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Review of the Environmental Impact of Wood Compared with Alternative Products Used in the Production of Furniture

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Review of the Environmental Impact of Wood Compared with Alternative Products Used in the Production of Furniture

Prepared for the

Forest & Wood Products Research & Development Corporation

by

J. Taylor
K. Van Langenberg

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TABLE OF CONTENTS

SUMMARY

Objective

The objective of this study was to produce a literature review on the current information available to compare the environmental impact of wood with other alternative products (such as plastics and metals) used in the production of furniture.

Key Results

The major results of the study were:

- There are no examples of studies comparing wood with other material for the production of furniture.
- There are examples that compare wood with other materials in the production of window frames, flooring material and a TV/video unit.
- There are many studies that have compared the environmental impact of wood with other materials in the building and construction industries.
- In all the examples studied, wood has been found to have the lowest environmental impact compared to other materials.
- Timber from sustainable forestry practices is a renewable resource whereas the production of plastics and metals is not.
- The incineration of timber for energy production can be regarded as CO_2 neutral.
- The use of other materials in the production of timber furniture (such as metal and plastic trimming, glues, varnishes etc) drastically increases the environmental burden of the furniture.

Application of Results

The results obtained from this literature survey form the basis of a compelling argument that the use of timber and timber products for the manufacture of furniture leaves a smaller impact on the environment than other alternative materials such as metals and plastics. This information can be used for advertising material highlighting the environmental benefits of wood to encourage the purchasing of wood-based furniture.

INTRODUCTION

Public perception has been suggested to be a key driver in determining the choice of timber versus other alternative materials when purchasing furniture. The furnishing industry currently lacks up to date information to distribute to furniture retailers, manufacturers and to consumers regarding the environmental benefits of timber furniture compared to furniture made with metal or plastic. The purpose of this review was to investigate the currently available information regarding the environmental impact of using timber for furniture production compared to alternative products made from metals and plastics.

RECOMMENDATIONS AND CONCLUSIONS

The purpose of this report was to review the current literature regarding the environmental benefits of using wood for the production of furniture compared to other materials such as metals and plastics. A number of examples are presented of studies that have looked at the environmental impacts of different materials (such as various plastics, steel, aluminium etc) that can be used for furniture. In every single case, the use of wood was found to be the most favourable in terms of minimising the impact on the environment. Wood harvested from sustainable logging practices is a renewable resource whereas other materials (such as steel, aluminium and plastic) are derived from non-renewable resources. The embodied energy of wood is very low compared to metals and plastics and is a measure of the fact that the production of metals and plastics is a high-energy intensive process. The embodied energy of wood is largely derived from the energy required to dry the timber. In many environmental impact categories (such as GWP, AP, EP, POCP), wood has been found to be superior to either metals or plastics. In many examples, timber has been considered to be CO_2 neutral when burned for energy production since the amount of CO_2 released is balanced by the uptake of CO_2 from trees.

In the production of timber furniture, it has been found that the use of even small amounts of other materials (such as metal or plastic trim, glues and varnishes) drastically increases the environmental impact of the furniture.

The use of Life Cycle Analysis (LCA) for the forest products industry is still in its infancy. As the methodology becomes more refined and more examples are studied, then it is anticipated that the benefits of wood will be further demonstrated. Future work should investigate these new results, particularly from an Australian perspective. Due to the lack of direct comparisons between furniture pieces of different materials (i.e. a steel chair versus a wooden chair), further work would help resolve the environmental impact of different building materials for furniture.

In summary, wood (especially from sustainable harvesting practices) has been shown to be the best material to use for many different applications as it has a very minimal impact on the environment compared to other materials such as metals and plastics.

RESULTS AND DISCUSSION

There is a growing appreciation of the fact that human activities are having an impact on the environment. Some human activities impact the environment on a global scale (such as the ozone hole, the enhanced greenhouse effect and acid rain) whilst other activities impact on a smaller, localized scale (such as landfill or water usage). With this increasing environmental awareness, many people are beginning to make lifestyle choices in which environmental impact is a key criterion.

Everything that we purchase, use or consume is manufactured from raw materials that have been derived from natural resources. The use of these raw materials to produce manufactured goods will have an impact on the environment. Some materials have a much larger impact than others. Many people around the world are now beginning to quantify the impact of producing manufactured goods from certain raw materials and resources.

There are a number of different tools available for measuring the impact that a product or process might have on the environment. Dr Magerholm Fet has listed the best known tools as being[1]:

- Cleaner Production (CP)
- Environmental Accounting (EAc)
- Life Cycle Analysis (LCA)
- Life Cycle Screening (LCS)
- Life Cycle Costing (LCC)
- Material, Energy and Toxic analysis (MET)
- Material Input per service Unit (MIPS)
- Design for the environment (DfE)
- Environmental Auditing (EA)
- Environmental Performance Evaluation (EPE)
- Environmental Management Systems (EMS)

These tools can be classified according to a classification relative to a macro, meso and micro levels.[1] They can also be classified according to whether they assess a process or a product.[1] A brief description of each of these tools can be found in the cited reference.

The most common method of assessing a product's impact on the environment has been the use of Life Cycle Analysis (LCA).

