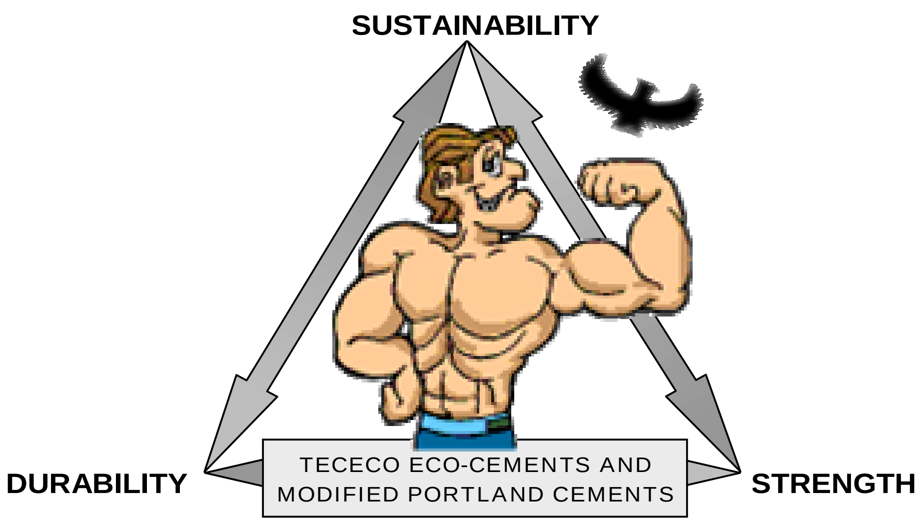
TecEco Pty. Ltd.
Sustainable Technologies

FOR THE NEW MILLENIUM



CONFIDENTIAL TECECO SUBMISSION TO THE INQUIRY INTO THE SUSTAINABILITY OF AUSTRALIAN CITIES

(House of Representatives Committee Inquiry on Sustainable Cities 2025).

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EXECUTIVE SUMMARY

The Federal Government invited submissions to the House of Representatives Committee of Inquiry on Sustainable Cities 2025. This submission has been prepared by TecEco Pty Ltd (TecEco), a small and innovative Australian company that has developed the worlds leading technology for mineral sequestration of carbon dioxide (CO_2).

This submission addresses the terms of reference and draws attention to the critical role of construction materials in the quest for a sustainable built environment. It also demonstrates how magnesium based cements, as developed by TecEco, are able to offer sustainable benefits to the built environment and can result in CO_2 sequestration on a massive scale.

As Fred Pearce reported in New Scientist[1] Magazine, “There is a way to make our city streets as green as the Amazon rainforest. Almost every aspect of the built environment, from bridges to factories to tower blocks, and from roads to sea walls, could be turned into structures that soak up carbon dioxide - the main greenhouse gas behind global warming. All we need to do is change the way we make cement”.

[1] Fred Pearce, *Green Foundations*, New Scientist, vol 175 issue 2351, 19 July 2002, page 39.

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INTRODUCTION

The Federal Government of Australia in 2003 announced an inquiry into the Sustainability of Australian Cities (House of Representatives Committee Inquiry on Sustainable Cities 2025) with the following terms of reference:

1. The environmental and social impacts of sprawling urban development;
2. The major determinants of urban settlement patterns and desirable patterns of development for the growth of Australian cities;
3. A ‘blueprint’ for ecologically sustainable patterns of settlement, with particular reference to eco-efficiency and equity in the provision of services and infrastructure;
4. Measures to reduce the environmental, social and economic costs of continuing urban expansion; and
5. Mechanisms for the Commonwealth to bring about urban development reform and promote ecologically sustainable patterns of settlement.

This submission addresses the terms of reference and draws attention to the ***critical role of building materials in the quest for sustainability***. It also demonstrates how magnesium based cements, as developed by TecEco, are able to offer sustainable benefits to the built environment including hugely significant CO_2 sequestration on a massive scale.

The Critical Role of Materials

Materials are the key to our survival on the planet. The choice of materials that we use to construct our physical world ultimately controls air emissions, lifetime and embodied energies, maintenance of physical and economic utility, recyclability and the properties of resulting wastes that eventually are required to be returned to the biosphere.

