCA involves identifying the product or function that is replaced or "substituted" by the co-product/co-function of the main product which is being studied, and then quantifying the emissions which *would have* occurred if this product had been produced. The emissions which *would have* occurred are then credited to the main product which is being studied[6]. So, for instance, substitution accounts for the benefits of recycling steel, which is much less energy / $CO_2$ intensive than the production of virgin steel.

Substitution in relation to timber includes the effect of avoiding fossil fuel emissions due to biomass substitution, and is a contentious issue within the LCA world and one where the timber industry often finds disagreement with the concrete and steel industries. Substitution allows accounting in the LCA process to quantify the benefit of using timber waste by assuming that burning of timber displaces the use of carbon-intensive fossil fuel, such as diesel.

This is well explained by Sathre and O'Connor (2009) as follows:

*The wood contained in a finished forest product is only a part of the total biomass flow associated with the product. Substantial biomass residues are generated during forest thinning and harvest operations, and during primary and secondary wood processing. At the end of its service life, unless it is recycled for additional material use, the wood product itself becomes combustible residue. These by-products can be used as biofuel to replace fossil fuels, thus avoiding fossil carbon emissions. The quantification of GHG benefits due to the use of residues from the wood product value chain is not straightforward; issues include the allocation of benefits to the different biomass fractions, varying carbon intensity of the fossil fuel replaced, leakage (i.e., a unit of additional biofuel does not necessarily lead to a unit*

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the wider impact of active forest management – posing this question, "What is the effect on the total forest carbon stock – long-term, does it increase or decrease?" [Which equates to what is the long-term C balance in the atmosphere – does timber construction reduce atmospheric carbon?]. See a very up-to-date paper by Dodoo and Gustavsson (2012).

[6] 1. A production process creates 3kg CO2e and produces 1 unit of product A (the main product studied), and 1 unit of co-product B.

2. The production of co-product B means that product C is not produced (i.e. 1 unit of B "substitutes" 1 unit of C), and producing 1 unit of C *would have* emitted 4kg CO2e.
3. Using the substitution method, the avoidance of 4kg CO2e is credited to product A (for avoiding the production of C), so the overall result for product A is -1kg CO2e (3kg CO2e – 4kg CO2e = -1kg CO2e).

The problem with using substitution in attributional LCA is that it introduces a value for emissions which don't happen (i.e. the emissions associated with the product which is substituted don't happen), and this means the result of the assessment will not be a true inventory of actual physical emissions and actual physical removals. It is not clear what the results of an attributional LCA which uses substitution mean, as they are neither a true inventory of actual physical emissions and actual physical removals, nor do they show the full consequences of a change in the level of production (which is the purpose of consequential LCA). Substitution in attributional LCA creates a strange mixture of attributional and consequential analysis.

*reduction of fossil fuel use), potential soil carbon stock change due to removal of harvesting residues, and uncertainties about how post-use wood products will be handled by future waste management systems. Nevertheless, the recovery and combustion of the biomass by-products associated with wood products appears to be the single most significant contributor to the life cycle GHG benefits of wood product use.*

Note particularly above – "[substitution] *appears …. the most significant contributor to the life cycle GHG benefits of wood product use*"[7].

Wood waste, which could substitute for carbon-intensive fossil fuels is generated both initially in the forest at the time of harvest, then during production and manufacture of timber components and lastly, at end-of-life during deconstruction. This review is concerned mainly with the wood waste generated at end-of-life.

## 5.7 Land Use Change

Land use change can be important when considering carbon balances of complex lifecycles and particularly depends on the system boundaries adopted. However, it is beyond the scope of this report and rarely accounted for in most LCA studies.

## 5.8 Carbon dynamics in landfills

Some wood products are deposited in landfills at the end of their service life. Carbon dynamics in landfills are recognized to be quite variable, and can have a significant impact on the life cycle GHG balance of the wood product. A fraction of the carbon content in landfilled wood will likely remain in semi-permanent or permanent storage, providing climate benefits (Ximenes, 2008). Another fraction may decompose into methane, which has much higher global warming potential (GWP) than $CO_2$. However, methane gas from landfills can be partially recovered and used as a biofuel to replace fossil fuels. Thus, the landfilling option for post-use wood products carries great uncertainties, and could result in climate benefits (partial sequestration in landfills, and partial production of methane bio-fuel) or adverse climate impact (emission of methane or $CO_2$ to the atmosphere).

This issue will be more fully discussed in Section 8, together with examples from a number of studies (Section 9).

## 5.9 Recommendations for assessing end-of-life of timber using LCA.

The following are recommendations made with regard to the way in which LCA should consider the end-of-life disposal option for timber building materials.

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[7] Indeed, Gustavsson in Europe has argued very strongly that end-of-life disposal of timber through incineration and energy generation must fully account for substitution for alternative marginal energy, namely fossil fuels. (However, another leading exponent of LCA in Europe, Prof Stefan Winter of TUM argues equally vehemently that substitution should not be allowed).

1. Any LCA study – and associated datasets - should be transparent and clearly state all assumptions that have been made. Where possible, all raw data should be available for inspection and checking by other parties. However, often, in reality, sensitive commercial (competitive) considerations mean that only aggregated data is available, at best.
2. A complete (full) LCA study should include end-of-life. Historically, timber has been ‘questioned’ around end-of-life issues due to the uncertainties associated with landfilling and the release of methane and has sometimes ‘evaded’ the issue. For this reason, timber building materials should pay extra care and attention to end-of-life issues, (maybe) ensuring even greater transparency than other materials. Any discussions / statements around the environmental impacts of timber should clearly state whether data is cradle-to-grave or cradle-to-gate. Any cradle-to-gate information, that is embodied values, should clearly define that end-of-life has not been considered.
3. System boundaries must be clearly defined and, where any comparative data is used, boundaries should be the same. At present, it is unrealistic to include all the complexities of what happens within a forest (soil carbon changes, etc.) and the impacts and consequences of land-use change, so boundaries for timber products should be clearly drawn to include the growing and harvesting of timber, which would be in-line with the extraction processes associated with steel and cement and aggregates for concrete.
4. 100 years is often a suitable timeframe for considering the environmental impacts of building materials, and in-line with PAS 2050. The timeframe and its starting point must always be stated for an environmental impact. For timber products placed in landfill, extension of the period to encompass longer decomposition should take place with an associated sensitivity analysis.
5. Any LCA must clearly state the basis for allocation and system expansion. The ‘norm’ for buildings appears to be attributional LCA with system expansion to cater for material re-cycling and substitution, including avoided fossil fuel emissions due to conversion of biomass to useful energy.
6. Carbon storage (sequestration) in building materials should be included in any LCA, going in-hand with impacts at end-of-life.

# 6.0 End-of-life for timber building materials – the options.

The destructive earthquakes in Christchurch in 2010 and 2011 have meant that a significant number of large buildings have had to be completely demolished, giving rise to an unprecedented amount of construction and demolition (C&D) waste building material (estimated at around 8.75 M tonnes), including much timber, a large amount of which was chemically treated with preservatives at the time of building construction.

C&D waste may represent up to 50 percent of all waste generated in New Zealand, 20 percent of all waste going to landfill and 80 percent of all waste going to clean-fill. C&D waste is a complex waste stream, made up of a wide variety of materials including concrete, plasterboard, wood, steel, brick and glass. Much C&D waste can be reduced, re-used and recovered, dramatically reducing the amount sent to landfill.

The following NZ websites provide much good general information about building waste:

- NZ Government Ministry for the Environment, MfE, http://www.mfe.govt.nz/issues/waste/construction-demo/index.html
- REBRI (Resource efficiency in the building and related industries) http://www.branz.co.nz/REBRI

Broadly there are three options for C&D timber waste at the end-of-life:

1. Re-use or recycling.
    - Re-use is to use an item again after it has been used and includes conventional reuse where the item is used again for the same function, and new-life reuse where it is used for a different function. For building materials, re-use can involve the recovery of largely intact materials, components or building systems for further construction (re-use of timber products such as framing, floorboards, windows and doors), and;

    - Recycling is the breaking down of the used item into raw materials which are used to make new items, to prevent waste of potentially useful materials, reduce the consumption of fresh raw materials, reduce energy usage, reduce air pollution (from incineration) and water pollution (from landfilling) by reducing the need for "conventional" waste disposal, and lower greenhouse gas emissions as compared to virgin production. Recycling is a key component of modern waste reduction and is the third component of the "Reduce, Reuse, Recycle, Recover and Residual (landfill)" *5R* waste hierarchy. (Timber cannot be recycled in the way that steel and aluminium are recycled as basic elements).

2. Disposal with energy recovery – an end-of-life option for timber which is almost unique for a building material by:
    - Incineration
    - Gasification
    - Pyrolysis

    However, whether C&D timber waste is chemically treated or untreated timber has a large determining effect on the practical options currently available for end-of-life of timber in NZ.

3. Disposal through landfilling - the process for the disposal of waste materials by burial and is the oldest form of waste treatment. Historically, landfills have been the most common methods of organized waste disposal and remain so in many places around the world.
    - Cleanfill – or C&D landfill, which accepts largely hard waste, material that when buried will have no adverse effect on people or the environment. Cleanfill material includes virgin natural materials such as clay, soil and rock, and other inert materials such as concrete or brick that are free of combustible,

putrescible, degradable or leachable components and hazardous substances. In reality in NZ, cleanfill sites may contain timber.

- MSW (municipal solid waste) landfill - consisting of everyday items that are discarded by the public. The composition of municipal waste varies greatly from country to country and changes significantly with time. In countries which have a developed recycling culture, the waste stream consists mainly of intractable wastes such as plastic film, and un-recyclable packaging. In developed countries without significant recycling it predominantly includes food wastes, yard wastes, containers and product packaging, and other miscellaneous wastes from residential, commercial, institutional, and industrial sources (Most definitions of municipal solid waste do not include industrial wastes, agricultural wastes, medical waste, radioactive waste or sewage sludge).

