The Environmental Impact of Building Materials

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Summary of

Actions Towards Sustainable Outcomes

Environmental Issues/Principal Impacts

- Building materials globally consume 30-50% of available raw resources and produce about 40% of waste to landfill in OECD countries. In Australia they constitute one-third of total waste to landfill, and their production and use generates significant environmental pollution, including greenhouse gas emissions. (Some impacts, such as the impact on biodiversity and carcinogens remain difficult to quantify but are potentially highly significant).
- Data indicate that the impacts associated with many building fitouts, can, over the life of buildings, be as large as the impacts of the construction of a building initially.
- The range of tools and systems to assist decision-making by specifiers and designers has not been available until recently, and there still remains significant gaps in the resources designers need.
- Building materials use in Australia, and indeed globally, is not environmentally sustainable on the basis of known system principles.

Basic Strategies

In many design situations, boundaries and constraints limit the application of cutting EDGe actions. In these circumstances, designers should at least consider the following:

- Building materials in Australia contribute significantly towards national emissions of greenhouse gasses and a range of other environmental impacts.
- Some impacts, such as those on biodiversity both in Australia and overseas (where many of our building products are sourced from) are still poorly understood.
- Major impact contributors by material include steel, concrete, brick and aluminium.
- Using greenhouse gases as an indicator, the environmental impact of construction in Australia is dominated by the residential sector, particularly detached residential development and home improvements.

Cutting EDGe Strategies

- An appreciation of the basic tools and units of measuring and communicating environmental impacts is useful. These include eco-footprint, embodied energy, life-cycle assessment and materials intensity per service unit (MIPS).
- A useful approach for understanding the sustainability or otherwise of building materials is a systems perspective based on scientific knowledge of the healthy and long-term functioning of ecological systems. Sustainable systems have characteristics such as no waste, no degradation of the functioning and capacity of natural systems, and do not consume resources faster than they can be replaced.

Synergies and References

BEDP Environment Design Guide:

- Gen 22 Life-Cycle Energy Analysis
- Gen 51 Life-Cycle Assessment – Application in Buildings
- Gen 58 Embodied Water of Construction
- Des 35 Building Materials Selection – Greenhouse Strategies

BEDP ENVIRONMENT DESIGN GUIDE

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This note reviews the quantities and types of building materials use internationally and in Australia, with projected trends for Australia to 2055. It introduces methods available to evaluate environmental impacts and then goes onto analyse current impacts using life-cycle assessment. It concludes by reviewing the sustainability of contemporary patterns of use and future trends, using a systems perspective. It is intended to be read in conjunction with PRO 8, 'Strategies and Resources for Material Selection'

1.0 Introduction

Identifying what constitutes a sustainable material or more usefully as we shall see, the use of materials sustainably, remains one of the major challenges of 'green' building. There are a number of issues in this area:

- Until recently data on the environmental impacts of building materials has been scarce or missing in Australia and internationally.
- Tools and systems to assist decision-making by specifiers and designers have not been available until recent years, and there still remain significant gaps in the information provided and what would be required.
- The assessment of options requires tools and a body of knowledge not yet familiar to most designers and specifiers.

This note brings together recent Australian and international research to review the importance of environmental impacts of building materials, and draws on new research from the Commonwealth Government. It reviews key findings, and overviews commonly used assessment methods that readers will encounter. (This note is intended to be read in conjunction with the *Environment Design Guide* notes listed on the summary sheet).

2.0 Improving Building Material Sustainability

In 2005 the Commonwealth Government through the Department of the Environment and Heritage (now the Department of the Environment and Water Resources) commissioned a scoping study to 'Investigate Measures for Improving the Environmental Sustainability of Building Materials' (Department of Environment and Heritage, 2006 #1180). Unless cited otherwise, this note references the findings of that report and the research undertaken by RMIT, CSIRO, BIS Shrapnel, Deni Green Consulting, and Syneca Consulting. The report is now available for public review.