For greater sustainability, materials used to construct the built environment should have low embodied energies, low lifetime energies, and low greenhouse gas emissions when considered on a whole of life cycle basis. The selection of materials should ideally also be made with regard to their ability to contain wastes. For example it is possible to make construction materials such as paving, bricks and kerbs that are fit for purpose and can sequester carbon dioxide or render nitrous oxides as harmless. Material selection should encourage the use of life cycle analysis, hence amortizing true costs to society over a longer lifetime. In this context, materials with superior durability and other properties will excel.

The Role of Government

Government has an important role in fostering the advantages of new materials for use in the built environment.

Tax incentives, prescriptive and performance based specification of products, are examples of mechanisms that would assist the development of essential new sustainable building products.

Properties of new materials need to be verified as fit for their intended purpose. Innovators like TecEco need to establish manufacturing operations, and ideally some level of Government support would be made available to overcome initial diseconomies of scale thereby allowing access to markets dominated by a few large internationally owned companies with vested interests.

DOCUMENT OBJECTIVE

This submission has the primary objective of:

- Addressing the terms of reference presented.
- Pointing out the huge potential of the built environment to achieve a much higher level of sustainability and that:
  - Mineral sequestration of carbon dioxide by modified concretes is feasible and potentially a lead CO_2 sequestration technology;
  - There are significant atmospheric CO_2 reduction outcomes.
- Proposing practical policy changes required to bring about the desired sustainable outcomes.

ADDRESSING THE TERMS OF REFERENCE

1. The Environmental and Social Impacts of Sprawling Urban Development

The consequences of the growing urban sprawl are influenced by factors including materials and construction methods, population growth, urban planning, public transportation, and social housing policy.

This submission primarily seeks to point out the influence of choice of materials during their extraction, use and eventual return on the impacts of the built environment and infrastructure.

Many materials such as aluminium and steel have a high embodied energy and are responsible for considerable emissions. Other materials such as some plastics and metals can affect health during use and introduce toxins into the environment when wasted.

Impacts of concrete

(See also Concrete the Largest Factor on page 38)

The main material used for buildings and infrastructure is concrete. Concrete is made by utilising a cement to bond stone and sand together. Ordinary Portland Cement (OPC) is the most common cement used and is an ideal construction material, as it is generally economic, durable, easily handled and readily available.

Concrete is relatively environmentally friendly. Portland cement concretes have low embodied energies compared to other building materials such as aluminium and steel (See also APPENDIX 7 - EMBODIED AND LIFETIME ENERGIES IN THE BUILT ENVIRONMENT on page 57.)

