LIFE CYCLE ASSESSMENT OF FOREST AND WOOD PRODUCTS IN AUSTRALIA*

Selwyn Tucker, Michael Syme & Greg Foliente
CSIRO Sustainable Ecosystems, Melbourne, Australia
Email: Mike.Syme@csiro.au

ABSTRACT

The first national rigorous Life Cycle Inventory (LCI) of representative Australian forest and wood products and processes was developed to provide quantitative information on sustainability imperatives which are starting to drive business decisions and government policies, particularly those relating to wood products. In devising solutions, it is required to assess how much energy, water or chemical has gone into manufacturing a product, and what greenhouse gas emissions or other emissions to the environment have been released in the process. The Life Cycle Inventory was created to allow the environmental impacts of the production of common engineered timber products and systems to be quantified and evaluated from cradle-to-gate. The Life Cycle Inventory database covers five categories: softwood plantation and hardwood native forests; softwood framing and hardwood timbers; veneer, plywood and LVL; particleboard and MDF; and glulam and engineered I-beams.

1. INTRODUCTION

Over the past decades there has been a growing recognition that consumption of manufactured products affects both resources and the environment [1]. The production of a product impacts the environment, beginning with the extraction of raw materials, through processing, subsequent manufacturing, use and disposal, as well as all necessary transportation. Concerns today are worldwide and include just about every production sequence.

Such sustainability imperatives are starting to drive business decisions and government policies [2]. As solutions are sought to growing environmental assessments, it is important to know how much energy, water or chemical has gone into manufacturing a product, and what greenhouse gas emissions or other emissions to the environment have been released in the process. The most obvious impacts include the effects of forest harvesting, the effects of increases in atmospheric carbon dioxide (CO_2), declining water quality, and waste disposal (landfill or recycle). Governments are increasingly incorporating consideration of environmental impacts and sustainable development in policy decisions and are also increasingly holding product manufacturers accountable for their actions.

2. LIFE CYCLE ASSESSMENT

Life Cycle Assessment (LCA) is described as an objective process to evaluate the environmental burdens associated with a product or process over its life cycle by identifying and quantifying energy and materials used and wastes released to the environment, to assess the impact of those energy and materials uses and releases on the environment, and to evaluate and implement opportunities to effect environmental improvements [3]. "Life cycle" refers to all activities from acquisition of raw materials through to product manufacturing, and to the end use of these products and their eventual disposal or recycle, i.e. from "cradle-to-grave". Thus, Life Cycle Assessment quantifies the flow of materials and energy into and out of a system, as shown in Figure 1.

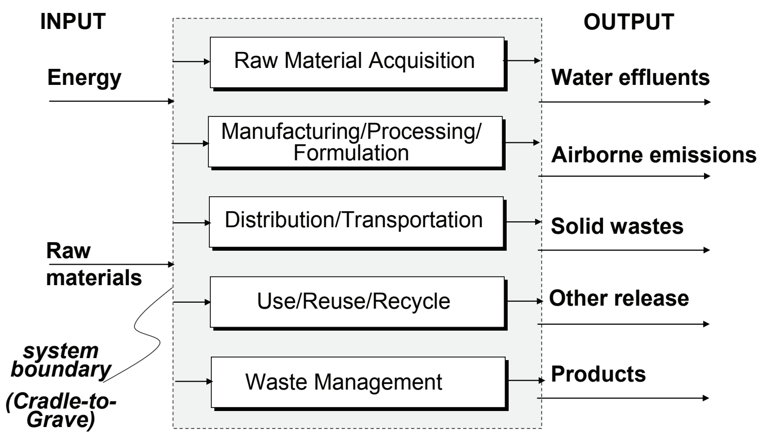

Figure 1. Life cycle assessment flow diagram showing indicative inputs and outputs.