2.1 Materials Use Internationally

Buildings are linked to significant material-related environmental impacts, consuming approximately 30–50% of available raw materials, and producing about 40% of waste to landfill in OECD countries (OECD 2002, 2003). Production of cement, virgin iron and aluminium alone consumes 6% of global electricity and contributes to over 12% of anthropogenic global greenhouse gas emissions. Agenda 21, of the overarching United Nations Sustainability Framework, makes explicit reference to the potential for building materials to be a major source of environmental damage "*…through depletion of the natural resource base, degradation of fragile eco-zones, chemical pollution, and the use of building materials harmful to human health*" (UN-DESA). The extraction of resources for materials is also known to have large, if often poorly understood or communicated effects.

2.2 Materials Use in Australia

Australians have been doing a lot of building, adding to the building stock at 3.8% or $35.5 billion per annum in recent years (with a trend growth of 3.4%). In 2005 new construction accounted for:

- 33 million m² of new separate houses
- 9.5 million m² of multi-unit dwellings
- 7 million m² of home improvements and
- 10 million m² of new non-residential construction.

During the 20 years to 2005 residential building size has ballooned by 40%, with 60% of new residential activity today being alterations and maintenance. In the non-residential sector, potentially 75% of spending occurs on maintenance and replacement.

The Australian Bureau of Statistics' (ABS) mean asset life of dwellings varies from 58 years (for timber), to 88 years (for brick). Commercial and industrial buildings are considered to have a 38–58 year life.

Building materials use as tracked in the DEH study accounted for approximately 30 million tonnes of finished building products in 2005. Up to 85% of total quantities by mass are dominated by concrete, brick and steel. Ashe et al found that in Australia, construction accounts for the use of:

- 55% of timber
- 27% of plastics and
- 12% of iron and steel (Ashe, Pham & Hargreaves, 2003).

Table 1 shows total mass flows in residential, multi-residential, non-residential and home improvements in Australia based on BIS Shrapnel data. Note that

	% Total flows	Total	Separate houses	Home improvement	Multi-unit residential	Non-residential buildings
	Thousands of Tonnes					
Aluminium	0.2	47	21	22	4	2
Brick	23.2	6,270	3,760	1,440	387	683
Concrete	56.2	15,200	6,730	2,210	2,160	4,110
Fibre cement	1.0	270	106	118	21	26
Glass	0.4	96	41	34	9	13
Hardwood	0.53	143	24	115	1	3
Mortar	3.85	1,040	606	229	72	127
Plasterboard	3.1	837	437	162	119	119
Plywood	0.2	43	11	29	0	4
Softwood	3.3	889	460	305	110	14
Steel	6.3	1,690	266	352	115	961
Total	100	27,013	12,462	5,016	2,998	6,062