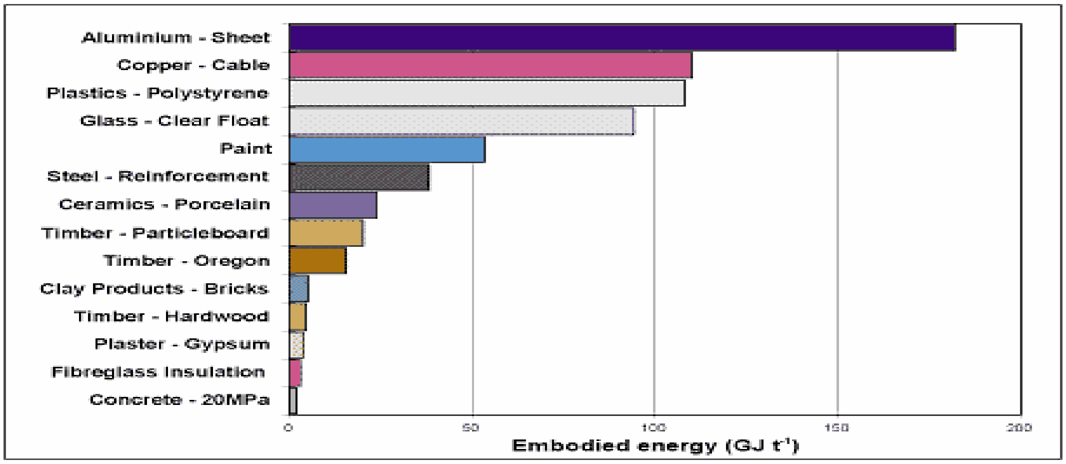
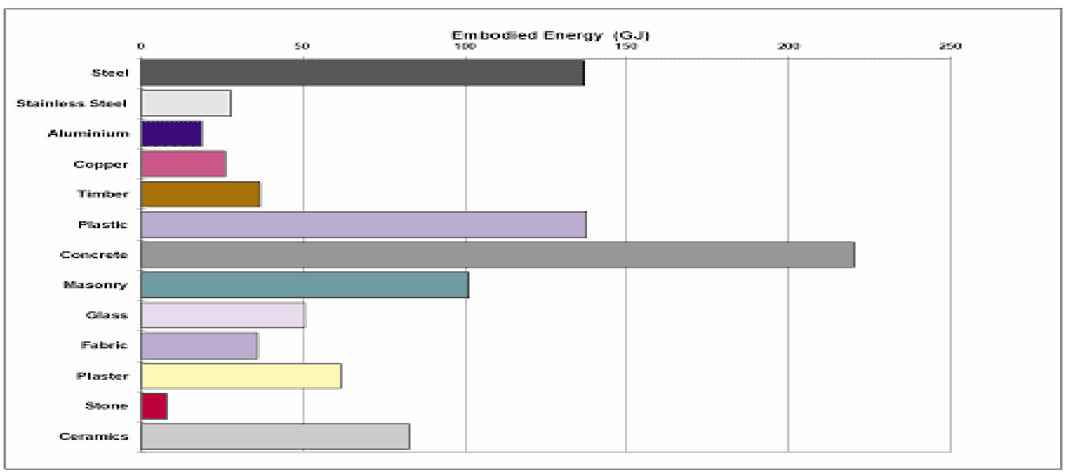


Figure 1 - Embodied Energy of Building Materials[3]

However "Concrete, based mainly on Portland cement clinker, is the most widely used material on Earth. Current estimates of world cement manufacture are of the order of 1.7 X 10^9 tonnes/yr., enough to produce over 6 cubic km of concrete per year or about one cubic metre per person[4]" resulting in significant global emissions.



[3] URL: www.dbce.csiro.au/ind-serv/brochures/embodied/embodied.htm (last accessed 07 March 2000)

[4] Gartner, E., *Scientific and Societal Issues Involved in Developing Sustainable Cements* Roles of Cement Science in Sustainable development. Ed. Dhir, Ravindra K., Newlands, Moray D., Csetenyi, Laszlo J. Thomas Telford, 2003 at page 446.

Figure 2 - Embodied Energy in Buildings[3]

As a consequence of the huge volume of Portland cement manufactured, considerable energy is consumed (See Figure 2 - Embodied Energy in Buildings[3] on page 8) resulting in carbon dioxide emissions. Carbon dioxide is also released chemically from the calcination of limestone used in the manufacturing process.

Approximately 1 tonne of carbon dioxide is emitted to the atmosphere for every tonne of Portland cement manufactured[5]. This is due to:

- the burning of fossil fuels in the kilns used;
- emissions associated with electricity used during the manufacturing process, and;
- the chemical release of CO_2 from calcining limestone.

In Australia, seven million tonnes per year of Portland Cement (OPC) worth nearly a billion dollars is produced[6]. This accounts for more embodied energy than any other material in the construction sector[7]. The manufacture of OPC is one the biggest single contributors to the greenhouse effect, accounting for between 5%[8] and 10%[9,10] of global anthropogenic[11] CO_2 emissions.

Australian and global production of cement is likely to increase significantly over the coming decades as:

- global population grows;
- GDP grows;
- urban development continues; and,
- through increasing industrialisation.

A direct consequence of such huge usage is the associated enormous potential for environmental benefits and improvements in sustainability and the triple bottom line if the material could be improved.

Research is being carried out all over the world to try and develop less energy-intense building material alternatives of which the TecEco blended cement system is the most promising.