* *Presented at World Conference on Timber Engineering (WCTE) 2008, Japan.*

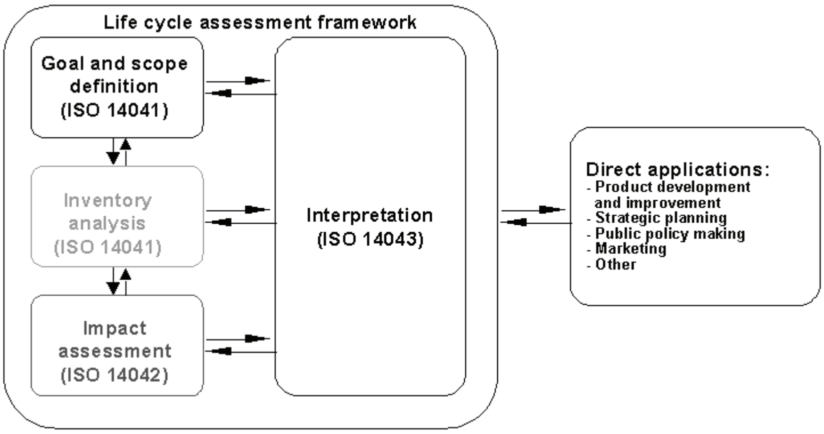

Figure 2. Life cycle assessment framework according to ISO 14040.

The measures of environmental impact of the materials investigated are based on the outputs from the processes defined within the system.

2.1 LIFE CYCLE ASSESSMENT FRAMEWORK

According to the ISO 14040 guidelines [4] to the Life Cycle Assessment methodological framework, a Life Cycle Assessment shall include four elements: goal and scope definition, inventory analysis, impact assessment, and interpretation of results as shown in Figure 2.

The key component is the inventory (known as a Life Cycle Inventory) which contains the values of all the inputs and outputs for relevant activities undertaken to produce a product. It is this information which provides a quantitative basis for comparing wood products, their manufacturing processes and, most importantly from the forest industry point of view, wood products performance against competitors who use other resources to create alternative products.

The scope of a typical Life Cycle Inventory only includes the inputs and outputs up to the factory gate, i.e. up to when a product is produced for a market as the consequent inputs and outputs depend on the application of that product. In addition, the development of a thorough inventory results in the forest and wood products industry benefiting through a more advanced understanding of the life cycle of its products and processes.

There has been little verified life cycle information available on forestry and wood products in Australia; and the Life Cycle Inventory (LCI) information for forestry and wood products is the least well defined of any building material in any current Australian Life Cycle Inventory database.

Thus, wood products were at a distinct disadvantage compared to other products, such as steel and concrete, with little data to provide strategic insight for use in proactive environmental marketing, process improvement, comparison for product substitution, and, importantly, supply of information for building evaluation tools. Building designers and material specifiers currently did not have quality information based on scientific methods to determine when wood is a superior or competitive choice.

2.2 LIFE CYCLE INVENTORIES

Over the past decade there has been an increasing application of Life Cycle Assessment to forestry and wood products. Countries in Europe and North America have completed detailed analysis of forestry and wood products in close collaboration with industry and timber research organizations [5], as have Asian countries such as Japan [6]. Organisations such as CORRIM in North America have worked extensively with a variety of stakeholders including the American Forestry and Pulp and Paper Association and the Engineered Wood Association to produce a sophisticated Life Cycle Inventory of forestry and wood products in the United States.

Major international research studies conducted on the forest resource (*i.e.* production of logs) and major wood products relate principally to the timber framing of houses and wood building construction [7, 8]. Many other counties have adopted their own national standards, as well as developing guidelines for specific industries, an example of which is the American Forest and Paper Association user's guide for the US forest industry [9].

There are several national LCI database in the Asian region such as those of JEMAI (Japan Environmental Management Association for Industry), Japan; MoCIE (Ministry of Commerce, Industry and Energy) and MoE (Ministry of Environment), Korea; SIRIM, Malaysia and MTEC and MOI, Thailand.

