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EXTENDED PRODUCER RESPONSIBILITY OF TREATED TIMBER WASTE

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ABSTRACT

Extended producer responsibility (EPR) is defined by the OECD as ‘an environmental policy approach in which a producer’s responsibility for a product is extended to the post-consumer stage of the product’s life cycle’. EPR is a concept that ideally should provide incentives for producers to take responsibility for the environmental impact of their products throughout the entire life cycle of the product. It also aims to enhance post-consumer resource recovery and recycling.

The New Zealand Timber Preservation Council (TPC) estimates 5,000 tonnes of copper, chromium and arsenic (CCA) salt equivalent are used annually to treat an estimated 650,000 m^3 of timber to various treatment grades. Much of this treated timber ends up as waste from construction sites, while demolition sites also provide a source of waste treated timber. EPR policies could significantly reduce the amount of waste timber being dumped or stockpiled, and could result in benefits for the environment as well as for the producer, in the form of new products from waste wood. This literature review has assessed the options for EPR in the timber industry in New Zealand, and has resulted in recommendations for future implementation of EPR schemes.

KEYWORDS:

Extended producer responsibility; treated timber; timber waste;

INTRODUCTION

Extended producer responsibility (EPR) is a concept which places the responsibility for the end-of-life environmental impacts of a product on the producer. Formal EPR schemes can involve a great deal of planning, as well as administrative functions, collection, transport and processing of waste materials, and consumer education. The benefits of an EPR scheme include improved utilisation of resources and reduction/recycling of waste.

Treated wood would be an excellent target for an EPR scheme as it is a waste that is potentially hazardous, takes up unnecessary space in landfills, and has the potential for energy recovery. With the Waste Minimisation (Solids) Bill appearing before parliament, producers are becoming aware of the need to be responsible with their waste. The current statistics, situation and policy surrounding EPR will be discussed, with a focus on treated timber. Following this, techniques to sort and process waste treated timber will be investigated. Currently treated timber is very rarely sorted, and is usually landfilled. Other options do exist, such as reuse of treated wood, production of particleboard (and other recycled products) and thermal treatment. These techniques will be explained, and possible ways of moving forward will be proposed.

At this point in time, the potential of treated timber is not being realised. This literature review serves to examine ways of reducing an important waste stream, while getting the maximum benefit from an underutilised resource. The focus will be on end-of-life processes for the waste timber, as this is the area where most change can be implemented – the end-of-life processes examined in this paper can apply to treated timber that has been in use for many decades.

TIMBER STATISTICS

Production Statistics

The 2005 statistics for rough sawn timber in New Zealand indicate a total production figure of 4,215,000 m^3 (MAF, 2007). Perhaps more relevant to this project are production figures for treated timber, specifically Copper Chromium Arsenic (CCA)-treated timber. Formal statistics on timber treatment are no longer kept, and preservative suppliers are unlikely to reveal how much and of what they sell. (Hedley, 2007) There are approximately 120 treatment plants in New Zealand, and annual statistics would have to compile data from all of these. However, estimates for the year 2006 have been made below, extrapolated from 1998 figures. These show a total treated timber estimate of 830,250 m^3 in 2006. Note that not all CCA-treated timber will be sawn timber; there will be a percentage of New Zealand's small logs treated for use as posts and poles.

PRESERVATIVE	Estimated Production 2006 (m^3)
CCA	574,750
Boron	175,000
TBTN/Triazoles (Hazard class 3)	75,000
TBTN/TBTO (Hazard class 1)	10,000
ACQ/CuAz	5,000
Permethrin	1,000
TOTAL	**830,250**

Table 1: Estimated production of treated timber in New Zealand in 2006 (Hedley, 2007)

It is estimated that in 2006, 574,750 cubic metres of timber was treated with CCA treatments. Additionally, 255,500 cubic metres of timber was treated with other treatments (the most common of these being boron).

Waste Statistics

The Ministry for the Environment has instituted a Solid Waste Analysis Protocol (SWAP) Baseline Programme to provide solid waste composition information at four indicator sites from around New Zealand. The purpose of this programme was to acquire generic landfill data to use as a baseline figure for New Zealand waste. Between 1996 and 2004, the percentage of timber in landfill waste ranged from 8 to 13%. (MFE, 2007). These figures can be used as reference point to estimate the amount of treated timber in landfills; however, accurate statistics are unavailable. It should be noted that the 8-13% figure is for landfills only, and does not include cleanfills. It is up to regional councils to set the definition of what is acceptable to send to cleanfills, and in some cases this may include timber.

