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Greenhouse Gas Emissions Assessment for Accoya® Wood – Public Version

climatechangesolutions

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Camco – climate change solutions

With a 20 year track record in consulting and one of the largest and most diverse carbon portfolios under management, Camco has established itself as one of the world's leading climate change and sustainable development companies.

Camco have undertaken over 1,000 greenhouse gas (GHG) emissions assessments in line with current best practice in GHG quantification and reporting. These assessments cover all six Kyoto greenhouse gases and encompass Scopes 1, 2 & 3 emissions sources in line with the World Business Council for Sustainable Development and World Resources Institute's (WBCSD/WRI) Greenhouse Gas Reporting Protocol best practice guidelines.

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Contents

1 Introduction

Camco have been commissioned to carry out a “cradle-to-gate” green house gas emissions assessment for the Accoya® wood product. This is a public version of the original report, and hence excludes some sensitive data relating to the Accoya® wood production process.

1.1 Background

Climate change presents a serious challenge for responsible business leaders in the 21st century. Most scientists now agree that rising atmospheric concentrations of greenhouse gases, particularly carbon dioxide (CO_2), threaten to have severe impacts on food production, natural ecosystems and human health over the next 100 years. Industrialised and rapidly industrialising countries are the main sources of greenhouse gases. The greatest potential impacts will be felt by people in developing countries, particularly those in low lying coastal regions and marginal agricultural areas. However, developed countries are far from immune to impacts.

There is a clear need to develop more sustainable solutions to everyday demands. Titan Wood believes that Accoya® wood offers an alternative to conventional construction materials which is less environmentally damaging than current de facto materials, while offering comparable or improved durability. This report provides a ‘carbon footprint analysis’ for the product which enables environmental comparisons against other materials.

1.2 Why carry out a Carbon Footprint Assessment?

National governments, individual states, and regional groupings, such as the European Union, are taking a variety of steps to reduce greenhouse gas (GHG) emissions, including emissions trading schemes; voluntary reduction and reporting programmes; carbon or energy taxes; and regulations and standards on energy efficiency and emissions. Increasingly, companies will need to understand and manage their GHG risks in order to maintain their license to operate, to ensure long-term success in a competitive business environment, and to comply with national or regional policies aimed at reducing corporate GHG emissions (Source: World Business Council for Sustainable Development & Development & World Resource Institute (WBCSD/WRI), 2004).

A GHG assessment is the first step in the carbon management process, giving a company an estimate of the size and breakdown of its ‘carbon footprint’. A GHG assessment provides the basis for further initiatives such as public reporting, target setting and implementation of mitigation activities.

A product carbon footprint is the total set of greenhouse gas emissions caused directly and indirectly by the product. Measuring the carbon footprint of products across their full life cycle is a way for companies to collect the information they need to:

- Reduce GHG emissions
- Identify cost savings opportunities
- Incorporate emissions impact into decision making on suppliers, materials, product design, manufacturing processes, etc.
- Demonstrate environmental/corporate responsibility
- Meet customer demands for information on product carbon footprints

1.3 Product Details

The technology behind Accoya® wood is based on wood acetylation, a non-toxic wood modification process that has been studied by scientists around the world for more than 75 years.

The physical properties of any material are determined by its chemical structure. Wood contains an abundance of chemical groups called "free hydroxyls" (represented as OH in Figure 1). Free hydroxyl groups absorb and release water according to changes in the climatic conditions to which the wood is exposed. This is the main reason why wood swells and shrinks. It is also believed that the digestion of wood by enzymes initiates at the free hydroxyl sites - which is one of the principal reasons why wood is prone to decay.

Acetylation effectively changes the free hydroxyls within the wood into acetyl groups. This is performed by reacting the free hydroxyls within the wood with acetic anhydride. This process is illustrated below in Figure 1. When the free hydroxyl group is transformed to an acetyl group, the ability of the wood to absorb water is greatly reduced, rendering the wood more dimensionally stable and, because it is no longer digestible, extremely durable (durability class I according to EN 350-1). As such Accoya® wood can serve as a viable alternative for the most durable tropical hardwood species and many manmade materials based on fossil resources. Acetyl groups are naturally present in all woods, but the acetylation process increases the acetyl content to a much higher level. Titan Wood, the producer of Accoya® wood, derives all its timber from sustainably managed plantations including Forest Stewardship Council (FSC) and Programme for the Endorsement of Forest Certification (PEFC), and generally uses fast growing softwood species such as Radiata Pine for the acetylation process.

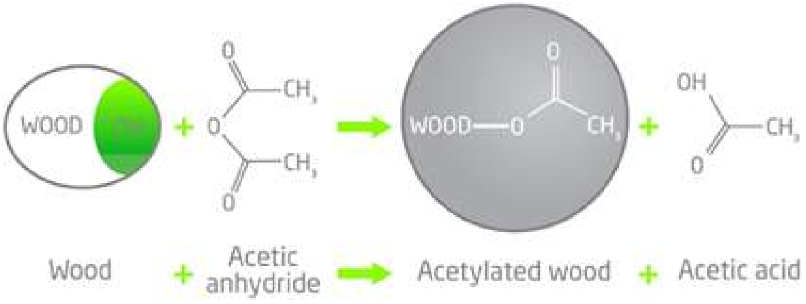

Figure 1: Chemical reaction of the acetylation process (Source: Titan Wood)

2 Assessment Methodology

Camco's approach is to carry out a cradle-to-gate greenhouse gas (GHG) emissions assessments in line with current best practice in GHG quantification and reporting. Our assessments therefore cover all six Kyoto greenhouse gases and encompass Scopes 1, 2 & 3 emissions sources in line with the World Business Council for Sustainable Development and World Resources Institute's (WBCSD/WRI) *Greenhouse Gas Reporting Protocol* best practice guidelines. All emissions factors used are the most up to date available from referenced sources such as Department for Environment, Food and Rural Affairs (Defra), WBCSD/WRI, Intergovernmental Panel on Climate Change (IPCC), Energy Information Administration (EIA), and the Swiss Centre for Life Cycle Inventories (SCLCI, also known as 'Ecoinvent').

A summary of the procedure followed to complete this assessment is described below:

1. Completion of the process map from forest to factory exit gate (see Figure 3)

2. Review inclusion and exclusion of activities throughout the supply and process chain building a high level carbon footprint model to identify relevance of emissions sources (based on generic published data and previous assessments).

3. Development of specific data collection forms for the contractors involved in the supply chain in order to obtain primary data wherever possible.

4. Research to obtain secondary data wherever primary data was not available to derive carbon emission factors for each stage of the supply chain. The data and emissions factors derived represent the production of each material back to their component's raw state (i.e. back to growing or back to specific chemicals). A carbon emission factor (kgCO_2e/unit) for each part of the supply chain was derived.

3 Greenhouse Gases - Overview

A GHG Emissions Assessment should include all six greenhouse gases covered by the Kyoto Protocol, which are set out in Table 1. The global warming potential (GWP) of each greenhouse gas may be expressed in CO_2 equivalents. For those gases with a high global warming potential, a relatively small emission can have a considerable impact.

Table 1: The global warming potential (GWP) of the Kyoto gases and potential emissions sources

Kyoto Gas	Potential sources	GWP[1]
CO_2	▪ Combustion of fossil fuels: ▪ Transport ▪ Manufacturing processes ▪ Energy generation ▪ Direct releases during manufacturing	1
CH_4	▪ Anaerobic degradation of waste ▪ Landfill of waste ▪ Digestion of food matter	25
N_2O	▪ Nitrification and denitrification in soils ▪ Fuel combustion ▪ Production of adipic and nitric acid ▪ Waste	298
HFCs	▪ Releases into the atmosphere: ▪ From refrigerants, ▪ During chemical manufacturing ▪ Use in foams & aerosols	22,800
PFCs	▪ Releases into the atmosphere during aluminium or electronics manufacture	7,390 – 12,200
SF_6	▪ Releases into the atmosphere: ▪ during magnesium smelting, electronics manufacturing ▪ from high voltage switchgear	124 – 14,800

The GHG emissions covered by this assessment are listed below:

- CO_2, CH_4 and N_2O emissions arising from fuel combustion;
- CH_4 emissions arising from landfill waste;
- CO_2, CH_4 and N_2O released directly to the atmosphere from processing of raw materials (e.g. CO_2 released from precipitation of calcium carbonate).

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[1] *IPCC 2007, Climate Change 2007: The Physical Science Basis. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change [Solomon, S., D. Qin, M. Manning, Z.Chen, M. Marquis, K.B. Averyt, M. Tignor and H.L. Miller (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA, 996 pp., Chapter 2, Table 2.14.*

4 Assessment Boundary

The aim of the assessment will be to quantify the GHG emissions associated with the production of the Accoya® wood product. The scope of the emissions assessment is illustrated in Figure 2, and includes:

- The embodied energy of the primary materials;
- Fuel consumed for timber harvesting and transportation to the processing facility;
- The energy consumed during sawmill operations;
- The energy consumed during timber acetylation process;
- Waste produced during the manufacturing process.

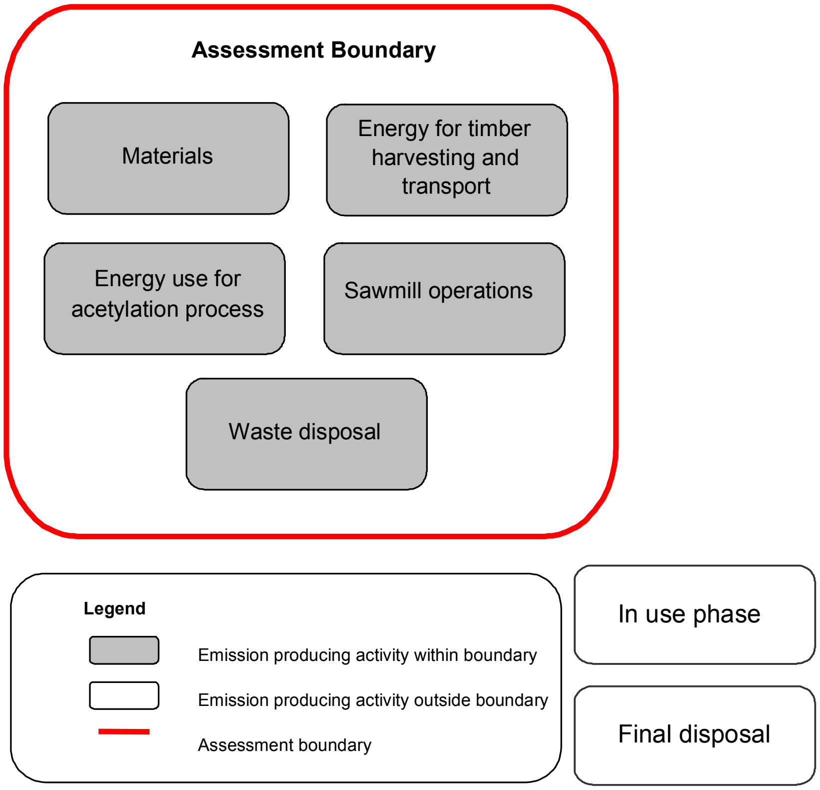
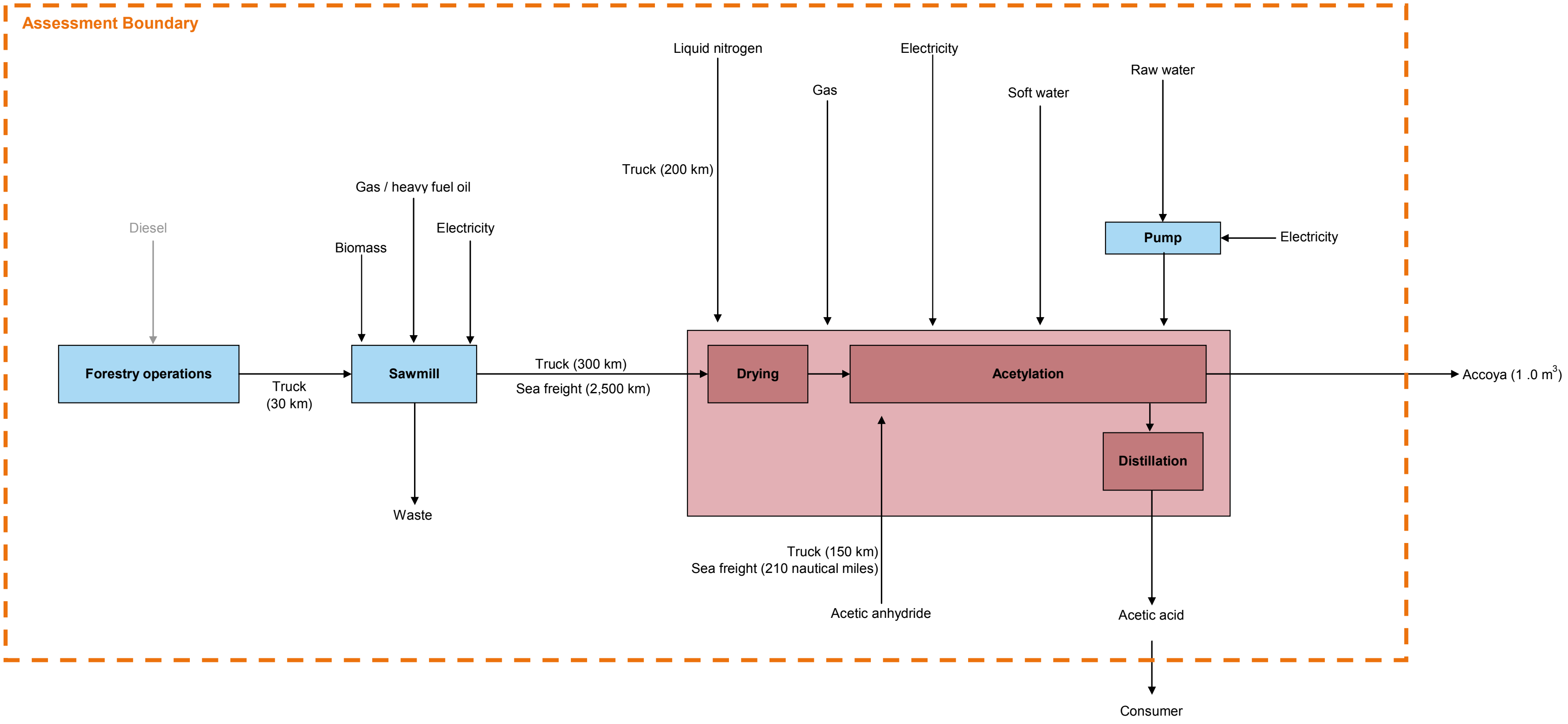


Figure 2: Scope of the Accoya® wood emissions assessment

The assessment will determine the associated greenhouse gas emissions to produce one cubic meter ($1m^3$) of acetylated wood using the Accoya® acetylation process. Figure 3 presents the assessment boundary and all inputs to the process in greater detail.