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5 Pearce, F., "The Concrete Jungle Overheats", New Scientist, 19 July, No 2097, 1997 (page 14).
6 Email communication, Tom Glasby, Manager, Construction Solutions, Cement & Concrete Association of Australia, 02/05/2003
7 Dr Selwyn Tucker, CSIRO on line brochure at http://www.dbce.csiro.au/ind-serv/brochures/embodied/embodied.htm valid 05/08/2000
8 Hendriks C.A., Worrell E, de Jager D., Blok K., and Riemer P. Emission Reductions of Greenhouse Gases from the Cement Industry. International Energy Agency Conference Paper at www.ieagreen.org.uk.
9 Davidovits, J A Practical Way to Reduce Global Warming The Geopolymer Institute info@geopolymer.org, http://www.geopolymer.org/
10 Pearce, F., "The Concrete Jungle Overheats", New Scientist, 19 July, No 2097, 1997 (page 14).
11 Anthropogenic – human produced

The TecEco cement technology is far more sustainable than either the production of lime or Portland cement and would significantly reduce the impact of these materials. There are many reasons for this.

- The manufacture of reactive magnesia is a benign process that can be achieved with waste or intermittently available energy. The new TecEco kiln technology will result in around 25% less energy being required and the capture of chemically released CO_2 during production resulting in lower costs and carbon credits.
- A high proportion of Brucite compared to Portlandite is water and of magnesite compared to calcite is CO_2. Every mass unit of TecEco cements (containing MgO) therefore produces a greater volume of built environment than Portland and other calcium based cements. Less need therefore be used reducing costs/energy/emissions.
- Energy and emissions are lower, particularly on a volume of built environment created basis.
- Improved durability and other properties will result in lower long run costs/energies/emissions due to less frequent replacement. Brucite is less soluble, mobile or reactive than Portlandite and not attacked by salts or carbon dioxide to the same extent. The drier internal environment and lower long term pH results in greater stability resulting in less delayed reactions, salt attack, etching and other problems. The pH is still however high enough to maintain the passivity of steel.
- A wider range of aggregates can be utilised effectively, including many wastes reducing transport and other costs/energies/emissions.
- Because of the higher pH during the early plastic stage of tec-cements many marginally pozzolanic materials, many of which are wastes, become reactive and add strength.
- Lower binder/strength ratios are achieveable in some tech-cement formulations resulting in less net emissions.
- In porous materials such as bricks, blocks, pavers and mortars that utilise eco-cement CO_2 is reabsorbed as brucite carbonates forming strong binding minerals such as magnesite and hydromagnesite. With capture of CO_2 during manufacture enormous amounts of carbon dioxide could be sequestered. What distinguishes the TecEco technology is that utility (value in products) is added at the same time. Combined with chemical sequestration based on forsterite or serpentinite the potential sequestration utilising TecEco technology is massive:

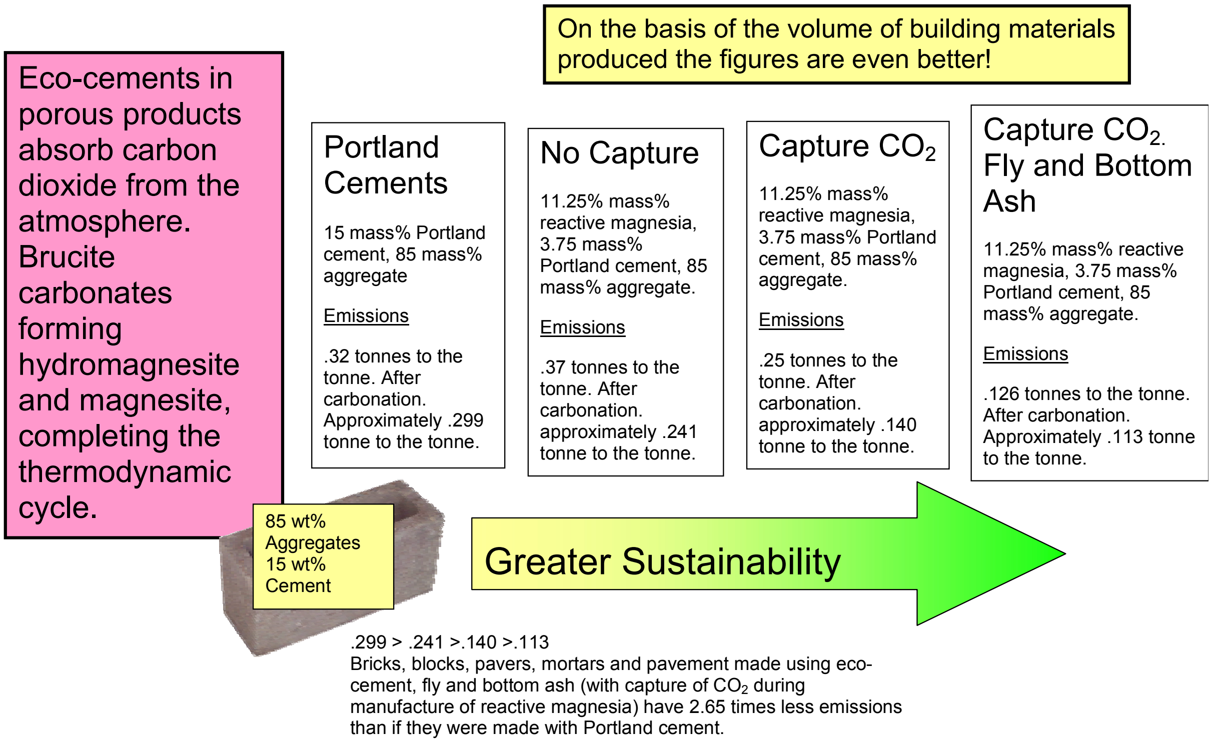

Figure 3 - CO2 Abatement in TecEco Eco-Cements

Impacts of Cement Manufacture.

Cement manufacture is traditionally carried out in large industrial plants located near to a source of the main raw materials which are limestone and clay, and as close to markets as is possible.

Large industrial operations are generally unsightly and cement manufacture generally has detrimental impacts on local areas including noise, dust and heavy metal pollution as well as nitrous oxide, sulphurous and CO_2 emissions. Many cement plants are converting to burning tyres as a fuel source, however there are some consequential detrimental effects on community health[19].

[19] Research worldwide indicates that tyre burning kilns have a serious detrimental impact on community health and the integrity of the surrounding environment. Kiln emissions have been found to cause cancer and respiratory illness. Environmental degradation ranges from physical alteration to heavy metal and chemical contamination http://www.ichetucknee.org/health.html (valid 07/02/2004).

Impacts of Other Building Materials Manufacture.

The manufacture of bricks is a polluting business banned now in many parts of China and India. Timber yards relentlessly devour timber much of which is wasted and all contribute significantly to atmospheric and waterway pollution.

Conclusion

Sprawling urban development will be difficult to stop.

The manufacture of many building materials such as cement and clay bricks is environmentally unfriendly and very polluting.

The impact of the built environment can be reduced by changing the materials and methods of construction used as this will reduce the affect of extractive processes, emissions on manufacture, ability to be recycled and pollutants on eventual return.

2. The major determinants of urban settlement patterns and desirable patterns of development for the growth of Australian cities;

Rapid urbanisation driven by population growth is inevitable[20]. The concentration of the urban population in large cities, the sprawl of cities into wider geographical areas and the rapid growth of mega-cities are among the most significant transformations in Australia and globally in the last hundred years.