One of the key distinctions between Australian and international Life Cycle Inventory efforts has been the lack of coordination, the minimal representation of industry and the insubstantial detail of the final output in

Australian databases, almost all of which are held in-house and not made public so that the data collection processes lack coordination and documentation is variable. In other countries, the process of effectively engaging industry has not only led to a comprehensive Life Cycle Inventory database, the process of data collection has also informed industry of the value and use of a Life Cycle Inventory database. As a result the Life Cycle Inventory database becomes a useable resource for industry.

The international experiences in developing Life Cycle Inventory databases for a range of products show that it is a time consuming activity, particularly in obtaining adequate and consistent data. Many of the projects have taken years with consequent high costs of collection. The wood products industry in Australia was able to build on the international experiences in both determining protocols for data collection and Life Cycle Inventory process modelling.

In Australia, there have been a few Life Cycle Assessment studies undertaken for construction and packaging materials. Moreover, these studies did not so much include a full Life Cycle Assessment of wood or timber products but focused on embodied energy for timber products [10]. Todd and Higham [11] reviewed Life Cycle Assessments of forestry and wood products. Some researchers have tried to compare environmental impacts of wood products with other alternatives using a Life Cycle Assessment method [12]. However, these Life Cycle Assessment and Life Cycle Inventories have had very limited work on the detail of forestry and wood products. The Cooperative Research Centre for Construction Innovation [13] has developed a building product Life Cycle Inventory database for use with LCADesign, a software tool for eco-assessment of buildings direct from a 3D CAD model.

3. AUSTRALIAN LIFE CYCLE INVENTORY OF FOREST AND WOOD PRODUCTS

The Australian Life Cycle Inventory database covers the following categories of forest and wood products: softwood plantation and hardwood native forests; softwood framing and hardwood timbers; veneer, plywood and LVL; particleboard and MDF; and glulam and engineered I-beams. The components were pursued in parallel.

A Life Cycle Inventory database for forestry and wood products aimed to be of high quality, contain a range of representative products, and be consistent, credible, and demonstrably independent. Practicalities such as focusing on a limited but representative range of wood products, availability of resources, and availability of data meant that many decisions were made on what would constitute a satisfactory Life Cycle Inventory database. The content was compatible with international standards and with an Australian National Life Cycle Inventory Database (AusLCI) whose specifications were being determined concurrently [14].

The underpinning principle was to obtain substantial industry input into a forestry and wood products life cycle inventory (LCI) database to confirm the processes and values used in creating a LCI database of timber products. The target was to obtain data from those producing between them at least 50% of Australian production in the defined categories. Industry generally was very cooperative but data collection was slower than anticipated in most areas.

3.1 KEY OBJECTIVE

The overall objective was to create the first national rigorous Life Cycle Inventory (LCI) of representative Australian forestry and wood products to enable evaluation and benchmarking of the environmental impacts of wood products for comparison with selected competing products.

3.2 SCOPE

The data collection was up to the consumption phase for the wood products when sold to a consumer (known as a cradle-to-factory-gate study) as shown in the dashed box under "Manufacturing" in Figure 3. This provides an accurate database of Australian wood products for various users to examine a wood product and consider

