Review of CO_2-e Emissions from Concrete versus Timber Sleepers

Report prepared by Energy Strategies
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Energy Strategies was asked to estimate the lifetime greenhouse gas emissions associated with two options for replacing and maintaining sleepers over 60 years, on the majority of ARTC's main east coast route between Melbourne and Brisbane.

Option 1 is for a complete replacement of existing timber sleepers with concrete over a two and a half year period. The life of a concrete sleeper is 60 years.

Option 2 is for replacements of existing timber sleepers with new timber. Just over one quarter (27.5%) of existing timber sleepers are replaced in Year 1, followed by progressive replacement of 3.75% of the initial count of sleepers on a rolling basis over the next 20 years[1]. The life of timber sleepers is 20 years. Therefore, this cycle is repeated two more times over the full 60-year period.

ARTC provided figures for the total numbers of sleepers for each case: there are about 10% fewer concrete than timber sleepers because the spacing is greater.

The principal materials used are concrete, hardwood (red gum) timber and steel. Steel is used in fastening rails to the sleepers and also, in the case of concrete sleepers, as reinforcing, and, in the case of timber sleepers, as gang nail plates. ARTC provided data on the mass of steel used in the two different types of fastening assemblies, as well as the concrete reinforcing and timber gang nail plates. Total quantities of materials per sleeper used for this estimation are as follows:

- concrete sleepers — concrete 285 kg, — steel 7.2 kg
- timber sleepers — air dry hardwood[2] 65.7 kg, — steel 11.7 kg

It is assumed that the amount of energy used, and hence emissions resulting, from the physical process of replacing sleepers are the same for the two cases. It was also assumed that energy use and emissions associated with transporting sleepers from where they are produced to where they are laid are also equal in the two cases. Such transport emissions are typically only a small proportion of total life cycle emissions, and therefore unlikely to materially affect relativities even if they are different for the two cases. Hence, differences arise only from the different activities used to produce concrete and timber sleepers.

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[1] In calculating the timber replacement time series, to contrive an exact 100% replacement figure, a smaller percentage of the initial count is replaced in the 21st year: 27.5 + 19 * 3.75 + 1.25 = 100

[2] There are two species of Red Gum used for sleepers - both are Class 1 durable:
Forest Red Gum, Eucalyptus tereticornis, has a green density of 1,200kg/m^3, while
River Red Gum, E. camaldulensis, has green density of 1130kg/m^3 and an approximate density of 900kg/m^3 air dry. These figures are from: Bootle, Keith R. Wood in Australia. Sydney: McGraw-Hill, 1983 - a recognised Australian authority on the mechanical properties of commercial timbers and are consistent with Australian Greenhouse Office National Carbon Accounting System (www.greenhouse.gov.au/ncas), Technical Report 18 Woody Density Phase 1 (www.greenhouse.gov.au/ncas/reports/tr18final.html)

Data on embodied energy for various types of construction and structural materials were obtained from a variety of sources. The initial source consulted was the life cycle assessment tool compiled on behalf of the Commonwealth Government by the Centre for Design, RMIT (http://buildlca.rmit.edu.au/menu10.html). This source provides data on life cycle energy use per tonne of each material, disaggregated by fuel type. These energy consumption figures are then converted to emissions using appropriate fuel specific emission factors taken from the *Australian Greenhouse Office Factors and Methods Workbook*[3].

However, this source is energy oriented, rather than emissions oriented, and it does not provide data on emissions from other sources, notably the industrial process emissions associated with production of cement and steel, resulting respectively from the calcination of limestone and use of dolomite. Moreover, on close examination, some of the data proved hard to reconcile with other sources, such as the environmental reports of manufacturing businesses and industry associations.

This was particularly the case for cement (as input to concrete production) and steel, which are by a wide margin the two most emissions intensive materials used. For these reasons, the emissions intensity of cement, the data source was the cement industry emissions intensity, published by the Cement Industry Federation (www.cement.org.au), and for the emissions intensity of steel the source was the Community, Safety and Environment Report of BlueScope Steel (csereport.bluescopesteel.com).

In each case, the reported emissions intensity figures, which include direct emissions from all fuels consumed plus indirect emissions from purchased electricity, were increased by a factor of 1.2 to allow for full fuel cycle emissions of fuels and upstream emissions associated with the production (mining and quarrying) of raw materials. Additionally, a figure of 144 kg cement per tonne of concrete was used, based on advice from Cement, Concrete and Aggregates Australia.

