CARBON MASS BALANCE RELATED TO ARCHITECTURAL WOOD BASED ON MATERIAL FLOW ANALYSIS

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Summary

Focusing on reducing greenhouse gas (GHG) emissions, this study analyzed the carbon mass balance related to architectural wood based on material flow analysis. We present the evaluation involves not only the carbon mass balance of wood, but also the carbon emissions from the fossil fuel consumption during the production and transport of architectural wood. Furthermore, attention is also focused on the regeneration of wood and an overall evaluation of the carbon mass balance is considered, including new carbon assimilation following reforestation after harvesting. We estimated that the total carbon stock increment in Japanese architectural wood in the year 2000 was nearly 3.79 Mton-C (Carbon mass) and carbon emissions from the incineration or decomposition of unutilized and waste wood were nearly 4.29 Mton-C. In addition, the estimated carbon emissions via fossil fuel consumption during the production and transport of architectural wood were nearly 2.97 Mton-C. Assuming 30 years as the average service life of buildings, the carbon assimilation in 30 years following reforestation after harvesting is nearly 4.47 Mton-C, which exceeds the carbon emissions from architectural wood after the demolition of these buildings.

## 1.	Introduction

In the Conference of Parties to the United Nations Framework Convention on Climate Change (COP) which addresses the global warming issue, the evaluation of forest carbon assimilation was determined in order to achieve the goal of reducing greenhouse gases. In the first commitment period of the Kyoto Protocol (2008-2012), wood harvesting is considered as a carbon emission. Wood, however, is a carbon pool when it is used for buildings and furniture, which has led to ongoing examination of the carbon mass balance related to wood by the COP.

Several studies (Hashimoto and Moriguchi, 2004, Hashimoto, et al, 2003, Soma and Arima, 2004) on the carbon mass balance of harvested wood and the methods for its estimation are now underway in response to this. The environmental advantages of wood are highly valued, such that it is renewable and can be reproduced through the appropriate management of forests, as well as its effect of stocking carbon in long-term use.

In this paper, the carbon mass balance related to architectural wood is evaluated, and is aimed at the field of architecture through which wood resources are stocked for the longest period of time, based on an understanding of wood materials flow. Recently, studies (Miura, 2003, Soma and Arima, 2003, Tonosaki and Tsunetsugu, 2001) have been conducted regarding the evaluation of carbon stock in architectural wood and estimations of carbon flows. We present the evaluation involves not only the carbon mass balance of wood, but also the carbon emissions from the fossil fuel consumption during the use of wood. Furthermore, attention is also focused on the regeneration of wood and an overall evaluation of the carbon mass balance is considered, including new carbon assimilation following reforestation after harvesting.

2. Overview of the wood flow and the method of estimation

The flow of architectural wood in Japan and the flow of waste wood related to it are shown in Figure 1. The input of architectural wood (with the estimation based on roundwood for the production of sawnwood and plywood mainly in demand in the field of architecture) and the volume of waste wood that is generated are estimated based on this flow diagram. The method of estimating the input of wood and the volume of wood discarded in relation to imported wood is basically the same as for domestic wood. The estimation has been made for the year 2000.
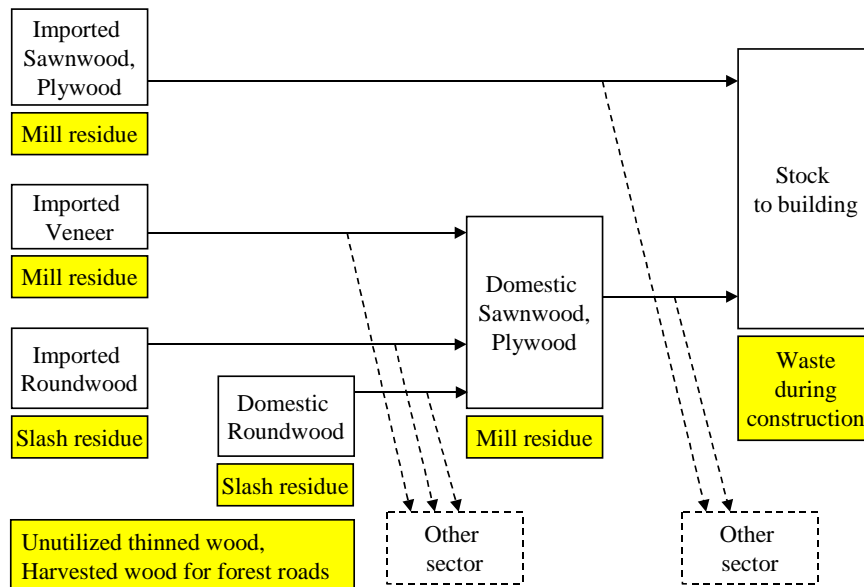
Imported Sawnwood, Plywood