The most important factor influencing this trend is population growth however other factors such as:

- the cost of housing.
- access to employment.
- transport and communications infrastructure
- facilities.
- amenities and social fabric.
- environmental qualities (view, microclimate, weather etc.)

motivate population shifts within Australia and from outside the country to Australia

“Infrastructure, especially transportation, shapes cities……Controversy exists between those advocating more compact cities and those advocating reduced densities with technological changes to cars. The debate over size and density includes a consideration both of the efficiency of energy use and liveability. Partial resolution of the controversy may be to enable some parts of cities to be developed more intensely for reductions in energy (and more

[20] Whether population growth continues to be desirable is not the subject matter of this submission, but should be questioned as the most relevant question relating to urban growth.

intensely urban economic activity) and other parts to remain low in density so that green activities can occur there (including urban agriculture and bio diversity restoration activities). It is also possible to maintain the concept of a garden city by combining landscape and buildings in new ways[21]". An option for serious consideration is cluster housing whereby linkages to natural areas are created behind houses in the streetscape in what amounts to continuous park behind houses.

TecEco advocate making cities as green as the cities they replace utilising TecEco eco-cement technology (See APPENDIX 4 - CARBONATE SEQUESTRATION IN THE BUILT ENVIRONMENT on page 38.) in combination with the garden city approach above.

The fact that trees and greenery are essential in cities for the psychological well being of the inhabitants has been the finding of many authors.

Conclusion

Desirable patterns of development will be more sustainable and need to include greater sympathy for the environment.

3. A 'blueprint' for ecologically sustainable patterns of settlement, with particular reference to eco-efficiency and equity in the provision of services and infrastructure;

The 1987 Brundtland Report commissioned by the World Commission on Environment and Development recognized that sustainable development meant adopting lifestyles within the planet's means. The report also clearly identified that the current patterns of economic growth could not be sustained without significant changes in attitudes and actions.

Australia's response was to adopt and further refine the concept of sustainable development, taking into account our unique natural environment, the aspirations and values of the Australian people and the prevailing patterns of economic production and consumption. In the Australian context Ecologically Sustainable Development (ESD) meant using, conserving and enhancing the community's resources so that ecological processes, on which life depends, are maintained and quality of life for both present and future generations is increased.

According to the Australian Government Department of Environment and Heritage[22] "ESD requires changes in the nature of production and consumption so that they can better satisfy human needs while using fewer

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[21] ISOS Online Conference Communiqué at www.isosconference.org.au/

[22] Australian Government Department of Environment and Heritage, An Overview of the National Strategy for Ecologically Sustainable Development December 1992, http://www.deh.gov.au/esd/national/nsesd/overview/

raw materials and producing less waste. The key to ESD is integrating environment and development considerations in decision-making."

Missing is any discussion on the role and importance of materials which are the link between the biosphere and technosphere and key to a more sustainable future. It is not just the quantity of raw materials and volume of waste but what the raw materials comprised of and hence what the wastes contain that matters. If we used less fossil fuel we would for example produce less CO_2 as a waste.

Also missing is significant attention to the design of infrastructure with sustainability in mind. For example the use of porous pavement would significantly reduce the cost of run off and improve the quality of water.

Several ways of reducing energy used and/or greenhouse gas emissions in the built environment, reducing other environmental impacts and improving sustainability are currently being investigated and/or adopted and include:

- Minimising Lifetime Energies.
  Architects, engineers and designers are working to minimise the lifetime energies of buildings. Design improvements are proving relatively easy to implement using building codes and approvals regulations.

- Reducing Embodied Energies.
  The use of supplementary cementitious materials such as fly ash and in the case of TecEco cements reactive magnesia will reduce net emissions. Some international building practice codes such as Green Star[23], encourage the use of supplementary waste materials[24] in concrete mixes. The utilisation of materials such as fly ash in Australia is still however relatively low[25]. Even though TecEco have demonstrated the benefits of the use of reactive magnesia in hydraulic cement blends, the mineral is specifically excluded by outdated formula based standards[26].

- Improving the properties exhibited by materials.

  The development and use of a whole new generation of smarter materials will reduce the impact of urban sprawl and result in improvements in sustainability and the triple bottom line.

  Henry Ford was first to enunciate the sustainable (and doubtless penny pinching) concept that less should be required to do more. As an

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[23] Green Star is the green building programme developed by the Green Building Coiuncil Australia

[24] Fly Ash, a waste product from power station electricity generation, is an example of supplementary materials

[25] 3.85 million tonnes was effectively utilised out of 12 million tonnes produced of fly ash produced in Australia during 2001. *Ash Utilisation – an Australian Perpective*, Craig Heidrich, CEO, Ash Development Association of Australia Inc., 2003 at page 1.