Table 1. Identified Materials Flows by Selected Materials Building Type

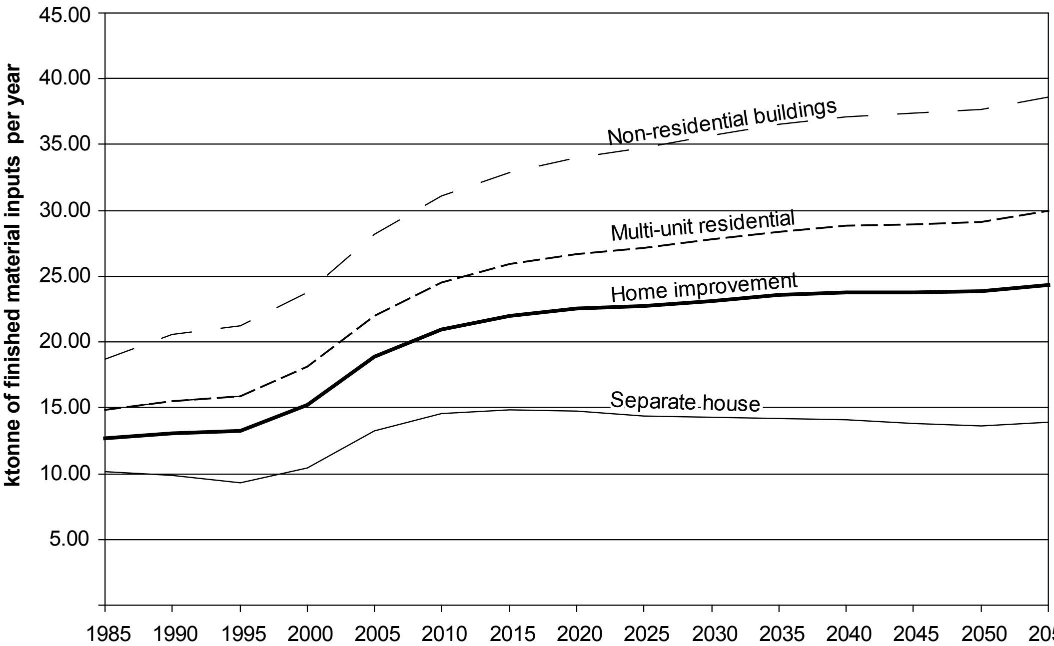

Figure 1. Total Finished Material Requirement by Construction Sector per Year over Next 50 Years

while many other materials are used (glues, a wide range of plastics, metals, glass and so forth), in mass terms some are not included. Some are too small to show here, and some are excluded from the study such as fitouts[1].

Table1 identifies some of the major materials flows identified, and the split of these by building type. A surprise in the study was the quantity of materials associated with the home-improvement market. This shows that in mass terms residential construction is much larger than non-residential, and that some of the largest mass flows occur in a relatively small number of building materials specifically: brick, concrete, steel and timber.

2.3 Projected Australian Materials Use

Using the CSIRO Australian Stocks and Flows Framework (ASFF), a population based model of the whole economy, the research looked at what the future flows of materials are likely to be. A major determinant of this is trends in residential house size, which have increased by 40% over the last 20 years to an average of 258m^2 in 2005. These figures excluded fitouts.

1 The research was based on materials flows as identified by BIS Shrapnel data analysis. Primary finished products/ materials were estimated rather than all materials as used in the finished building. A number of materials flows may not be included, including a number of smaller but potentially environmentally significant flows such as the glues, some plastics and so forth. Refer to the online report for additional information.

3.0 Environmental Impact Evaluation Methods

Quantities of materials used are not however a measure of sustainability. Are current patterns of use for building materials sustainable? How do we evaluate these? A number of different approaches are available, with each giving insight into important aspects, and many of which will be familiar to readers. These are briefly outlined in Table 2.

Approaches for evaluating sustainability
Materials Intensity per Service Unit (MIPS) A unit of eco-efficiency that examines sustainability of production by breaking down products into services they provide, and examining the amount of materials that needs to be displaced in order to provide a unit of service, e.g. a wall or roof[2]. MIPS is expressed in Kg or tonnes of non-renewable and renewable materials, air, and water. • MIPS helps conceptualise the scale of activities associated with the use of a product or service (such as the quantity of materials required for the manufacture of a tonne of steel or plastic). • The scale of activities (e.g. materials inputs) does not necessarily relate or scale to environmental impacts, and MIPS does not produce site-specific data. • It provides information on a relatively small number of environmental criteria.
Embodied energy A measure of the energy (measured in Mega or Giga Joules) embodied in a (required to make or supply) product or service. • Energy is a useful basis for comparison as it is relatively easily quantified, can be adapted to a number of methodologies, and because it is a useful proxy for broader impacts – many environmental impacts are associated with energy production. However energy is not always a useful indicator of impact – energy may be from renewable or fossil sources for example. It does not provide specific information on other impact categories, and there is no standardised method for evaluation.
Embodied Water A measure of the water (measured in litres) embodied in (required to make or supply) a product or service over a given period of time. • As for embodied energy; this is useful data to have but is not always an indicator of equivalent impacts, and is narrow in focus.
Ecological Footprint Seeks to measure human demands on nature and compares human consumption of natural resources with the earth's ecological capacity to regenerate them. • A powerful communication tool that, however, lacks precision for detailed comparative evaluation between options.
Life-Cycle Analysis A method to analyse over an identified life-cycle (cradle to grave, or cradle to cradle) a range of environmental indicators e.g. greenhouse emissions, water, human and environmental toxicity, resource depletion. A decision-support tool that assesses a variety of environmental impacts during the whole life-cycle of a product or process. It provides powerful analysing options, such as trend analysis, comparing alternatives and determining the main impacts in a life-cycle. It determines potential regional and global environmental impacts and therefore is not particularly useful for determining exact specific effects. LCA results can be scientific and quite complex, or more subjective and easier to communicate. Ecological footprint is an example of the latter.
Environmental Impact Assessment An assessment of the likely influence a specific project may have on a specific environment over a given period of time. • The approach used to evaluate the environmental impacts of a range of activities such as mining, dredging, etc using site-specific information. Typically not available to specifiers, as such data is not typically tracked through the supply chain. Timber certification is a partial exception to this, where a certified level of forest management is communicated through the supply chain.
Systems Analysis e.g. Natural Step Defining system conditions for sustainability against which comparative analysis can be undertaken e.g. 'Society depletes or degrades resources faster than they are regenerated.' • A powerful framework for expert analysis and evaluation, but difficult to use for comparative analysis between products or services. (Referred to in Table 3)