Figure 3: Process flow diagram and raw data used for the 'base case' emissions assessment



5 Results

This section demonstrates the embodied greenhouse gas emissions within Accoya® wood. A number of scenarios have been investigated which can be summarised as:

- **Base case** – This scenario is based upon Accoya® wood production at Titan Wood's Arnhem facility in The Netherlands. It uses production data from a certification run undertaken in 2007, and includes the sourcing of input utilities and materials as was typical at this time. The base case is set out in Figure 3 on page 9, and the results can be found in section 5.1.
- **Acetic anhydride production scenarios** – Acetic anhydride is the source of the acetyl group attached to the wood during the acetylation process. There are two major production methods for this chemical, each being significantly different to the other. Hence, scenarios for the source of acetic anhydride have been investigated in section 5.2.
- **Timber sourcing scenarios** – The acetylation process is suitable for a range of wood species which can be sourced globally. While the wood species does not substantially alter the acetylation process itself, the emissions arising from transport of the timber can vary greatly. Also, more dense wood species will create greater emissions in transit simply because they are heavier. Scenarios were undertaken to understand the impact of local and intercontinental timber sourcing, and can be found in section 5.3.
- **Fuel used for kiln drying** – Lumber arriving at a sawmill will have a moisture content close to that of standing wood. This moisture needs to be driven-out through an energy-intensive drying process. The fuel used for this process can vary between sawmills, but can have a significant bearing upon greenhouse gas emissions. Section 5.4 investigates the effect of fuel choices in more detail.

5.1 Base case

The base case greenhouse gas emissions per cubic meter of Accoya® wood have been calculated as: 290 $kgCO_2e/m^3$.

This is applicable to the scenario laid out in Figure 3, which from here on is referred to as the 'base case'. This process flow diagram uses data taken from a certification run at Titan Wood's Arnhem acetylation facility in The Netherlands. The arrangement illustrated is deemed to represent a conservative case in that it is a test facility, and hence further process optimisation will potentially lead to more efficient and lower emission batches.

Table 2 summarises the greenhouse gas emissions for each stage of the acetylation process. Units of 'kilograms of equivalent carbon dioxide per cubic meter of Accoya® wood' are used. Equivalent carbon dioxide (CO_2e) is the universal method of reporting all Kyoto greenhouse gases using a single unit. This quantifies the cumulative effects of all six Kyoto gases (see

Table 1) which are emitted by the process, and compares this to how much 'equivalent' CO_2 would be required to have the same global warming impact.

Table 2: Summary table of greenhouse gas emissions for the base case

Source of emissions	Equivalent CO_2 emissions (kg/m^3 Accoya)	Key assumptions
Forestry & saw milling	109	Heat is provided by heavy fuel oil (80%) and biomass (20%)
Transport of timber	36	Wood is sourced in Scandinavia and transported 300 km by truck and 2,500 km by sea freight to the Arnhem facility in The Netherlands.
Transport of other input materials	13	Acetic anhydride sourced from UK. Liquid nitrogen sourced locally.
Acetylation facility – utilities & input materials	563	Facility located in The Netherlands. Cooling water is sourced from a local closed loop system.. Acetic anhydride is produced using methyl acetate carbonylation.
Acetylation facility - acetic acid production	-432	Acetic acid, as a by-product of the acetylation process, is sold to a consumer displacing other sources of acetic acid in the open market. Emissions associated with the acetic acid are allocated to the consumer of the by-product (hence negative value).
Total	**290**	

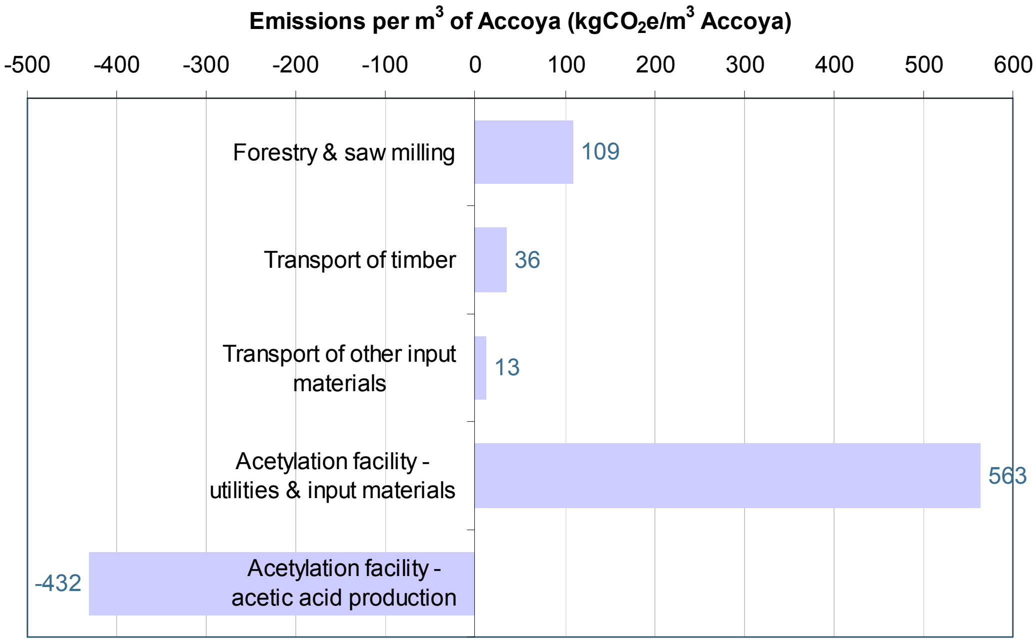


Figure 4: Base case greenhouse gas emissions from Accoya® wood - by process component

5.1.1 Discussion of base case results

There are three key components of the base case which have the greatest bearing upon Accoya® wood's embodied greenhouse gas emissions. The acetic acid by-product has the single greatest effect upon emissions in that it is sold as a by-product and hence its emissions subtracted from that applicable to Accoya® wood. This is discussed in further detail in section 5.1.2. Acetic anhydride is the largest input from a CO_2 perspective, followed by utilities consumption.

The majority of the product's emissions are generated either within the acetylation facility, or embodied within the raw materials consumed on-site. This is advantageous, as it means that Titan Wood is in control of the majority of their greenhouse gas sources.

5.1.2 Acetic acid

Acetic Acid is produced as a co-product to the acetylation process. Titan Wood sells this chemical to a wide range of industries including terephthalic acid (TPA) producers, ester producers and the general chemical industry. This creates a slightly complex situation in terms of allocating greenhouse gas emissions.

The acetic acid should be considered as a product of the acetylation process, in the same way that Accoya® is. Hence, the emissions which are generated through the acetylation process should be split between Accoya® wood and the acetic acid. That is, not all of the greenhouse gas emissions of the acetylation process are attributed to Accoya® wood. This is depicted in Figure 5.

There are a number of methods for determining how to 'split' the greenhouse gas emissions between these co-products. In the UK, PAS 2050[2] suggests two methods for achieving this split. The first method looks to separate a process into discreet sections for each co-product. For Titan Wood's acetylation process, this is not possible since the Accoya® and acetic acid emerge from the same single batch process (refer to the process diagram on page 9).

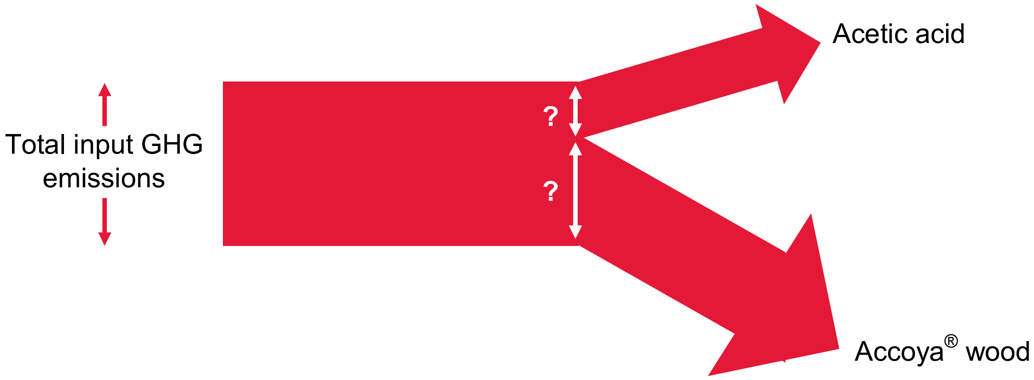


Figure 5: Schematic for allocating greenhouse gas emissions between the acetylation process co-products

The second of PAS 2050's methods is to assume that the process is displacing alternative supply streams of the co-product in the open market. Hence, it can be considered that the GHG emissions arising from the alternative process represent the GHG emissions of the co-product. Referring to the acetic acid example is a good illustration of this: Acetic acid is a commonly produced chemical which is refined on an industrial basis. It was assumed that any acetic acid which was produced by Titan Wood's acetylation process will displace some of the supply via the refinery process. Therefore, Titan Wood's acetic acid can be assumed to have equal greenhouse gas emissions as the refinery acetic acid.

This is the methodology which has been applied to this emissions assessment. The greenhouse gas emissions of the acetic acid have been subtracted from the emissions of the Accoya® wood product, hence the large negative bar in Figure 4. This enables the dedicated emissions for Accoya® wood to be identified.

5.2 Scenarios for acetic anhydride production

Acetic Anhydride is a key ingredient in the production of Accoya® wood – both chemically and in the volume consumed. It is a common chemical that is produced via multiple technologies which have a considerable impact on the carbon footprint. Camco have worked closely with Titan Wood to identify the most accurate greenhouse gas emissions associated with its production.

There are two common methods for producing acetic anhydride:

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[2] *PAS 2050:2008 Specification for the assessment of the life cycle greenhouse gas emissions of goods and services (BSI, Carbon Trust and Defra)*

1. Methyl acetate carbonylation (used in the base case); and
2. Ketene route (cracking acetic acid to ketene followed by reaction of the ketene with additional acetic acid)

Each of the above processes generates differing greenhouse gas emissions. The results of the analysis for each of these production scenarios is detailed in Figure 6 and Table 3, along with a production mix, which is based upon globally available merchant acetic anhydride production. Sections 5.2.1 through to 5.2.3 discuss each of these scenarios in further detail.

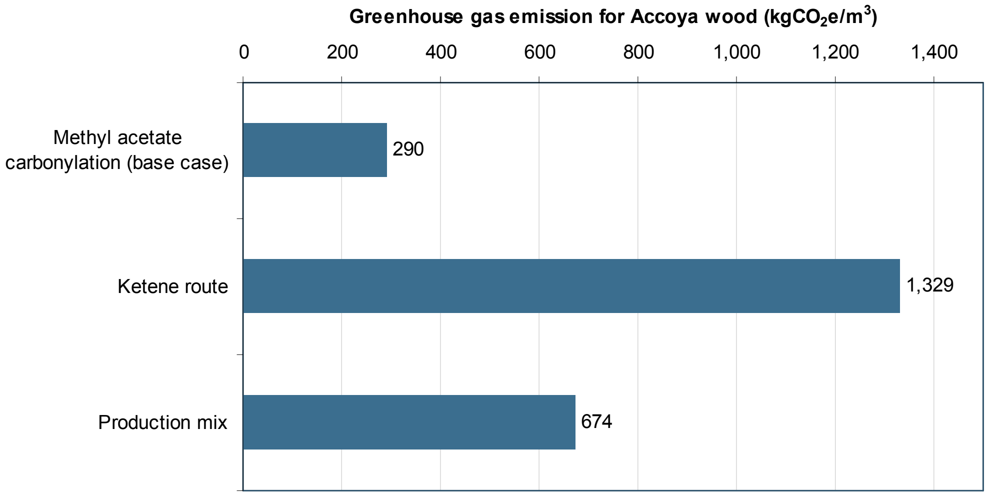

Figure 6: The choice of acetic anhydride production method, and how it impacts upon overall Accoya® wood greenhouse gas emissions

Table 3: Comparison of emissions factors for acetic anhydride

Acetic anhydride production method	Existing emissions factors		Camco derived emissions factors			Comments
	$kgCO_2e/kg$ acetic anhydride	Source	$kgCO_2e/kg$ acetic anhydride	Source	Accoya® wood emissions ($kgCO_2e/m^3$)	
Methyl acetate carbonylation (base case)	0.7 – 1.5	Dr Richard Murphey, Imperial College London, April 2009, personal communication	0.638	Imperial College London - Cladding LCA[3]	290	Camco factors sit slightly below both the quoted range from Imperial College, and the IdeMat reference for the Halcon process (another carbonylation method route).
	0.798	IdeMat database, 2009, for production via the Halcon process,				
Ketene route	3.822	SCLCI[4], 2008, report #6609	2.874	Confidential raw data, 2009	1,329	Camco's calculations provide an emissions factor which is 25% smaller than that quoted by SCLCI. The SCLCI data was perceived as out of date and incorrect (based on energy consumption data for propylene glycol instead of acetic anhydride production)
Production mix	3.532	SCLCI[4], 2008, report #361	1.466	Derived from above using Titan Wood market mix	674	SCLCI refer to a production mix for European anhydride of 77% by ketene route and 23% through the oxidation of acetaldehyde. However, the oxidation of acetaldehyde was abandoned as production technology over a decade ago, and it is believed the global current production mix is instead a balance between methyl acetate carbonylation (64%) and ketene route (36%). This split is further evidenced in section 5.2.3.

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[3] *Hillier & Murphy, 2002, LCA for acetylated wood – cladding for use in a domestic dwelling, (Imperial College London report), p.52-53*

[4] *Swiss Centre for Life Cycle Inventory / Ecoinvent*

5.2.1 Methyl acetate carbonylation

In March 2002, academics at Imperial College London undertook a life cycle assessment of acetylated wood used for cladding, issued for The Ministry of Housing, Spatial Planning and the Environment (VROM) in The Netherlands (referenced as ‘Hillier & Murphy, 2002’ in the appendices). This listed economic and environmental inputs and outputs for the production of acetic anhydride via methyl acetate carbonylation. This data was agreed as seeming more modern and appropriate than the reported emissions factors within the SCLCI database.