Mill residue

Imported Veneer

Mill residue

Imported Roundwood

Slash residue

Domestic Roundwood

Slash residue

Unutilized thinned wood, Harvested wood for forest roads

Other sector

Domestic Sawnwood, Plywood

Mill residue

Stock to building

Waste during construction

Other sector

Figure 1   Flow of architectural wood in Japan and the flow of waste wood

2.1 Flow of architectural wood

2.1.1 Domestic production and the volume of roundwood imports. (Forestry Agency of Japan, 2002a)

2.1.2 Domestic production of sawnwood and plywood, and the volume of sawnwood, plywood and veneer imports. (Forestry Agency of Japan, 2002a)

2.1.3 Wood input in buildings.

The input of wood in construction sites is calculated by multiplying the embodied sawnwood and plywood intensity according to type of structure (m^3/m^2) (Ministry of Land, Infrastructure and Transport of Japan, 2002a) by the floor area of construction starts (Ministry of Land, Infrastructure and Transport of Japan, 2002b). This is on the assumption that 10% (Akiyama, 1998) of the input of wood comprises the generation of wood residues associated with construction. The actual input of architectural wood is estimated by subtracting the generation of wood residues from the input of wood.

2.2 Flow of waste wood

2.2.1 Volume of slash residues generated

The volume of roundwood is divided by a conversion factor for standing trees of 0.8 (Forestry Agency of Japan, 2001) and converted into the standing tree volume of roundwood. The volume of slash residues is estimated by multiplying the standing tree volume by a rate of generation of residues of 15% (Forestry Agency of Japan, 2001).

2.2.2 Volume of slash residues associated with thinning and unutilized thinned wood generated

The volume of slash residues associated with thinning is estimated using a conversion factor for the standing trees and the rate of residue generation in the same way. Since 60% (Forestry Agency of Japan, 2001) of the thinned wood are left unutilized in the forests, they are included in volume of waste wood.

2.2.3 Volume of harvested wood at the time of the construction of forest roads

The area of forest roads is calculated by multiplying the length of new forest roads (Forestry Agency of Japan, 2002b) by an average width of 5 m. The volume of harvested wood generated during the construction of forest roads is estimated by multiplying the area of forest roads by the standing tree volume of forest per unit area. The standing tree volume of forest per unit area is calculated from the figure for private forests in Japan (Forestry Agency of Japan, 1995).

2.2.4 Volume of mill residues generated

The mill residues, such as wood residues generated in the production of sawnwood and plywood, are calculated by subtracting the production of sawnwood and plywood from the shipment volume of roundwood to the factories. Since 93% of the mill residues are recycled and 7% are incinerated (Japan Wood-Products Information and Research Center, 2000), respectively, the volume of incinerated residues (7%) is estimated as the final waste wood.

2.2.5 Volume of construction waste wood generated

Assume that 10% of the input of wood in construction sites represents the volume of wood residues generated during construction as described in 2.1.3. The volume of wood used during construction (Ministry of Land, Infrastructure and Transport of Japan, 2002a), including the plywood for concrete forms used in building the foundations, is estimated as the waste wood generated as a result of the construction.