Life Cycle Analysis (LCA)

Life cycle analysis (or assessment) is a method of evaluating the impact the use or manufacture of a particular product or material has on the environment. It has been defined by the Society of Environmental Toxicology and Chemistry as:[2,3]

"…an objective process to evaluate the environmental burdens associated with a product, process or activity 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 affect environmental improvements. The assessment includes the entire life cycle of the product, process or activity, encompassing, extracting and processing of materials; manufacturing, transportation and distribution; use, reuse, maintenance; recycling and final disposal. LCA only addresses environmental impacts and not other consequences of human activities such as economic and social effects…"

LCA is an attempt to quantify the environmental impact that is brought about by the use of a product. LCA measures the impact at all stages of a products life; from procurement of raw materials through to manufacture, transport, use and final disposal or recycling. For this reason, LCA is commonly referred to as a "cradle-to-grave" assessment of a product. LCA considers all inputs (such as materials used and energy required for manufacture) and outputs (such as

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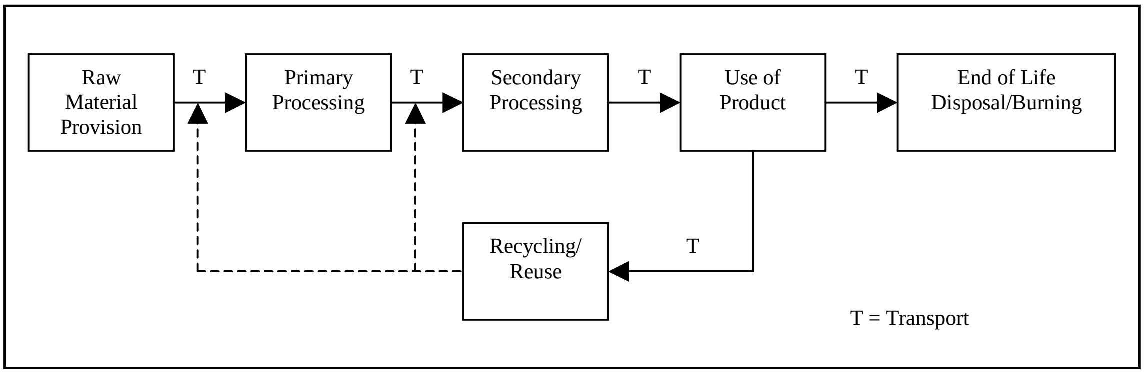
[1] Dr Annik Magerholm Fet, *"Environmental Management Tools and their Application- A Review with References to Case Studies"*, http://www.incose.org/norsec/Dokumenter_og_nedlastbare_filer/NORSEC_moter/19991019/teknisk_referat19991019_4.htm

[2] Gunilla Jönson, *"LCA- a tool for measuring environmental performance."* Pira International, 1996.

[3] Frank Consoli, *"Guidelines for Life Cycle Assessment: A Code of Practice."* Society of Environmental Toxicology and Chemistry (SETAC), Pensacola, Florida, 1993.

products, by-products and emissions to air, water and soil) in producing a product.[4] A schematic representation for a life cycle of a product is given in Figure 1 (reproduced from reference 4).

Figure 1. A schematic representation of a Life Cycle for a product. (Reproduced from reference 4).



LCA involves four generally accepted stages.[2,3]

- Goal and scope definition
- Inventory analysis
- Environmental impact assessment
- Improvement assessment.

The stages involved in a LCA are shown schematically in Figure 2 (reproduced from reference 4). During the *Goal and Scope* part of the LCA, the purpose, assumptions and boundaries of the process are defined. In the past, different boundaries have been defined by different studies and this can affect the final result. The *Inventory Analysis (LCI)* phase of a LCA quantifies the material and energy inputs and environmental releases or emissions associated with the production process. One aspect commonly used in this phase is the ***Embodied energy*** of a product. [5] Embodied energy is the energy consumed by all the processes associated with producing a product. This includes the acquisition of the natural resources to the final, finished product. Embodied energy has been used to assess the impact different building materials and designs have on the environment.[5] The *Environmental impact assessment* takes the information from the LCI and evaluates the environmental burdens attributable to the substances released during the production process. This gives rise to a measure of the total impact that this process has on the environment. Some examples of impact categories are global warming, ozone depletion, resource depletion, land use impacts, eutrophication, acidification and toxicity to humans, aquatic and land-based life. Finally, the *Improvement assessment* phase is where possible improvements in the production process are identified.[2,4]

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[4] A. Frühwald, “Life Cycle Assessment of Particleboard and Fibreboard”, a lecture held by Prof. Dr. A. Frühwald und J. Hasch, http://www.oekobilanzen-holz.org/

[5] Geoff Milne, “Embodied Energy”, http://www.greenhouse.gov.au/yourhome/technical/pdf/fs31.pdf

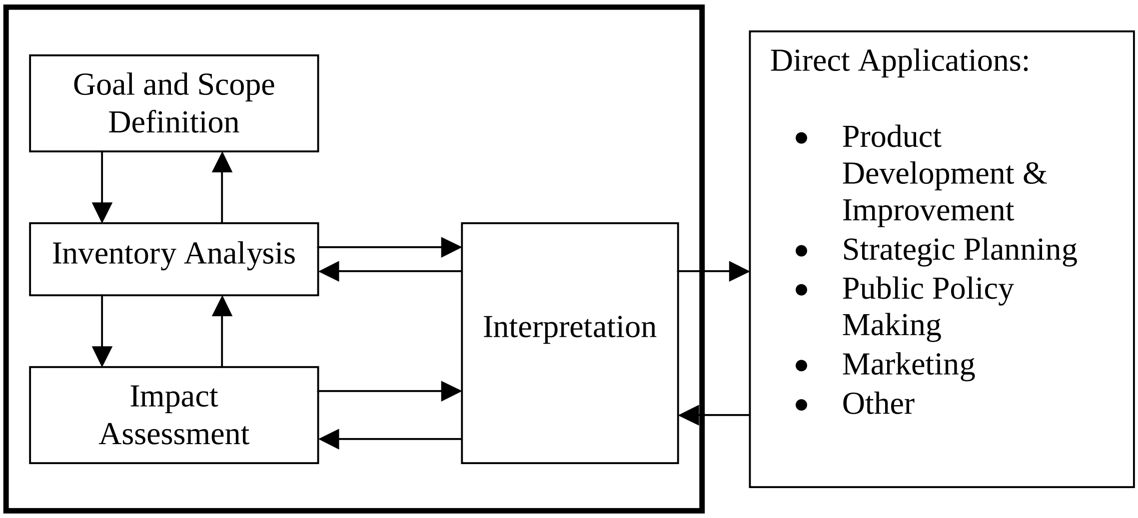

Figure 2. The stages of a LCA according to ISO 14040 (reproduced from reference 4).