This production method was assumed for the base case as set out in section 5.1, and leads to overall product emissions of 290 $kgCO_2e/m^3$ Accoya®. Procuring acetic anhydride, which has been produced by methyl acetate carbonylation, enables Accoya® wood to claim significantly lower embodied emissions compared to when using other production methods.

Emissions factors for the UK are employed due to the acetic anhydride being sourced from BP in Hull for the base case scenario.

5.2.2 Ketene route

The second method to produce acetic anhydride is by cracking acetic acid to ketene followed by reaction of the ketene with additional acetic acid, referred to as “ketene route” in this report. The Swiss Centre for Life Cycle Inventory’s greenhouse gas emissions factors was viewed as being insufficient in quality: The description of the ketene cracking process was seen as out of date compared to current production methods, and it used energy values for the production of propylene glycol and not those for the manufacture of acetic anhydride. Titan Wood was able to provide manufacturer certified modern (2009) production data from an acetic anhydride supplier who applied the ketene route to manufacture acetic anhydride.

Table 3 demonstrates that acetic anhydride via the ketene route has a GHG intensity of 2.874 $kgCO_2e/kg$ – over four times greater than the methyl acetate carbonylation method. This has a significant effect upon Accoya® wood’s embodied emissions, raising the product’s overall emissions to 1,329 $kgCO_2e/m^3$ Accoya® wood. This is almost a five-fold increase upon the base case. The overall results of this scenario are illustrated in Figure 7.

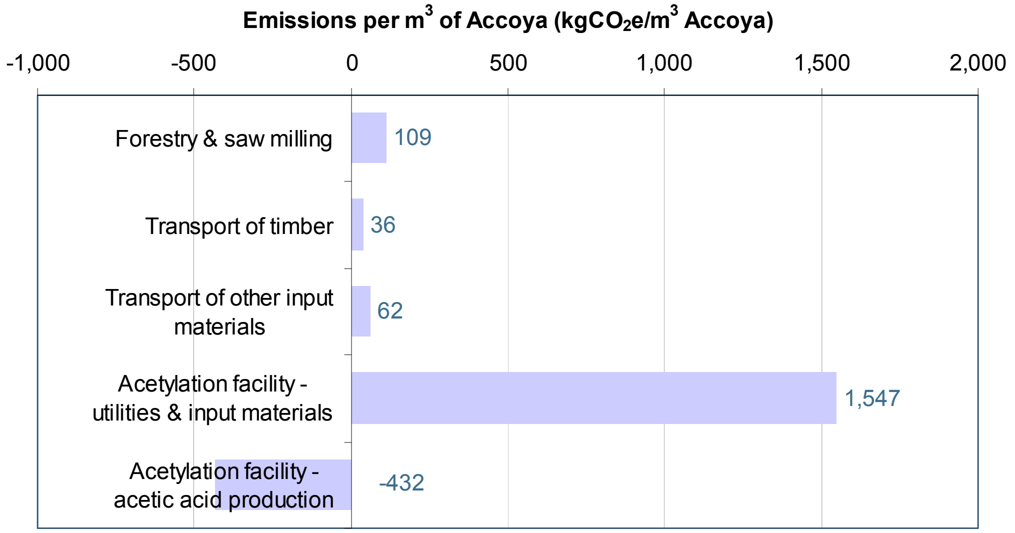

Figure 7: Greenhouse gas emissions from Accoya® wood – using acetic anhydride produced via the ketene route

A possible scenario in the future could be that the acetic acid by-product could, instead of being sold to the food industry, be recycled and cracked into acetic anhydride onsite. This will prevent the need to purchase acetic anhydride, as well as reduce transportation requirements. Additionally, on-site cracking is likely to see greater energy efficiency compared with industrial scale production due to the lessened distillation requirement of the low grade acetic acid which is acceptable as input.

However, in that case the emissions associated with the acetic acid would not be allocated to a third party consumer but instead would be perceived as an internal input reducing the amount of acetic acid required to produce acetic anhydride of a sufficient grade to produce Accoya® wood.

5.2.3 Production mix

A production mix has been derived, which considers the current quantities of acetic anhydride in the open market which have been supplied through the two afore mentioned processes. Although production mix figures change rapidly with the commissioning and decommissioning of chemical plants, Table 4 provides a well informed estimate of current production of acetic anhydride in Europe and North America. Figures for Asia are lacking but are estimated to be considerably lower. Note that the figures are based on production of merchant acetic anhydride; that is acetic anhydride available on the open market to Titan Wood for use in the acetylation process. Thus the table excludes acetic anhydride production which is reprocessed internally by cellulose acetate producers which will never be available on the open market.

Table 4: Merchant acetic anhydride available on the open market

Region	Supplier	Production process	Annual production (Mt)	Proportion of total
North America	Eastman	Carbonylation (Halcon)	544,000 [5]	53%
		Ketene route	272,000 [5]	26%
	Celanese	Ketene route	100,000 [6]	10%
Europe	BP	Carbonylation (other)	115,000 [6]	11%
TOTAL	-	-	**1,031,000**	**100%**

The overall split for an acetic anhydride production mix is therefore 64% methyl acetate carbonylation, and 36% ketene route. This has been applied to generate the figures within Table 3.

The above split results in a production mix emissions factor of 1.466 kgCO2e/kg acetic anhydride. This still has a significant impact upon Accoya® wood's overall emissions compared to the base case – at 674 $kgCO_2e/m^3$ Accoya® wood it is still over two times larger than the base case. Figure 8 depicts the production mix as a component of the overall product emissions.

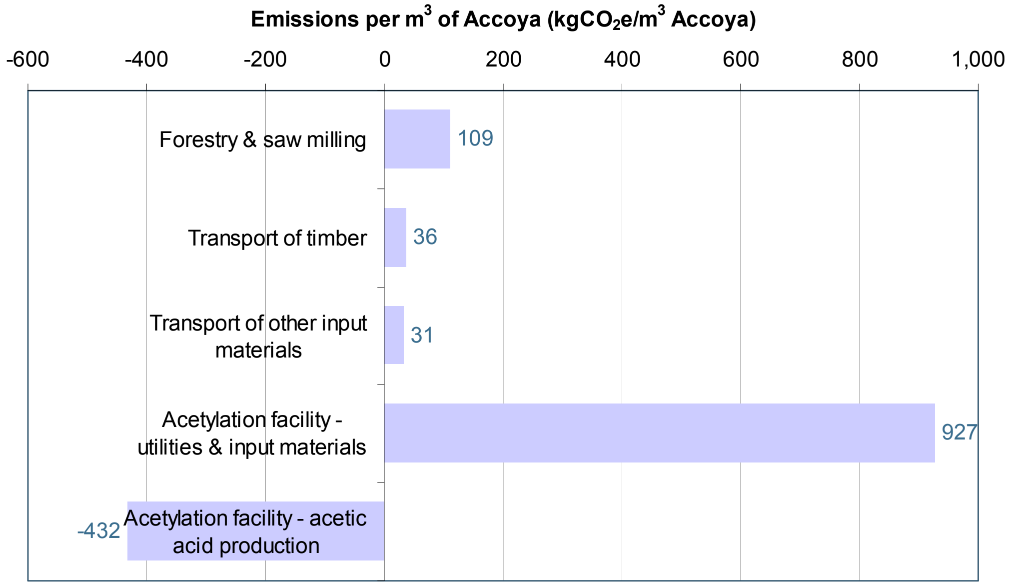

Figure 8: Greenhouse gas emissions from Accoya® wood – using a production mix of acetic anhydride sourced from a North American and Europe

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[5] *William Johnson, Uwa Fink, Yasuhiko Sakuma (1999). Chemical Economics Handbook Product Review, Acetic Anhydride. SRI International, publication number 603.5000*

[6] *Celanese Chemicals. Titan Wood correspondence with acetyl division*

5.3 Scenarios for the location of the wood source

The distance that timber has to travel between the forest and the acetylation facility, in combination with the transport mode, will have an impact upon the embodied emissions of the Accoya product. Additionally, the density of the wood affects the weight per unit volume, which further affects transport emissions. Table 5 demonstrates two scenarios against the 'base case' – one for locally sourced wood with no sea transport, and an intercontinental scenario where sea transport distance is very long (New Zealand to the Netherlands). Note that the overall emissions are based on Accoya® made from acetic anhydride though methyl acetate carbonylation.

Figure 9 demonstrates that the source location - and hence transport distance - of the timber can make a considerable difference to the embodied emissions of the transport phase. The locally sourced scenario, which assumes a total of 230 km of truck transit, produces 19 $kgCO_2e/m^3$ Accoya® wood. This is over seven times less 'carbon intensive' than the intercontinental scenario.

In the context of the overall Accoya® wood emissions, these variations are significant. The intercontinental scenario causes a 34% uplift from the base case, increasing Accoya® wood's embodied emissions to 390 $kgCO_2e/m^3$.

The following emissions factors may be of interest for comparison, revealing that per tonne.km, sea freight is over 11 times less carbon intensive than trucking.

Truck	0.148 $kgCO_2e$/tonne.km [7]
Sea freight (large container vessel)	0.013 $kgCO_2e$/tonne.km [8]

Refer to Appendix II for full calculations of timber sourcing.

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[7] *Derived from Renewable Fuels Agency, 2008 (appendix tables B and F)*

[8] *Defra, 2008, Guidelines to Defra's GHG conversion factors, Annex 7 (appendix table F)*

Table 5: The effect of different sourcing scenarios upon the embodied greenhouse gas emissions of Accoya® wood

Timber sourcing scenario	Scenario rationale	Forest to sawmill (truck km)	Sawmill to port (truck km)	Port to port (vessel km)	Port to acetylation facility (truck km)	Transport emissions ($kgCO_2e/m^3$ Accoya)	Overall Accoya Emissions ($kgCO_2e/m^3$ Accoya)
Base case	Scots Pine (520 kg/m^3 at 12%MC) sourced from Scandinavia, with the acetylation facility at Arhnem, the Netherlands.	30	200	2,500	100	41	**290**
Locally sourced	Southern Yellow Pine (540 kg/m^3 at 12% MC) from South-Eastern USA near proposed licensee plant site. No sea transport is required, truck carries timber 200 km from sawmill directly to acetylation facility.	30	200			19	**268**
Intercontinental	Radiata Pine (450 kg/m^3 at 12% MC) sourced from New Zealand (Northern Island, coastal region), acetylated at Arnhem, the Netherlands.	30	50	20,811	100	142	**390**

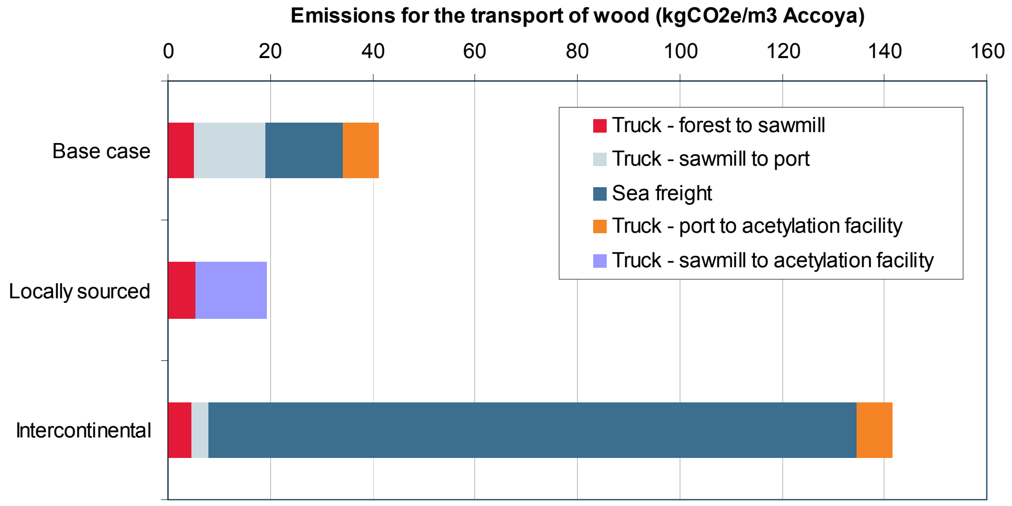

Figure 9: Greenhouse gas emissions for the wood transport components of Accoya® wood

5.4 Scenarios for the choice of fuel for kiln drying

Kiln drying is used to reduce the moisture content of timber. The fuel used to produce the heat for this process will influence the emissions. Table 6 indicates the effect of choosing between heavy fuel oil, natural gas, and biomass. The results are also illustrated in Figure 10.

Table 6: The effect of varying the fuel source for kiln drying[11]

Scenario name	Thermal energy source: Heavy fuel oil	Thermal energy source: Natural gas	Thermal energy source: Biomass	Kiln drying emissions ($kgCO_2e/m^3$)	Accoya emissions ($kgCO_2e/m^3$)
1. 'Base case' – Heavy fuel oil as main fuel source	80%	0%	20%	37	290
2. Natural gas as main fuel source	0%	80%	20%	35	287
3. Biomass as only fuel source	0%	0%	100%	1	254

Biomass fuel sources offer an almost carbon zero solution to the kiln drying phase, and creates a 12% improvement in emissions upon the 'base case'. Note, however, that the kiln drying facility may not be in direct control of Titan Wood.

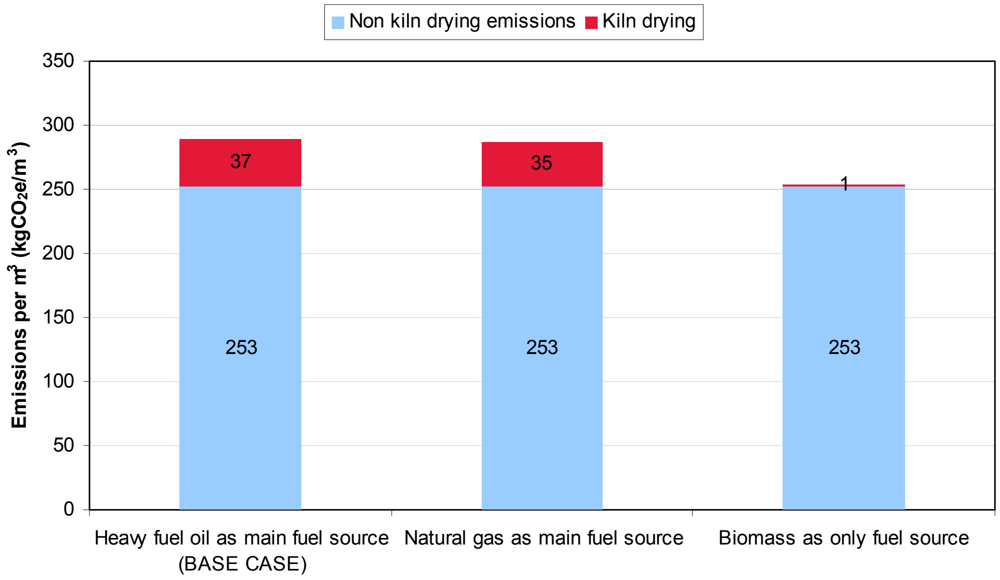

Figure 10: The effect of varying the fuel source for kiln drying

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[11] *Note that the results assume timber of density 546 kg/m^3 (moisture content = 55%) is dried to 450 kg/m^3 (m/c = 14%)*

6 Comparable materials

Accoya® wood competes in the market against other traditional materials. It is of interest to compare how greenhouse gas emissions differ between Accoya® wood and its market rivals. A number of greenhouse gas inventories have been examined to identify the cradle-to-gate emissions arising from traditional materials, and the results are illustrated in Figure 11. The three Accoya® wood scenarios for acetic anhydride production (refer to Table 3) are included for comparison. Full references and calculations for the comparable materials can be found in Appendix III, with expanded calculations for red meranti and western red cedar in Appendices Appendix IV and Appendix V respectively.