Table 2. Approaches for evaluating sustainability

4.0 Australian Research Assessment

4.1 Life-Cycle Assessment

Life-Cycle Assessment (LCA) was selected as the most appropriate methodology for the DEH Scoping Study. Life-Cycle Analysis can be undertaken using different approaches, and a crucial consideration for practitioners seeking to make sense of the results, such as cumulative

2 Source: Wikipedia. For additional information on these approaches Wiki. is a useful information source: http://en.wikipedia.org/wiki/Main_Page

energy use, or total life cycle greenhouse emissions, is the 'boundary' selected in a study. For example, the fuel required to carry a log to the saw mill may be included in the assessment, but what of the energy required to manufacture the truck itself? Another key consideration is the source of data to be used.

Process LCA, a widely used approach, focuses on inputs and outputs from specific processes identified in the system studied. This allows process-specific quantification in detail (such as energy inputs and emissions from smelting a tonne of steel). To use our analogy, *Process LCA studies* would commonly. Invariably, process LCA practitioners set a boundary for the system they study, outside which (from experience and scoping level calculations) there are no significant issues or impacts. Using this approach, a process LCA may include the fuel for the timber truck, but exclude the manufacture of the truck itself, since many previous studies including the truck have shown that this is invariably too far removed from the logging process to be significant.

Input-Output LCA (I/O LCA) uses financial measures through the system of national accounts to allocate environmental impacts by sector (e.g. the construction sector). I/O LCA has the advantage of including a much wider boundary, but the disadvantage of potentially including more than is strictly relevant. For example I/O LCA would commonly include the truck, and potentially a percentage of the drivers' personal greenhouse emissions. This method has at least two principal disadvantages. First, it relies on proxy economic data for process activities, so that dollars spent on economic sectors are converted into proportionate impact. Second, national accounts data is highly aggregated so that a particular sector will invariably include a wide range of activities, and a wide range of impacts. Hence, the particular process being studied may not be representative of the I/O sector in which it is included, leading to skewed results.

Unsurprisingly, the results from input/output studies can be dramatically different from process LCA, and the decision to use either method varies across cases. Combination approaches known as Hybrid LCA have been developed seeking to minimise 'truncation' effects of process LCA while maintaining its strengths in accuracy and applicability (for example, by Treloar and Lenzen, as referenced in Notes in this Guide).

The DEH study used process LCA data, and will therefore in absolute terms, underestimate the full emissions and resource use within the building materials. The following table identifies impacts from different building types across a range of LCA indicators.

4.2 Greenhouse Gas Emission Analysis

The study found that greenhouse gas emissions associated with the materials identified account for 2% of total Australian greenhouse gas contributions per annum., It is possible that if the study had included fitouts and some other materials flows a total similar to the 3-8% range identified for other countries would be found. For comparison, a preliminary and unpublished I/O LCA analysis undertaken separately by Treloar (2007) which would also include fitouts, suggests greenhouse emissions from building materials may be up to 54 Mt, or 12.1% of national greenhouse gas emissions, excluding capital (e.g. production plant for building products) and non-building construction (e.g. roads).