CURRENT EPR SCHEMES

International

Extended producer responsibility schemes exist for other products in some countries. In general, most EPR schemes exist in the European Union. The EU is leading the way with legislation also, and this will be described in the 'Policy Relating to EPR' section below. EPR schemes in the EU are currently in place for electronics, end-of-life vehicles, packaging and batteries. (Foresite, 2007) Elsewhere around the world, EPR schemes exist for batteries, tyres, electrical equipment, whiteware, packaging and plastics, used oil, and mobile phones. (Infield, 2007)

The only true EPR scheme for treated timber in the world exists in Finland and is run by Demolite Oy. The scheme is funded by charging a fee at the time of purchase, as well as disposal fees for larger quantities. At present, the waste impregnated wood is being stored and chipped at a facility that accepts both CCA- and creosote-treated wood, free of soil and large metal objects. (Kestopuu website, 2007) In 2008, construction of an incineration plant will be completed. This incineration plant will be designed to process 50,000 tonnes per annum of waste treated timber, and will be a controlled combustion system with an efficient flue gas cleaning system. Upon completion, the plant should provide 80 GWh of heat to local customers and 40 GWh of electricity to the national grid (assumed to be predicted annual figures) (Svanaes, 2007).

Wood waste incineration facilities exist in many other European countries, however these are all designed to use untreated wood, and are part of waste reduction programmes rather than integrated into EPR schemes. In Australia, wood is able to be used in some cement kilns and coal power plants, though this too is untreated timber. (Taylor, 2005).

New Zealand

The Ministry for the Environment (MfE) has commissioned a series of case studies on product stewardship for certain products in New Zealand, undertaken by URS, Product Ecology Pty Ltd. and Responsible Resource Recovery (3R) Limited. (MfE Website, 2007) These studies cover whiteware, tyres, cellphones, paint products and agrichemical containers. Though these studies are not specifically focussed on EPR (product stewardship has a broader definition, placing responsibility on not just the producer but all other parties involved), they can still give insight into implementation of EPR schemes in New Zealand.

Of the product stewardship schemes above, the majority are focussed on producer responsibility, with end-of-life tyres being the exception (funded by a fee at time of disposal, charged to consumers). Fisher & Paykel has a well-established recycling system which is a voluntary take-back scheme. Fisher & Paykel’s recycling division handles approximately 30,000 end-of-life whiteware units per year. (Product Ecology, 2006). This kind of example shows what can be achieved with a voluntary EPR scheme. Another voluntary scheme, Paintwise, was set up by Resene Paints to take back unwanted/unused paint. This paint is either donated to graffiti abatement groups or is sent for solvent recovery. The scheme is funded through a small fee at time of purchase, included in the price of the paint. (3R, 2006)

The AgRecovery scheme is a scheme being set up to recover used plastic agrichemical containers. This scheme will involve the collection of washed containers from retailers, and following collection recycling will take place. Again this scheme will be funded by a small fee at the time of purchase (3R, 2006a). Finally, Telecom and Vodafone have take-back schemes in place for cellphones. However, since New Zealand does not have any cellphone recycling or refurbishment facilities, the cellphones must be exported overseas. (URS, 2006)

New Zealand currently has no timber EPR schemes in place. To set up such a scheme would involve substantial costs, and these costs would have to be met, most likely by a levy integrated into the price of the timber at the time of purchase. This price would have to cover the costs of processing wood that has been produced before the scheme was implemented. The Agrecovery scheme for example has estimated yearly costs of $1.5 million, and processing of treated timber is likely to be substantially more than this, due to the volumes involved. A processing plant would need to be set up, as well as collection facilities, transport systems, awareness campaigns and administration. The scheme could charge a fee for disposal of timber, and, provided this is lower than landfill fees, there would be an incentive to dispose of treated timber waste properly.

Recycling of untreated wood waste does take place in New Zealand. This recycling appears to be market-driven, with the recyclers receiving wood waste for a fee, and selling mulched wood products to customers. These products are usually chipped wood for boiler fuel or shredded wood for use as garden mulch.