## 6.1 The problem of treated timber in New Zealand.

More than half of the timber used for construction in NZ is chemically treated to prevent premature decay. Treated timber poses a number of problems for its disposal at end-of-life and due to the large amount likely to enter landfills in Christchurch, Environment Canterbury[8] (ECan) undertook work to research the options for the disposal of this treated timber. This excellent work was conducted by Chris Keeling, a Hazardous Substances and Waste Officer at ECan, and much of the following section has been reproduced from a 2011 ECan report conveyed by personal communication (Keeling, C. 2011). In particular, this work relates to the situation in Canterbury but the authors believe that, excluding earthquake waste, the region is typical of other areas of NZ and thus the findings are applicable to the whole country. This is also considered applicable across much of Australia, although a smaller proportion of construction timber is treated in Australia compared to NZ.

Treated timber is a common building material in New Zealand, used because of its resistance to insect/fungal attack and general decay. Radiata pine is the most commonly used timber species in New Zealand. Compared with other softwoods, radiata pine has low natural durability, but its porous cell structure makes it very receptive to chemical treatment. The Building Regulations 1992 dictate that the structural elements of a building must have a lifespan of at least 50 years, which means that for timber-framed buildings, the timber must last the lifetime of the building. Treated radiata pine can fulfil this criterion.

Chromated copper arsenate (CCA) is probably the most well-known timber treatment but is only one of many, such as other high-pressure, water-based treatments, alkaline copper quaternary (ACQ), copper azole (CA-B / CA-C) and low-pressure, solvent-based light organic solvent preservatives (LOSP), copper naphthenate, boron and of course paint, creosote and varnish.

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[8] Environment Canterbury (ECan) is the regional council working with the people of Canterbury to manage the region's air, water and land.

Love (2007) estimated the volume of treated timber produced in New Zealand in 2006 to be 830,250m$^3$. Of this, it is estimated that 574,750m$^3$ of timber was treated with CCA and 255,500m$^3$ of timber was treated using other treatments. Using Love's figure, even just over the last 20 years, 16.6 million cubic metres of treated timber have been put into circulation in New Zealand. This suggests massive volumes of treated timber currently in use in NZ that will eventually require disposal. This is a legacy that will continue long after earthquake-related C&D waste from Christchurch has been disposed of.

In addition to treated timber, MDF, particleboard/chipboard and plywood also have few other disposal option than landfilling. Due to the formaldehyde or phenolic binding agents used in their manufacture, these wastes should be considered in the same light as treated timber.

## 6.2 Current treated timber disposal options for Canterbury

Following earthquake-related demolitions, it is estimated that 300,000 – 500,000 tonnes of timber will require disposal; however, the proportion of treated timber is unknown. Current disposal options are limited. Cement kilns on the West Coast (Holcim) and Whangarei (Golden Bay) may be able to take treated timber for fuel but haulage costs make this solution prohibitive and the likely calorific value of the treated timber (estimated at 6MJ/kg) reduces its commercial value. In Canterbury, the most cost-effective disposal option is disposal in a MSW landfill, such as Kate Valley. The main concern with landfilling treated timber is that leachate may be produced, containing contaminants from the treatment process such as arsenic and chromium. Jambeck et al. (2004) ran laboratory simulations with CCA-treated wood in different disposal scenarios to understand leaching characteristics. Scenarios included mono-fill and co-disposal with MSW. The highest metal concentrations were recorded in leachate from the 100% CCA-treated timber mono-fill scenario. The co-disposal scenario, where CCA-treated timber was mixed with MSW, reported only slightly lower concentrations of arsenic and chromium in leachate, but copper concentrations remained relatively low. However, these experiments used newly treated timber, which will have higher leaching potential than older treated timber.

Treated timber in Canterbury is not permitted to be disposed of to cleanfills as it is not considered by Environment Canterbury to be an inert material. This is regulated through resource consents, issued and monitored by Environment Canterbury. In Christchurch City, this is also regulated by a council bylaw, which does not permit treated timber in cleanfills. According to the Ministry for the Environment (MfE) cleanfill guidelines (2002), any "processed" timber is not acceptable cleanfill material due to the difficulty of identifying whether wood has been treated. The rationale for this is that chemicals used for timber treatment, including CCA, LOSP, PCP, boron and creosote, may leach out of the timber and contaminate soils and groundwater, having a detrimental effect on human health and the environment. The term "processed" is not clearly defined.

## 6.3 Potential treated timber disposal options

### 6.3.1 Landfilling

This is currently the most viable disposal option for treated timber in New Zealand. However, this option is the least sustainable; getting zero recovery, requiring landfill space and contributing an on-going source of treatment chemicals to landfill leachate. Economically, the on-going landfilling of treated timber will become more costly in the future if the waste levy is increased and as landfill space becomes more limited.

### 6.3.2 Landfilling for later recovery

This option is a combination of two methods; landfilling the treated timber with the aim of later recovery for an alternative disposal solution. The benefit is that the waste is dealt with temporarily, meaning that storage space is not required above ground. There is also the potential for energy or resource recovery in the future. However, the treated timber is still landfilled and contributes the leachate to the landfill while it is buried. The largest disadvantage of this method is the numerous handlings; landfilling, recovery and further treatment/processing, each with their own associated costs. Resources are not yet scarce enough to make this option particularly viable simply based on cost. An additional disadvantage with this option is the unknown timeframes for recovery as it is reliant on future technology or processes. It is possible that, as priorities and economics change, buried waste will never be recovered.

### 6.3.3 Treated timber reuse/recovery

The simplest method of ‘disposal’ would be to recover and reuse treated timber. There are two main options for this:

1. Direct reuse of lengths of timber in construction - any timber would require sorting to identify usable lengths that could be reused instead of using new treated timber. This would have a two-fold effect; reduce the demand for new treated timber and reuse treated timber already in circulation, reducing disposal volumes. However, one issue with this method is finding reliable lengths of treated timber; all timber recovered would need to be building-worthy according to the Building Regulations 1992. As a result of the earthquakes, it is anticipated that there would be a low yield of reusable lengths of treated timber following demolition of mainly older buildings.
2. Economically, this may be a costly method due to the time, space and labour needed to sort through C&D timber wastes and extract useable lengths. Other automatic methods are available such as X-Ray Fluorescence (XRF) and Laser-induced Breakdown Spectroscopy (LIBS), which use both x-ray and laser, respectively, to identify wood type. However, at the current time, it is unlikely that these methods present a viable, cost effective option for sorting wood waste. Additionally, the current low cost of new treated timber makes the time and effort spent on reusing old timber less enticing.

3. Recycling treated timber into synthetic board – Some untreated wood waste is currently recycled in this way, being chipped to use as feedstock for chipboard or particleboard production. A report undertaken for WRAP (2005) in the UK summarises some experimentation with various recycling methods. There are a number of barriers to using treated timber in this way. In the UK, limits have been put in place to restrict the concentrations of heavy metals and other contaminants in particleboard. This limits the use of treated timber waste to very small quantities. Love (2007) states that Auckland Regional Council had put in place regulation preventing the use of treated timber in particleboard manufacture; it is unknown if these regulations are still in place.

   Love (2007) also makes reference to the inclusion of treated timber in wood-cement and wood-plastic composites. The addition of CCA-treated wood has been shown to improve the performance of these products. However, despite the recycling benefits, incorporation of treated timber into these products could be merely shifting the problem of difficult waste further along the life cycle.

### 6.3.4 Energy recovery

Recovering energy from treated timber must be accomplished through the application of heat. There are three ways of doing this:

1. **Incineration** – burning in the presence of oxygen. In some countries, such as Switzerland, incineration is used to dispose of treated timber waste. There are currently no waste incinerators in New Zealand. The issue with this method is the volatilisation and emission of timber treatment chemicals into the air due to the high temperatures involved. To prevent this, a scrubber system would be required to remove heavy metals from the emissions. These could then potentially be recovered and used as a resource. A study undertaken by a Dutch engineering consultancy, Tauw (2000), suggests that in small quantities (~1%), MSW incinerators can burn CCA treated wood, and comply with Dutch emission limit values. An additional issue with this method is that the residual ash requires disposal and, when incinerating CCA-treated timber, the ash contains a concentration of heavy metals.
2. **Gasification** – reacting in an oxygen deficient environment at high temperatures (800°C +). This process produces gas, often called syngas, which can then be mixed with oxygen and used for energy production. The problem with this method is that due to the high temperature, volatilisation of arsenic from the treated timber will occur. This means that any extracted syngas will require scrubbing to remove the arsenic content prior to being used as a fuel. There are currently no commercial waste gasification plants in New Zealand but an experimental unit has been constructed at the University of Canterbury.
3. **Pyrolysis** – burning in an oxygen deficient environment at temperatures less than 700°C. There are three outputs of this process; pyrolysis gas, pyrolysis

oil and charcoal. Some arsenic may still be volatilised but this is reported to be less than incineration or gasification so should be easier to capture prior to emission (Love, 2007). The gas can be used as a fuel to run the plant, meaning that this method can be relatively self-sustaining. Pyrolysis has been trialled in Auckland to dispose of tyres. In Europe, the Chartherm process, developed by a French company, has been used to recover energy from both treated and untreated timber on a commercial scale.

Apart from the generation of energy, the benefit of energy recovery methods are that, with the right equipment, the treated timber is combusted without the treatment chemicals reaching the atmosphere. Also, unlike the generation of energy from fossil fuels, the energy is generated without releasing fossil carbon (Jambeck et al., 2007). The disadvantage in these methods is that the ash still contains the treatment chemicals, albeit the volume of waste to landfill is much reduced. However, the concentration of copper, chromium and arsenic becomes concentrated in the ash (Solo-Gabriele et al., 2002). It has also been reported that when CCA-treated timber is incinerated, the chromium can be oxidised into Cr(VI), the more mobile and toxic form of chromium (Song et al., 2006), which may increase the toxicity of any residual wastes.