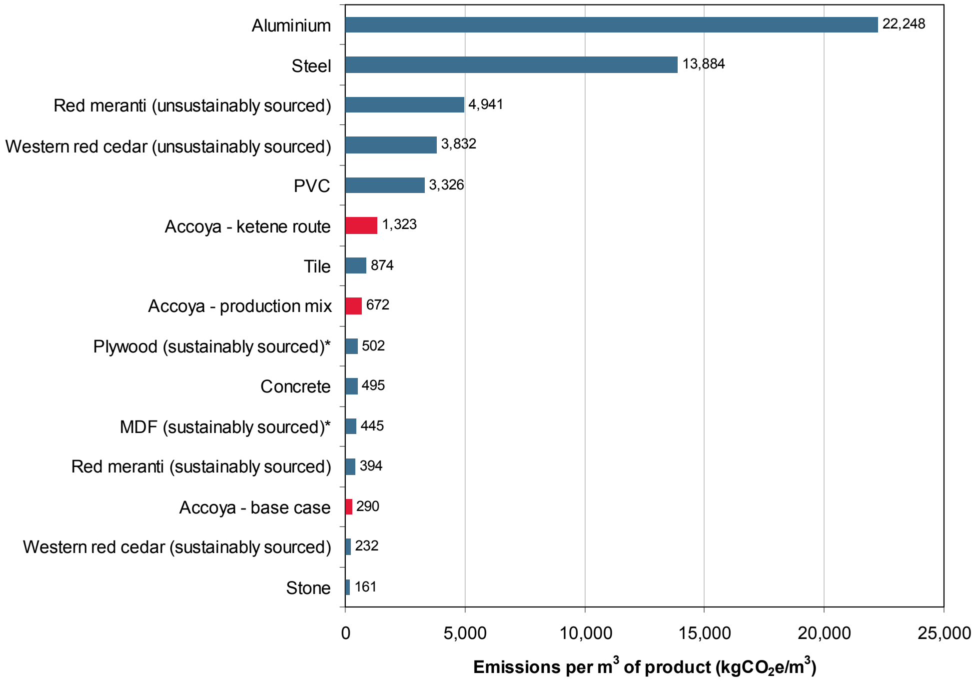

Figure 11: Comparison of cradle-to-gate embodied emissions (* It is assumed that wood in ply and MDF is sustainably sourced, and hence emissions from land use changes are not included)

Accoya® wood offers extremely competitive emissions compared to a range of typical building materials, on a cradle-to-gate basis. The base case embodied emissions are comparable to sustainably sourced woods, and offer significant improvements against unsustainably sourced woods, plastics and metals.

Note that Figure 11 shows results on a cradle-to-gate basis. Referring back to Figure 3 on page 9, cradle-to-gate includes:

- Sourcing and transporting raw materials; and
- Energy and consumption of materials within manufacturing / processing.

A cradle-to-gate analysis does not consider the in-use phase of a product. For the materials illustrated above, in-use emissions are likely to be centred around:

- Material properties such as density or strength, which dictate the volume of material required;
- Durability of the material which influences lifespan;
- Maintenance procedures and maintenance frequency;
- Carbon sequestration properties of renewable materials; and
- Disposal / recycling routes available.

Adding these components to the analysis may present different outcomes in terms of each materials' environmental performance and could provide additional benefits to Accoya® wood. The potential for developing this analysis to consider cradle-to-grave factors for Accoya® wood is discussed further in section 7 of this report.

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[13] Factor 3 less, see Bongers H. P. M. (2005) Performance of coatings on acetylated Scots pine sapwood in outdoor exposure. 3.330-366. SHR Timber Research, Wageningen

7 Looking Forward

Through working with Titan Wood it is clear that there could be further work to develop the emissions factor for Accoya® wood for specific applications and to reflect the countries where the process could be licensed. This would support the environmental credentials of Accoya® wood for the “in-use” phase.

As explained in section 6, adding the in-use phase would draw a completely different picture from the comparable materials illustrated in Figure 11, which is based on the emissions per cubic meter of material. Therefore, for a more complete emissions assessment the cradle-to-gate results represented in Figure 11 would need to be translated in actual applications relevant for Accoya® wood, where wood with a very high durability is required, such as in window frames, decking, cladding or structural outdoor applications (e.g. bridge components). In such an in-use assessment of the embodied emissions for Accoya® wood, the following aspects should be taken into account:

7.1 Amount of material (kg) per functional unit (application)

For example, a beam in a bridge from steel volume-wise might use less material (m^3) than wood because of the efficient design in an I-beam, compared to the rectangular solid volume of a wooden beam.

7.2 Life Span

Because of the very high durability, Accoya® wood is expected to have a longer lifespan than most material alternatives in several applications. For example, Titan Wood guarantees the quality of Accoya® wood both in applications above ground (guaranteed for 50 years in user classes 1, 2 and 3 according to EN 335-1) and in direct ground contact (guaranteed for 25 years in user class 4 according to EN 335-1).

7.3 Coatings & maintenance cycle

Applications such as window frames are for aesthetic & technical reasons often coated. The kind of coating and the frequency of coating also has an impact on the embodied emissions of the application.

The high dimensional stability and other properties of Accoya® means it does not have to be coated as much as regular wood species[13], which means that for the same lifespan the amount of coatings (and corresponding GHG emissions) will be lower for Accoya®.

7.4 Carbon sequestration

Trees absorb CO_2 during growth, and this is locked in the wood until it rots or is burnt at the end of its useful life – this is known as carbon sequestration. According to PAS 2050[15], the CO_2 locked into the wood can be included as a negative CO_2e value (calculated using the formula in annex C in the PAS 2050 guidelines). A higher negative CO_2e value is allocated if the life span of the wood is longer, which might be beneficial for Accoya® wood due to predicted life spans of 50

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[15] *Document freely available to download from http://www.bsigroup.com*

years or greater in some applications. However, the carbon benefits of sequestration can only be applied when a product's emissions are assessed on a life cycle basis. This is due to the fact that the benefit of the locked-in CO_2 is only realised during the life of the product, where that CO_2 would otherwise have been emitted under natural conditions. Hence, since the analysis in this report is cradle-to-gate (i.e. it does not consider the in-use and disposal phases of the product) sequestration cannot be included.

7.5 End of Life Scenario

A cradle-to-grave assessment should also explore the end of life phase of the product. Typically, a product is disposed (landfill/incineration) or recycled. If the product contains harmful materials then a treatment phase may be added before disposal, however this is not needed in the case for Accoya® wood. The greenhouse gas impact of these end of life routes vary considerably.

Favourable cases will be where there are little or no greenhouse gas emissions from disposal which can be attributed to the product. These cases are where a third party gains benefit from the disposal of the product. A simple example is if the original product is 100% recycled. In this case, the original product is recycled either in its complete form, or it is processed into another form. A third party who uses the recycled product benefits from the end of life of the original product. As a consumer, this third party is responsible for any emissions involved with the recycling process, and hence these are not allocated to the original product.

Another favourable case is if the original product is used by a third party as a fuel source, such as an incinerator which generates electricity and/or heat. Using the same principles as for recycling, a third party who benefits from the energy generated will be responsible for the emissions of the energy generation process. Zero end of life emissions are allocated to the original product.

Less favourable cases are typically when the product is disposed with no environmental benefit to a third party. Disposal by landfill or incineration without energy/heat recovery are two good examples. In both cases, no party receives a benefit from this disposal route, and as a result there is no third party to allocate the emissions of the original product during its degradation. The emissions are allocated to the original product.

7.6 Real world application: Sneek Bridge

Figure 12 shows one such in-use application for Accoya® wood. Sneek Bridge is the first ever heavy traffic road bridge constructed with a wooden bearing structure, and illustrates the potential for Accoya® wood to replace traditional, 'carbon-intensive' materials such as metals and concrete.

Figure 12: A large scale application of Accoya® wood – Sneek bridge, the Netherlands

The following calculations follow the PAS2050 methodology for identifying the CO_2 sequestered in Accoya® wood. This shows that once cubic meter of Accoya® wood sequesters 660 $kgCO_2e$ with an 80 year life span.

CO_2 sequestered in the wood

[1]	Density of wood (kg/m^3 based upon radiate pine at 12% moisture content)	450
[2]	Assumed carbon content of wood	50%
[3]	CO_2 sequestered excluding PSA 2050 weighting ($kgCO_2/m^3$) [1] x [2] x 44 / 12	825
[4]	Expected lifespan of the bridge (years)	80
[5]	CO_2 sequestered including PSA 2050 weighting ($kgCO_2/m^3$) [3] x ([4] / 100)	660

Accoya® wood cannot claim to be a net sequester of carbon until a full cradle-to-grave assessment has been completed, which would determine whether the carbon locked in the wood exceeds the greenhouse emissions of production, in-use and disposal phases. This should be the subject of a further study. However, based on the content of this study and Camco's experience, there is a good possibility that Accoya® wood may be a net sequester of carbon under the following conditions:

- Cradle to grave emissions are for the 'base case' scenario set out in section 5.1;
- Accoya® wood requires minimal maintenance during its in-use phase; and
- Accoya® wood is recycled at the disposal phase.

Appendix VII discusses further how value could be obtained by the carbon credentials of Accoya® wood.

Appendix I: Glossary of terms

Carbon Dioxide Equivalent (CO_2e). The universal unit of measurement used to indicate the global warming potential (GWP) of each of the 6 Kyoto greenhouse gases. It is used to evaluate the impacts of releasing (or avoiding the release of) different greenhouse gases.

Climate change. A change of climate which is attributed directly or indirectly to human activity that alters the composition of the global atmosphere and which is in addition to natural climate variability over comparable time periods (Source: United Nations Framework Convention on Climate Change).

Control. The ability of a company to direct the operating policies of a facility or organisation. Usually, if the company owns more than 50% of the voting interests, this implies control. The holder of the operating licence often exerts control, however, holding the operating licence is not a sufficient criteria for being able to direct the operating policies of a facility or organisation. In practice, the actual exercise of dominant influence itself is enough to satisfy the definition of control without requiring any formal power or ability through which it arises.

Direct emissions. Emissions that are produced by organisation-owned equipment or emissions from organisation-owned premises, such as carbon dioxide from electricity generators, gas boilers and vehicles, or methane from landfill sites.

Equity share. The percentage of economic interest in/benefit derived from an organisation.

Global warming The continuous gradual rise of the earth's surface temperature thought to be caused by the greenhouse effect and responsible for changes in global climate patterns (see also Climate Change).

Global Warming Potential (GWP) The GWP is an index that compares the relative potential (to CO_2) of the 6 greenhouse gases to contribute to global warming i.e. the additional heat/energy which is retained in the Earth's ecosystem through the release of this gas into the atmosphere. The additional heat/energy impact of all other greenhouse gases are compared with the impacts of carbon dioxide (CO_2) and referred to in terms of a CO_2 equivalent (CO_2e) e.g. Carbon dioxide has been designated a GWP of 1, methane has a GWP of 25.

GHG (Greenhouse gases). The current IPCC inventory includes six major greenhouse gases. These are Carbon dioxide (CO_2), Methane (CH_4), Nitrous oxide (N_2O), Hydrofluorocarbons (HFCs), Perfluorocarbons (PFCs), Sulphur hexafluoride (SF_6).

IPCC. The Intergovernmental Panel on Climate Change. A special intergovernmental body established by the United Nations Environment Programme (UNEP) and the World Meteorological Organisation (WMO) to provide assessments of the results of climate change research to policy makers. The Greenhouse Gas Inventory Guidelines are being developed under the auspices of the IPCC and will be recommended for use by parties to the Framework Convention on Climate Change.

Indirect emissions. Emissions that are a consequence of the activities of the reporting company but occur from sources owned or controlled by another organisation or individual. They include all outsourced power generation (e.g. electricity, hot water), outsourced services (e.g. waste disposal, business travel, transport of company-owned goods) and outsourced manufacturing processes. Indirect emissions also cover the activities of franchised companies and the emissions associated with downstream and/or upstream manufacture, transport and disposal of products used by the organisation, referred to as product life-cycle emissions.

Kyoto Protocol. The Kyoto Protocol originated at the 15th Conference of the Parties (COP) to the United Nations Convention on Climate Change held in Kyoto, Japan in December 1997. It specifies the level of emission reductions, deadlines and methodologies that signatory countries (i.e. countries who have signed the Kyoto Protocol) are to achieve.

Appendix II: Timber Sourcing Scenarios

Base case

Transportation - Forest to sawmill - BASE CASE

Source of emissions	Tonne-km of timber (tonne.km/m^3 Accoya)	Total CO_2e emitted (kg/m^3 Accoya)	Total C emitted (kg/m^3 Accoya)
Truck - forest to sawmill	35	5.2	1.4
Total	**35**	**5.2**	**1.4**

Data collection period: *For the batch production of 1 m^3 of Accoya® wood*

All figures in italics are supplied by the client

Assumptions

It is assumed that timber is transported via diesel truck a distance of 30 km from the point of felling to the sawmill, and that 55% of the felled timber is converted into useful lumber.
It is assumed that all timber deliveries are exclusively for Titan Wood.
A world wide average truck fuel efficiency is applied.
The calculations are based upon the transport of fresh (wet) Scots Pine.