POLICY RELATING TO EPR

International Policy on Waste Treated Timber

CCA-treated timber has been banned from use in some countries, including Japan, Indonesia, Sweden and Germany. Also, in the USA, Australia and the UK there are restrictions on the use of CCA-treated timber. In general these restrictions designate the timber to commercial or industrial uses and prevent it from use in situations where frequent skin contact is likely to occur. In Massachusetts, construction and demolition waste (including treated timber) was banned from landfills from 1 July 2006, though it is not clear what is currently happening to the waste wood. (Massachusetts Department of Environmental Protection, 2007) One point to note in regards to international policy is that under the Kyoto Protocol, treated timber that is landfilled is not considered sequestered carbon.

Germany's 'ordinance on the requirements for the recycling and disposal of waste wood' states that if waste wood cannot be recovered, it must be disposed of using thermal processes. Landfilling is not permitted. Additionally, two European directives that have an influence on the waste wood stream are the Landfill Directive (which limits biodegradable waste going to landfill) and the Packaging Directive (which includes targets for recycling wood packaging). In Australia targets are being set for renewable electricity generation, encouraging the use of wood waste in coal power plants.

While the policies above encourage EPR schemes to be set up, they are not directly responsible for initiating EPR schemes. A more in-depth review of international legislation can be found in the Australian 'End-of-Life Disposal of Timber Products' report. (Taylor, 2005)

EPR policy in general has been under the spotlight in Europe in recent years, with the arrival of legislation such as the Waste Electronic and Electrical Equipment (WEEE) directive and End-of-Life Vehicle (ELV) legislation. This sort of legislation is resulting in the implementation of EPR schemes, and this can have a flow-on effect to countries outside of Europe, as products imported from other countries will have to abide by European law. As yet, there are no international EPR laws specifically for waste wood (treated or untreated).

New Zealand Policy

Again in New Zealand there is no legislation directly requiring EPR schemes for treated wood waste to be implemented. In saying this, the upcoming Waste Minimisation Bill specifies that the Waste Minimisation Authority will be set up, which will collect a Waste Disposal Levy. This levy will be charged at the time of disposal of waste, and will fund the authority, as well as funding projects to assist with waste minimisation.

The Waste Minimisation Bill contains a section on EPR, though it uses the terms EPR and product stewardship interchangeably. This section does not propose legislation for compulsory product stewardship/EPR schemes. Instead, it allows for product stewardship/EPR schemes to be set up for wastes of concern, and producers who contribute to that waste must participate. This is to help stop 'free-riders', from benefiting when they do not contribute to waste minimisation. This participation would include provision of collection facilities, and a minimum recycling, reuse or material recovery rate of 75% of end-of-life products received at these recycling facilities. The bill also states that sufficient notice will have to be given if there is an intention to consider the need for a product stewardship programme for any product.

The Waste Minimisation Bill is being put forward to give effect to the MfE Waste Strategy. The most relevant part of this strategy to treated timber is the statement: "By December 2008, there will have been a reduction of construction and demolition waste to landfills of 50 percent of December 2005 levels measured by weight". This will significantly affect wood waste, as inert wastes such as concrete are already sent to cleanfills.

Air quality is another area where policy may affect EPR schemes for treated timber. Thermal treatment of treated timber will of course be subject to National Environmental Standards for Air Quality.

OPTIONS: SORTING OF WOOD WASTE

The recycling of treated wood waste could involve a sorting process to separate treated timber from untreated wood. Ideally, a recycling/disposal technology that can process both treated and untreated timber would be employed. However, if this is not feasible then the following options could offer sorting solutions.

Visual Sorting and PAN Stain

Visual sorting can be used for wood waste on construction sites, as treated timber is in general easily identifiable through dyes or labels. Demolition waste however contains wood that cannot accurately be identified as treated or untreated. This wood may have been painted or stained, or the markings may have been worn off. Visual sorting, regardless of the type of waste wood, is a slow process. A PAN (short for 1-(2-pyridylazo)-2-naphthol) stain formulation is an alternative to visual sorting that can detect copper-containing preservatives. (Jacobi, 2006) It is applied directly to the wood, and if copper-containing preservative is present the wood will stain a magenta colour. If not, the wood will stain an orange colour. There are many drawbacks to this system – dirty, wet or coated wood cannot be tested, the reaction time is roughly twelve seconds for each piece of wood, and the stain cannot distinguish between CCA and other copper-containing preservatives. These characteristics make PAN an unrealistic option for sorting larger amounts of timber waste.