Work by Jambeck et al. (2007) investigated the lifecycle trade-offs between CCA-treated wood disposed to municipal solid waste landfill (MSW) and burned using a waste-to-energy (WTE) method. WTE was estimated to be nearly double the cost per tonne of timber waste than using MSW. However, the advantages are that energy is generated from the waste without the release of fossil carbon and smaller areas are required in landfill for the residual ash (as opposed to the equivalent volume of timber), which may offset the higher costs. The significant disadvantage is that the treatment metals, copper, chromium and arsenic, are more concentrated in the residual ash after WTE combustion. Following laboratory-scale leachate testing on both disposal methods, it was found that copper was not leached from the WTE ash at levels out of the range of normal landfill leachate. Arsenic was released at a slower rate from the ash annually than the MSW method but, due to a smaller disposal area requirement, showed higher release rates per area. Chromium was released at the same rates for both methods, but similarly to the arsenic, was released at higher rates per area from WTE ash when compared to MSW. Additionally, as chromium may be oxidised to the chromium(VI), both the toxicity and mobility may be increased generating a more hazardous leachate. This may make management and disposal of the leachate more difficult and costly.

### 6.3.5 Chemical extraction

Chemical extraction is a process where the treatment chemicals are recovered from the timber leaving timber that can be disposed of as normal timber and a solution containing the extracted treatment chemicals. A number of extraction methods have been developed to experimental levels, such as bioremediation, chemical removal and electrodialysis (Love, 2007). When used on CCA-treated timber, these methods have achieved high extraction rates of up to 94% copper, 95% chromium and 98% arsenic.

However, prior to putting treated timber through any of these processes, the timber needs to be chipped or ground up, increasing the surface area to facilitate the reactions and achieve high extraction rates; this requires high energy input. Also, all the methods require the timber to have long residence times in the solution, which will limit these methods in scale. Another potential issue with these processes is that they produce a hazardous solution which contains all the treatment chemicals. It is anticipated that the treatment chemicals could be extracted for reuse, but this would involve further processing. The viability of this method is questionable due to the high energy and time requirements compared to benefit.

# 7.0 Disposal Options Appraisal

Table 1 (from Keeling, 2011) gives a summary of pros and cons for each disposal option. Table 2 ranks each option against different criteria to ascertain which may be the most viable.

Following the Canterbury earthquakes, ECan has anticipated that large quantities of treated timber will require disposal following the demolition of large numbers of commercial and residential buildings. Along with the normal intake of treated timber into Canterbury transfer stations, larger than usual quantities of treated timber will be available, presenting an opportunity to develop a commercial-scale alternative to landfilling in conjunction with earthquake recovery.

ECan considers that currently, the most viable method of treated timber disposal in Canterbury is landfilling in an engineered landfill. Following appraisal of potential disposal options for treated timber, ECan recommends that serious consideration should be given to waste to energy methods, such as gasification and pyrolysis. Despite the high costs, these methods could offer attractive trade-offs such as energy/fuel generation and reduced space requirements in landfill. The drawback to these methods is the continuing generation of residues which contain heavy metals. These residues still require landfilling (albeit taking up much less landfill space) and will still contribute contaminants to landfill leachate.

A further drawback to the development of waste to energy methods within Canterbury is the uncertainty of long-term supply of suitable waste material – the considerable waste from the recent Canterbury earthquakes has given rise to an abnormal, but relatively short-term potential for suitable waste which in the future will not be so readily available, nor perhaps in the same form as the waste currently available.

**Table 1 - Pros & cons of available disposal methods (**From: Keeling, 2011)

| Disposal Option | Pros | Cons |
|---|---|---|
| **Landfilling (MSW)** | - Most cost-effective solution at present time<br>- Infrastructure already in place<br>- Does not require above ground space for storage | - Unsustainable practice – requires space and leaves legacy of on-going source of contamination<br>- Limited to disposal in engineered landfills such as Kate Valley<br>- Addition of timber treatment chemicals into landfill leachate<br>- In the future, will become more cost prohibitive |
| **Landfill for later recovery** | - Treated timber will be extracted for better disposal in future<br>- Leaves time to develop technology/processes to recycle/recover treated timber<br>- Landfilling most cost-effective solution at present time<br>- Does not require above ground space for storage, prior to recovery | - May be ‘forgotten’ and not recovered<br>- Relies on development of future technology, which may not happen<br>- Additional time and cost of recovery and further processing on top of landfilling costs<br>- Addition of timber treatment chemicals into landfill leachate<br>- Limited to disposal in engineered landfills such as Kate Valley<br>- Must keep detailed records of where treated timber is buried<br>- Burying large quantities of treated timber in area of mono-fill may increase concentration of leachate locally |
| **Reuse/ recovery** | - Will produce resource and remove some treated timber from the waste stream<br>- Relatively low energy input required for direct reuse in construction | - Labour intensive - not economic due to time and cost<br>- Reuse will depend on lifespan of timber – anticipate yield of reusable treated timber<br>- Using in synthetic boards prohibitive due to treatment chemicals |
| **Incineration** | - Energy recovered<br>- Energy generated without release of fossil carbon to atmosphere<br>- Ash takes up less landfill space than timber equivalent – possible cost savings | - High cost<br>- Treatment chemicals are more concentrated in ash<br>- Ash still requires landfilling – will contribute to landfill leachate<br>- Chromium can be oxidised into more toxic and mobile Cr(VI)<br>- Emissions will need to be scrubbed |
| **Gasification** | - Syngas recovered<br>- Energy generated without release of fossil carbon to atmosphere<br>- No emissions<br>- Ash takes up less landfill space than timber | - High cost<br>- Treatment chemicals are more concentrated in ash<br>- Ash still requires landfilling – will contribute to landfill leachate<br>- More arsenic volatilised that other energy recovery methods due to high temperatures |
| **Pyrolysis** | - Gas, fuel and charcoal recovered<br>- Resource recovered without release of fossil carbon to atmosphere<br>- No emissions<br>- Potentially self-sustaining using pyrolysis gas | - High cost<br>- Treatment chemicals can be concentrated in residues<br>- Residues still require landfilling – will contribute to landfill leachate |
| **Chemical Extraction** | - Potential high extraction rates<br>- Treatment chemicals may be reused after extraction | - Technology only experimental at this stage<br>- High energy input required<br>- Long timescales for all processes<br>- Will need large scale plant to process commercial volumes |

**Table 2 – Treated timber disposal options Appraisal (**From: Keeling, 2011)

**Scoring: 10 = excellent, 1 = poor**

| Disposal Option | Cost | Availability of method | Environmental impact | Resource recovery | Total | Comment |
|---|---|---|---|---|---|---|
| **Landfilling (MSW)** | **8** | **10** | **3** | **1** | **22** | Currently most cost effective method although long-term cost will increase; infrastructure already in place; long-term, continuing source of treatment chemicals in leachate; no resource recovery. |
| **Landfill for later recovery** | **2** | **6** | **4** | **4** | **16** | Currently landfilling most cost effective method but additional cost to recover, handle and process; infrastructure already in place for landfilling but mining/recovery not widely undertaken in New Zealand; long-term continuing source of treatment chemicals in leachate until removal; resources may be recovered but reliant upon technology and human desire to recover. |
| **Reuse/recovery** | **2** | **8** | **5** | **5** | **20** | Will be labour, time and space intensive for reuse and costly to sort for recovery into synthetic board; infrastructure generally available to undertake these methods (space may be an issue for reuse); some treated timber diverted from waste stream; yield of timber fit for reuse likely to be low and inclusion into synthetic board has limited potential due to presence of treatment chemicals. |
| **WTE incineration** | **5** | **5** | **5** | **6** | **21** | High cost but trade-offs with lower landfill space requirement and energy generation; no incinerators currently in NZ (operational commercial unit in Finland); emissions would include treatment chemicals but filters can be fitted; ash reduces landfill space requirement but has higher concentration of treatment chemicals (leachate still produced); energy generated as part of process without releasing fossil carbon. |
| **Gasification** | **5** | **6** | **5** | **8** | **24** | High cost but trade-offs with lower landfill space requirement and energy/fuel generation; no commercial gasification plant currently in NZ (experimental plant operational at University of Canterbury); no emissions – syngas would include treatment chemicals (especially arsenic) but can be filtered; ash reduces landfill space requirement but have higher concentration of treatment chemicals (leachate still produced); energy generated as part of process without releasing fossil carbon. |
| **Pyrolysis** | **5** | **7** | **5** | **8** | **25** | High cost but trade-offs with lower landfill space requirement and energy/fuel generation; pyrolysis plant trialled in Auckland/commercial- scale plants in France; no emissions – gas would include treatment chemicals but can be filtered; residues reduces landfill space requirement but have higher concentration of treatment chemicals (leachate still produced); gas, fuel and charcoal generated as part of process without releasing fossil carbon. |
| **Chemical Extraction** | **2** | **2** | **7** | **6** | **17** | Lots of processes, very high cost; method not available (experimental) anywhere in world; removes treatment chemicals but waste timber must still be disposed of along with hazardous solution; metals may be recovered and reused. |

From: Keeling C (2011) *Briefing paper: Treated Timber Disposal Options Appraisal (Draft).* Environment Canterbury TRIM number C11C/65724

### 7.1 Burwood Resource Recovery Park (BRRP).

The Christchurch earthquakes gave rise to an unprecedented amount of construction and demolition waste to deal with, much of which is mixed timber material of varying quality. What happens to this timber material in the next couple of years will provide valuable insights into future timber disposal in New Zealand.

In June 2012, Christchurch City Council (CCC) and BRRP Ltd (a subsidiary company of Transwaste Limited) applied for resource consents to process and recycle earthquake waste at BRRP, and permanently dispose of earthquake waste at Burwood Landfill. TransWaste Canterbury Ltd.[9] has developed the site and operates the sorting area. The CCC website http://www.ccc.govt.nz/homeliving/rubbish/burwoodresourcerecoverypark.aspx states that BRRP has sorted, processed and recycled 350,000 tonnes of building rubble so far, with another 150,000 tonnes of demolition waste expected as the rebuild continues. However, very little other information is forthcoming on specific intentions or progress!