Distance transported: *30* km

Required volume of lumber entering Titan Wood plant: *0.9* m^3/m^3 Accoya
Proportion of timber which is converted into lumber: 55% (Hillier & Murphy 2002)
Quantity of timber felled: 1.6 m^3 (derived from above)

Density of Scots Pine (moisture content = 12%): 520 kg/m^3 (Wiselius 2001)
Moisture content of Scots Pine for the above reference: 12% (Wiselius 2001)
Moisture content of fresh Scots Pine: *55%* (Assumption, Titan Wood)
Density of Scots Pine (moisture content = 55%): 720 kg/m^3 (derived from above)

Truck fuel efficiency - Global average: 1.72 MJ/tonne.km (derived from RFA 2008)
Diesel emissions factor: 0.086 kgCO_2e/MJ (RFA 2008)

Global warming potential (in CO_2 equivalents) of CH_4: 25 (IPCC 2007)
Global warming potential (in CO_2 equivalents) of N_2O: 298 (IPCC 2007)

Transportation - Sawmill to acetylation facility - BASE CASE

Source of emissions	Tonne-km of lumber (tonne.km/m^3 Accoya)	Total CO$_2$e emitted (kg/m^3 Accoya)	Total C emitted (kg/m^3 Accoya)
Truck - Sawmill to export port	94	13.9	3.8
Sea freight	1,170	15	4.1
Truck - Import port to acetylation facility	47	6.9	1.9
Total	**1,310**	**36**	**9.8**

Data collection period:	*For the batch production of 1 m^3 of Accoya® wood*
All figures in italics are supplied by the client	

Assumptions

It is assumed that the lumber is transported 200 km by truck from the sawmill to the local port for export. A sea freight vessel will then float the lumber 2500 km to a port local to the acetylation facility.
Finally, the lumber is then loaded back onto a truck for 100 km before delivery to the acetylation facility.
It is assumed that all timber deliveries are exclusively for Titan Wood.
A world wide average truck fuel efficiency is applied.
It is assumed that 'large container vessels' are used for sea freight.
CH_4 and N_2O emissions factors are not available for sea freight.
The calculations are based upon the transport of dried Scots Pine (12% MC).

The distances set out below are modelled upon sourcing wood in Scandinavia, loading the timber between the ports of Lulea, Sweden, and Rotterdam, The Netherlands, before delivery at the Anhem acetylation facility.

Distance transported from sawmill to export port - truck:	*200*	km
Distance transported from export port to import port - sea frieght:	2,500	km (E-ships.net)
Distance transported from import port to acetylation facility - truck:	*100*	km
Required volume of lumber entering Titan Wood plant:	*0.9*	m^3/m^3 Accoya
Density of Scots Pine (moisture content = 12%):	520	kg/m^3 (Wiselius 2001)
Truck fuel efficiency - Global average:	1.72	MJ/tonne.km (derived from RFA 2008)
Diesel emissions factor:	0.086	kgCO$_2$e/MJ (RFA 2008)
Emissions factor - Large container vessel:	0.013	kgCO$_2$/tonne.km (Defra 2008)

Locally sourced

Transportation - Forest to sawmill - LOCALLY SOURCED

Source of emissions	Tonne-km of timber (tonne.km/m^3 Accoya)	Total CO_2e emitted (kg/m^3 Accoya)	Total C emitted (kg/m^3 Accoya)
Truck - forest to sawmill	37	5.4	1.5
Total	**37**	**5.4**	**1.5**

Data collection period:	*For the batch production of 1 m^3 of Accoya® wood*
All figures in italics are supplied by the client	

Assumptions

It is assumed that timber is transported via diesel truck a distance of 30 km from the point of felling to the sawmill, and that 55% of the felled timber is converted into useful lumber.

It is assumed that all timber deliveries are exclusively for Titan Wood.

A world wide average truck fuel efficiency is applied.

The calculations are based upon the transport of fresh (wet) southern yellow pine.

Distance transported:	*30*	km

Required volume of lumber entering Titan Wood plant:	*0.9*	m^3/m^3 Accoya
Proportion of timber which is converted into lumber:	55%	(Hillier & Murphy 2002)
Quantity of timber felled:	1.6	m^3 (derived from above)

Southern yellow pine (moisture content = 12%):	540	kg/m^3 (Wiselius 2001)
Moisture content of southern yellow pine for the above reference:	12%	(Wiselius 2001)
Moisture content of fresh southern yellow pine:	*55%*	(Assumption, Titan Wood)
Density of southern yellow pine (moisture content = 55%):	747	kg/m^3 (derived from above)

Truck fuel efficiency - Global average:	1.72	MJ/tonne.km (derived from RFA 2008)
Diesel emissions factor:	0.086	kgCO_2e/MJ (RFA 2008)

Global warming potential (in CO_2 equivalents) of CH_4:	25	(IPCC 2007)
Global warming potential (in CO_2 equivalents) of N_2O:	298	(IPCC 2007)

Transportation - Sawmill to acetylation facility - LOCALLY SOURCED

Source of emissions	Tonne-km of lumber (tonne.km/m^3 Accoya)	Total CO_2e emitted (kg/m^3 Accoya)	Total C emitted (kg/m^3 Accoya)
Truck - Sawmill to acetylation facility	94	13.9	3.8
Total	**94**	**14**	**3.8**

Data collection period: *For the batch production of 1 m^3 of Accoya® wood*

All figures in italics are supplied by the client

Assumptions

It is assumed that the lumber is transported 200 km by truck from the sawmill to the acetylation facility.
It is assumed that all timber deliveries are exclusively for Titan Wood.
A world wide average truck fuel efficiency is applied.
It is assumed that 'large container vessels' are used for sea freight.
CH_4 and N_2O emissions factors are not available for sea freight.
The calculations are based upon the transport of dried southern yellow (12% MC).

The distances set out below are modelled upon sourcing wood in South Eastern USA, with acetylation taking place at a proposed licensee plant site 200 km away.

Distance transported from sawmill to acetylation facility - truck:	*200*	km
Required volume of lumber entering Titan Wood plant:	*0.9*	m^3/m^3 Accoya
Southern yellow pine (moisture content = 12%):	540	kg/m^3 (Wiselius 2001)
Truck fuel efficiency - Global average:	1.72	MJ/tonne.km (derived from RFA 2008)
Diesel emissions factor:	0.086	kgCO_2e/MJ (RFA 2008)

Intercontinental

Transportation - Forest to sawmill - INTERCONTINENTAL

Source of emissions	Tonne-km of timber (tonne.km/m^3 Accoya)	Total CO$_2$e emitted (kg/m^3 Accoya)	Total C emitted (kg/m^3 Accoya)
Truck - forest to sawmill	31	4.5	1.2
Total	**31**	**4.5**	**1.2**

Data collection period: *For the batch production of 1 m^3 of Accoya® wood*

All figures in italics are supplied by the client

Assumptions

It is assumed that timber is transported via diesel truck a distance of 30 km from the point of felling to the sawmill, and that 55% of the felled timber is converted into useful lumber.

It is assumed that all timber deliveries are exclusively for Titan Wood.

A world wide average truck fuel efficiency is applied.

The calculations are based upon the transport of fresh (wet) radiate pine.

Distance transported:	*30*	km
Required volume of lumber entering Titan Wood plant:	*0.9*	m^3/m^3 Accoya
Proportion of timber which is converted into lumber:	55%	(Hillier & Murphy 2002)
Quantity of timber felled:	1.6	m^3 (derived from above)
Radiate pine (moisture content = 12%):	450	kg/m^3 (Wiselius 2001)
Moisture content of radiate pine for the above reference:	12%	(Wiselius 2001)
Moisture content of fresh radiate pine:	*55%*	(Assumption, Titan Wood)
Density of radiate pine (moisture content = 55%):	623	kg/m^3 (derived from above)
Truck fuel efficiency - Global average:	1.72	MJ/tonne.km (derived from RFA 2008)
Diesel emissions factor:	0.086	kgCO$_2$e/MJ (RFA 2008)
Global warming potential (in CO$_2$ equivalents) of CH$_4$:	25	(IPCC 2007)
Global warming potential (in CO$_2$ equivalents) of N$_2$O:	298	(IPCC 2007)

Transportation - Sawmill to acetylation facility - INTERCONTINENTAL

Source of emissions	Tonne-km of lumber (tonne.km/m^3 Accoya)	Total CO_2e emitted (kg/m^3 Accoya)	Total C emitted (kg/m^3 Accoya)
Truck - Sawmill to export port	23	3.5	0.9
Sea freight	9,740	127	34.5
Truck - Import port to acetylation facility	47	6.9	1.9
Total	**9,810**	**137**	**37.4**

Data collection period: *For the batch production of 1 m^3 of Accoya® wood*

All figures in italics are supplied by the client

Assumptions

It is assumed that the lumber is transported 50 km by truck from the sawmill to the local port for export. A sea freight vessel will then float the lumber 20811 km to a port local to the acetylation facility.
Finally, the lumber is then loaded back onto a truck for 100 km before delivery to the acetylation facility.
It is assumed that all timber deliveries are exclusively for Titan Wood.
A world wide average truck fuel efficiency is applied.
It is assumed that 'large container vessels' are used for sea freight.
CH_4 and N_2O emissions factors are not available for sea freight.
The calculations are based upon the transport of dried radiate pine (12% MC).

The distances set out below are modelled upon sourcing wood from the coastal regions of New Zealand's Northern Island, with acetylation taking place at Titan Wood's Arnhem facility in The Netherlands.

Distance transported from sawmill to export port - truck:	*50*	km
Distance transported from export port to import port - sea frieght:	20,811	km (E-ships.net)
Distance transported from import port to acetylation facility - truck:	*100*	km
Required volume of lumber entering Titan Wood plant:	*0.9*	m^3/m^3 Accoya
Radiate pine (moisture content = 12%):	450	kg/m^3 (Wiselius 2001)
Truck fuel efficiency - Global average:	1.72	MJ/tonne.km (derived from RFA 2008)
Diesel emissions factor:	0.086	kgCO_2e/MJ (RFA 2008)
Emissions factor - Large container vessel:	0.013	kgCO_2/tonne.km (Defra 2008)

Appendix III: Comparative materials

Material	Emissions factor ($kgCO_2e/m^3$)
Stone	161
Western red cedar (sustainably sourced)	232
Accoya - base case	290
Red meranti (sustainably sourced)	394
MDF (sustainably sourced)*	445
Concrete	495
Plywood (sustainably sourced)*	502
Accoya - production mix	672
Tile	874
Accoya - ketene route	1,323
PVC	3,326
Western red cedar (unsustainably sourced)	3,832
Red meranti (unsustainably sourced)	4,941
Steel	13,884
Aluminium	22,248

* It is assumed that wood in plywood and MDF is sustainably sourced, and hence emissions from land use changes are not included

Assumptions

Emissions factor - general aluminium (UK typical):	8.24	kgCO$_2$/kg (ICE 2008)
Density - aluminium:	2,700	kg/m^3 (ICE 2008)
Emissions factor - tile (UK typical):	0.46	kgCO$_2$/kg (ICE 2008)
Density - tile:	1,900	kg/m^3 (ICE 2008)
Emissions factor - prefabricated concrete (UK typical):	0.215	kgCO$_2$/kg (ICE 2008)
Density - dense, reinforced concrete:	2,300	kg/m^3 (ICE 2008)
Emissions factor - PVC general (UK typical):	2.41	kgCO$_2$/kg (ICE 2008)
Density - PVC:	1,380	kg/m^3 (ICE 2008)
Emissions factor - steel section (UK typical):	1.78	kgCO$_2$/kg (ICE 2008)
Density - steel:	7,800	kg/m^3 (ICE 2008)
Emissions factor - general stone:	0.056	kgCO$_2$/kg (ICE 2008)
Density - hard stone:	2,880	kg/m^3 (ICE 2008)

It is assumed that wood in ply and MDF is sustainably sourced, and hence emissions from land use changes are not included.

Emissions factor - plywood:	0.81	kgCO$_2$/kg (ICE 2008)
Density - plywood:	620	kg/m^3 (ICE 2008)
Emissions factor - MDF:	0.59	kgCO$_2$/kg (ICE 2008)
Density - MDF:	755	kg/m^3 (http://hypertextbook.com/facts/2000/ShirleyLam.shtml)