XRF

X-Ray fluorescence (XRF) is a non-destructive characterisation technique that can detect different elements in solid or liquid samples. The technique involves irradiating the target with x-rays, which are absorbed by the sample and re-emitted at different wavelengths. This fluorescence can be used for quantitative and qualitative analysis of the sample. This technique has been used not only for wood preservative detection but also for detection of lead in paint and sorting scrap mental (Taylor, 2005). This technique can be used to determine which type of treatment has been used on the wood, though elements with low relative atomic masses such as Boron cannot be reliably detected, and thus the technique would be less effective for boron-based treatments.

Hand-held XRF devices have been used in the USA to sort wood, however one study concluded that hand-held XRF units were too costly and slow for efficient sorting. (Jacobi, 2006). An earlier study from 2004 found that a stationary XRF system could analyse a sample in three seconds, and had the potential to be designed for on-line sorting with a much shorter analysis time. (Solo-Gabriele, 2004). Overall the technique can be fast, is durable and requires no sample preparation. Its weaknesses include not being able to detect elements with atomic numbers lower than sodium, it is a source of x-ray radiation, and it can confuse a combination of Magnesium and Iron with Chromium. (Taylor, 2005)

LIBS

Laser-induced breakdown spectroscopy (LIBS) is a technology that uses a laser to ablate and ionise wood into a plasma. Each element in this plasma releases characteristic spectral lines, and from the intensity of these lines the presence and approximate ratio of elements in the sample can be evaluated. The technology can be used quickly (sample time of a few seconds) and simply on waste treated timber, and can distinguish between different treatment types. The technology can be used with no sample preparation, and from distances of up to 20 m from the sample. (Rochester, 2004) The drawbacks to LIBS are the setup costs, constant calibration and the safety hazard of having a powerful laser in a sorting line.

A paper published in 2004 describes the effectiveness of LIBS technology on wood pieces 1 to 8 cm in thickness. (Solo-Gabriele, 2004) The technology had some problems with very rotten pieces of wood, but could detect treated wood even when wet, very dirty, painted or coated in some other way. It was mentioned that a higher-energy LIBS system may have been able to sort wood of greater thickness, and also detect treatment in the very rotten wood.

Others & Conclusion

There are other techniques that could be used to sort treated and untreated timber waste, though in general these are too expensive, slow or impractical to consider at this stage of development. The viable technologies for sorting wood are relatively limited at the moment as none have been perfected. However, XRF and LIBS show promise in their abilities, and LIBS in particular has practical aspects that would make it useful for sorting waste wood. The fact that it is a practically non-destructive technique, can be used from a distance and has rapid analysis times make it particularly suitable for this purpose. Again it must be noted that ideally sorting would not be needed at all as the chosen recycling/disposal option will not require differentiation between wood types.

RECYCLING & DISPOSAL TECHNOLOGIES

Untreated Wood Options

Untreated wood has many recycling options, and because it has no chemical preservatives it requires no special processes to prepare it for use in other applications. Because untreated timber is not the subject of this paper, the options will not be explained in detail. Possible options include reuse (the simplest of all options), mulch, fibreboard, chipboard, animal bedding, compost, energy/heat recovery (incineration or other thermal processing methods) and use in cement kilns.

Treated Wood Options: Pre-processing and Chemical Removal

Research has been conducted into methods of removing the treatment from timber, thus rendering it safe for recycling, landfill disposal or incineration without the use of complex filtration systems. These techniques include chemical removal, bioremediation, electrodialysis and a small number of other treatments. These other treatments are in general elaborate, time consuming, expensive and in general unfeasible, and will not be discussed in this report.

Kazi and Cooper describe using a peroxide solution to remove CCA treatment from timber, with average extraction efficiencies of 95% for Cr, 94% for Cu and 98% for As. (Cooper, 2006) This technique involved placing the wood in a 10 % H_2O_2 solution at 50 °C for 6 hours. The advantage of this method is that further processing of the solution can result in re-use of the treatment chemicals for further timber treatment.