The authors understand that BRRP has constructed a very large sorting facility and this is due to become operational around March 2013 (Pers. comm. Richard English).

## 8.0 What happens to timber when it is placed in a landfill?

This report will use the LCA case study undertaken by ScionResearch (Love, 2010) on NZ-manufactured LVL to demonstrate the current knowledge on what happens to timber materials at end-of-life when they are placed in landfills. Much of the research and background information in this study can be applied to other different timber materials.

### 8.1 Behaviour of timber in landfill – the problem.

Behaviour of wood in landfill is a complex issue. In the 2006 IPCC National Greenhouse Gas Inventory guidelines (IPCC, 2006), it is stated that:

> "*The reported degradabilities especially for wood, vary over a wide range and is yet quite inconclusive. They may also vary with tree species. Separate DOCf [fraction of organic cabon that decomposes] values for specific waste types imply the assumption that degradation of different types of waste is independent of each other [sic]…scientific knowledge at the moment of writing these Guidelines is not yet conclusive on this aspect*".

End-of-life degradability of timber assumes such significance because timber placed in landfill has the potential to generate quantities of methane ($CH_4$) which is a very potent greenhouse gas. Whilst timber sequesters carbon during the growth phase of trees, this 'benefit' can be entirely

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[9] Transwaste Canterbury Limited is a joint venture. Half of its shares are owned by five local authorities (Christchurch City Council, Hurunui, Waimakariri, Selwyn and Ashburton District Councils), with the other 50% of its shares owned by Canterbury Waste Services Limited.

eroded over the full lifecycle if significant quantities of $CH_4$ from landfills are emitted back into the atmosphere at end-of-life.

## 8.2 Limited research on timber in landfills.

The only known reference that uses research-derived evidence in the form of wood products buried in a real landfill and later removed after a length of time to determine actual decomposition rates is that of Ximenes et al., (2008). This research paper has assumed real significance in both the Australasian LCA community and with those people concerned with evaluating the 'green credentials' of timber (often vis-a-vis concrete and steel). For this reason, the paper's abstract is included below:

> *Abstract: Three landfill sites that had been closed for 19, 29 and 46 years and had been operated under different management systems were excavated in Sydney. The mean moisture content of the wood samples ranged from 41.6% to 66.8%. The wood products recovered were identified to species, and their carbon, cellulose, hemicellulose and lignin concentration were determined and compared to those of matched samples of the same species. No significant loss of dry mass was measured in wood products buried for 19 and 29 years, but where refuse had been buried for 46 years, the measured loss of carbon (as a percentage of dry biomass) was 8.7% for hardwoods and 9.1% for softwoods, equating to 18% and 17% of their original carbon content, respectively. The results indicate that published decomposition factors based on laboratory research significantly overestimate the decomposition of wood products in landfill.*

This paper has assumed such importance because any full-lifecycle LCA study on timber building materials must present an end-of-life scenario and because end-of-life can have such a major effect on the overall, full-lifecycle environmental impacts of timber. In NZ and Australia, most C&D waste, including timber, is currently placed in landfills.

In NZ, ScionResearch, who have undertaken a number of LCA studies on timber materials and timber buildings, use the evidence from this research to establish a 'default position' end-of-life scenario, based on the present predominant disposal method for timber building materials in NZ being landfilling (the author believes the scenario is the same in Australia).

This almost 'rigid' adherence to an end-of-life scenario (based on Ximenes work) has come about because of a lack of any other sound research in this area and no known corroborative work. Furthermore, the work undertaken by Ximenes, whilst based on sound science, is not extensive, either over time, geographical area, or sampling size. The question then must be asked as to whether so much 'reliance' should be placed on one study?

Indeed, that question is asked by both sides of the debate – by the timber proponents who claim that this default position is a 'worst-case' scenario (who state that using figures which show less decomposition for timber in landfill (equals less $CH_4$ to the atmosphere) would improve the environmental profile of timber) to the supporters of alternative structural materials, concrete and steel, who point out the scarcity of good research in this area and the doubt that should be placed on the validity of making 'claims' for timber based on a single piece of research (this camp would suggest that much more 'damage' could be being done at the end-of-life as timber degrades to produce CH4 and, also, that the impacts must be considered to extend beyond the 100 years measured by $GWP_{100}$).

Perhaps most significantly, Ximenes paper states that '*published decomposition factors based on laboratory research significantly overestimate the decomposition of wood products in landfill'.* Does this 'summary' then support the pro-timber lobby?

There are indeed a range of scientific papers which present vastly different decomposition rates for wood arising from laboratory experiments on degradation of wood under anaerobic conditions (Peltola et al., (2000); Tong et al. (1990); US EPA (1998)).

A recent paper by Milke et al. (2010) reviews the research of a number of studies into the anaerobic degradability of wood. This study confirms that wood is relatively non-biodegradable in anaerobic environments, though there is a wide variety of results ranging from roughly <1% to 20% of wood carbon converted to methane carbon. This contrasts sharply with IPCC assumptions that 50% of wood will degrade in landfill environments. Milke states that the most reliable and recent laboratory results found 1.5% conversion for softwoods and 6% conversion for hardwoods at <20 mm size, after 1.5 years under ideal laboratory conditions. Milke further states that the review shows relatively strongly that untreated wood degradation in anaerobic environments is best estimated to be 0-20%, or 10% as a good overall estimate, with roughly 5% of the carbon in wood converted to methane. The literature indicates lower anaerobic degradability for pine and eucalyptus wood. At these efficiencies, wood disposed in landfills should be roughly carbon-neutral with the negative of methane production balanced by the positive of carbon sequestration.

The ScionResearch default end-of-life scenario assumes the decomposition of the wood is to reach a maximum of 18%, and the product of carbon decomposition is assumed to be 50% carbon dioxide, and 50% methane (Ximenes et al., 2008, IPCC, 2006). To restate an important point made above, the 18% figure is the only reference found that uses evidence in the form of wood products removed after a length of time in a landfill (Ximenes et al., 2008). This figure was given for softwood after 46 years in landfill. ScionResearch state that they believe these figures to be a conservative estimate (even more so as only 20 years of landfill emissions would be included in the 100-year timeframe).

ScionResearch further state that in addition, anecdotal evidence would suggest that a compressed, coated and treated engineered wood product would decompose more slowly than bare softwood, making the default decomposition rate likely to be an overestimate, particularly for treated LVL.

The wide-spread of results and the lack of field data, especially over a long time period, lead the authors to be highly sceptical of any dogmatic statements about end-of-life of timber in landfills. Perhaps then it is only fair to adopt a conservative scenario, which can only improve the reasoned standpoint of ScionResearch in due course. Section 9 describes a sensitivity analysis which shows the effect of adopting varying degrees of degradation of timber in landfills.

Beyond the variability (and unpredictability) of how much degradation of timber occurs in landfills and what gases are produced over time, there are still a number of variables to consider, particularly with respect to whether landfill methane is captured, flared or simply escapes to the atmosphere. This depends greatly on the type of landfill. Love (2008) offers the following scenarios for the consideration of NZ-produced LVL:

> *Three different landfill types are modelled: an unmanaged landfill (with no methane capture), an 'average' NZ landfill in 2010 (where 51% of the methane is captured), and a future prediction (for 2050 instead of 2110 as this is the farthest prediction that MfE figures include) for a managed NZ landfill, where 60% of the methane is captured (MfE,*

> *2008). Of this methane, not all will be used for energy generation – some is flared. As of 2007, 6 out of 11 NZ landfills with methane capture technology generated energy (MfE, 2007). Using these figures, an assumption has been made that 43% of captured methane is used for energy generation, and 57% is flared. For a future (2050) scenario, it has been assumed that 90% of captured methane is used for energy generation.*

## 8.3 Incineration – an alternative end-of-life.

Love (2010) proposes an alternative (to the default landfilling) end-of-life for timber such as LVL of incineration.

> *For modelling of incineration, it is assumed that complete combustion occurs, releasing all stored CO2-e. This scenario is therefore an assumption of no permanent carbon storage. In the future, it is unlikely that wood products would be incinerated without energy recovery. Therefore, this scenario assumes the energy produced from burning the wood waste is used for cogeneration of heat and electricity. This heat could be utilised by industry, displacing heat from natural gas, and the electricity could replace electricity from the national grid. The GWP impacts of these displacements (using current NZ environmental data from Barber, 2009) have been taken into account.*