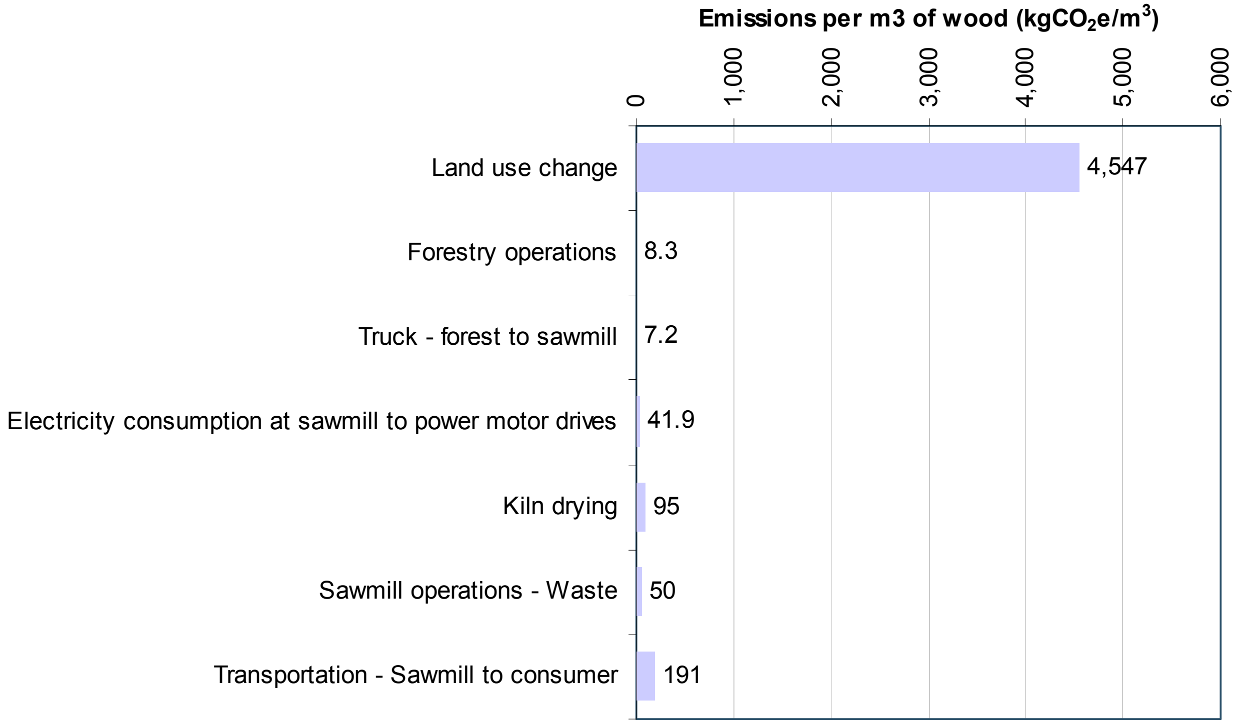
References

Inventory of Carbon & Energy (ICE), 2008, Version 1.6a

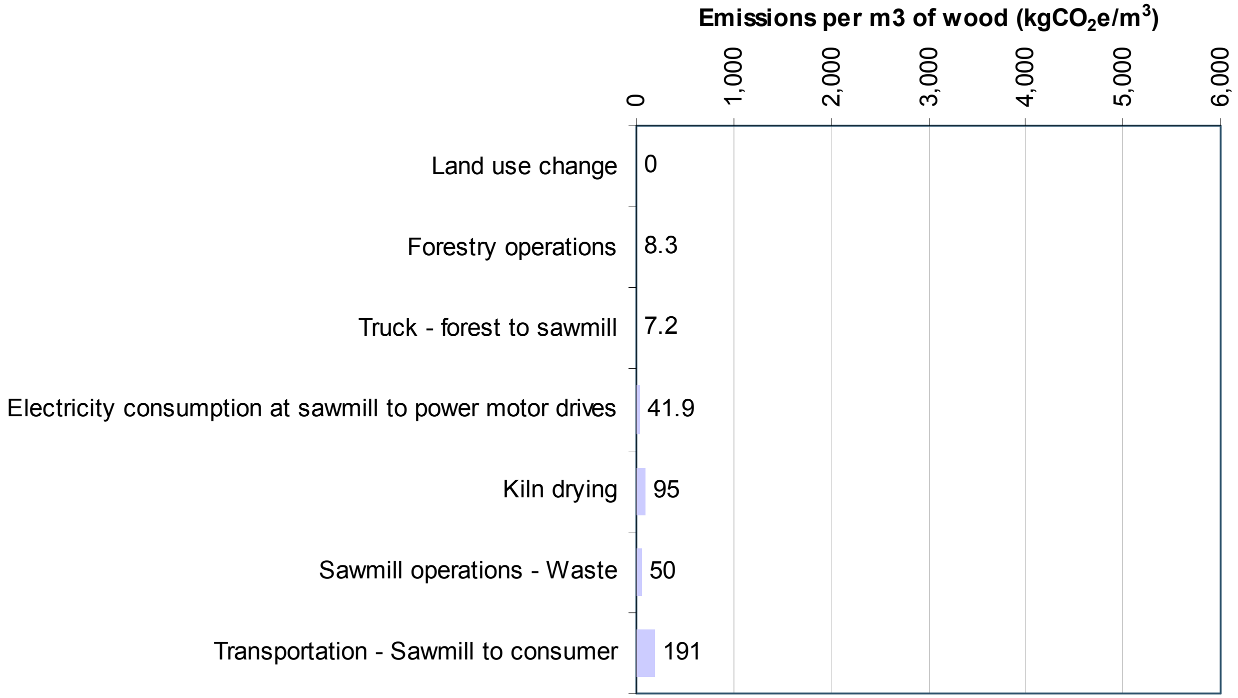
Appendix IV: Comparative material – red meranti

Source of emissions	Source table	Equivalent CO_2 emissions (kg/m^3)	
		Unsustainably sourced	Sustainably sourced
Land use change	A	4,547	-
Forestry operations	B	8.3	8.3
Truck - forest to sawmill	C	7.2	7.2
Electricity consumption at sawmill to power motor drives	D	41.9	41.9
Kiln drying	E	95	95
Sawmill operations - Waste	F	50	50
Transportation - Sawmill to consumer	G	191	191
Total	-	**4,941**	**394**

Unsustainably sourced red meranti



Sustainably sourced red meranti



A. Land use change

Source of emissions	Volume of timber (m^3)	Total CO_2e emitted (kg/m^3)	Total C emitted (kg/m^3)
Land use change	1.0	4,547	1,240
Total	**1.0**	**4,547**	**1,240**

Data collection period: *For the unsustainable sourcing and machining of 1 m^3 of red maranti*

All figures in italics are supplied by the supplier

Assumptions

If the wood is unsustainably sourced, then the effect of land use changes must be considered. Removal of trees results in a loss of ability to absorb (or sequester) carbon, and therefore an increase in emissions.
It is assumed that tropical hardwoods are deforested and that the land is not reforested (i.e. 100% unsustainably sourced).

Sawmill yield:	55%	(Hillier & Murphy 2002)
Expansion factor for tropical natural forests (above-ground biomass/m3 merchantable wood):	1,100	kg/m^3 (IPCC 2006)
Ratio of below-ground biomass to above-ground biomass in tropical moist deciduous forests:	0.24	(IPCC 2006)
Carbon content in biomass:	50%	

B. Forestry operations

Source of emissions	Volume of timber (m^3)	Total CO_2e emitted (kg/m^3)	Total C emitted (kg/m^3)
Forestry operations	1.0	8.3	2.3
Total	**1.0**	**8.3**	**2.3**

Data collection period: *For the unsustainable sourcing and machining of 1 m^3 of red maranti*

All figures in italics are supplied by the supplier

Assumptions

Forestry emissions reference (NTC 2008) is based upon felling Picea Abies (Norway Spruce). It is assumed that forestry operations are similar for wood species sourced in this assessment.
Data source assumes 50% of timber is converted to useful lumber at the sawmill. Hence, an extra 100% (by weight) of timber is cut as part of forestry operations.

Emissions from all forestry operations: 8.26 kg CO_2e/m^3 sawn timber (NTC 2008)

C. Transportation - Forest to sawmill

Source of emissions	Tonne-km of timber (tonne.km/m^3)	Total CO_2e emitted (kg/m^3)	Total C emitted (kg/m^3)
Truck - forest to sawmill	48	7.2	2.0
Total	**48**	**7.2**	**2.0**

Data collection period: *For the unsustainable sourcing and machining of 1 m^3 of red maranti*

All figures in italics are supplied by the client

Assumptions

It is assumed that timber is transported via diesel truck a distance of 30 km from the point of felling to the sawmill, and that 55% of the felled timber is converted into useful lumber.
It is assumed that all timber deliveries are exclusively for the product user.
A world wide average truck fuel efficiency is applied.
The calculations are based upon the transport of fresh (wet) red meranti.

Distance transported:	*30*	km
Required volume of lumber:	*1*	m^3
Proportion of timber which is converted into lumber:	55%	(Hillier & Murphy 2002)
Quantity of timber felled:	1.8	m^3 (derived from above)
Density of red maranti (moisture content = 12%):	640	kg/m^3 (Wiselius 2001)
Moisture content of red meranti for the above reference:	12%	(Wiselius 2001)
Moisture content of fresh red meranti:	*55%*	(Assumption, Titan Wood)
Density of red maranti (moisture content = 55%):	886	kg/m^3 (derived from above)
Truck fuel efficiency - Global average:	1.72	MJ/tonne.km (derived from RFA 2008)
Diesel emissions factor:	0.086	kgCO_2e/MJ (RFA 2008)
Global warming potential (in CO_2 equivalents) of CH_4:	25	(IPCC 2007)
Global warming potential (in CO_2 equivalents) of N_2O:	298	(IPCC 2007)

D. Sawmill operations - Electricity

Source of emissions	Volume of lumber (m^3)	Total CO_2e emitted (kg/m^3)	Total C emitted (kg/m^3)
Electricity consumption at sawmill to power motor drives	*1.0*	41.9	11.4
Total	**1.0**	**41.9**	**11.4**

Data collection period: *For the unsustainable sourcing and machining of 1 m^3 of red maranti*

All figures in italics are supplied by the supplier

Assumptions

Electricity consumption reference is for a sawmill cutting only Picea abies (Norway spruce)
It is assumed that the electricity demand would be identical regardless of the wood species being sawn.
It is assumed 50% of timber is converted to useful lumber at the sawmill. Hence, an extra 100% (by weight) of timber is cut as part of forestry operations.
In this scenario, red meranti is sourced in Malaysia, hence the appropriate electricity emissions factor is applied.

Typical electriticity consumption at sawmill to power motor drives:	73	kWh/m^3 sawn timber (NTC 2008)
CO_2e emissions for electricity, including upstream - Malaysia:	0.577	$kgCO_2/kWh$ (Carbon Trust 2008)

E. Sawmill operations - Kiln drying

Source of emissions	Volume of lumber (m^3)	CO_2 emitted (kg/m^3)	CH_4 emitted (kg/m^3)	N_2O emitted (kg/m^3)	Total CO_2e emitted (kg/m^3)	Total C emitted (kg/m^3)
Kiln drying	*1.0*	94	0.011	0.0017	95	26
Total	**1.0**	**94**	**0.011**	**0.0017**	**95**	**26**

Data collection period: *For the unsustainable sourcing and machining of 1 m^3 of red maranti*

All figures in italics are supplied by the supplier

Assumptions

Energy consumption reference (Hillier & Murphy 2002) is for kiln drying of Picea abies (Norway spruce) with an original 55% mc and kiln dried to 14% mc.
It is assumed that the energy demand for kiln drying would be identical regardless of the wood species being dried.
All other tables have assumed that dry lumber will have a 12% mc, where as the Hillier & Murphy referece assumes a 14% mc wood. It is assumed that the additional energy requirement to achieve a 12% mc is negligable, and is hence ignored.

Energy required for Kiln drying:	5.5	MJ/kg water (Hillier & Murphy 2002)

Density of red maranti (moisture content = 12%):	640	kg/m^3 (Wiselius 2001)
Moisture content of red meranti for the above reference:	12%	(Wiselius 2001)
Moisture content of fresh red meranti:	*55%*	(Assumption, Titan Wood)
Density of red maranti (moisture content = 55%):	886	kg/m^3 (derived from above)

Breakdown of thermal energy by source for the sawmill:

Heavy fuel oil:	80%	Working assumption
Biomass:	20%	Working assumption
Natural gas:	0%	Working assumption

Fuel oil required for Kiln drying red meranti in the sawmill:	300	kWh/m^3 sawn timber
Biomass required for Kiln drying red meranti in the sawmill:	75	kWh/m^3 sawn timber
Natural gas required for Kiln drying red meranti in the sawmill:	0	kWh/m^3 sawn timber

CO_2 emissions for fuel oil (NCV):	0.282	$kgCO_2/kWh$ (Defra2008)
Upstream CO_2 emissions for fuel oil (NCV):	0.032	$kgCO_2/kWh$ (SCLCI 2007)
CH_4 emissions for fuel oil (NCV):	0.011	gCH_4/kWh (derived from IPCC 2006)
N_2O emissions for fuel oil (NCV):	0.002	gN_2O/kWh (derived from IPCC 2006)

Fossil CO_2 emissions for biomass:	0	$kgCO_2/kWh$ (Defra2008)
CH_4 emissions for biomass (NCV):	0.108	gCH_4/kWh (derived from IPCC 2006)
N_2O emissions for biomass (NCV):	0.014	gN_2O/kWh (derived from IPCC 2006)

CO_2 emissions for natural gas (net):	0.206	$kgCO_2/kWh$ (Defra 2008)
Upstream CO_2 emissions for natural gas - European high (NCV):	0.088	$kgCO_2/kWh$ (derived from IEA 2007, DUKES 2006, Defra 2008 and SCLCI 2007)
CH_4 emissions for natural gas:	0.004	gCH_4/kWh (derived from IPCC 2006)
N_2O emissions for natural gas:	0.004	gN_2O/kWh (derived from IPCC 2006)

Conversion from kWh to MJ:	3.6	MJ/kWh

Global warming potential (in CO_2 equivalents) of CH_4:	25	(IPCC 2007)
Global warming potential (in CO_2 equivalents) of N_2O:	298	(IPCC 2007)

NCV = net calorific value

F. Sawmill operations - Waste

Source of emissions	Waste arisings (kg/m^3)	CH_4 generated (kg/m^3)	CH_4 emitted (kg/m^3)	Total CO_2e emitted (kg/m^3)	Total C emitted (kg/m^3)
Sawmill operations - Waste	209	6.0	2.0	50	14
Total	**209**	**6.0**	**2.0**	**50**	**14**

Data collection period:	*For the unsustainable sourcing and machining of 1 m^3 of red maranti*
All figures in italics are supplied by the client	

Assumptions

It is assumed that wood chips are used as a fuel source for the kiln drying, however sawdust and bark are waste products.
No other waste streams are considered.
It is assumed that all waste goes to landfill.

Required volume of lumber:	*1.0*	m^3
Proportion of timber which is converted into lumber:	55%	(Hillier & Murphy 2002)
Proportion of timber which is converted into chips:	27%	(Hillier & Murphy 2002)
Proportion of timber which is converted into sawdust:	9%	(Hillier & Murphy 2002)
Proportion of timber which is bark:	9%	(Hillier & Murphy 2002)
Quantity of timber felled:	1.8	m^3 (derived from above)
Quantity of timber diverted to waste:	0.3	m^3 (derived from above)
Density of red meranti (mc=12%):	640	kg/m^3 (Hillier & Murphy 2002)
Methane generated from landfilled commercial waste:	0.029	$kgCH_4/kg$ waste (see below)
Methane emitted from landfilled commercial waste:	0.010	$kgCH_4/kg$ waste (see below)

To calculate carbon emissions from general industrial waste the following parameters were used:

Degradable organic C content (DOC) of typical MSW (doc):	7.2%	(Smith et al 2001)
Proportion of dissimilable DOC (di):	60%	(Brown et al 1999)
Proportion of dissimilable DOC decaying to methane (dm):	50%	(IPCC 2006)
Methane oxidation factor (ox):	10%	(Brown et al 1999)
Average landfill gas collection efficiency for UK landfills (gc):	63%	(Smith et al 2001)
Global warming potential of CH_4:	25	(IPCC 2007)

Notes

CH_4 generated (mg) = mass x doc x dm x di x 16/12
CH_4 emitted = mg x (1-gc) x (1-ox)
16/12 is the conversion factor carbon to CH_4
44/12 is the conversion factor carbon to CO_2

G. Transportation - Sawmill to consumer

Source of emissions	Tonne-km of lumber (tonne.km/m^3 Accoya)	Total CO$_2$e emitted (kg/m^3)	Total C emitted (kg/m^3)
Truck - Sawmill to export port	320	47.4	12.9
Sea freight	10,349	135	36.7
Truck - Import port to consumer	64	9.5	2.6
Total	**10,733**	**191**	**52.2**

Data collection period: *For the unsustainable sourcing and machining of 1 m^3 of red maranti*

All figures in italics are supplied by the client

Assumptions

It is assumed that the lumber is transported 500 km by truck from the sawmill to the local port for export. A sea freight vessel will then float the lumber 8731 nautical miles to a port local to the consumer. Finally, the lumber is then loaded back onto a truck for 100 km before delivery to the consumer.