The respective life cycle embodied emissions calculated from these sources are:

concrete	0.128 kg CO_2-e/kg
hardwood timber	0.014 kg CO_2-e/kg
steel	2.88 kg CO_2-e/kg

These translate into the following emissions per sleeper:

concrete sleepers	57.2 kg CO_2-e
timber sleepers	34.0 kg CO_2-e

Almost all the emissions associated with the production of timber sleepers, and a significant proportion of the emissions associated with the production of concrete sleepers, relate to the associated steel because steel is an extremely emissions intensive material.

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[3] AGO Factors and Methods Workbook - For use in Australian greenhouse emissions reporting Australian Greenhouse Office, Department of the Environment and Heritage, December 2006 www.greenhouse.gov.au/workbook

With regard to timber sleepers, two post installation situations need to be taken into account. The first is the case where most of the steel fittings are re-used. Secondly, estimations must also be made of the emissions associated with eventual timber decay[4].

Accordingly, three timber sleeper scenarios were modelled for comparison to concrete sleepers:

- The first scenario assumes all virgin steel and no emissions from eventual timber decay.

- The second scenario is based on re-used fittings but no emissions from eventual timber decay. A significant proportion of the timber sleepers' steel fastenings may be re-used when wooden sleepers are replaced. Full re-use would eliminate emissions associated with the use of steel. .

- The third scenario includes estimates of the emissions that will eventually result from the decay of timber sleepers after they have been replaced. Assuming the carbon mass content of 50% in hardwood timber[5], decay emissions per sleeper would be approximately 106 kg CO_2 per sleeper. Of course some replaced timbers will be recycled for landscaping and other uses, but it is probable that some will be burnt or otherwise be left to rot. Complete exclusion of this source of emissions would under-estimate emissions associated with use of timber sleepers.

From the above assumptions and analysis, total emissions over 60 years for the two sleeper options are estimated to be:

	Sleeper scenario	**Emission Totals**
C1	Concrete	93 kt CO_2-e
T1	Timber – all virgin steel, not including decay emissions	152 kt CO_2-e
T2	Timber – re-used fittings, not including decay emissions	72 kt CO_2-e
T3	Timber – re-used fittings plus emissions from decay	540 kt CO_2-e

Comparing C1 with T1, the main reason for the higher emissions from timber sleepers is that, over the 60 years, approximately three times as much steel is used as with concrete sleepers. Note that in the concrete sleeper scenario, all emissions occur in the first three years, whereas emissions from timber sleepers are spread over the whole 60-year period.

In scenario T2 (Timber – re-used fittings and no decay), the re-use of steel fittings reduces the projected emissions associated with this higher steel consumption.

[4] Methodology for the Estimation of Greenhouse Gas Emissions and Sinks 2005, **Land Use, Land Use Change and Forestry**, Australian Greenhouse Office Department of the Environment and Heritage 2005, www.greenhouse.gov.au/inventory/methodology (accessed Jan 2007)
[5] Methodology for the Estimation of Greenhouse Gas Emissions and Sinks 2005, **Land Use, Land Use Change and Forestry**, (cited above), carbon content is set to 50% of the basic density where air dry density has 12% moisture content.

The calculations for this scenario assume replacement of all fittings during the first 20-year period but with an effective 97% of steel components re-used per year for the next two 20-year periods. The fittings reused for entire 60 years include the clip in shoulders, clips and base plates. The lock-in spikes would be replaced with wooden sleeper replacement.

This leads to a more than 50% reduction in emissions compared to the T1 - all virgin steel scenario.

In scenario T3 (Timber – re-used fittings and emissions from decay), emissions from timber are still higher, a reflection of the substantial emissions from decaying timber.

The comparisons above are based on the total estimated emissions at the end of the sixty-year period. The emissions profiles in the following graphs depict the estimated emissions over time. The anomaly here is that emissions from timber are shown as the cumulative emissions from decay - as if the decay were instantaneous. This will be the case if the timber were burnt, however, emissions from non-combustion decay could extend over decades. The Methodology for the Estimation of Greenhouse Gas Emissions and Sinks 2005, Land Use, Land Use Change and Forestry assigns sleepers to a product lifespan pool with decay period of 10 to 30 years.