Bioremediation is a term used when biological agents are employed to remove timber treatment chemicals. The technique is often employed in conjunction with other methods. For example, removal of CCA treatment from treated wood has been demonstrated using oxalic acid and copper-tolerant bacteria. (Clausen, 2004) This process reported removal rates as high as 83 % for Cu, 86 % for Cr, and 95 % for As. The downside to this technology is the time and expense needed to complete this extraction. The method involves an 18-hour extraction using oxalic acid to remove the chromium and arsenic, followed by a 7 to 9 day bioleaching process to remove the copper. Some brown-rot fungi have displayed copper tolerance, and have been successfully used for the purpose of treatment extraction. (Taylor, 2005).

Electrodialytic remediation is a method developed and patented at the Technical University of Denmark (DTU). It uses an electric current to mobilise the metal ions in solution, and an ion exchange membrane to then separate the electrolytes out. Prior to electrodialytic treatment, wood is soaked in solutions of oxalic acid or a combination of phosphoric acid and oxalic acid. In experiments, this type of electrodialytic treatment removed up to 87% of the Cu, 81% of the Cr and >95% of the As in wood. (Christensen, 2004).

All of the remediation techniques mentioned above have a major drawback; the wood must be chipped or ground into small particles to achieve a high extraction rate. This is an energy-intensive process. Also, chemical removal for large volumes of wood would be difficult due to the lengthy time these processes take. A 10-day treatment time, plus drying time and the possibility of altered wood properties (important if the wood is to be recycled into particleboard etc.) renders these processes impractical at the current time. One very important point is that the literature articles describe how the processes result in virtually non-toxic wood, yet most of these articles neglect to mention what happens to the extraction liquid, which is where the heavy metals . The disposal or processing of this liquid could be of serious environmental concern. As mentioned in the sorting processes section, an ideal solution for end-of-life treated timber would be a recycling or disposal process that can deal with treated and untreated wood, without the need for additional processing.

Treated Wood Options: Recycling

A few different options for creating recycled products have been tested with treated timber. Many of these are mentioned in the 2005 UK-based report on treated wood waste (WRAP, 2005). Products such as particleboard, chipboard and oriented strand board (OSB) can theoretically be made with treated timber; however there are drawbacks to this. Firstly, in Europe and the UK, contamination standards are set for the production of particleboard (and similar products). These standards would mean that the percentage of CCA-treated timber that could be used in particleboard production would be less than 1[A1] %. In New Zealand, 1 % of the total fibreboard and particleboard production in 2006 was 11,170 m^3. As CCA waste in New Zealand is not currently measured, the closest comparison is with production. This figure equates to less than 2 % of the estimated CCA-treated timber production in 2006. (MAF, 2007; Hedley, 2007)

CCA-treated timber that has been subjected to oxalic acid chemical extraction and bacterial remediation displays a reduction in integrity and strength (but an increase in elasticity) once processed into particleboard. Standard CCA-treated wood waste used in particleboard results in similar physical properties, yet leaching of arsenic is relatively high. (Clausen, 2000 and

2001). Wet-processed fibreboard using CCA-treated timber can be made with very similar properties as normal untreated fibreboard, however, the product is processed in water, and the cleanup of this water could pose problems due to the leaching of arsenic. In New Zealand, the Auckland Regional Council has put in place regulations preventing the use of treated timber in particleboard production (McArthur, 2007)

Wood-plastic and wood-cement composites are another potential application of recycled treated timber. Wood-cement composites can include cement-bonded particleboard, wood fibre cement boards, concrete construction blocks, acoustic barriers and roof tiles. In general, these products perform well, in some cases better than alternatives using untreated wood. Properties such as susceptibility to leaching, bending strength and stiffness can be improved. Wood-plastic composites are at a very early stage and therefore little is known about their potential properties. Ultimately however, wood-cement and wood-plastic composites could be merely shifting the problem of difficult waste further along the life cycle[A2]. It is possible that this extension of life could have overall benefits, however waste disposal of these composites is likely pose further problems at the end of these products' lives.

Mulch and compost are other potential uses for treated timber waste. With the surface area vastly increased, and a high exposure to water, the risk of leaching of chemicals from CCA-treated timber is likely to be multiplied many times. These products therefore are unlikely to be acceptable solutions.

Treated Wood Options: Thermal Treatment

Thermal treatment encompasses incineration, gasification and pyrolysis. Incineration involves burning the timber waste in air. This can result in the volatilisation of the treatment chemicals in the wood, particularly arsenic when CCA-treated timber is burned. For an incineration process to be considered as an environmentally responsible end-of-life solution, the emissions from the incineration process must be within acceptable limits. This could be achieved with a filtration system. Incineration plants are currently being used to dispose of untreated waste wood in Europe.