Until recently, there has been no single universally accepted and recognised method of calculating a life cycle analysis. This has made comparisons between different products difficult where analyses have used different methods. The International Standardization Organization (ISO) has now developed five standards for the LCA process.[4,6] These are:

- ISO 14040:1997 Environmental management-Life Cycle Assessment-Principles and Framework
- ISO 14041:1998 Environmental management-Life Cycle Assessment-Goal and Scope Definition and Inventory analysis
- ISO 14042:2000 Environmental management-Life Cycle Assessment-Life Cycle Impact Assessment
- ISO 14043:2000 Environmental management-Life Cycle Assessment-Life Cycle Interpretation
- ISO 14048:2002 Environmental management-Life Cycle Assessment-Data Documentation Format

These standards give a detailed description on the mechanics of performing a LCA study. Unfortunately, many aspects of a LCA study are closely related to the product system being investigated and these aspects need to be determined during the course of that study.[4]

Environmental Impact of Wood and Other Materials used in the Furniture Industry.

It is very difficult to find any information on the environmental impact of different furniture materials. It has been proposed that furniture (particularly in the office environment) can be a significant factor in the overall environmental impact of a building. There have been several life cycle analyses undertaken for office and residential buildings.[7,8,9,10,11] One of the common themes in these analyses is that the structural elements of the building initially use by far the largest quantity of embedded energy. However, when the life-span of the building is taken into account, the embodied energy from the office furniture, which is replaced many times over the

[6] ISO Homepage, http://www.iso.ch/iso/en/prods-services/otherpubs/iso14000/family.pdf
[7] T. Goverse, M. Hekkert, P. Groenewegen, E. Worrell, R. Smits, *Resources, Conservation and Recycling*, **34**, 53, 2001
[8] D. Harris, *Building and Environment*, **34**, 751, 1999
[9] R. Cole, P. Kernan, *Building and Environment*, **31**, 307, 1996
[10] T. Chen, J. Burnett, C. Chau, *Energy*, **26**, 323, 2001
[11] McCoubrie, A. and Treloar, G. *"Life-Cycle Embodied Energy in Office Furniture"*, in "Proceedings of ""Embodied Energy - The Current State of Play""", pp. 113-118, Deakin University, Geelong, (1998)

life span of the building, actually becomes the most important item in the life cycle of the building.[7]

McCoubrie demonstrated that office furniture, compared to other elements in the building, account for 31% of the life cycle energy of a medium rise Melbourne office building over a 40 year period.[11] The cause of the high percentage of embodied energy is the frequent replacement of the office furniture. McCoubrie did state that the model did not allow for re-selling of used furniture for re-use, which would help to reduce the energy implications over the life-span of the building.

LCA comparing the use of wood, aluminium and plastic for a video/TV unit

Nedermark recently reported on the use of LCA to improve the design of the main chassis for the Beovision Avant.[12] The Beovision Avant is a TV/video system produced by Bang & Olufsen. The results of the LCA were calculated as person equivalents (PE) based on a normalization process and the results given as *milli* person equivalents (mPE).[12] Three different materials were considered.

1. Total plastic (polystyrene). Material consumption was found to be 3.3kg and 0.05kg waste produced.
2. Wood (MDF). Material consumption was found to be 7.2kg and the waste 3.7kg.
3. A structure of aluminium covered with wood. The aluminium consumption was 2.9kg with 0.3kg waste whilst the wood consumption was 3.1kg and 1.0kg waste.

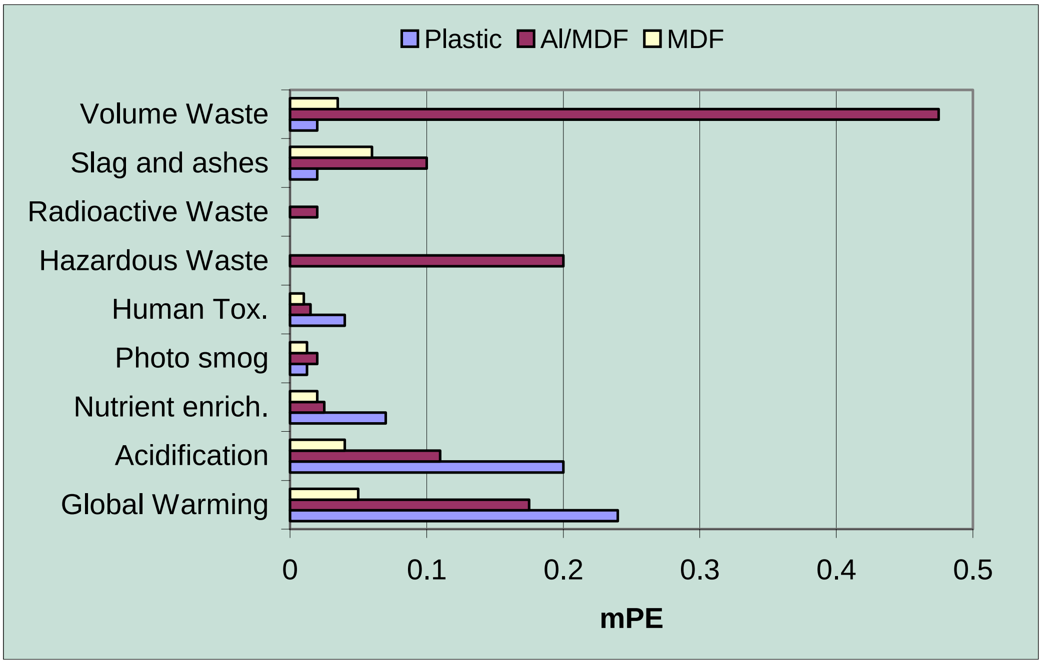

Figure 3. Evaluated potential environmental impacts for three different main chassis. (Reproduced from reference 12).