Impact category	Unit	Total	Separate houses	Home improvement	Multi-unit residential	Non-residential buildings
Global warming	Mt CO_2 e.q.	10.89	25%	25%	12%	38%
Photochemical oxidation (smog)	Kt C_2H_2 e.q.	21.61	36%	24%	13%	27%
Eutrophication (surplus nutrients)	Kt PO_4 e.q.	9.01	22%	28%	14%	35%
Carcinogens	DALY*	687.00	44%	44%	8%	4%
Land use	Ha a (000)s	1,024.00	45%	46%	8%	1%
Water use	Terra Litres H_2O	42.94	21%	45%	7%	27%
Solid waste	Mega tonnes	11.83	48%	24%	10%	19%
Cumulative energy demand	PJ	0.75	43%	28%	11%	20%
Minerals depletion	PJ Surplus	161.46	28%	30%	11%	31%

*Disability Adjusted Life Year - an LCA indicator derived from a methodology developed by the World Health Organization that takes into account mortality and morbidity arising from impacts such as smog and carcinogen releases. For additional explanation of other indicators please refer to the full report.

Table 3. Impact assessment results by Life-Cycle Assessment indicator

The following graph illustrates research findings on greenhouse gas emissions per building type and building element, for various building sectors:

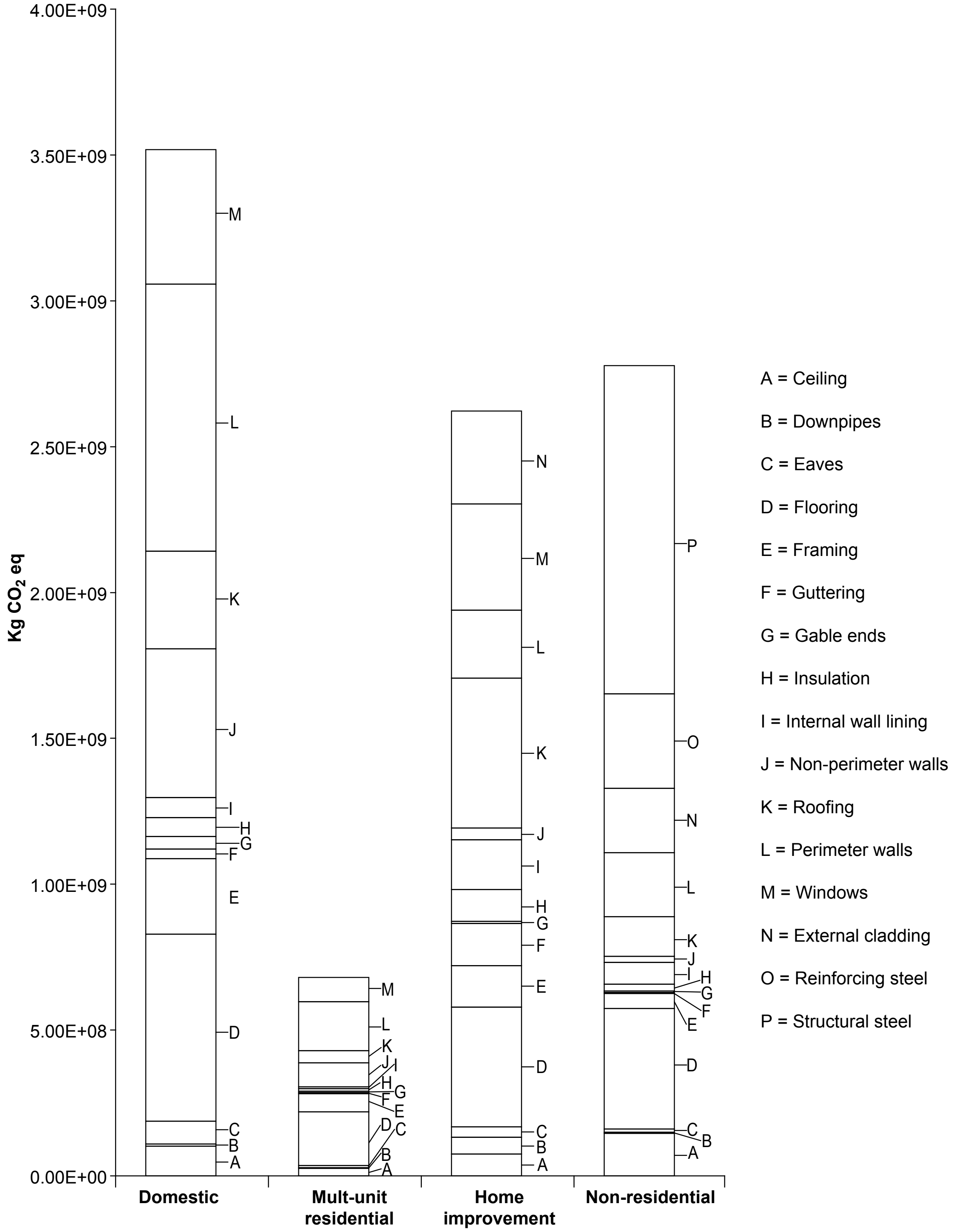

Figure 2. Contributions to Greenhouse Impacts from each Building Sector by Structural Elements

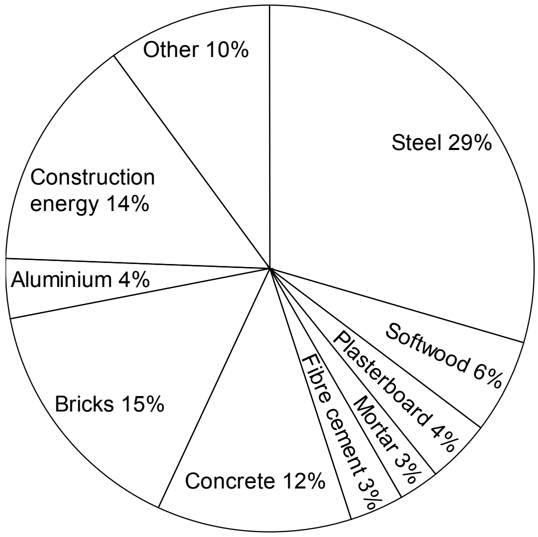

Figure 3. Global Warming Impacts by Material for all Building Sectors for 2005

4.3 Other Impacts