It is assumed that all timber deliveries are exclusively for the consumer.

A world wide average truck fuel efficiency is applied.

It is assumed that 'large container vessels' are used for sea freight.

CH$_4$ and N$_2$O emissions factors are not available for sea freight.

The calculations are based upon the transport of dried red meranti (12% MC).

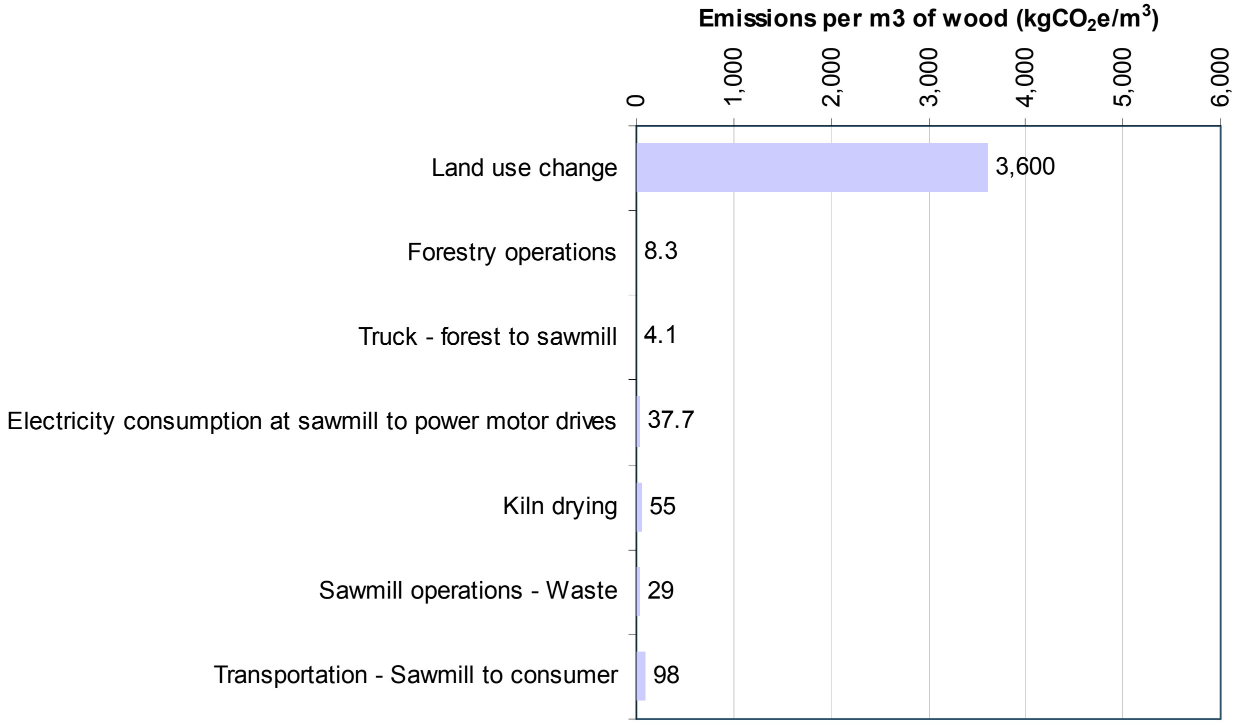
The distances set out below are modelled upon sourcing wood in Sarawack, Malaysia, loading the timber between the ports of Kuching, Malaysia and Rotterdam, The Netherlands, before delivery by truck to the consumer.

Distance transported from sawmill to export port - truck:	*500*	km (estimated distance using map)
Distance transported from export port to import port - sea frieght:	8,731	natical miles (E-ships.net)
Distance transported from import port to consumer - truck:	*100*	km
Required volume of lumber:	*1.0*	m^3
Density of red meranti (mc=12%):	640	kg/m3 (Hillier & Murphy 2002)
Unit conversion - kilometres to nautical miles (international):	1.852	km/nautical mile (international)
Truck fuel efficiency - Global average:	1.72	MJ/tonne.km (derived from RFA 2008)
Diesel emissions factor:	0.086	kgCO$_2$e/MJ (RFA 2008)
Emissions factor - Large container vessel:	0.013	kgCO$_2$/tonne.km (Defra 2008)

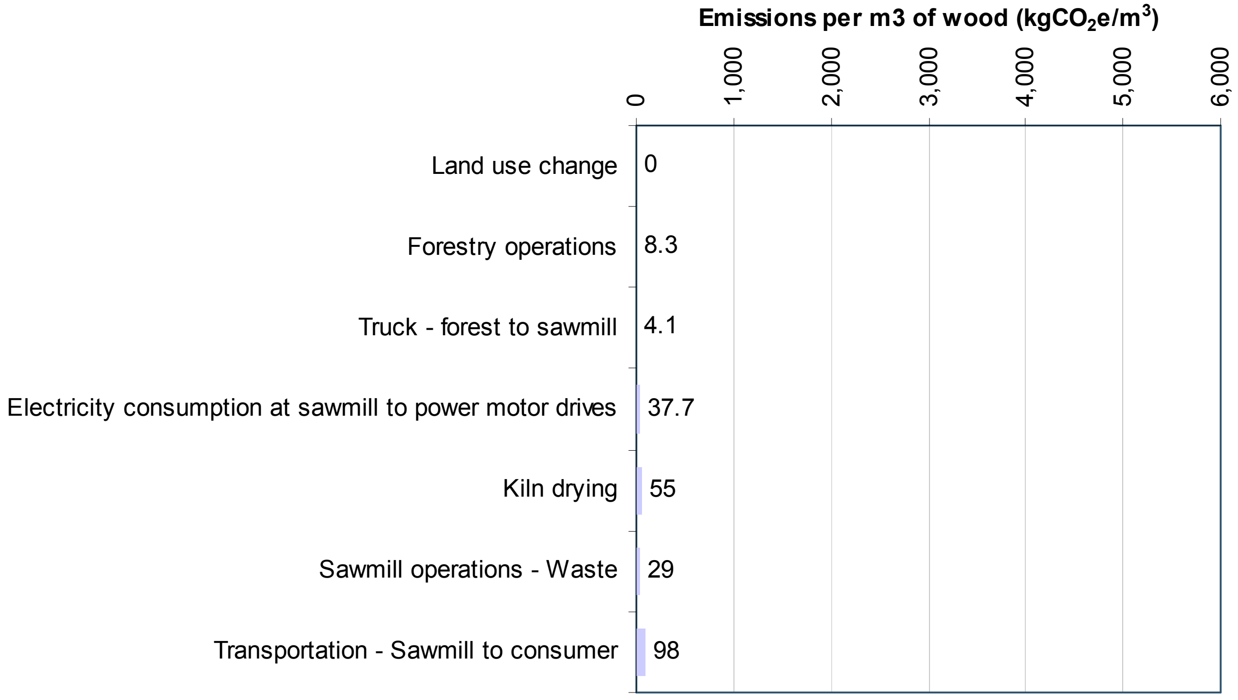
Appendix V: Comparative material – Western red cedar

Source of emissions	Source table	Equivalent CO_2 emissions (kg/m^3)	
		Unsustainably sourced	Sustainably sourced
Land use change	A	3,600	-
Forestry operations	B	8.3	8.3
Truck - forest to sawmill	C	4.1	4.1
Electricity consumption at sawmill to power motor drives	D	37.7	37.7
Kiln drying	E	55	55
Sawmill operations - Waste	F	29	29
Transportation - Sawmill to consumer	G	98	98
Total	**-**	**3,832**	**232**

Unsustainably sourced western red cedar



Sustainably sourced western red cedar



A. Land use change

Source of emissions	Volume of timber (m^3)	Total CO_2e emitted (kg/m^3)	Total C emitted (kg/m^3)
Land use change	1.0	3,600	982
Total	**1.0**	**3,600**	**982**

Data collection period: *For the unsustainable sourcing and machining of 1 m^3 of western red cedar*
All figures in italics are supplied by the supplier

Assumptions

If the wood is unsustainably sourced, then the effect of land use changes must be considered. Removal of trees results in a loss of ability to absorb (or sequester) carbon, and therefore an increase in emissions.
It is assumed that tropical hardwoods are deforested and that the land is not reforested (i.e. 100% unsustainably sourced).

Sawmill yield:	55%	(Hillier & Murphy 2002)
Expansion factor for conifers in temperate zones (above-ground biomass/m3 merchantable wood):	900	kg/m3 (IPCC 2006)
Ratio of below-ground biomass to above-ground biomass in conifer temperate forests:	0.2	(IPCC 2006)
Carbon content in biomass:	50%	

B. Forestry operations

Source of emissions	Volume of timber (m^3)	Total CO_2e emitted (kg/m^3)	Total C emitted (kg/m^3)
Forestry operations	1.0	8.3	2.3
Total	**1.0**	**8.3**	**2.3**

Data collection period: *For the unsustainable sourcing and machining of 1 m^3 of western red cedar*

All figures in italics are supplied by the supplier

Assumptions

Forestry emissions reference (NTC 2008) is based upon felling Picea Abies (Norway Spruce). It is assumed that forestry operations are similar for wood species sourced in this assessment.
Data source assumes 50% of timber is converted to useful lumber at the sawmill. Hence, an extra 100% (by weight) of timber is cut as part of forestry operations.

Emissions from all forestry operations: 8.26 kg CO_2e/m^3 sawn timber (NTC 2008)

C. Transportation - Forest to sawmill

Source of emissions	Tonne-km of timber (tonne.km/m^3)	Total CO_2e emitted (kg/m^3)	Total C emitted (kg/m^3)
Truck - forest to sawmill	28	4.1	1.1
Total	**28**	**4.1**	**1.1**

Data collection period:	*For the unsustainable sourcing and machining of 1 m^3 of western red cedar*
All figures in italics are supplied by the client	

Assumptions

It is assumed that timber is transported via diesel truck a distance of 30 km from the point of felling to the sawmill, and that 55% of the felled timber is converted into useful lumber.
It is assumed that all timber deliveries are exclusively for the product user.
A world wide average truck fuel efficiency is applied.
The calculations are based upon the transport of fresh (wet) western red cedar.

Distance transported:	*30*	km
Required volume of lumber:	*1*	m^3
Proportion of timber which is converted into lumber:	55%	(Hillier & Murphy 2002)
Quantity of timber felled:	1.8	m^3 (derived from above)
Density of western red cedar (moisture content = 12%):	370	kg/m^3 (Wiselius 2001)
Moisture content of western red cedar for the above reference:	12%	(Wiselius 2001)
Moisture content of fresh western red cedar:	*55%*	(Assumption, Titan Wood)
Density of western red cedar (moisture content = 55%):	512	kg/m^3 (derived from above)
Truck fuel efficiency - Global average:	1.72	MJ/tonne.km (derived from RFA 2008)
Diesel emissions factor:	0.086	$kgCO_2e/MJ$ (RFA 2008)
Global warming potential (in CO_2 equivalents) of CH_4:	25	(IPCC 2007)
Global warming potential (in CO_2 equivalents) of N_2O:	298	(IPCC 2007)

D. Sawmill operations - Electricity

Source of emissions	Volume of lumber (m^3)	Total CO_2e emitted (kg/m^3)	Total C emitted (kg/m^3)
Electricity consumption at sawmill to power motor drives	*1.0*	37.7	10.3
Total	**1.0**	**37.7**	**10.3**

Data collection period: *For the unsustainable sourcing and machining of 1 m^3 of western red cedar*

All figures in italics are supplied by the supplier

Assumptions

Electricity consumption reference is for a sawmill cutting only Picea abies (Norway spruce)
It is assumed that the electricity demand would be identical regardless of the wood species being sawn.
It is assumed 50% of timber is converted to useful lumber at the sawmill. Hence, an extra 100% (by weight) of timber is cut as part of forestry operations.
In this scenario, western red cedar is sourced in the USA, hence the appropriate electricity emissions factor is applied.

Typical electiticity consumption at sawmill to power motor drives:	73	kWh/m^3 sawn timber (NTC 2008)
CO_2e emissions for electricity, including upstream - US (west coast region):	0.519	$kgCO_2/kWh$ (Carbon Trust 2008)

E. Sawmill operations - Kiln drying

Source of emissions	Volume of lumber (m^3)	CO_2 emitted (kg/m^3)	CH_4 emitted (kg/m^3)	N_2O emitted (kg/m^3)	Total CO_2e emitted (kg/m^3)	Total C emitted (kg/m^3)
Kiln drying	*1.0*	55	0.007	0.0010	55	15
Total	**1.0**	**55**	**0.007**	**0.0010**	**55**	**15**

Data collection period: *For the unsustainable sourcing and machining of 1 m^3 of western red cedar*

All figures in italics are supplied by the supplier

Assumptions

Energy consumption reference (Hillier & Murphy 2002) is for kiln drying of Picea abies (Norway spruce) with an original 55% mc and kiln dried to 14% mc.
It is assumed that the energy demand for kiln drying would be identical regardless of the wood species being dried.
All other tables have assumed that dry lumber will have a 12% mc, where as the Hillier & Murphy referece assumes a 14% mc wood. It is assumed that the additional energy requirement to achieve a 12% mc is negligable, and is hence ignored.