An LCA analysis of the three possible systems showed that the aluminium system made a larger contribution to different types of waste (such as slag and ashes, volume waste, radioactive waste and hazardous waste) than the others whilst the plastic chassis made the largest contribution to global warming, acidification, nutrient enrichment and human toxicity (see Figure 3). A wooden chassis was found to make no major environmental impact. The wooden

[12] R. Nedermark, *"Ecodesign at Bang & Olufsen."*, in Product Innovation and Eco-efficiency. Twenty-three Industry Efforts to reach the Factor 4, Edited by J. Klostermann and A. Tukker, Kluwer Academic Publishers, 1998.

chassis was found to consume fewer natural resources (see Figure 4) than either the plastic chassis (which consumed natural gas, oil, and bituminous coal) or the aluminium chassis (which was found to consume brown coal, natural gas, oil and bituminous coal). It was concluded that the wooden chassis was the best of the three. It was also found to be the best in regards to finish, rigidity of the chassis, flexibility in production and initial costs. From these results, Bang & Olufsen chose to use the wooden chassis.[12]

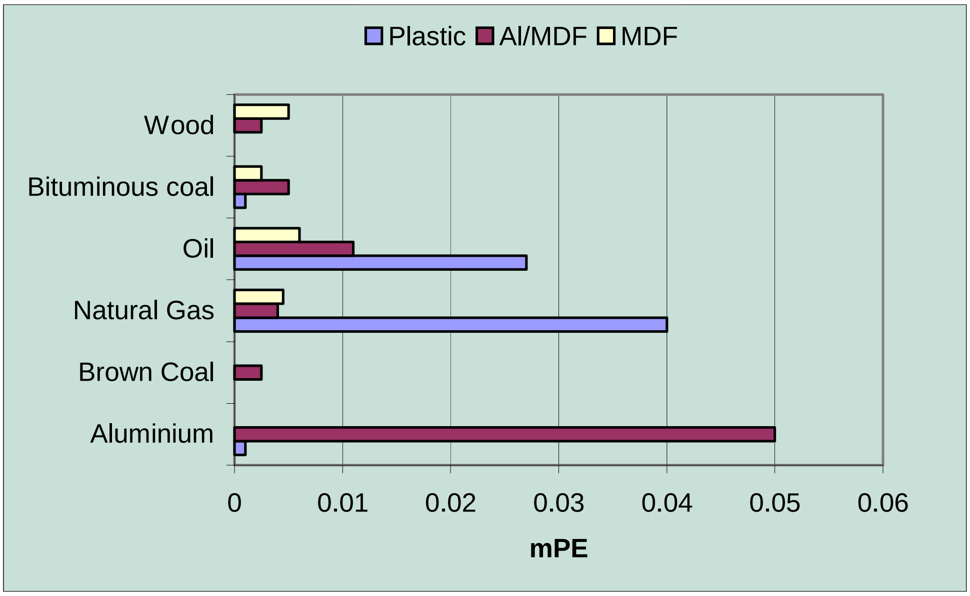

Figure 4. Evaluated resource consumption for the three different main chassis. (Reproduced from reference 12).

Flooring materials.

The environmental impact of three different types of material for flooring (solid wood, linoleum and vinyl) was recently assessed by Jönsson *et al* using an LCA approach.[13,14] The functional unit was defined as 1m^2 of flooring and the lifetimes of each of the products was defined as 25 years (linoleum), 20 years (vinyl) and 40 years (wood). It was assumed that the flooring materials would be incinerated after use to recover some energy. The wood flooring was found to consume the lowest amount of energy (electricity and fossil) followed by linoleum and PVC (Figure 5). In fact, the energy potential of the wood flooring exceeds the energy consumption and therefore the net energy consumption is negative. Burning wood at the end of the life cycle had no negative effect on CO_2 release because the wood was renewable whilst linoleum and vinyl had components that were non-renewable and added extra CO_2 to the atmosphere. Wood was found to be CO_2 neutral and could be used to substitute the equivalent amount of fossil fuels with a reduction of CO_2 in the surrounding atmosphere. PVC was found to have the highest global warming potential (GWP) of 4.2kg/m^2 (Figure 6). This was 2.5 times greater than linoleum (1.6kg/m^2) whilst the GWP of wood was negligible (0.42kg/m^2). In other measures such as acidification potential (AP) and photochemical ozone creation potential (POCP), wood was found to be the best performer.

[13] A. Jönsson, A. Tillman, T. Svensson, *Building and Environment*, 32(3), 245, 1997.
[14] M. Mohammad, J. Welling, *Environmental and energy balances of wood products and substitutes*., Food and Agriculture Organization of the United Nations (FAO), http://www.fao.org/DOCREP/004/Y3609E/y3609e00.htm

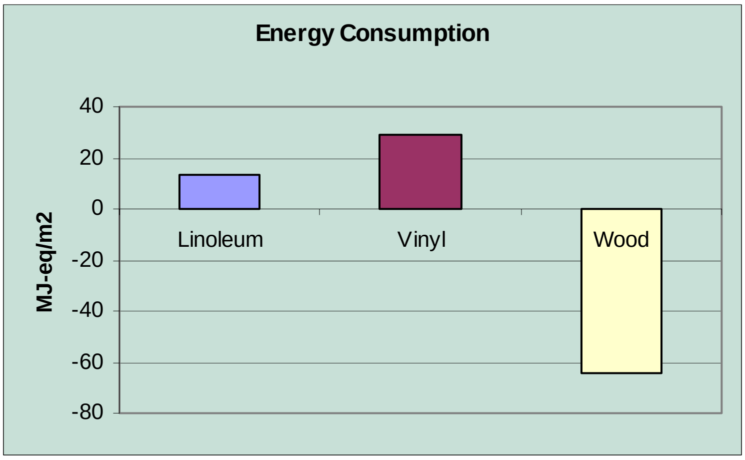

Figure 5. Net energy consumption for 1m^2 of flooring material. In the case of wood, this is a net gain in energy. (Reproduced from reference 14).