The data showed that impacts across other indicators varied widely. Waste constituted 44% of per capita impacts (in Australia construction and demolition waste accounts for one-third of all wastes to landfill by volume) while water accounted for only 0.01%. This equates to 86 Terra litres, equivalent to 100,000 Olympic swimming pools. Figure 4 shows the water use impacts by material for all building sectors for 2005. Other indicator results may be found in the full report.

4.4 Biodiversity Analysis

Impacts leading to biodiversity loss that are not readily tracked in the supply chain, are difficult to quantify in LCA, and could not be accurately quantified for the DEH report. There is, however, evidence that raw materials extraction is having profound impacts on our natural environment globally, as well as in Australia. The 1996 State of the Environment report found 11 plant species to be at 'present and future threat' from the mining sector, and 10 species from forestry activities (Commonwealth of Australia, 1996). The importance of apparently small or low level activities should not be assumed to be insignificant. As Schmidt Bleek, developer of the Materials Intensity per Service Unit approach notes, "*…irreversible disturbances of ecological equilibria are caused…(by) interference with environmental resources in situ*" (Schmidt-Bleek, 1999, p2). The problem for practitioners, tool developers, and indeed the entire sector, is to identify whether a disturbance (be it mining, water extraction or waste disposal) is having a trivial or catastrophic effect on related environments. At present neither the systems nor science are in place to allow the evidence-based assessment and communication of up and downstream impacts from building materials on our environment.