3.   Method of estimating the carbon mass balance based on the wood flow

3.1   Conversion from wood flow to carbon mass balance

The carbon mass balance related to architectural wood is evaluated based on the wood flow in the field of architecture as estimated above. Architectural wood that is integrated into buildings is treated as a "carbon stock." Waste wood is treated as a "carbon emission" since it ends up being incinerated or decomposed. When converting the volume of wood to the amount of carbon, use the weight converted into carbon weight at 50% (Forestry and Forest products Research Institute of Japan, 2004) and a wood density of 0.5 (Forestry and Forest products Research Institute of Japan, 2004).

3.2   Carbon emissions via fossil fuel consumption during wood production and transport

When conducting an overall evaluation of architectural wood from the perspective of the carbon mass balance, it is necessary to also consider carbon emissions via fossil fuel consumption during the production and transport of architectural wood. Thus the carbon emissions via fossil fuel consumption during wood production and transport are included in the carbon mass balance. The carbon emissions originating from fossil fuel consumption during the production and transport of wood are estimated by multiplying the embodied CO_2 intensity per consumer price according to the Japanese Input-Output tables for 1995 (Architectural Institute of Japan, 2003) by the volume of wood. Assuming that the production process for imported wood is the same as that for domestic wood, the same embodied CO_2 intensity is used. As for the carbon emissions via fossil fuel consumption during the international ocean transport of imported wood, it is assumed that the arrival point in Japan is Tokyo and it is estimated by multiplying the transport distance (Fujiwara, 2000) from each source to Tokyo by the embodied energy intensity (The Energy Date and Modeling Center, 2000) of each means of transport.

4.   Evaluation of the carbon mass balance concerning the flow of architectural wood

The results for the estimated carbon flow related to architectural wood in Japan in 2000 are shown in Figure 2. The estimated carbon stock of the wood used in buildings was 3.79 Mton-C (Carbon mass). The estimated results for the carbon emissions from wood residues generated construction activities, mill operations and waste wood such as slash residues left in the forests when they are incinerated or decomposed were 4.29 Mton-C. The estimated results for carbon emissions via fossil fuel consumption during wood production and transport was 2.97 Mton-C (CO_2 is converted to carbon mass). Total carbon emissions, which are the sum of these, came to 7.26 Mton-C.

The evaluation of the carbon stock of 3.79 Mton-C in the buildings, by type of structure, revealed that 83% of it was stocked in houses with wooden frames and 17% in houses with non-wooden frames. When focusing on the carbon emissions resulting from waste wood, slash residues and unutilized forest thinned wood made up a large proportion of these, and such emissions resulting from wood discarded in the forest accounted for 76% of the total carbon emissions from waste wood. In contrast, the final amount of residues disposed of in the wood mills was found to be less than this. The possible reason for this is that 93% of the mill residues