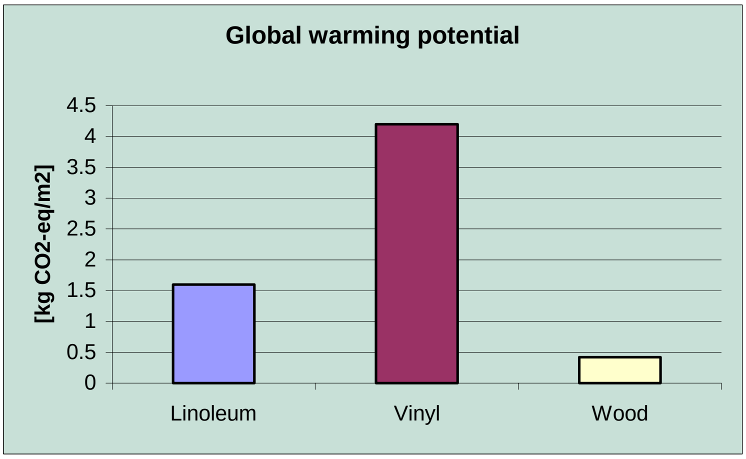

Figure 6. Global warming potential related to 1m^2 of flooring material. (Reproduced from reference 14).

Window Frames

Richter et al using LCA principles conducted an ecological study on window frames made from wood, PVC and aluminium. These results were summarised in a recent publication by the Food and Agriculture Organization (FAO) of the United Nations.[14] It was assumed that the PVC and the aluminium would be recycled at the end of the window's life whereas the wood would be used as energy.[14] The net weight of each of the three window frames was 31.65 kg (aluminium), 43.73 kg (PVC) and 26.43 kg (wood). The heat transition coefficients (k-value) of the PVC and wood frames were both 1.5 W/m^{2}K and were lower than the aluminium frame (1.9 W/m^{2}K).[14] The net input of aluminium, PVC and wood into the frames was found to be 28.5 kg, 26 kg and 20.7 kg respectively.[14] The difference between the net weight of the window frame and the raw materials used reflects the need of other components (such as glues, screws etc) for the different window frames.

When comparing the whole life cycle of the three different window frames, it was found that the total energy consumption was 26.6 GJ/unit for the aluminium window, 20.8 GJ/unit for the PVC window and 19.2 GJ/unit for the wooden window. With respect to the wood frame, if the frame was used as an energy source at the end of its life, then it was calculated that 5.15MJ was renewable. When assessing the environmental impacts of each window, the following categories were studied; global warming potential (GWP), acidification potential (AP), eutrophication potential (EP) and photochemical ozone creation potential (POCP). In every category studied, wood was found to have the lowest environmental burden.[14] The results for the wood frame were found to be only 40-47% of aluminium and PVC for AP and around two-thirds the aluminium and PVC results for EP and POCP.[14] The net environmental impact of the wooden window could have been even lower because the waste wood could replace fossil fuels.[14]

Further work was undertaken by investigating the different stages of the window frame lives. In doing this, the authors tried to highlight differences in the impact potentials at the different stages. In looking at the global warming potential, the lifetime impact of the wooden windows was significantly higher due to the periodical treatment of the frame with paint, lacquer or other chemicals.[14] This resulted in the wood frames having the highest GWP impact during its service life followed by PVC and aluminium. It was noted that when the entire lifecycle was studied, the wooden frame was still the most favourable product followed by PVC and aluminium in terms of GWP.[14] The AP, EP and POCP results for all three frames were almost the same but the wood frames were slightly higher than the other window types.[14]

With regards to transport, the aluminium and PVC windows were very similar in AP and EP results but were considerable higher than the wood frame.[14] The POCP results for transport showed that wood was best followed by aluminium and PVC.[14]

When looking at the frame material, wood was found to be the lowest in AP, EP and POCP with aluminium and PVC following.

In summary, the results of the LCA on the three different window frames concluded that the wood window frames gave the smallest environment footprint.

Danish LCA study on wooden furniture.

The Danish Environmental Protection Agency recently reported on a study looking at the environmental impact of wood and wooden furniture using a LCA approach.[15] The analysis took in the entire cycle from logging to processed products. As a raw material, wood harvested in a sustainable manner has a minimal effect on the environment. The consumption of wood generates no effect because it is a renewable resource. The impact is derived from logging and transport. The study found that wood is CO_2 neutral. The CO_2 liberated on combustion or decomposition is equal to the amount assimilated by the tree during its growth. The processing of the wood and the use of other materials such as glues, impregnating compounds and varnishes add to the environmental impact. The use of even minor amounts of metal and glass has an impact on wooden furniture since both raw materials are manufactured in highly energy intensive processes. The impact of the furniture can be significantly reduced if the production waste and finished products are disposed of by means of recycling and/or incineration for energy production.[15]

Environmental Studies on Building and Construction Materials

Unlike many other products, furniture generally doesn't consume resources during the usage stage. This means that the key environmental life cycle impacts for furniture occur during the extraction of raw material, production of furniture and at the disposal phase.[16] Therefore, one crude way of comparing the different materials for furniture could be to look at the embodied energy of the materials. Fortunately, there have been a number of studies investigating the use of different materials for building residential and commercial properties. Many of these materials (such as timber, steel and aluminium) are also used for the production of furniture.

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[15] see Dutch EPA report at http://www.mst.dk/project/NyViden/2001/09210000.htm
[16] see information *Demi guide to design for sustainability* website, http://www.demi.org.uk/index.html

Lawson has recently completed an in depth study on the embodied energy of many different building materials used in Australia.[17] In this report, two measures are defined. Gross Energy Requirement (GER) and Process Energy Requirement (PER). The GER is a measure of all energy inputs required to produce a building component. It includes the energy input required for transporting workers and equipment to the site, the energy used to construct the plants used to extract and process the raw materials and the cost of repairing damage caused by the manufacturing process.[17] The measurement of the GER can be difficult as some of the energy components are not readily assessable. A better measure for comparing materials is the Process Energy Requirement. This is the component of the GER that directly relates to the manufacture of the component or material and is generally 50-80% of the GER.[17] Lawson listed the PER for 32 common building materials.[17] Table 1 lists the PER for some of these materials.