# 9.0 An example of the effect of adopting different end-of-life scenarios for timber materials.

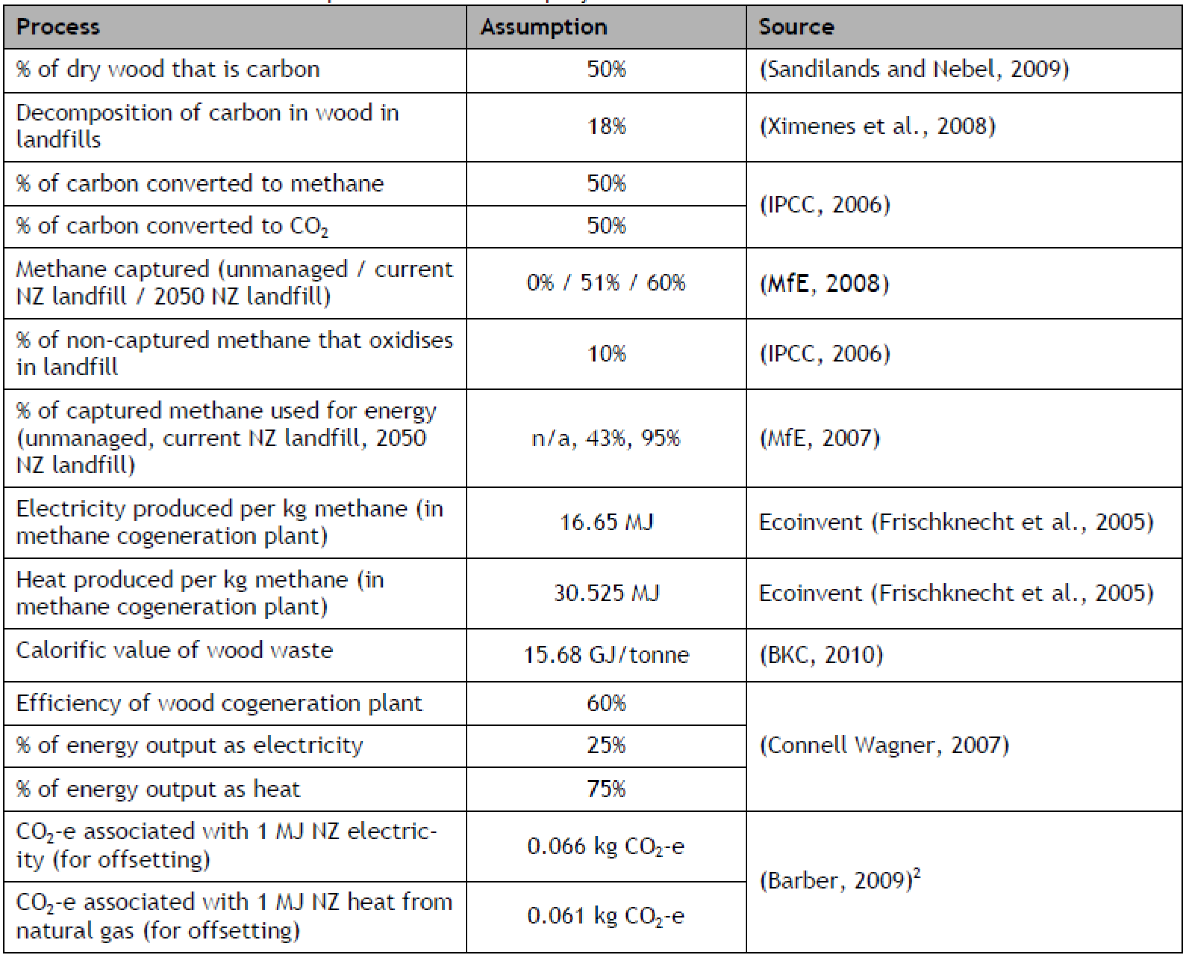
The ScionResearch LVL study (Love, 2010) excellently demonstrates the variability of results – and hence the different environmental credentials that can be claimed - for timber under different end-of-life scenarios, as presented above. End-of-life assumptions for the ScionResearch LVL project (Love, 2010) are summarised in Table 3.

The following is from Love (2010);

> *At the end of the products' life* [LVL]*, the overall impacts for likely end of life scenarios result in GWP emissions. The total net life cycle GWP values however, remain negative, either due to carbon storage in landfills, displacement of energy from other sources, or a combination of the two. Unmanaged landfills have the highest GWP emission (762 kg CO2-e), while a well-managed landfill, capturing 60% of the methane and using almost all of this for energy generation will result in the smallest GWP emission of 355 kg CO2-e. Incineration with energy recovery results in emission of - 584 kg CO2-e; this figure is reduced considerably due to offset of conventional energy*

Results giving GWP for alternative end-of-life processes for NZ-produced LVL are shown in Table 4.

**Table 3. End-of-life assumptions for timber placed in landfill (Love, 2010).**

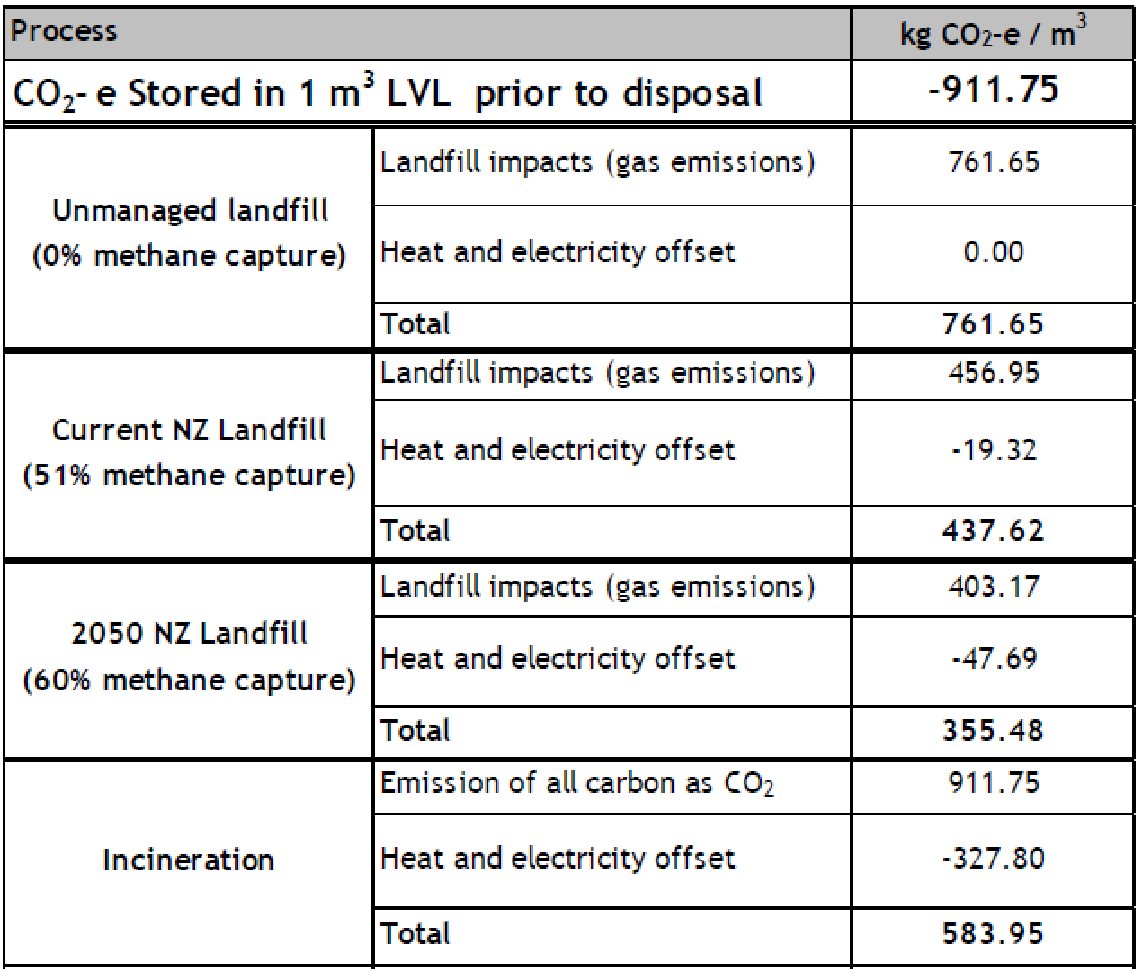


| Process | Assumption | Source |
|---|---|---|
| % of dry wood that is carbon | 50% | (Sandilands and Nebel, 2009) |
| Decomposition of carbon in wood in landfills | 18% | (Ximenes et al., 2008) |
| % of carbon converted to methane | 50% | (IPCC, 2006) |
| % of carbon converted to $CO_2$ | 50% | |
| Methane captured (unmanaged / current NZ landfill / 2050 NZ landfill) | 0% / 51% / 60% | (MfE, 2008) |
| % of non-captured methane that oxidises in landfill | 10% | (IPCC, 2006) |
| % of captured methane used for energy (unmanaged, current NZ landfill, 2050 NZ landfill) | n/a, 43%, 95% | (MfE, 2007) |
| Electricity produced per kg methane (in methane cogeneration plant) | 16.65 MJ | Ecoinvent (Frischknecht et al., 2005) |
| Heat produced per kg methane (in methane cogeneration plant) | 30.525 MJ | Ecoinvent (Frischknecht et al., 2005) |
| Calorific value of wood waste | 15.68 GJ/tonne | (BKC, 2010) |
| Efficiency of wood cogeneration plant | 60% | (Connell Wagner, 2007) |
| % of energy output as electricity | 25% | |
| % of energy output as heat | 75% | |
| $CO_2$-e associated with 1 MJ NZ electricity (for offsetting) | 0.066 kg $CO_2$-e | (Barber, 2009)[2] |
| $CO_2$-e associated with 1 MJ NZ heat from natural gas (for offsetting) | 0.061 kg $CO_2$-e | |

Table 5 presents a summary of the results for a full lifecycle cradle-to-grave LCA for NZ-produced LVL. In each different end-of-life scenario, tree growth sequesters carbon, whilst there are emissions to the atmosphere over the lifetime of the timber from forestry operations, production and transport. However, at end-of-life, the different scenarios give rise to very different net GWP, with an unmanaged landfill giving rise to a net lifetime emission of $CO_2$-e to the atmosphere, whilst the best scenario is the future 2050 NZ landfill with 60% methane capture, which gives rise to a significant long-term, permanent storage of $CO_2$-e.

The end-of-life contributions to emissions to the atmosphere in percentage terms for each different scenario vary from 79% (unmanged landfill) to 63% (2050 NZ landfill). In all cases it is obvious that the end-of-life has a very significant impact on the net overall GWP and only the unmanaged landfill would give rise to net $CO_2$-e lifetime emissions to the atmosphere.