Energy required for Kiln drying:	5.5	MJ/kg water (Hillier & Murphy 2002)

Density of western red cedar (moisture content = 12%):	370	kg/m^3 (Wiselius 2001)
Moisture content of western red cedar for the above reference:	12%	(Wiselius 2001)
Moisture content of fresh western red cedar:	*55%*	(Assumption, Titan Wood)
Density of western red cedar (moisture content = 55%):	512	kg/m^3 (derived from above)

Breakdown of thermal energy by source for the sawmill:

Heavy fuel oil:	80%	Working assumption
Biomass:	20%	Working assumption
Natural gas:	0%	Working assumption

Fuel oil required for Kiln drying western red cedar in the sawmill:	174	kWh/m^3 sawn timber
Biomass required for Kiln drying western red cedar in the sawmill:	43	kWh/m^3 sawn timber
Natural gas required for Kiln drying western red cedar in the sawmill:	0	kWh/m^3 sawn timber

CO_2 emissions for fuel oil (NCV):	0.282	$kgCO_2/kWh$ (Defra2008)
Upstream CO_2 emissions for fuel oil (NCV):	0.032	$kgCO_2/kWh$ (SCLCI 2007)
CH_4 emissions for fuel oil (NCV):	0.011	gCH_4/kWh (derived from IPCC 2006)
N_2O emissions for fuel oil (NCV):	0.002	gN_2O/kWh (derived from IPCC 2006)

Fossil CO_2 emissions for biomass:	0	$kgCO_2/kWh$ (Defra2008)
CH_4 emissions for biomass (NCV):	0.108	gCH_4/kWh (derived from IPCC 2006)
N_2O emissions for biomass (NCV):	0.014	gN_2O/kWh (derived from IPCC 2006)

CO_2 emissions for natural gas (net):	0.206	$kgCO_2/kWh$ (Defra 2008)
Upstream CO_2 emissions for natural gas - European high (NCV):	0.088	$kgCO_2/kWh$ (derived from IEA 2007, DUKES 2006, Defra 2008 and SCLCI 2007)
CH_4 emissions for natural gas:	0.004	gCH_4/kWh (derived from IPCC 2006)
N_2O emissions for natural gas:	0.004	gN_2O/kWh (derived from IPCC 2006)

Conversion from kWh to MJ:	3.6	MJ/kWh

Global warming potential (in CO_2 equivalents) of CH_4:	25	(IPCC 2007)
Global warming potential (in CO_2 equivalents) of N_2O:	298	(IPCC 2007)

NCV = net calorific value

F. Sawmill operations - Waste

Source of emissions	Waste arisings (kg/m^3)	CH_4 generated (kg/m^3)	CH_4 emitted (kg/m^3)	Total CO_2e emitted (kg/m^3)	Total C emitted (kg/m^3)
Sawmill operations - Waste	121	3.5	1.2	29	8
Total	**121**	**3.5**	**1.2**	**29**	**8**

Data collection period: *For the unsustainable sourcing and machining of 1 m^3 of western red cedar*

All figures in italics are supplied by the client

Assumptions

It is assumed that wood chips are used as a fuel source for the kiln drying, however sawdust and bark are waste products.
No other waste streams are considered.
It is assumed that all waste goes to landfill.

Required volume of lumber:	*1.0*	m^3
Proportion of timber which is converted into lumber:	55%	(Hillier & Murphy 2002)
Proportion of timber which is converted into chips:	27%	(Hillier & Murphy 2002)
Proportion of timber which is converted into sawdust:	9%	(Hillier & Murphy 2002)
Proportion of timber which is bark:	9%	(Hillier & Murphy 2002)
Quantity of timber felled:	1.8	m^3 (derived from above)
Quantity of timber diverted to waste:	0.3	m^3 (derived from above)
Density of western red cedar (mc=12%):	370	kg/m^3 (Hillier & Murphy 2002)
Methane generated from landfilled commercial waste:	0.029	$kgCH_4/kg$ waste (see below)
Methane emitted from landfilled commercial waste:	0.010	$kgCH_4/kg$ waste (see below)

To calculate carbon emissions from general industrial waste the following parameters were used:

Degradable organic C content (DOC) of typical MSW (doc):	7.2%	(Smith et al 2001)
Proportion of dissimilable DOC (di):	60%	(Brown et al 1999)
Proportion of dissimilable DOC decaying to methane (dm):	50%	(IPCC 2006)
Methane oxidation factor (ox):	10%	(Brown et al 1999)
Average landfill gas collection efficiency for UK landfills (gc):	63%	(Smith et al 2001)
Global warming potential of CH_4:	25	(IPCC 2007)

Notes

CH_4 generated (mg) = mass x doc x dm x di x 16/12
CH_4 emitted = mg x (1-gc) x (1-ox)
16/12 is the conversion factor carbon to CH_4
44/12 is the conversion factor carbon to CO_2

G. Transportation - Sawmill to consumer

Source of emissions	Tonne-km of lumber (tonne.km/m^3 Accoya)	Total CO$_2$e emitted (kg/m^3)	Total C emitted (kg/m^3)
Truck - Sawmill to export port	93	13.7	3.7
Sea freight	6,061	79	21.5
Truck - Import port to consumer	37	5.5	1.5
Total	**6,190**	**98**	**26.7**

Data collection period: *For the unsustainable sourcing and machining of 1 m^3 of western red cedar*

All figures in italics are supplied by the client

Assumptions

It is assumed that the lumber is transported 250 km by truck from the sawmill to the local port for export. A sea freight vessel will then float the lumber 8845 nautical miles to a port local to the consumer. Finally, the lumber is then loaded back onto a truck for 100 km before delivery to the consumer.

It is assumed that all timber deliveries are exclusively for the consumer.

A world wide average truck fuel efficiency is applied.

It is assumed that 'large container vessels' are used for sea freight.

CH$_4$ and N$_2$O emissions factors are not available for sea freight.

The calculations are based upon the transport of dried western red cedar (12% MC).

The distances set out below are modelled upon sourcing wood in west coast USA, loading the timber between the ports of Seattle and Rotterdam, The Netherlands, before delivery by truck to the consumer.

Distance transported from sawmill to export port - truck:	*250*	km
Distance transported from export port to import port - sea frieght:	8,845	nautical miles (E-ships.net)
Distance transported from import port to consumer - truck:	*100*	km
Required volume of lumber:	*1.0*	m^3
Density of western red cedar (mc=12%):	370	kg/m3 (Hillier & Murphy 2002)
Unit conversion - kilometres to nautical miles (international):	1.852	km/nautical mile (international)
Truck fuel efficiency - Global average:	1.72	MJ/tonne.km (derived from RFA 2008)
Diesel emissions factor:	0.086	kgCO$_2$e/MJ (RFA 2008)
Emissions factor - Large container vessel:	0.013	kgCO$_2$/tonne.km (Defra 2008)

Appendix VI: Calculation references

REFERENCES

BOC 1998, Safety data sheet - Liquid nitrogen

Boustead 2009, Bousead Model - materials procssing core, acetic acid, carbon dioxide equivalents (data sheet provided via personal communication with Philip Beall, Philip W Beall Ltd, 8 October 2009)

Brown et al. 1999. Methane Emissions from UK Landfills. Final report produced for The Department of Environment, Transport and the Regions. AEA Technology Environment.

Carbon Trust 2006. Energy and carbon conversions.

Defra 2008. Guidelines to Defra's greenhouse gas (GHG) conversion factors for company reporting.

Digest of UK Energy Statistics (DUKES), 2008, Annex A

E-Ships, 2009, <URL:http://www.e-ships.net/dist.htm>

Grundfos, 2009, Personal communication

Hillier & Murphy, 2002, Imperial College London, LCA for acetylated wood, Final report 1

IEA 2006, CO2 emissions from fuel combustion

IEA 2007. Key World energy statistics

IPCC 2006. 2006 IPCC Guidelines for National Greenhouse Gas Inventories: Reference Manual. Intergovernmental Panel on Climate Change.

IPCC 2007. Climate Change 2007: The Physical Science Basis. Cambridge University Press

Renewables Fuels Agency (RFA), 2008, Carbon reporting - Default values and fuel chains V1.1

Smith et al. 2001. Waste Management Options and Climate Change, AEA Technology, Luxembourg.

Wiselius, 2001, Houtvademecum. Wood Center Netherlands, Almere.

Appendix VII: Generating carbon value from Accoya® wood

As the governments and policy makers pursue a transition from a high carbon to a low carbon economy, products and services with a lower climate impact should be, and in some cases already are, rewarded for the public good they provide. Policy mechanisms to slow the onset of climate change can be broken down into three categories:

- Command and Control: tougher government regulation on the type of technology and materials used;
- Carbon taxes: a fixed levy on every tonne of CO_2 emitted; and
- Cap and Trade: a cap on national and/or regional emissions with the market setting the price according to the marginal CO_2 abatement cost.

These policies are not mutually exclusive: the UK for instance uses all three mechanisms: it promotes tougher regulations from power plants to capturing methane from landfill gas sites; the Climate Change Levy charges businesses a fixed amount per kilowatt hour of power used; and the European Union Emissions Trading Scheme, focused on large point sources of CO_2 emissions, applies a cap to over 40% of the UK's emissions.

For Titan Wood each of these policy measures will generate risks and opportunities. The focus here is on the opportunities presented by the development of cap-and-trade schemes around the world. Consequently the implicit and explicit value which could be generated through the:

- Processing and production of the Accoya® wood,
- The displacement of other more carbon intensive materials typically used instead
- The amount of carbon stored or the sequestration value of the product.

Value can potentially be extracted for projects which sequester CO_2 and which reduce CO_2 emissions below an established baseline. For the purposes of analysing the ability of Titan Wood to generate value through the processing attributable to the production of Accoya® wood and the carbon stored within the product itself each aspect of the production chain is broken down by process ownership and analysed below.

Ownership of emissions reductions or sequestered carbon needs to be defined at a company level and also at a country level. Under the Kyoto Protocol sovereign entities emissions reductions which occur in one country effectively belong to that country and require the consent of that country. Consent is then required, to be sold overseas and to third parties.

Primary Production and Pre-Processing

A number of opportunities may exist here to monetise the carbon benefits within this activity. Camco assumes that this activity takes place within a country which has ratified the Kyoto protocol (either an Annex I, developed country, or an non-Annex I developing country).

Afforestation, reforestation and forest management activities often provide a net CO_2 benefit provided that in the absence of any activity they would likely not have occurred. These activities typically apply where forest is not harvested on a regular basis (as will be delayed through the use of Accoya® Wood) and/or where forest management activities improve the productivity of the forest beyond what would have likely occurred naturally. One example of this is multi-cropping and growing and managing trees on coffee plantations. Forestry has, up until now, largely operated outside of the carbon markets for a variety of reasons: the difficulty in establishing baselines and land ownership, the accuracy of monitoring of the carbon stored and its non-permanent nature.

This is changing and post-2012 there will be a greater focus on avoided deforestation and forestry management reflecting the importance of forests in absorbing and reducing global emissions; however this new regime is unlikely to become established until 2012 at the earliest. In the short term it may be beneficial for Titan Wood, depending on the volume of timber utilised, to look more closely at forestry and land-use practices and the potential carbon benefits of improving these. Whilst it is unclear whether Titan Wood or its clients will have direct control over the forests where timber is sourced from, there may be the possibility that Titan Wood could secure the rights to carbon sequestered through assisting forest owners in undertaking changes in practices to improve the carbon stock.

Pre-processing is assumed to take place in the country, near to where the timber is sourced from. Pre-processing activities may be present a number of opportunities to generate emissions reductions beyond a business as usual scenario:

- Switching to less carbon intensive fuel (from oil to gas or oil to biomass) to provide heat;
- Generating clean electricity from the waste products of the cutting process; and
- Utilizing waste products to avoid the generation of methane from the anaerobic decomposition of piles of organic material.

Examples of each of these options have been developed as emissions reduction projects in both the developing and developed world. For Titan Wood to generate carbon revenue from any of these projects it would need to show that they represented a departure from business as usual in the locations where the pre-processing facility was sited. This would likely be easier to do if an existing facility was going to be used and needed retrofitting rather than a new unit.

Processing

It is assumed that processing of the dried wood used by Accoya® wood does not take place at the pre-processing facility but at a separate facility under separate ownership and perhaps in a different country. Similar to the fuel switching examples above opportunities to generate saleable emissions reductions may arise from the use of less heat and from switching to fuels and processes with lower carbon intensities. If this process is undertaken within the EU and the fuel input required for heating has a rating higher than 20MW (thermal) then the installation will fall under the EU Emissions Trading Scheme.

End Use

Accoya® wood may be used as a substitute for steel and other energy intensive materials in construction and large infrastructure projects. Based on Camco's analysis, the lifecycle embodied emissions are considerably lower than an equivalent amount of steel. In theory there is therefore a net carbon benefit to using Accoya® rather than steel for construction. Given this net carbon benefit there may be opportunities to utilize the carbon market to promote the use of a product which creates lower emissions.

Typically, emissions reduction projects developed under the Kyoto Protocol focus on reducing emissions at point sources or occasionally reducing emissions through substituting a material with one which has a lower carbon value. The latter projects have proved difficult to develop because of issues surrounding how to account for a baseline when the project owner does not have control over that baseline, how to avoid double counting (ensuring that somebody else isn't directly or indirectly claiming the emissions reductions) and how to monitor and verify emissions reductions which may take place in different countries and at different firms.

Where the production process, from cradle to gate, takes place in one country some of these issues are overcome. Certainly, under the current international framework it is highly unlikely that carbon value could be generated where the product is shipped across international borders. To establish the reductions below a business as usual case, i.e. the emissions attributable to producing the equivalent amount of steel, would also require the steel to have been produced within the same country. As the Kyoto Protocol is a treaty between sovereign countries, nations have the ultimate say over whether to permit or not permit a project to take place and for the reductions to be transferred or traded overseas. Where reductions are taking place across multiple countries, government agreement is required and title to those reductions, from forest to end user will need to be demonstrated in order to avoid the danger that emissions reductions are claimed twice.

Where the production process takes place in one country and where steel which would be substituted is likely to be sourced from that country, it should be possible to construct a baseline for steel emissions based upon available information on the technology and processes used. Providing data is available throughout the Accoya® wood supply chain and providing ownership of any emissions reductions can be vested in one entity it would be possible to generate carbon value from the substitution of steel with Accoya® wood.

Summary

Cap-and-trade policy and the carbon market are evolving rapidly. From a standing start in 2005, the market was valued at over a €100 billion in 2008 and is likely to continue to grow as more countries and sectors are required to limit their emissions and emissions growth. For Titan Wood and Accoya® wood this expanding market creates opportunities to generate additional value from the environmental benefits of the product.

The price of carbon intensive products, such as steel, is increasing within markets which have an explicit carbon price thus value is most likely to come from the generation of emissions reduction credits and the sale of those credits into those markets that must comply with Kyoto targets.

To assess these opportunities further Camco recommends that Titan Wood investigates:

- The economic potential for utilising the carbon markets to generate emissions reductions at pre-processing and processing stages of the production chain
- Procuring a more detailed study focused on a specific production scenario to better understand the economic and practical viability of generating emissions reductions from the substitution of steel and other materials with Accoya® wood
- Emissions saved by promoting better forestry management practices