Table 1. Process energy requirements (PER) for some common building materials. (Reproduced from reference 17)

Material	Embodied Energy (MJ/kg)
Kiln dried sawn softwood	3.4
Kiln dried sawn hardwood	2.0
Air dried sawn hardwood	0.5
Particleboard	8.0
Medium Density Fibreboard (MDF)	11.3
Plywood	10.4
Glued-laminated timber	11.0
Laminated veneer timber	11.0
Plastics (general)	90.0
PVC	80.0
Acrylic Paint	61.5
Glass	12.7
Mild steel	34.0
Galvanised mild steel	38.0
Aluminium	170.0
Copper	100.0
Zinc	51.0

It can be seen from Table 1 that sawn wood products have a very low PER compared to the plastics and metals, often an order of magnitude less. Composite and engineered wood products also generally have lower PER values. Lawson also investigated the process and production energy requirements and wastes, by-products and environmental effects for each of the building materials.[17] The results for each class of material were:

Australian plantation wood

- 75% of the energy requirements is consumed in the drying process. Most of the heat energy is generated by the combustion of waste timber. Purchased energy makes up only 15% of the PER value.
- Approximately 500kg of CO_2 are generated for 1 tonne of wood. However, plantations can be "carbon sinks", absorbing CO_2 from the atmosphere. Plantations also generate oxygen.
- Hardwood plantations are similar in environmental impact to softwood plantations. There may also be some positive environmental benefits such as using hardwoods to ameliorate soil salinity.

[17] Bill Lawson, "*Building materials energy and the environment. Towards ecologically sustainable development.*" The Royal Australian Institute of Architects, 1996.

Australian hardwood from native forest

- Harvesting operations are similar to plantation softwood. Diesel fuel consumption tends to be higher for hardwoods compared to plantation softwood.
- Hardwoods require significantly less artificial drying than softwoods.
- There is an environmental impact on native fauna. This impact arises from the forming of access roads, removal of forest canopy, use of fire as a management tool and the depletion of suitable habitat for native plant and animal species.

Particleboard and MDF

- 80% of softwood used for the production of MDF originates from plantation thinning operations, with the rest being sourced from sawmill residues.
- Particleboard is generally made entirely from softwood sawmill residues.
- Off-gassing of formaldehyde (present in the adhesive used to glue the panels) can present a potential low-level health hazard.
- The largest manufacturer of MDF and particleboard is developing a post-consumer recycling strategy to recycle these products.

Plywood, Glued laminated timber and laminated veneer lumber

- 1 tonne of plywood liberates 0.5kg of CO_2.
- 1 tonne of glued laminated timber releases 657kg of CO_2.
- 1 tonne of laminated veneer lumber releases 660kg of CO_2.
- Off-gassing of formaldehyde (present in the adhesive used to glue the panels) can present a potential low-level health hazard.

Plastics

- The raw materials used to produce plastics come from non-renewable fossil fuels. Usage equates to *ca* 5% of the oil and natural gas consumed each year.
- Synthetic plastics are energy intensive.
- Many plastics contain additives that are harmful to human health and the natural environment.

Steel

- 1 tonne of steel requires 1,500kg iron ore, 225kg limestone, 750kg coal (coke) and 150,000 litres of water.
- Each tonne of steel produced generats the following wastes: 145kg of slag, 230kg of granulated slag, 2 tonnes of CO_2 and 40kg of noxious gas (carbon monoxide, sulphurous oxides and nitrous oxides). Approximately 150,000 litres of contaminated water are also produced.

Aluminium

- 1 tonne of Aluminium requires 5 tonnes of bauxite.
- Open cut mining of bauxite degrades ca 50m^2 of land per tonne of Aluminium produced.
- The most notorious by-product of Aluminium production is caustic red mud and red sand. More than 15 million tonnes are produced each year in Australia with over 200 million tonnes stock-piled. Less than 1% of this material is used.
- Recycled Aluminium requires much less energy for processing (8MJ/kg).

Hekkert *et al* investigated the opportunities to increase the use of wood in Dutch residential buildings.[7] It was found that CO_2 emission reductions were technically feasible with a 12% reduction possible in the short term by an increased share of wood. Koch (reporting on the reduction of timber harvests in Washington, Oregon) found that the use of additional non-renewable structural materials such as steel, concrete, aluminium and plastics instead of structural wood would result in an increased consumption of 717 million gallons of oil and the production of 7.5 million tonnes of carbon dioxide annually.[18] Further information suggests that wood accounts for 50% of the industrial raw materials used in world, but only 4% of the energy required to convert these raw materials into useful products is consumed by wood.[19] This becomes important when the energy is derived from the burning of fossil fuels.[19]

A report from the Michigan State University compared the use of wood versus other raw materials for the construction of an interior wall.[20] Relative energy consumption to produce a unit-mass of material (based on 1976 data) was found to be:[20]

Aluminium	70
Steel	17
Dry Lumber	1

Net carbon emissions (kg C/metric tonne) in producing a tonne of material (based on 1992 data) were as follows:[20]

Framing Lumber	-460
Glass	630
Steel	1090
Aluminium	2400
Plastic	2810

Timber was found to sequester more CO_2 during its growing phase than it produces.

In comparing the emissions during the manufacture of wood and steel-framed interior walls, it was found that wood releases less pollutants in all categories compared to steel.[20]

Table 2. Comparative emissions in manufacturing wood versus steel-framed interior walls. (Taken from reference 20).

Emission	Wood Wall	Steel Wall
CO_2 (kg)	305	965
CO (g)	2450	11800
SO_x (g)	400	3700
NO_x (g)	1150	1800
Particulates (g)	100	335
VOCs (g)	390	1800
Methane (g)	4	45

Recent work by Glover investigated a comparative assessment of steel, concrete and wood.[21] In this work, the comparison of embodied energy was derived from data obtained by Lawson[17], Buchanan *et al*[22] and The Canadian Wood Council.[23] Wood was found to have the lowest embodied energy (0.6-41.2 MJ/kg) compared to steel (8.9-59 MJ/kg). These values were then used to calculate the embodied energy of a predominately steel house and a predominately wood house. Houses made of wood had lower embodied energy contents (approximately 50% less) than houses made out of steel. It was found that the higher the embodied energy of the house, the more air toxins (such as carbon dioxide, sulphur dioxide, particulates, nitrogen oxides and hydrocarbons) there were released to the atmosphere. The difference between

[18] P. Koch, *Forest Products Journal*, **42(5)**, 31, 1992.