**Table 4. GWP Results for end-of-life processes for NZ-produced LVL (Love 2010).**



| Process | | kg $CO_2$-e / $m^3$ |
|---|---|---|
| $CO_2$- e Stored in 1 $m^3$ LVL prior to disposal | | -911.75 |
| Unmanaged landfill (0% methane capture) | Landfill impacts (gas emissions) | 761.65 |
| | Heat and electricity offset | 0.00 |
| | Total | 761.65 |
| Current NZ Landfill (51% methane capture) | Landfill impacts (gas emissions) | 456.95 |
| | Heat and electricity offset | -19.32 |
| | Total | 437.62 |
| 2050 NZ Landfill (60% methane capture) | Landfill impacts (gas emissions) | 403.17 |
| | Heat and electricity offset | -47.69 |
| | Total | 355.48 |
| Incineration | Emission of all carbon as $CO_2$ | 911.75 |
| | Heat and electricity offset | -327.80 |
| | Total | 583.95 |

In ‘marketing terms’, it would be possible – and the authors believe ‘fair’ - to describe NZ-produced LVL as having a true negative carbon footprint for the scenarios of a currently operated NZ landfill, a future, improved 2050 NZ landfill and where timber is incinerated at end-of-life. All lifetime emissions associated with forestry, production, transport and end-of-life are offset by the initial sequestration of carbon in the growing tree and the permanent storage of carbon in landfills, together with displacement of energy from other sources.

Love (2010) states;

> *Clearly the carbon storage benefit from landfill disposal has a significant impact on the overall GWP, storing and/or offsetting 146 kg CO2-e per m3 over the incineration scenario. The conclusion that can be drawn …… is that, based on a range of assumptions, landfilling of waste LVL results in a lower GWP result.*

**Table 5. Summary results for different end-of-life scenarios for untreated LVL (Love 2010).**

| Process | Unmanaged landfill (kg $CO_2$-e / $m^3$) | Current NZ landfill (kg $CO_2$-e / $m^3$) | 2050 NZ landfill (kg $CO_2$-e / $m^3$) | Incineration (kg $CO_2$-e / $m^3$) |
|---|---|---|---|---|
| Tree growth (sequestration) | -912 | -912 | -912 | -912 |
| GWP emissions due to forestry, production and transport | 208 | 208 | 208 | 208 |
| GWP end-of-life emissions | 762 | 438 | 355 | 584 |
| Total | **58** | **-266** | **-349** | **-120** |

## 9.1 End-of-life sensitivity analysis.

Once again, the ScionResearch work on NZ-produced LVL offers a valuable insight into the importance of end-of-life assumptions (and data).

From Love (2010);

> *A sensitivity analysis on the decomposition of wood in landfill has been performed, and results are shown in Figure* (1). *The figure of 18% decomposition (over 46 years) has been used as the base scenario for calculations in this* (NZ-produced LVL) *project (Ximenes et al. 2008), and because this extends beyond the 100-year timeframe of the project, it is considered a conservative estimate. The IPCC uses default figures for wood of 43% degradable organic carbon, and a total of 50% decomposition of this carbon with a half-life of 23 years (which is within the scope of this study) (IPCC, 2006). Results using the IPCC results for 20 years (the scope of this study) and 50 years (well beyond the scope of this study) are shown.*

## 9.2 System Expansion – electricity substitution.

Love also highlights one of the difficulties for LCA noted in Section ?, that of system expansion, noting "These results are another indicator that transparency at the end of life stage is essential, as assumptions for energy displacement can have a significant bearing on results".

> *Another paper discussing the decomposition of forest products estimates that 0-3% of the carbon in wood is ever emitted as landfill gas (Micales and Skog, 1997). The lower value has been used to show the low extreme of decomposition estimates, which results in a large net storage of carbon. These results show that the 'end of life' stage is very important to the LVL life cycle – if the decomposition of wood products in landfill is*

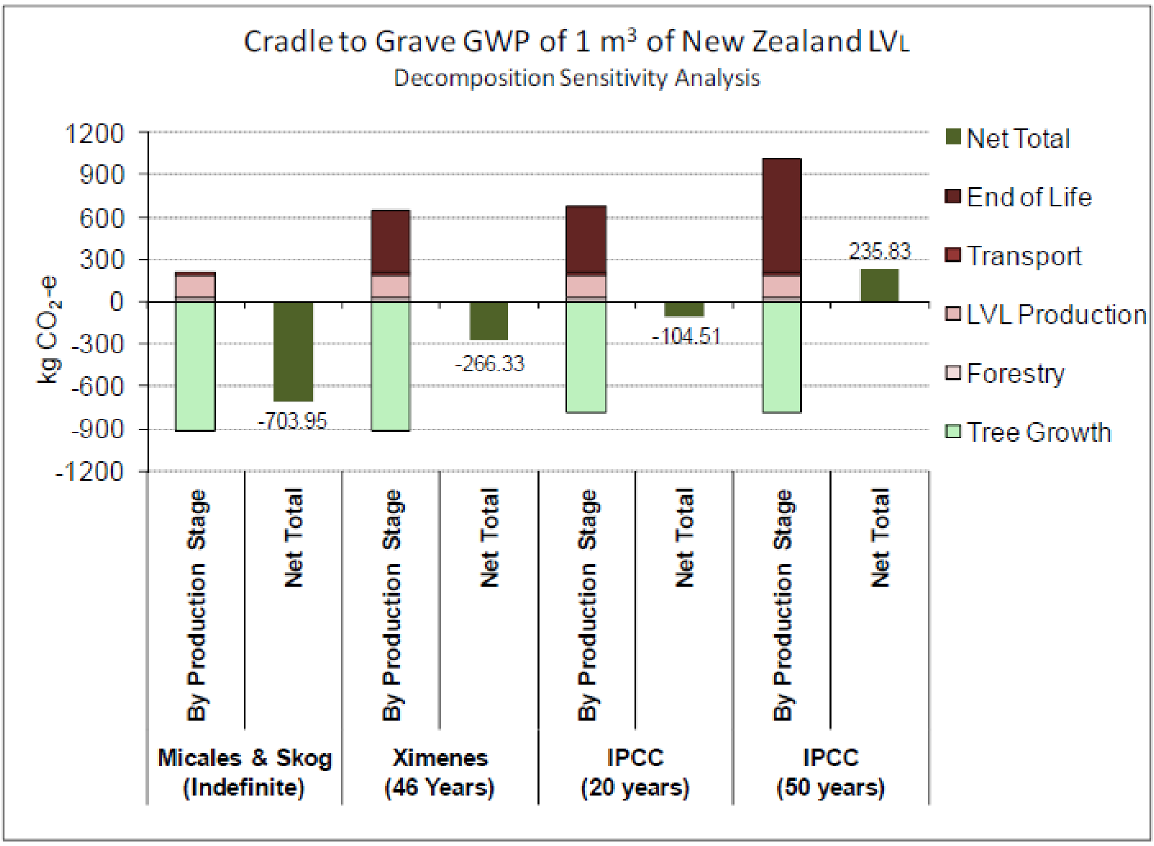


**Figure 1. Effect of decomposition in landfill (Love 2010), comparing 18% decomposition (Ximenes et al., 2008) with 0% (Micales and Skog, 1997) and IPCC first-order decay models (IPCC, 2006), assuming the current (51%) methane capture rate (MfE, 2008).**

> *higher than expected, then incineration may become a more favourable choice (with regards to GWP) for disposal. It is also very likely that for treated LVL in landfill, decomposition rates will be much lower than the default figure used in this report, making landfilling look more feasible from a GWP perspective.This same princple may apply for LVL in landfills in very dry countries, where decomposition rates may be slowed.*

From Love (2010);

> *The end of life stage for LVL in this study* (Love, 2010) *considered two options: landfilling of LVL, and incineration. To examine the full impact of these scenarios, 'system expansion' has taken place, which results in a change in demand for heat (assumed to be conventionally generated from natural gas) and electricity. In the base calculations, electricity is assumed to be the average grid mix, which is deemed as an acceptable proxy for the 'short-term marginal' electricity mix, for small changes in demand using the International Reference Life Cycle Data System (ICLD, 2010). While it is difficult to predict the electricity source that waste LVL would substitute, it is likely that the 'short-term marginal' electricity mix is 'peak' demand, which in NZ is likely to be generated from thermal (gas and coal) sources.*

*With this in mind, a sensitivity analysis has been undertaken investigating substitution of the average grid mix (the base scenario in this report), electricity from coal, and electricity from natural gas. This analysis is to investigate the significance of changes in electricity source, as opposed to estimating three realistic scenarios. Results for the landfilling of LVL found that the overall net results differed by a maximum of 3% (untreated) and 5% (treated) from the base scenario, and thus these results are not investigated further. Results for incineration found that end of life impacts decrease by 39 kg CO2-e per m3 of LVL if electricity from coal is substituted, and increase by 7 kg CO2-e per m3 LVL if electricity from natural gas is substituted. This shows that if waste LVL is incinerated and the electricity replaces electricity from coal, the overall GWP is a larger net offset than the base scenario. These results are another indicator that transparency at the end of life stage is essential, as assumptions for energy displacement can have a significant bearing on results.*

## 10.0 Looking to the future ('lessons' from Europe).

The negative environmental impacts of buildings and cities all around the world are being increasingly realised , the tools to measure these impacts are becoming more sophisticated and building designers, owners and operators are paying greater attention to 'greening' the built environment. European countries are leading the way, and it is likely that what happens in the future in Australasia will follow current developments and regulations in Europe.

Many European countries have stated goals and policies to encourage and facilitate moving rapidly towards 'zero waste' – landfilling in many EU countries is simply no longer an option. European LCA practitioners do not consider landfilling as a viable end-of-life scenario – as a consequence, the author on a visit to Europe in 2012 learned very little regarding research on the placement of timber in landfills (and nothing, at all, to substantiate or otherwise the research of Ximenes in Australia).

For many in Europe, recycling of construction and demolition waste is the only viable way forward – with regard to timber, this means 'cascading' timber products, a means of extending the useful life of timber materials by firstly reusing recoverable timber components in other buildings, then re-processing timber waste material into composite products, such as fibre board, pulp (for paper, etc.), etc. Cascading is seen to extend the C-sequestration potential of timber materials – with the view that if this cascading can be shown to operate over at least a number of 'cycles', then the 'logical' conclusion is that timber can be re-used ad infinitum (and hence C can be considered to be stored long-term)! However, if the time frame is extended out many years (beyond 100 years), this 'argument' is flawed because timber will eventually decay and C will return to the atmosphere (unless some permanent secure storage for timber waste, for instance, underground is available).