4.5 Embodied and Operational Energy

The study found that greenhouse gas emissions embodied in base building fabric materials (i.e. excluding fitout) accounted for 10-15% of total building greenhouse gas emissions. This means that operational energy consumption dominates the impact of the built environment. On this basis retrofitting to improve the energy efficiency of Australia's existing building stock should be a national priority for reducing greenhouse emissions.

As a building's energy efficiency improves, the ratio of its embodied energy to operational energy changes. Recent research has concluded that embodied energy on highly energy efficient houses can constitute 40-60% of total life-cycle energy inputs (Thormark, 2002).

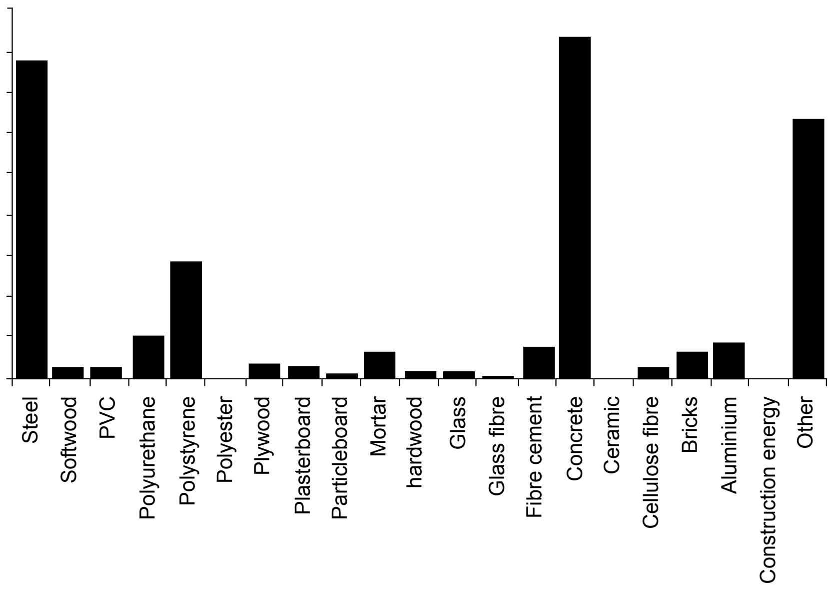

Figure 4. Water use Impacts by Material for all Building Sectors for 2005

5.0 How Sustainable is Australia's Use of Building Materials?

Evaluating what is a 'sustainable' product or material has been the subject of extensive study (Betz et al, 2001; Smith Cooper, 2003; Weidema, 2000). Numerous guidelines and techniques have been put forward specifically for to assess building materials' environmental credentials (Anderson, 2002; Berge, 2000; Curwell et all, 2002; Wooley et al, 1997).

Despite this, there remains no empirical answer to what is 'sustainable' per se. This is fundamentally because we don't understand the capacity or resilience of natural systems. However there is broad consensus as to the characteristics and principles describing sustainability, and an understanding that sustainability depends on a systems perspective. Using this approach, targets, strategies and current performance is summarised briefly in Table 4.