are recycled for use in wood-based panels, woodchips for paper production, woodfuel and so on (Figure 3). In addition, the estimated results for the carbon emissions derived from fossil fuel consumption during international ocean transport of the imported wood was 1.21 Mton-C, which was shown to be equivalent to 41% of the total carbon emissions via fossil fuel consumption during wood production and transport. Carbon emissions close to this figure of 1.21 Mton-C could possibly be reduced if domestically produced wood substitutes for all the imported wood (Figure 4).
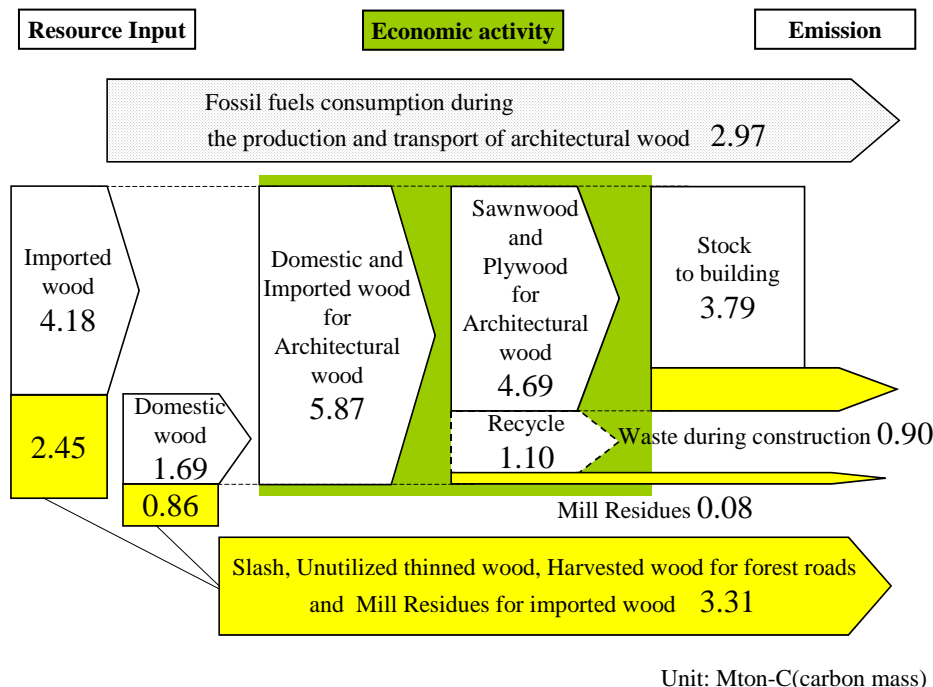

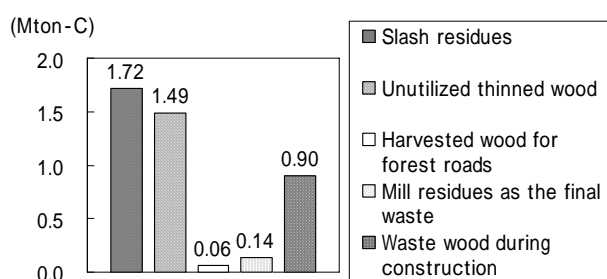*Figure 2   Carbon flow related to architectural wood in Japan in 2000*

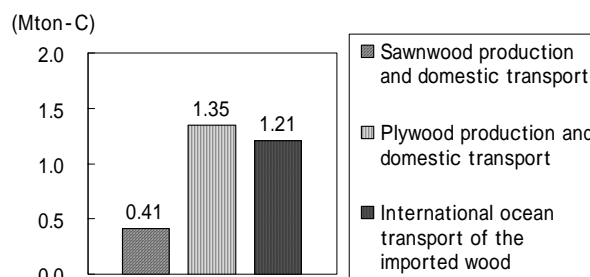*Figure 3   Carbon emissions from waste wood*

Figure 4   Carbon emissions from fossil fuel consumption during wood production and transport

5.   Evaluation of the carbon mass balance including carbon assimilation following reforestation

Carbon assimilation following reforestation in cut-over areas was tentatively estimated, including its carbon assimilation capacity as renewables as well as its benefit as a long-term carbon stock, from the viewpoint of evaluating the carbon mass balance of architectural wood. We attempted to comprehensively evaluate the carbon mass balance in the architecture field while relating the silviculture period following reforestation to the carbon stock period of the wood (equivalent to the service life of the buildings).

The area available for reforestation after wood-harvesting was estimated by dividing the total supplies of wood (architectural wood and waste wood) in the architecture field in Japan in 2000 by the average biomass accumulation (Otani, 2001) in each terrestrial ecosystem where wood-harvesting takes place. The estimated result of 0.105 million ha was assumed to be the maximum area available for reforestation after harvesting. This value represents a basic area in order to evaluate new carbon assimilation following the input of wood resources into the architecture field. The value of 1.42ton-C/ha/year (Intergovernmental Panel on Climate

Change, 1997a, 1997b, Wackernagel, 1998), commonly used to calculate the ecological footprint indicator (Wada, 2001), was used for the carbon assimilation rate of the forests during the silviculture period.