Burning wood waste is normally considered the 'final' end-of-life option in Europe, often only chosen when no better, useful alternative exists. Burning is viewed as C-neutral. There are a number of commercial-sized, energy-generating wood waste plants in the Scandinavian and northern European countries and subsidies are in place in some countries to encourage further investment.

For LCA practitioners, when timber products are 'cascaded', this poses a problem of defining the end-of-life for each timber product at each stage – for instance, if timber from a building is recycled into another product, should the C-burden be passed on to the next product or fully accounted for in the initial building product? This is an allocation problem.

In Europe, the author noted very strong support for believing that the end-of-life for timber products will look very different in 60 years time (even in 10 years time). This went hand-in-hand with a 'belief' that cascading and then finally incineration would position timber much more favourably in the future, particularly with respect to concrete and steel (even allowing both these materials to benefit from increased recycling). However, the author was not made aware of any research studies that specifically supported the above optimism.

Overall, the European message was to adopt a more aggressive approach with respect to end-of-life scenarios for timber buildings by only considering future disposal methods because current disposal practices are not relevant to buildings constructed now! This would assume full (100%) reuse / recycling of timber and address the issue of allocation of C balance to cascaded timber products.

In America, the respected Athena Sustainable Materials Institute confirmed that landfilling of C&D waste is the norm, yet even here the author discovered no new material or research on the behaviour of timber placed in landfills. Athena is the leading proponent of LCA practices and tools in America, yet its own environmental impact assessment tools do not make any consideration for end-of-life (timber receives no C credit but neither does it receive any penalty for end-of-life disposal). Note that in North America, land-filling is still the normal end-of-life scenario for C&D waste (note the word waste!).

A soon-to-be-released version of Athena software will include more detailed end-of-life scenarios for building materials and will also include C-sequestration in tree growth. The author understands that three end-of-life scenarios will be covered - firstly, landfill will result in net sequestration; secondly, re-use of all timber products over the same length lifetime as the building life which will (apparently) effectively halve the impact of timber in the buildings and be a better scenario for timber than landfill and thirdly, combustion of timber, a marginal analysis with displacement of coal or gas, stated to be an even better option. At the time of the author's visit to Athena, no research evidence was given in support of these three options.

# 11.0 The future in New Zealand.

Considering the above, it is realistic to expect that in New Zealand (and Australia), there will be increasing restrictions placed on materials going into landfill, particularly materials which could be re-used or recycled, such as timber. The success or otherwise of the Burwood Resource Recovery Park will be a practical demonstration of the political and economic will to recycle timber.

To date, there are no large-scale energy-producing incineration plants in NZ and certainly none that can handle significant quantities of treated timber. There is no publicly available information to suggest that this will change in the near future.

With respect to landfills, Love (2010) shows that a future 2050 landfilling scenario, where there is increased collection and use of methane would be an improved end-of-life option for timber. So, whilst landfilling will certainly not cease to exist overnight in NZ, much greater restrictions are being placed on the capabilities of new landfills to restrict the input of unsuitable materials which may increase the conditions for degradation of materials in the landfills, to minimise and retain any leachate and gases that are produced and to capture whatever emissions, such as methane, occur which can then be used for energy production.

# 12.0 Discussion and points to note for the NZ timber industry.

The environmental impact of building materials extends well beyond their simple, useful, but relatively short life as components of a building. How and from where the materials are sourced, their processing and manufacture and finally their so-called ‘disposal’ can all make major contributions to the material’s full lifecycle impacts, as well as being the source of ‘raw’ materials for other further lifecycles.

Indeed, modern ‘lifecycle thinking’ does not really recognise an ‘end-of-life’ phase of a material, where that material and its environmental impacts somehow simply ‘disappear’ from the planet; rather, it is recognised that all materials, even those that may be buried deep underground, have the potential to be recycled or reused, and to continue to have impacts on the environment many, many years into the future. Hence, the lifecycle of a material does not end; it flows into the next lifecycle and so on, ad infinitum. Recognising that a material (or its fundamental components) has an infinite life - where the material will often continue to be ‘useful’ - means that it is no longer appropriate to just ‘*dig a hole, throw it in and any problem will go away*’ (we call this landfilling!*)*. This largely outdated approach is not just ‘head-in-the-sand’ but potentially a hugely wasteful misuse of the planet’s limited energy and resources.

Thus, there is an increasing demand, on many fronts, to severely reduce the amount of timber construction materials that are placed in landfill by finding new and innovative ways to extend the useful life of timber components, recycle and incorporate (sometimes) degraded timber materials into other forms of materials and new components or to generate energy.

## 12.1 Timber end-of-life options

### 12.1.1 Today in New Zealand.

At a practical level, today, in New Zealand the options for timber materials produced when a building reaches the end of its useful life are limited – the building’s timber is either placed in a construction and demolition (C&D) landfill or timber components / pieces are recovered and reused or recycled. There is a very limited capacity to separate timber and burn it for energy recovery. Whilst reused or recycled timber many enter another useful phase, maybe even in another building, the same ‘choice’ will come around again at the end of the next lifecycle and eventually, due to degradation and reduction of piece size, most timber will find it’s way to landfill.

### 12.1.2 In the future

Present activities in Europe point to where NZ will be in the future in terms of end-of-life options for timber. Landfill is no longer considered a viable option for timber 'disposal' in many European countries. 'Cascading' of materials, whereby the material at the end of one lifecycle provides the 'raw' material for another material's lifecycle is growing rapidly. This is not the simple 'reuse' of a component for the same or similar purpose (for instance, wooden windows) but the use of (normally) modified timber material/s into other materials (such as fibre-board). It may be possible to carry out cascading over a number of lifecycles, thus extending the useful life of the original timber. This approach can be likened to recycling steel. The question remains open as to how often this cascading could take place – and what happens to materials when they can no longer be 'cascaded'.

### 12.1.3 Energy recovery.

Timber is a unique building material – it quite literally 'grows' in our forests, harnessing 'free' solar energy, which is 'bound' into the timber fibres and can be recovered at a later date. The production of the raw material requires minimal input of fossil fuel energy (or none at all), whilst solar energy is limitless and does not deplete any of the earth's natural resources.

In its simplest form, burning wood waste produces heat. There is increasing demand around the world for woody materials to feed biomass energy systems, such as co-generation (or combined heat and power, CHP) plants, which generate electricity and useful heat at the same time, and wood waste from the construction industry could be directed to help fulfil this demand. The timber processing industry itself is a very good example of this co-generation (due to the ready-availability of wood waste), whilst, especially in Scandinavia and eastern Europe, CHP captures some or all of the by-product heat for heating purposes, often very close to the plant as hot water for district heating with temperatures ranging from approximately 80 to 130 °C. (This is also called Combined Heat and Power District Heating or CHPDH and is mooted to be being seriously debated as an important part of the Christchurch re-build).

However, at present, there is limited opportunity for burning wood waste to recover energy in NZ for a number of reasons. Firstly, it is not yet an economically feasible alternative to other energy sources (and the NZ Government does not provide any subsidies or other incentives, as happens in several European countries). Secondly, wood and wood waste has a low energy density (making it uneconomical to transport) and NZ does not present a happy marriage of large, dense industrial and urban areas in close proximity to a long-term, sustainable source of wood fuel (which would improve the long-term prospects for a viable economic return on a large capital investment). Lastly, and particularly relevant to burning C&D waste that would otherwise go to landfill, much of the present and future wood waste stream in NZ is treated timber, which poses a problem all around the world for its disposal.

The alternative technologies being trailed, such as gasification and pyrolysis, which appear near to achieving technological developments which can be reproduced on an industrial scale, suffer from similar problems to above.

Excellent work is being undertaken by a number of groups in NZ, including ScionResearch, to harness the potential of timber waste routinely produced in large quantities throughout NZ's commercial forests, which if successful should also be able to 'mix in' a substantial amount of timber C&D waste from the building industry . (It has recently been reported in the *NZ Herald* that the Norwegian company, Norske Skog, is investing around NZ$50M in a biofuel test plant at Kawarau, to produce bio-crude from radiate pine sawdust).

The problem of utilising treated timber is rather more intractable, with no commercially viable system or treatment apparent in the near future.

## 12.2 End-of-life and LCA

Whilst LCA is increasingly being used to recognise and quantify the various environmental impacts that a material can have over its lifetime – and beyond - the process does not yet provide a totally *level playing field*. LCA both suffers from a lack of internationally agreed rules and regulations (although huge advances have been made in the last couple of years), as well as being a complex and expensive process, able to be 'manipulated' by various interest groups and industries to portray a product in a favourable (or not so good) light.

LCANZ (Life Cycle Association of NZ) and ALCAS (Australian Life Cycle Assessment Society) are two organisations leading the way in their respective countries to develop rigorous rules and methodologies to underpin the developing science. See http://lcanz.org.nz/mission for the key objectives of the NZ organisation, which includes the need to identify, prioritise and address barriers to widespread uptake of LCA and relevant resources, such as country-specific data- sets.

Section 5 of this report discusses some of the problems of LCA, end-of-life and, in particular, how to assess the impacts of timber materials sourced from deconstructed buildings. Section 5.9 offers some of the author's own recommendations. Whilst the 'problem' is complex, establishing firm rules and procedures, encompassing the whole life cycle of all building materials and extending the assessment of impacts well beyond the normal 100 year lifetime for a building will help to ensure that any comparisons made between the environmental impacts of various materials is fair.

It is normal for a building material LCA to establish a base scenario, which will stipulate important factors such as system boundaries, allocation and system expansion, which provides for material re-cycling and substitution, including avoided fossil fuel emissions due to biomass. However, it is strongly argued that for any materials currently being produced and used for construction, their future end-of-life disposal options could be very different to what is available at present (the base scenario). Many European countries no longer send timber waste to landfills, firstly cascading timber products for many years and the default option for LCA studies is burning for energy recovery. It is considered very likely that such disposal options (and others, not yet foreseen) will be available in NZ in the future. Hence, it is strongly recommended that any LCA studies in NZ and Australia include different end-of-life scenarios, especially for timber materials (as shown in Section 9).