[19] *"Eco-link"* Temperate Forest Foundation publication, Volume 11, No. 2. See their website at http://www.forestinfo.org/index.htm

[20] see http://forestry.msu.edu/msaf/pdf/rawmaterialenergy.pdf

[21] J. Glover, *"Which is better? Steel, concrete or wood. A comparison of assessments on three building materials in the housing sector."*, Fourth Year thesis, Department of Chemical Engineering, University of Sydney, 2001

[22] A. Buchanan, B. Honey, *Energy and Buildings*, **20**, 205, 1994.

[23] Canadian Wood Council Technical Bulletin No. 5 *"Life cycle analysis for residential buildings"*, 1994-2000, http://www.cwc.ca/publications/tech_bulletins/tech_bull_5/

wood and steel in the amount of CO_2 released was reported to be 25 tonnes per house. Wood houses also used 41% of the fossil fuels used in a steel house.[21]

The Canadian Wood Council has published several technical bulletins regarding the environmental impact of different building materials.[23,24,25] The system used in these studies was a computer model developed by the ATHENA™ Sustainable Materials Institute.[23] The model can assess and integrate life cycle inventory databases and environmental profiles of many common building materials such as wood, steel and concrete. ATHENA™ has six output measures.[23] These are:

1. Embodied energy used in the extraction, manufacture, transport and installation of materials.
2. Solid waste calculated by mass. Waste is not divided into hazardous or non-hazardous categories.
3. Raw resource use which is reported using a weighted system that takes into account differences in resource extraction (such as biodiversity and ground water quality).
4. Weighted resource use accounts for the sums of the resource requirements for all materials used in the finished product.
5. Global warming potential takes into account all relevant process emissions of greenhouse gases to produce a global warming potential measure.
6. Air and water toxicity is estimated based upon the materials used at different stages of their life cycle.

The Canadian Wood Council reported that the environmental effects of resource extraction were difficult to quantify due to the wide variety of variables involved.[24] Nevertheless, the following points were highlighted.[24]

1. Mining extractions are more intensive than forest extractions. The ecosystem of the mining site is totally removed, but it is limited in area.
2. Forest extractions are more extensive than mining extractions. They cover more land but the effects are temporary in nature.
3. The variation in ecological impacts of forest cutting can differ by several orders of magnitude from best practice to worst practice.
4. The differences between the best and worst practices within each industry may be greater than differences between them.

The six measurements described above were used to study the environmental impact of three types of houses, a wood house (framed with lumber and wood I-joists), a sheet metal house (with a light steel frame) and a concrete house (using insulated concrete forms (ICF) and a composite floor consisting of open-web steel joists with a concrete slab).[23] The results of this study were:

- The embodied energy of the wood house was 53% less than for the sheet metal house and 120% less than for the concrete home.
- The global warming potential for the wood house was 23% and 50% lower than for the metal and concrete houses respectively.
- The air toxicity index for the wood house was 74% less than for the steel house and 115% less than for the concrete house.
- The water toxicity index for the wood house was 247% less than for the sheet metal house and 114% less than for the concrete house.
- The weighted resource use for the wooded house was 14% less than for the sheet metal house and 93% less than for the concrete house.
- Solid waste generation was lowest for the steel house. Wood waste was 21% higher.

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[24] Canadian Wood Council Technical Bulletin No. 2 *"Environmental effects of building materials"*, 1994-2000, http://www.cwc.ca/publications/tech_bulletins/tech_bull_2/

[25] Canadian Wood Council Technical Bulletin No. 4 *"Comparing the environmental effects of building systems"*, 1994-2000, http://www.cwc.ca/publications/tech_bulletins/tech_bull_4/

These results showed that the use of wood was significantly better for the environment in five of the six measured outputs. The environmental impact of the wood house would have been even greater if both the sheet metal and concrete houses did not have a wood roof.[23] Further studies on the construction of office buildings[25] and non-load bearing exterior walls[24] found similar results. It was stated that wood is a renewable resource, harvested and planted in developed countries on a sustainable basis. Steel, aluminium and plastic are produced from finite resources in which the use of the materials contributes to their depletion. The harvesting of trees actually helps to reduce greenhouse gases. Forests consume carbon dioxide (CO_2) as they grow and release oxygen. Figures from the Canadian Wood Council suggest that in a growing forest, to produce 1 pound of wood, a tree absorbs 1.47 pounds of CO_2 and releases 1.07 pounds of oxygen into the atmosphere.[23] When forests reach maturity, they then start to consume oxygen and produce CO_2 because of decay. By harvesting mature forests and converting them to wood products, the CO_2 is locked in and thus, not released into the atmosphere.

The manufacture of metals was found to be energy intensive. The process of manufacturing the metals used a great deal of energy and also produced high CO_2 emissions. The manufacture of metals also results in high levels of air and water pollution. Of the energy used to convert logs to sawn timber, a large proportion of that energy is supplied by wood waste, which is also renewable. In summary, all the studies suggested that the use of wood was significantly better for the environment than either steel or concrete.[23,24,25]

Comparison between glulam and steel beams

Recently, an article was published which examined greenhouse gas emissions, life cycle inventory and cost efficiency of using laminated wood (glulam) instead of steel for the construction of beams in an airport in Oslo, Norway.[26] The steel was assumed to contain 50% scrap steel. It was found that the total energy consumption required in the manufacture of steel beams was two to three times higher than for the manufacture of glulam beams. Fossil fuel use was six to twelve times higher for steel compared to glulam and greenhouse gas emissions were five times higher. These numbers would be higher if the steel was entirely derived from iron ore. Waste handling of glulam, compared to steel, could be considered either favourable (if the wood was used for energy production) or unfavourable (if the wood was sent to landfill).