The estimate under these conditions showed that reforestation after harvesting could absorb 3.73 Mton-C, which is approximately equivalent to the carbon accumulation of buildings if the silviculture period is 25 years (Figure 5). The current average service life of buildings in Japan is reported to be 37 years for houses with wooden frames, and 21 years for houses with non-wooden frames (Housing financial corporation, 1987). Forest carbon assimilation until the demolition of the buildings (silviculture period is 30 years) can be estimated to be 4.47 Mton-C using the above method of estimation on the assumption that the average service life of such buildings is 30 years. In other words, carbon emissions due to waste wood associated with future demolition and disposal of the buildings can be expected to be compensated for by the potential carbon assimilation of the forests following reforestation after harvesting at the time of construction as long as the current average service life is maintained.

The potential carbon assimilation capacity of the forests with future reforestation after harvesting is estimated to be 8.05 Mton-C if the silviculture period (equivalent to the service life of buildings) is extended to 54 years. This figure for forest carbon assimilation exceeds the carbon emissions related to architectural wood even though carbon emissions are added due to the waste wood generated at the time of construction together with that due to waste wood associated with the demolition and disposal of buildings. Moreover, carbon assimilation of the forests where reforestation after harvesting is estimated to be 11.03 Mton-C if the silviculture period (equivalent to the service life of the buildings) is extended to 74 years. This value is approximately equivalent to the total carbon emissions, including carbon emissions from fossil fuel consumption during the production and transport of architectural wood, as well as the emissions due to the waste wood associated with the demolition and disposal of buildings and those from waste wood at the time of construction. It is necessary, however, not only to extend the silviculture period (service life of the buildings), but also to prepare for the possible expanded demand for new wood to maintain an appropriate harvest cycle in forest management since carbon absorption in an over-matured forest declines due to limitations on its carbon assimilation capacity.
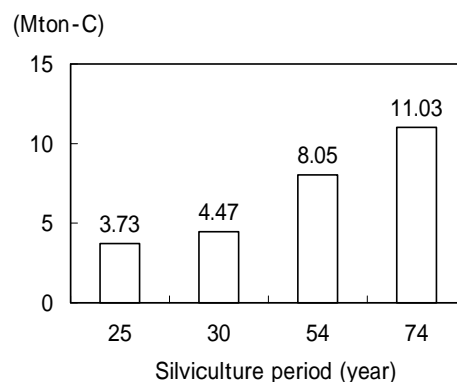

Figure 5   Carbon assimilation following reforestation in cut-over areas

6.   Conclusion

In this paper, an overall evaluation of carbon mass balance related to architectural wood was attempted based on wood flow analysis in the field of architecture in 2000. The main results are as follows.

The carbon stock of the architectural wood used in buildings in 2000 was estimated to be 3.79 Mton-C, of which 83% was stored in houses with wooden frames.

The carbon emissions from waste wood related to architectural wood were estimated to be 4.29 Mton-C, of which 76% was derived from wood left unutilized in the forests.

The carbon emissions via fossil fuel consumption during the production and transport of architectural wood were estimated to be 2.97 Mton-C, of which 41% was due to emissions generated during the international ocean transport of imported wood.

The forest carbon assimilation following reforestation after harvesting for architectural wood was found to be equivalent to the carbon stock of buildings when the silviculture period, namely, the service life of buildings, was 25 years.

The forest carbon assimilation following reforestation after harvesting for architectural wood was found to be equivalent to the sum of the carbon stock of buildings and the carbon emissions of waste wood related to architectural wood when the silviculture period is 54 years.

The forest carbon assimilation following reforestation after harvesting for architectural wood was found to be equivalent to the overall carbon emissions related to the flow of architectural wood, including the emissions via fossil fuel consumption during the production and transport of architectural wood, when the silviculture period is 74 years.

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