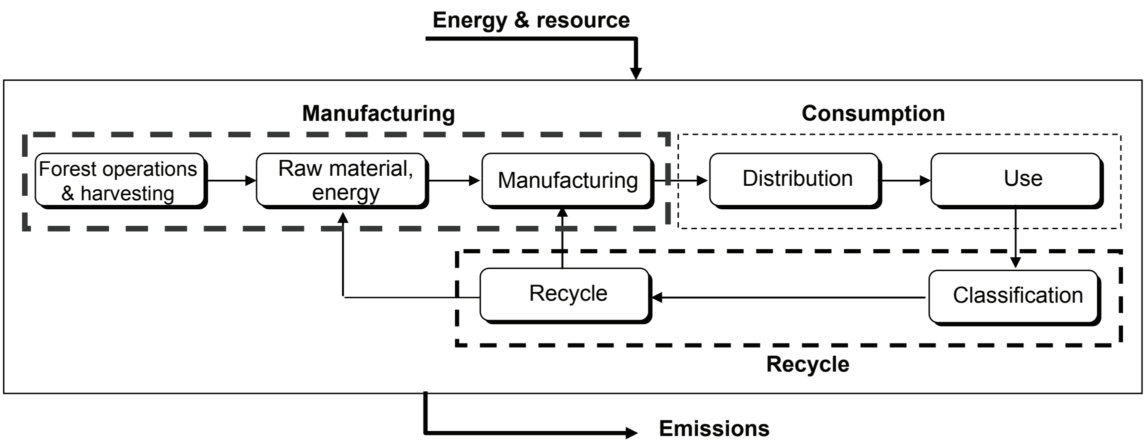

Figure 3. Process chain for life cycle analysis

Table 1. Products in the Life Cycle Inventory database.

Category	Products
Logs - Softwood	Peeler log, High quality saw log, Low quality saw log, Pulp log, Chips
Logs - Hardwood	Peeler log, Saw log, Pulp log
Sawn timber – Softwood and Hardwood	Rough sawn green timber, Rough sawn kiln dried timber, Planed kiln dried timber, Bark, Chips (as sawmill co product)
Veneer	Veneer, Interior Plywood, Exterior Plywood, Formply, T&G Flooring, Structural Plywood (each 3 thicknesses)
LVL	LVL (3 thicknesses)
Particleboard	Raw and Decorated (each 3 thicknesses)
MDF	Raw and Decorated (each 3 thicknesses)
Glulam	Pine, Hardwood
I-beams	OSB web and pine flanges, Plywood web and LVL flanges

various users to examine a wood product and consider its production history. Most importantly, it provides industry with a reference of production practices and the ability to benchmark and monitor performance over time.

A cradle-to-gate study is a practical point to collect data for a Life Cycle Inventory database. For example, beyond this point, the useful life and maintenance requirements of wood products used in a building will depend upon a number of factors, including the exposure to various elements and the use and type of preservatives and paints, all highly variable and not within the responsibilities of producers and manufacturing plants.

The range of data collected was, of necessity and lack of unlimited resources for its collection, restricted by what data industry had available or was willing to provide or what could be obtained from existing sources. The cooperation of the industry was excellent and resulted in good quality data and desired industry coverage.

3.3 RANGE OF FORESTRY AND WOOD PRODUCTS

While the original aim was to develop Life Cycle Inventories for generic wood products, the detailed data was sufficient to provide information on common categories of the generic products. Table 1 shows the original categories of products and the expanded (more specific) range of products actually developed for the Australian timber products Life Cycle Inventory database. Each is essentially a variation on the generic processes.

3.4 GUIDELINES, DOCUMENTATION AND QUALITY ASSURANCE

It is most important to create a Life Cycle Inventory for wood products thoroughly for each type of product to ensure a quality database both for the forestry and wood products industry and for the industries who produce products which compete with wood products. There are established guidelines for creating a Life Cycle Inventory database in the form of the ISO 14040 series of standards [4], including ISO 14044 Life cycle assessment — Requirements and guidelines [15] and ISO/TS14048 Life cycle assessment — Data documentation format [16].

CORRIM generally followed these guidelines in developing a Life Cycle Assessment methodological framework for their studies, but found it is essential to provide very detailed information on every aspect of data collection and process modelling to ensure consistency, compatibility and credibility in meeting the objectives of a Life Cycle Inventory database. Thus, the plan for developing a Life Cycle Inventory database included a preliminary step where standards are set and strict guidelines developed. The development of the Australian Life Cycle Inventory for forestry and wood products was no different.