Sustainability

Australian forests consist of 155 million hectares (ha) of native forests, which can be divided into closed forest (4.6 million ha), open forest (39.2 million ha) and woodland (112 million ha).[27] Of the open and closed forest (43.8 million ha), 26.6% is state forest, 24.6% is crown land, 22.7% is National Parks and conservation reserves and 26.1% is privately owned.[28] Approximately 80% of the forest is eucalypt forest.[27]

Australia has about 1.3 million hectares of plantation, including softwood and hardwood.[27] In the past five years, timber derived from plantation softwood has increased by over 20%.[27]

The Federal Government's Forest taskforce (1995) estimated that the number of people employed in forestry, logging and forest product industries in Australia to be approximately 82,500.[29] As such, it is the second largest manufacturing industry in Australia.[27]

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[26] A. Petersen, B. Solberg, *Environmental Science & Policy*, **5**, 169, 2002.
[27] See *"Forestry Fact: An overview"* at the NAFI website at http://www.nafi.com.au/faq/index.php3?fact=2
[28] See *"Sustainability and the environment"* at the TPC website at http://www.tpcvic.org.au/page_sust_envir.htm
[29] Forest Taskforce 1995, Wood and Paper Industry Strategy, Department of the Prime Minister and Cabinet, Canberra.

The federal government has recently announced participation in the Australian Forestry Standard. This standard applies international environmental and sustainability standards toward obtaining independent certification for forests harvested in Australia. More information on the Australian Forestry Standard can be located on the internet at http://www.forestrystandard.org.au/.

Within Victoria there are 5 million hectares of native forests. Timber harvesting is permitted on 1.2 million hectares of the forest on a sustainable level, which is guaranteed under Regional Forest Agreements.[28] This sustainable level allows for only 0.1% of the available forest to be logged per year.[28]

The use of sustainable forests for the production of timber does have an effect on the environment. These effects have been described as both positive and negative and are listed below.[14] As can be seen, there appears to be more positives for using timber than negatives.

Table 3. The environmental effects of forestry activities and operations. (Reproduced from reference 14).

Positive Effects	Negative Effects
• general positive functions of a diverse ecosystem • use of solar energy and carbon dioxide and its conversion into wood as an important fuel and raw material • forest and wood function as carbon sinks • wood is renewable and, by sustainable forest management practices, permanently available • forest functions as an air cleaner • forest protects soil, water and wildlife • forest has an important recreation role • forests are part of the landscape	• influencing the natural processes of the ecosystem (eg changing plant societies and age structure of trees) • use of fossil energy for the necessary operations • use of land and soil

Wood Strength and Durability

One question a consumer may have is how strong or durable is wood compared with other materials. Unfortunately, there is no simple answer to this question. Strength means many things and can be measured in various ways. For example, cricket bats are made of willow because the latter is a tough wood that does not splinter from hard impact. Floors and stairs were often made of Victorian ash because it is a highly resistant to wear. Fence posts are often made of redgum or red or yellow box or cypress. These timbers are very resistant to decay and insects because of chemicals produced naturally in the wood.

One of the most widely accepted methods of measuring wood strength is determining its **modulus of rupture**. This is measure of the maximum load carrying capacity of wood in bending, and is determined from the force necessary to break a sample of wood. The force is then used in a formula to describe the maximum bending stress. Some other ways of measuring strength of wood are as follows[30]:

Work to maximum load in bending – describes the ability of a timber specimen to absorb shock without structural deformation of the specimen.

[30] Green, D.W., J.E. Winandy and D.E. Kretschmann (1999) Mechanical Properties of Wood. Wood Handbook: Wood as an Engineering Material. Gen. Tech. Rep. FPL – GTR – 113. Madison, WI: U.S. Dept. of Agriculture, Forest Service, Forest Products Laboratory. pp. 4-1 – 4-45.

Compressive strength parallel to grain – puts force on a wood sample in such a way that the wood fibres are shortened lengthwise. An example would be a house stump.

Compressive stress perpendicular to grain – is where stress is applied perpendicular to the grain. For example, the stress created by the weight of a heavy cabinet sitting on a wooden floor.

Shear strength parallel to grain – is the ability to resist shearing along the grain.

Impact bending – where an impact of a given weight is repeatedly tested from increasing heights until the wood sample ruptures. The height of the drop that causes the failure represents the ability of the wood to absorb shocks.

Tensile strength perpendicular to grain – The ability of a wood sample to resist forces acting against the grain resulting in splitting. This occurs when splitting firewood.

Hardness – Resistance to indentation. The Janka hardness test is the standard method of measuring the ability of wood to resist indentation and reflects the measurement of the load required to embed an 11.28 mm ball to one-half its diameter.

Tensile strength parallel to grain – Is where the wood sample is held at either end and pulled apart, in the direction parallel to the grain.

There are many factors that affect the strength of wood. Natural characteristics, such as the presence of knots, the specific gravity of the wood (wood substance per unit volume) and slope of grain are some of the natural characteristics of wood that can have a detrimental effect on its strength. There are also environmental factors that can affect the strength of wood[31], eg the moisture content and temperature of wood, can decrease the strength of wood.[31]

By far the greatest influence on the strength of furniture manufactured with wood, or any other material, is the design. Furniture should be designed and manufactured by a reputable manufacturer to ensure no shortcuts are made in the design or manufacture of the product. Obviously, furniture made from substandard materials and poor manufacturing techniques will have a much shorter lifespan than furniture made of high quality materials and professional craftsmanship. Homeowners can extend the lifespan of their wooden furniture by taking a few simple precautions. For instance, keep wooden furniture out of direct sunlight to prevent bleaching of the timber. Keeping the humidity and temperature as stable as possible to protect the wood from movement due to extremes in moisture and temperature. For example, wooden furniture should not be placed in front of heating vents. Protect outdoor furniture from the weather by storing it under cover when not in use. Protect all furniture from water. And last, but not least, perform regular maintenance on wooden furniture by oiling or waxing it regularly.

[31] Hoadley, R. Bruce (1980) Strength of Wood. Understanding Wood: A Craftman's Guide to Wood Technology. The Taunton Press. Newtown, CT. pp. 107 – 135.