Caution is required however, as the author has encountered the widespread belief within both the timber industry and LCA circles that burning timber waste at end-of-life will reduce the overall GWP impacts of timber materials used in buildings in NZ. The LVL case study in Section 9 shows that this is not always the case. From a GHG point of view, the best case scenario for wood may well be one where timber C&D waste is placed in a modern landfill, a considerable amount of any methane generated is captured, and this is then used for efficient generation of alternative energy, displacing carbon-based fossil fuels.

The biological degradation of timber products in landfills is not well understood, with research based mostly on small-scale laboratory studies, not real, field case studies. The default position adopted by many in NZ and Australia is based solely on the work of Ximenes (2008) where the generation of methane may have been calculated to be higher than actually occurs. As a result, the overall GWP for timber materials is near to a 'worst-case' scenario with several comments provided to the author by overseas LCA practitioners that their 'gut-feeling' is that NZ studies (such as those on the Biological Sciences building at University of Canterbury (John, et al. 2009) and the Arts and Media Centre at Nelson Marlborough Institute of Technology in Nelson (John, 2011)) overestimate the adverse end-of-life impacts of timber materials.

Present-day data sets for global warming potential of various building materials in NZ are limited and based on a small number of studies. Hence, it is common to refer to overseas (often European) data-sets, which may not be entirely relevant to the local industry. In particular, the energy mix for producing electricity in NZ is very different to most other countries and this can have a marked effect on any marginal analysis.

## 12.3 Green Building Rating Schemes

The NZ Green Building Council has indicated a commitment to incorporating at least some degree of LCA of building materials into future building rating tools, such as Greenstar (this would be in-line with developments in rating tools around the world). There is a need for a quantitative tool for environmental impacts that can be both used practically by architects and engineers, who are not 'experts' in LCA, as well as being affordable. The author is concerned that a 'quick and dirty' tool in Greenstar will not portray the full lifecycle of materials, nor recognise the potential benefits of using more wood in buildings.

For instance, GWP data-sets do not normally account for end-of-life disposal of materials (being only cradle-to-gate). Buchanan et al. (2012) proposed a calculation method for estimating the GWP associated with production, transport and disposal of all the materials in a building but a GWP data-set to achieve this is not yet available.

## 12.4 Lessons for the NZ Timber Industry.

The authors have been involved with research on the sustainable benefits of timber and timber buildings for many years. Six years ago, at the height of world-wide attention on climate change, there was great 'optimism' in the industry that the environmental credentials of timber would finally be recognised and help lead to timber being the building *material of choice in a new, greener world*.

Whilst the 'green timber story' is being promoted very strongly all around the world by many large and influential organisations and practitioners (indeed with evidence of some success), here in NZ, what happens to timber materials at the end of the useful life of a building has always been seen to be somewhat of an *Achilles heel* – the potential release of methane from landfills cancelling out much (if not all) of the benefits of carbon sequestration and low embodied energy. The steel and concrete industries have been very proactive in detailing the advantages of recycling of their own building materials, whilst highlighting the lack of practical recycling for timber materials, the lack of facilities for burning timber and in particular the problems of dealing with treated timber. The authors have also experienced first hand the apparent lack of willingness, indeed stubbornness, by both the concrete and steel industries to engage in *open* dialogue about the environmental credentials of their products, particularly vis a vis those of timber, and the importance of LCA and its incorporation into building rating tools.

However, worldwide, LCA is increasingly being seen as a way to provide a level playing field comparison for building materials. The world-leading Athena Sustainable Materials Institute in North America (http://www.athenasmi.ca/) has now incorporated LCA into its assessment tools which in turn are central components of the LEED (http://new.usgbc.org/leed) green building programme (US Green Building Council) in the US. Similar moves are taking place in Europe. As noted in the section above, the Green Building Councils in both NZ and Australia are committed to providing at least some form of LCA assessment in future rating tools and this will become more prevalent and robust over the next few years.

The NZ timber industry should continue to embrace and support the relevance and suitability of LCA as a tool to highlight the environmental credentials of building materials. However, this should be tempered with a realisation that several studies to date have not shown timber to be *such* a clear winner over concrete and steel. The authors believe that the more in-depth, robust studies which consider the full lifecycle impacts (energy and GWP) position timber *alongside* both concrete and steel – often better but not to the extent that was anticipated by some practitioners and supporters of the timber industry. This position is particularly important when considering engineered wood products (EWP), such as LVL, which is largely untreated but utilises large quantities of glues which are based on fossil fuels and energy intensive to produce. This is in contrast to some studies which consider only part of the lifecycle of materials (cradle-to-gate), willing to accept the benefits of early carbon sequestration but failing to recognise the consequent end-of-life implications, often over a limited time period which fails to account for the on-going, long-term impacts of a material. Note that in the simplest form, air-dried, untreated framing timber does indeed have some clear environmental advantages over concrete and steel products but, this is not a fair comparison – structural timber for large commercial buildings of the future will increasingly be EWP and must be compared to similar structural concrete and steel. New organic adhesives, currently under development, will greatly reduce the environmental impacts of EWPs in due course.

End-of-life of timber materials should always be thoroughly, openly and robustly addressed – this is the only way to demystify the perceived problems associated with timber disposal in landfill, the present lack of facilities to cascade timber products and, then to utilise the benefits of burning timber for energy recovery. The present day disposal of most timber waste in landfills should be clearly acknowledged, whilst robustly presenting the future, highly reasonable - and logical – arguments and evidence that shows that future, different disposal options will be available. Disposal - and use - of the vast mass of timber materials generated by the recent Canterbury earthquakes should be closely 'watched' and where possible, encouragement should be given to maximising the benefits of this resource, as it will provide good indications of how NZ as a country views and treats timber waste.

These future options may not be a 'silver bullet' but are very likely to improve the environmental credentials of timber – from constructing more secure (less leaky) landfills, to collecting and utilising more efficiently more of the gases produced by timber degradation, to increased investment in alternative energy sources and biofuels in particular.

The timber industry should be prepared to support research into better understanding what happens to timber when it is placed in landfill. In this way, the industry would have more country-specific information to use and to refute the 'base-scenario' end-of-life currently used by researchers (such as ScionResearch). Similarly, the options for how to deal more productively with treated timber must be better understood in the future, as more of this material becomes available for disposal / recycling / reuse / burning.

# 13 Conclusions

**Disposal options**

- At deconstruction / demolition of a building in NZ, most timber materials end up being buried underground in landfill. This disposal option is likely to continue to be the most feasible option in NZ for at least the next 10 – 15 years, both from a practical / technological position and economically. However, future legislation may limit this option.
- Some timber materials and building components are recycled / reused. This is increasing due to legislation (in some parts of Europe timber can no longer be placed in landfill), voluntary 'greening' of the construction industry, increased landfill costs, and community pressures.
- Other disposal options will become available over time. These include cascading timber products (waste timber forms the raw material for engineered wood products), chemical modification (gasification, pyrolysis, chemical extraction) and burning separated timber waste to recover energy (and displace the use of other fossil fuels).

**Treated timber**

- Treated timber disposal remains a problem in NZ (and elsewhere) and into the foreseeable future. Careful, 'smart' design at the architectural and engineering design stages of a building's life should seek to reduce the use of treated timber.

**Life cycle assessment**

- Life cycle assessment (LCA) is increasingly being used to demonstrate and quantify the environmental impacts (notably energy and GWP) of all building materials. The Greenstar building rating system in NZ will include LCA within its range of rating tools in the near future.
- LCA should make every effort to create a *level playing field* for assessment of all materials, based around (preferably international) rules and regulations and clear boundaries.
- LCA must cover the whole life cycle of all building materials, including end-of-life. Any nominated 'lifetime' should extend well beyond the initial disposal of the materials, as impacts will continue for many years after a building is deconstructed.
- LCA must utilise country-specific data sets, whenever possible. The NZ construction industry should play an active part in populating such data-sets with robust information.
- LCA should account for carbon sequestration of all materials, as well allowing for recycling of materials through system expansion.
- LCA should present a number of scenarios for end-of-life disposal of materials – for instance, a study could offer a present-day base scenario, a worst-case scenario (often the present-day scenario) and a future, realistic scenario (any building standing or being constructed today, will quite obviously be deconstructed at some future date, which could be many, many years away).
- The timber industry should be aware that LCA will extend in the future to cover many other environmental impacts than just energy and GWP; the use of water may be one impact that will be highlighted with regard to timber (and growing and harvesting forests). The timber industry would be wise to be proactive in understanding what other impacts timber has on the environment and how these may be presented.

**Landfill and burning**

- The behaviour (degradation) of timber materials in landfill is not well understood. In NZ, the data most frequently used to calculate the emission of methane to the atmosphere may be near to the worst-case scenario (Ximenes, 2008). Further research in this area could provide data to show that timber disposal in landfills provides very long-term sequestration of carbon.
- Future improvements in the technology and operation of NZ landfills should allow increased, efficient utilisation, of any methane generated from timber degradation or other sources. The development of infrastructure to facilitate the burning of timber waste to generate heat and power will allow greater energy recovery and displacement of carbon based fossil fuels.
- Burning timber waste for energy recovery at the end-of-life is normally recognised to provide the lowest adverse environmental impacts (at least from a GWP perspective). However, the difference between timber disposal through burning for energy recovery and a secure landfill may not be hugely significant.

**Overall**

- The NZ timber industry should continue to 'champion' the environmental credentials of timber, over and above those of the other major building materials (concrete and steel). End-of-life should not be considered the 'Achilles heel' of the timber story – rather open discussion, robust data and forceful, logical explanation should present timber as, at worst, on a par with other materials, and at best, a far better 'green' choice to build a sustainable world.

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