ISO 14044:4.2.3.1 clearly states that the scope of a Life Cycle Inventory study shall specify the following items: product system to be studied; functions of the product system; functional unit; system boundary; allocation procedures; data requirements; assumptions; limitations; data quality requirements; type of critical review, if any; and type and format of the report required for the study. Documents setting out the specific guidelines, quality assurance and documentation procedures and the Life Cycle Inventory database relating to the development of the Australian Life Cycle Inventory were prepared. An example of the detailed specifications is the system boundaries as shown in Figure 4. A quality assurance plan was put in place and data documentation spreadsheets developed in spreadsheet form with accompanying checklists to ensure documentation met ISO standards.

The raw materials are the materials obtained directly from the environment. The inputs between the Life

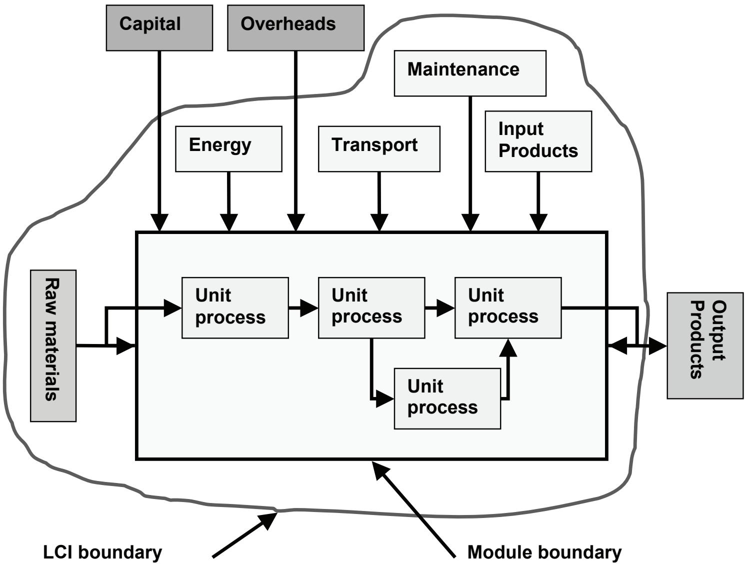

Figure 4. System boundaries for the LCI Timber project.

Cycle Inventory boundary and the module boundary are common or pre-defined processes which can be called upon by any of the inventory product models. The common processes include logs from forests, glues, imported products and materials (glues and timber products such as oriented strand board), energy supplies (electricity, gas, etc), transport modes (ships, aeroplanes, rail, trucks, cars etc) and equipment. The output products include the main product, by-products and wastes.

3.5 DATA COLLECTION

Survey forms identifying all required data were developed in collaboration with relevant industry input from each of the five areas: forests, sawmills, veneers and plywood, particleboard and MDF, glulam and engineered I-beams. From a comprehensive list of Australian forests, sawmills and wood product manufacturing plants, a list of the industry providers of forest and wood products who would be sufficient to achieve a target of 50% of Australian production was drawn up and approached for participation in the surveys. Typical forests, mills and plants were visited for visual inspection, initial data collection and identification and understanding of processes.

Six case study regions – softwood plantations in the three States of Australia; and hardwood native regrowth forests also in three States of Australia became the representative sources of forest data. A seventh softwood plantation area was added later in a different State of Australia.

Because of the large number and hugely varying scale of sawmill operations, a sampling procedure was set up to capture data from as many as possible of the large sawmills (approximately 22 softwood mills and 66 hardwood mills) using detailed data surveys. A simplified data form was sent randomly to a large number of the small sawmills to ensure that data from a full cross section of sawmills were included.

For the remaining plants manufacturing wood products in Australia, in any one category, there are less than ten producing almost all of the production in Australia so plants producing approximately 80% of Australian production were approached. Where clear differences in processes among the competing plants could be identified, effort was made to include representatives of each identified type. The resulting coverage is shown in Table 2 for each category of forestry and wood product.