Gasification of waste wood involves the extraction of gaseous fuel from wood by heating in an oxygen-free environment. The gas from the wood (which can include hydrogen and methane) is then mixed with oxygen and used for energy production, for example in gas turbines. This method can be an effective way of recovering energy from waste wood. The problem with using gasification for waste treated timber is the same as with incineration. Gasification usually occurs at above 800 °C, and at this temperature volatilisation of arsenic will occur. Again the waste gas stream would have to be cleaned before it could be released to the atmosphere. Currently there are no commercial projects that use gasification to process treated waste wood.

Pyrolysis is a similar process to gasification, except the decomposition of the wood happens at much lower temperatures (<700 ºC, and can be lower than 400 ºC). Pyrolysis results in three products: pyrolysis oil, pyrolysis gas and charcoal. A lower temperature process may still result in some arsenic being volatilised, however a 2005 report states that "the amount of arsenic volatilised [in a pyrolysis process] is much less compared to gasification or incineration and therefore the arsenic released may be easier captured by for example chemisorption".(Helsen, 2005).

An example of pyrolysis being used for large-scale thermal treatment of treated wood is the Chartherm process. This process has been developed in lab-scale and pilot plant experiments, and a fully functional industrial plant has been successfully operating for a year (Hery, 2007). The plant can process roughly 10,000 tons of treated wood per annum. The process is a low-temperature pyrolysis, which results in some energy production, and end products of metals/minerals and clean charcoal (separated in a centrifuge). The biggest upsides to this technology are that the metals in the treated timber would not reach the atmosphere, the system can process all types of treated timber, and there is no sorting of input timber waste needed (no harmful consequences if untreated timber is in the mix). The downsides to the Chartherm process are that the waste metals/minerals[A3] at the end of the process still need to be separated into individual components if they are to be re-used, and that the energy balance shows that some extra energy is needed to run the process – it is not completely self-sustainable (unless the calorific value of the charcoal is taken into account). The carbon product however could be sold, or used as fuel for extra energy.

FUTURE RECOMMENDATIONS

New Zealand's treated timber producers should strive to establish a voluntary EPR scheme before any legislation is put in place. This would require establishing who the responsible producers of treated timber are (for example wood producers, treatment chemical producers, forestry companies, timber merchants) and what processes should be implemented to deal with treated timber waste. There are many different sorting & treatment options available, in varying stages of maturity, and the option that should be chosen depends on whether carbon sequestration, energy production or life-cycle thinking are the key priorities. Landfilling would offer carbon sequestration at the expense of leaching risks & landfill storage space. Incineration would offer energy production at the expense of carbon storage, and other thermal treatments offer a clean life-cycle approach, though still at the expense of carbon storage. Without clear priorities it is difficult to recommend a 'best' option at this stage.

CONCLUSIONS

Extended producer responsibility is a concept that is becoming more and more prevalent worldwide. With schemes already in place in New Zealand for whiteware, paint and cellphones, plus future schemes planned for agrichemical containers and tyres, EPR is a relevant notion. Treated timber, especially CCA-treated timber, is a waste stream of significant volume, though exact figures are not available in New Zealand. With the Waste Minimisation Bill appearing in parliament, waste reduction and disposal issues are becoming more relevant for producers, and treated timber is a waste that is already in the spotlight internationally. Ideally, a voluntary extended producer responsibility scheme would be the preferred option for New Zealand. However, a certain amount of legislation will undoubtedly have an effect on the introduction of EPR for waste treated timber, for example the result of the Waste Minimisation (Solids) Bill. As part of the bill, a waste levy is planned, which could potentially be used for assisting in the setup of EPR schemes.

Ultimately, the best option for New Zealand depends on the priorities of government and industry. If carbon sequestration is a high priority, then thermal treatment of waste treated timber is not the best option. In that case the best option would be storage of the timber, whether in landfills (this involves the issue of leaching) or specially-designed locations. If the priority is on energy recovery from waste wood then incineration or gasification could be seen as the best options. Finally, if waste minimisation and life-cycle thinking is taken into account, then pyrolysis processes such as the Chartherm process would be the best option.

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