Defining the system requires:	**Understand core functions of the ecosphere**
Australia's Performance	Very poor: "we are just starting to appreciate the role of biodiversity in the provision of ecosystem services and important products that support the economy… the sustainable management of Australia's resource base will not be possible unless (more resources) are directed to support improved understanding and management of the nation's terrestrial and marine ecosystems". (Commonwealth of Australia, 2001, Biodiversity Report, p 4, 7)
Identifying outcomes and success criteria:	• Create only products that are nutrients or raw materials for future resources i.e. waste = food (MBDC) • Consume resources no faster than they can be replenished (NS) • Use available solar income, high energy effectiveness (NS) • Do not degrade the functioning and capacity of natural systems (NS) • Do not lead to concentrations of substances in the earth's crust (NS)
Australia's Performance	Not succeeding: • World-leading per capita waste levels • Rapid growth in use of non-renewable resources thousands or millions of times replacement rates • Dependant on non-renewable fossil fuels contributing 10.89 million tonnes CO_2e to the atmosphere • Broad management practices leading to degradation; a number of species are listed as being at risk from raw materials extraction (note; construction materials use constitutes a small percentage of overall raw materials extraction activities in Australia) (Commonwealth of Australia, 1996) • Extensive evidence of build up of persistent organic pollutants, some of which are from construction materials and practices
Articulate strategies for moving forwards:	• Principles for strategic investments in place in society at large, as well as in individual organisations • Ensuring Industry and sectoral action-plans are under way • Resolve the political means for forwarding issues
Australia's Performance	Mixed/very limited: • Policy road maps in development at Federal and state levels • A number of industry associations and organisations currently undertaking sustainability development • Uptake by small number leading manufacturers • Limited data on research to identify or quantify success of measures
Determine actions:	Including renewable energy, dematerialisation, recycling, etc as long as these comply with all system conditions
Australia's Performance	Not succeeding: • Recycling levels for some materials relatively high; use of recycled content growing, interest in low-toxicity, design for disassembly and dematerialisation growing. However level 2 results indicate these insufficient.
Use relevant assessment tools:	Life Cycle Assessments (LCA), Eco-efficiency tools etc
Australia's Performance	Mixed: • Sustainable Minerals Project, wood products life-cycle inventory (current). However limited systematic use or uptake to date

NS = Natural Step

Table adapted from DEH and (Waage 2005 p1147). *Refer DEH for additional detail.

Table 4. Comparison of current practices to sustainability principles and conditions

Globally and in Australia today, the traditional industrial systems in use in the building products sector typically do not conform to sustainability principles. They are highly linear, taking raw materials from the ecosphere, and returning them as 'waste' (in forms that natural systems cannot use). In theory there is no reason why non-natural materials cannot be used in their own industrial closed-loop cycle, as outlined in the book *Cradle to Cradle* (Mcdonough and Braungart, 2002). However, present patterns of use fail to meet such sustainability criteria and indicators.

5.1 Forward projections for Increased Use of Materials

On the basis of CSIRO's ASFF analysis and using an environmentally optimistic analysis of building size trends (i.e. a projection that means separate dwelling size will reduce over the next 50 years), the study found that annual figures are expected to rise in the next 50 years by:

- 40% Total materials use (by mass).
- 64% Water use.
- 53% Land use.
- 45-50% Minerals, cumulative energy demand, carcinogens and solid waste.
- 36-38% Smog and eutrophication.
- 36% Greenhouse impacts (from 10.89Mt CO_2e (2005) to 15.22MT per annum).

5.2 Environmental impacts of fitouts

Fitouts were excluded from the DEH study scope, but a number of studies indicate they are a significant source of materials use and therefore of environmental impacts arising.

Most studies use embodied energy to measure fitout vs. structural building element impacts. In non-residential buildings these include a range of studies (Scheuer, 2003, Suzuki and Oka, 1998, Howard and Sutcliffe, 1994, Treloar, 1999, Treloar, 2000). Their findings indicate that the impact of refurbishment can be significant in building types such as commercial offices, with inputs equivalent to, or greater than the initial embodied energy of the base building (Cole and Kernan, 1996, Treloar, 1999).

One study found that the grade of fitout was crucial. The difference in impacts between 'high-end' frequently upgraded fitouts, and lower grade, less-frequently churned fitouts, was three-fold (Howard & Sutcliffe (in Cole 1996)).

On residential buildings there is less information available, but a recent study of a New Zealand house found finishes (which included repainting, cladding, roofing, carpets, flooring, curtains, kitchen upgrades, and interior painting) constituted 26-34% of total life-cycle energy inputs (Mithraratne and Vale, 2004).

6.0 Conclusion

It is clear from the above that building materials will be an important component in sustainability efforts in coming decades. The environmental performance of building material, whether it is implications for land management, biodiversity, or climate change, will increasingly come under the spotlight.

Greenhouse emissions are already a focus for reform, and building materials are a contributor to these, both in energy use in manufacture, and in their impact on the life and operational efficiency of buildings. The value of a combined strategy, optimising the environmental performance of materials and buildings as a whole, is apparent. Specifiers and designers will increasingly be looking for practical and quantifiable ways to make a difference.

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