Table 2. Coverage of Australian Production

Category	Proportion of Australian production (approx %)
Forests - softwood plantation areas	60
Forests - hardwood regrowth forest areas	30
Sawmills - softwood	40
Sawmills - hardwood	30
Veneer and plywood manufacturing plants	90
LVL plants	50
Particleboard manufacturing plants	60
MDF plants	80
Glulam plants	60
I-beam plants	70

Cooperation levels were generally very high and some very detailed data was made available thus ensuring a thorough understanding of the processes, their inputs and outputs and comprehensive maps of the processes.

3.6 ENVIRONMENTAL IMPACT MODELLING

The data inputs and outputs per functional unit (e.g. usually m^3 or m^2 of a standard product) were then averaged for input into models developed in the SimaPro life cycle assessment software [17] for all products except logs from forests where seven individual models were created.

From the visits to forests, mills and plants, comprehensive process maps were drawn up and then related individual processes were aggregated into a small number of processes which became the unit processes required of a life cycle inventory. The selection of unit processes was based on clearly defined steps in the process of producing the output products and influenced by the availability of data (or lack of being able to disaggregate available data).

These unit processes were modelled in an integrated Simapro model to calculate the resulting inputs and outputs per functional unit (e.g. cubic metre of log or sawn timber or square metre of a plywood or particleboard) including all raw materials from growing forests and common processes such as Australian energy sources. The result is a Life Cycle Inventory of all inputs and outputs for the products listed in Table 1.

4. BENEFITS

A major benefit of the Life Cycle Inventory of forest and wood products for the industry is to have a credible quantitative basis for comparison of competing timber products and non-timber alternatives. Collection, enhancement and verification of data provide the industry with reliable environmental impact information to improve the environmental bottom line as well as providing data for assessing choice in building products on the basis of environmental impacts.

The future potential in obtaining this information for the forestry and wood products industry means greater acceptance of wood as an environmental material choice, give wood products a greater prominence in evaluation tools, and greater understanding by the industry of future growth areas, such as recycling opportunities, service provision potential, and take back schemes, which would greatly add to the bottom-line in the future market place.

The project has produced the first national Life Cycle Inventory database on Australian forestry and wood products production with benefits including:

- The compilation of a common database for the wood industry,
- An objective and quantitative basis for comparison of competing wood products and non-wood alternatives,
- An objective and quantitative basis for comparing systems which incorporate wood products to those systems which use alternative materials, for example, complex composite products or whole houses,
- A method of comparing the environmental impacts of wood products from improved production processes,
- A database for use with Life Cycle Assessments of wood products and the buildings in which they are used,
- Provision of up-to-date credible industry based life cycle inventory information for life cycle assessment of wood products from Australian manufacturers,
- Support to manufacturer's on environmental performance and impact assessment measures so environmental improvements can be addressed,
- Facilitating communication of environmental information to customers and other stakeholders,
- Setting an industry standard for handling of environmental data, and
- Marketing material highlighting the environmental benefits of wood to encourage the purchasing of wood-based products.

5. CONCLUSIONS

The development of a Life Cycle Inventory for Australian forest and wood products is a major step forward in the provision of quality data on the environmental impacts of wood products used in building. The quality assurance procedures, in following the ISO Standards procedures and documentation, have set a high level for all following contributions to the developing Australian Life Cycle Inventory database (AusLCI). The wide forest and wood industry coverage also makes the resulting Life Cycle Inventory very representative of Australian wood products and an excellent basis for assessing the environmental impacts of any application of wood products.

6. ACKNOWLEDGEMENTS

The work reported in this paper was part of a research project conducted for, and substantially funded by, Forest and Wood Products Australia in collaboration with CSIRO, Ensis and RMIT. A wide range of forest and wood products industry participants cooperated and willingly supplied the data necessary for the development of the Australian forestry and wood products LCI database.