Graphs

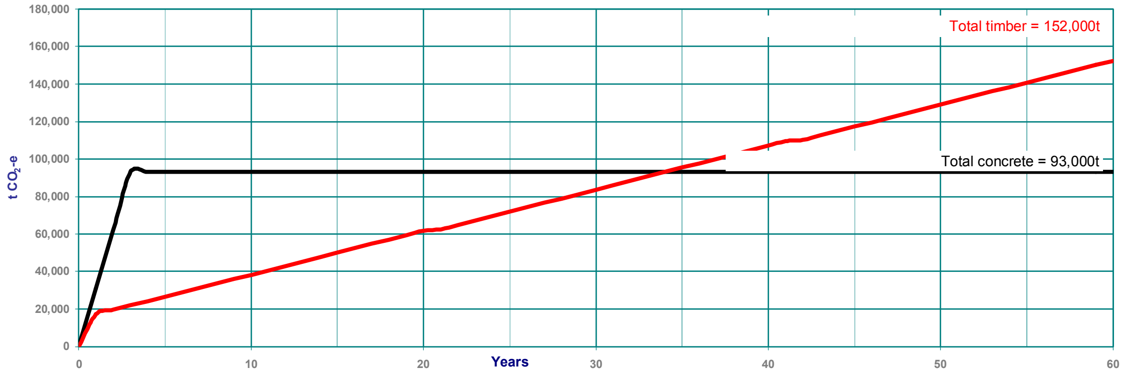

Figure 1. Concrete versus Timber with all virgin steel fittings, not including emissions from timber decay

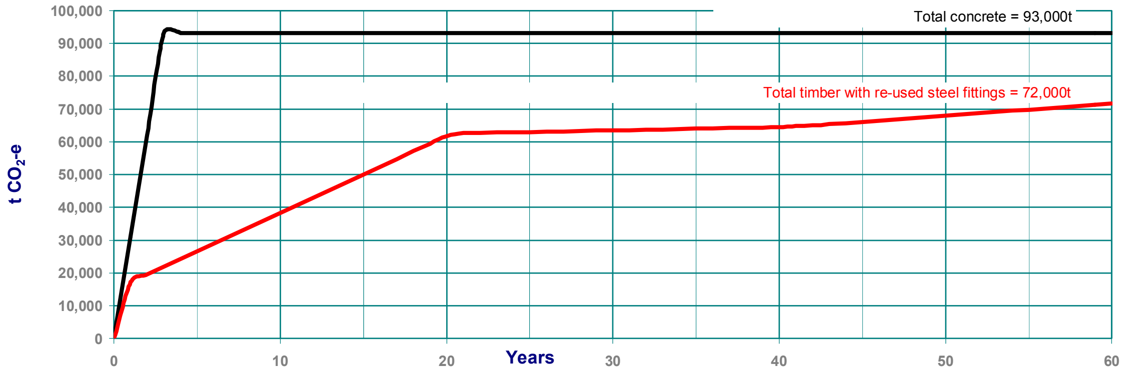

Figure 2. Concrete versus Timber with re-used fittings, not including emissions from timber decay

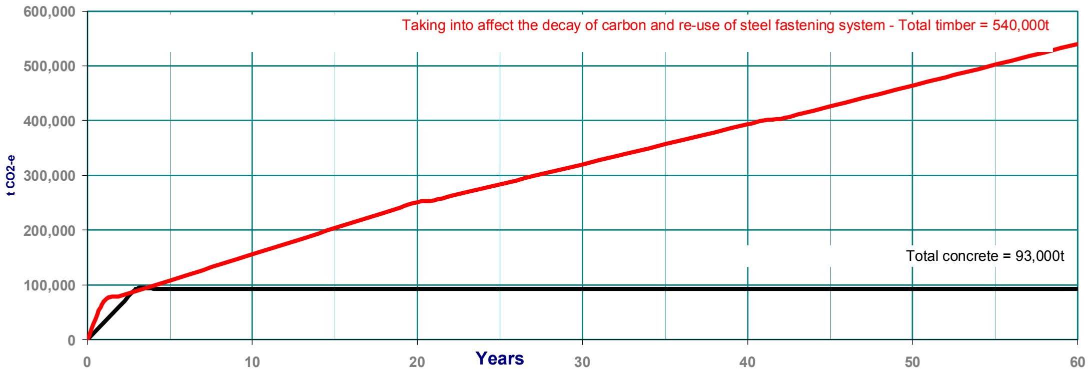

Figure 3. Concrete versus Timber with re-used fittings plus emissions from timber decay