7. REFERENCES

[1] RMIT Centre for Design, *Introduction to EcoReDesign: Improving the environmental performance of manufactured products*, Centre for Design at RMIT, Energy Research and Development Corporation, EcoRecycle Victoria, New South Wales Environmental Protection Authority, 1997

[2] Australian Government, Business Roundtable on Sustainable Development http://www.industry.gov.au/content/itrinternet/cmscontent.cfm?objectID=36D93D3A-65BF-4956-B66BEC060380DBC3, accessed 30 January 2008.

[3] Consoli, F., et al, *Guidelines for Life-Cycle Assessment: A 'Code of Practice'*, SETAC (Society of Environmental Toxicology and Chemistry), Brussels, 1993.

[4] ISO 14040, International Standard ISO 14040: Environmental Management – Life Cycle Assessment – Principles and Framework, Geneva, Switzerland: International Organization for Standardization, 1998.

[5] Wilson, J.B., "Documenting the environmental performance of wood building materials", *Wood and Fiber Science*, Vol. 37, 2005, pp. 1-2 and all other papers in this CORRIM Special Issue.

[6] Tsuda, K., Murakami, S., Ikaga, T., Kuma, K., Hondo, H. and Narita, N. "Environmental impact assessment of local structural glued laminated timber based on field survey", *Proceedings of the 7th International Conference on EcoBalance*, Tsukuba, Japan, 14-16 November, 2006, pp. 649-652.

[7] Seppala, J., Melanen, M., Jouttijarvi, T., Kauppi, L. and Leikola, N., Forest industry and the environment: a life cycle assessment study from Finland, *Resources Conservation and Recycling*, 23, 1998, pp. 87–105.

[8] Kakita, H., Yagita, H., Narita, N., Kato, A., Kimura, M., Aoki, R. and Inaba, A., "LCI Analysis of a Detached Wooden House", *Proceedings of the 7th International Conference on EcoBalance*, Tsukuba, Japan, 14-16 November, 2006, pp. 263-264.

[9] American Forest and Paper Association, *Sustainable Forestry Principles and Implementation Guidelines*, Washington, 1996.

[10] Lawson, B., *Building Materials Energy and the Environment. Towards Ecologically Sustainable Development*, The Royal Australian Institute of Architects, 1996.

[11] Todd, J. J. and Higham, R. K., *Life-Cycle Assessment for Forestry and Wood Products Volume 1: Review and Discussion*, Forest and Wood Products Research and Development, Queensland, 1996, 115p.

[12] Taylor, J. and Van Langenberg, K., *Review of the Environmental Impact of Wood Compared with Alternative Products Used in the Production of Furniture*, Forest and Wood Products Research and Development Corporation, 2003, 16p.

[13] Tucker, S. N., Johnston, D. R., Jones, D. G., Remmers, T. R., Newton, P. W., and Paevere, P. Environmental assessment of commercial buildings during design using 3D CAD, *2005 World Sustainable Building Conference "Action for Sustainability"*, Tokyo, Japan, 27-29 September, 2005.

[14] Woodard, A. and Grant, T., *Developing the Australian Lifecycle Inventory (AusLCI)*, http://www.sustained.com.au/index.php?option=com_content&task=view&id=656&Itemid=29, accessed 30 January, 2008.

[15] ISO 14044, International Standard ISO 14044: Environmental management – Life cycle assessment – Requirements and guidelines, Geneva, Switzerland: International Organization for Standardization, 2006.

[16] ISO/TS 14048, International Standard ISO 14048 (Technical Specifications): Environmental management – Life Cycle assessment – Data documentation format, Geneva, Switzerland: International Organization for Standardization, 2002.

[17] PRé Consultants, Amersfoort, The Netherlands, http://www.pre.nl/simapro/, accessed 30 January, 2008.