[26] The trend is towards performance rather than formula based standards.

example, materials with durable properties maintain utility longer, thus fewer manufacturing cycles are required and are therefore more sustainable.

Improving the strength, durability, insulation safety and other properties of concrete from the point of view of and idealised purchaser would result in less being used and less steel, aluminium and other higher embodied energy materials being substituted.

- Reducing Emissions and Releases
  Two kinds of gaseous emissions are of concern.

  - Off gassing: Many modern building materials release gases trapped in their structures or as they breakdown. Examples are vinyl, polyurethane varnishes and urea formaldehyde glues. These gases result in what is known as “sick building syndrome.”

  - Gases are produced during the manufacture of most building materials[27]. Developing manufacturing methods that reduce the amount of greenhouse gas emissions associated with existing materials is important. Apart from carbon dioxide, other gases such as nitrous oxides are produced at the high temperatures in a cement kiln and are also of concern.

- Encouraging the development of new environmentally friendly materials such as TecEco tec and eco-cements which when combined with mineral and geological sequestration techniques have the potential for sequestering in the built environment large amounts of CO_2 (See SEQUESTRATION FROM MAKING ECO-CEMENT on page 33).

Conclusion

A recent RMIT University (Australia) press release stated that "new research is showing that careful materials selection can reduce the energy required to construct buildings by more than one third and that materials specification is crucial to indoor air quality, well being and productivity".

It is imperative that the importance of materials as the key to sustainability of the built environment is understood (See also Materials - The Key to Sustainability on page 29).

The built environment is our footprint, a major proportion of the technosphere and our lasting legacy on the planet. It is the dominant proportion of all materials flows.

By carefully selecting appropriate materials to construct the built environment, it is possible to reduce emissions and even provide net sequestration, reduce the take from the environment and improve the effective life of built resources

[27] Bricks for example are heated in a kiln, steel in furnaces and so on.

resulting in any detrimental impacts associated with a material being amortised over a longer period. It is also possible to reduce waste, as correctly selected materials can be recycled for use in the same or different applications.

Using more of the right inputs in a sustainable manner and manufacturing with a life cycle philosophy will reduce outputs that the biosphere can no longer manage without undesirable consequences such as global warming and pollution.

The challenge embraced by TecEco is to create materials that:

- have comparable if not superior properties,
- maintain greater utility longer,
- do not have to be down or out cycled, and
- result in less outputs to the biosphere that cannot naturally be re assimilated.

The challenge facing the Australian government is how to foster the development of new materials such as those being developed by TecEco with triple bottom line benefits and reduced linkages with the biosphere such as the TecEco eco-cement technology.

4. Measures to reduce the environmental, social and economic costs of continuing urban expansion;

Measures required to reduce the environmental, social and economic costs of continuing urban expansion are essential. This submission focuses on the environmental and sustainability issues with a focus on materials.

The impact of transport infrastructure is controlled by the public purse and hence relatively easy to reduce by better design, construction techniques and materials use.

Fostering Good Design and Sound Urban and Engineering Principles

Good design of our urbane landscape extends beyond street layout, land use zoning and building approvals. It includes the way the built environment is constructed and the materials it is constructed out of.

For example roads and curbing carpet urban land, keeping rain water out of aquifers and redirecting it to the sea causing enormous runoff and pollution problems. The use of porous pavement overcomes many of these problems and should as a matter of urgency be contemplated. (See APPENDIX 9. POROUS PAVEMENTS - AN OPPORTUNITY FOR SUSTAINABILITY on page 64)

Utilising Sustainable Materials Technology

Whilst the use of more sustainable materials will not reduce urban development, their use for buildings and infrastructure will reduce the impact.

Provided the environmental impact of urbanisation can be curtailed, the well managed growth of cities has the capacity to result in improvements in living standards.

The Habitat Agenda points out[28] that "during the course of history, urbanization has been associated with economic and social progress, the promotion of literacy and education, the improvement of the general state of health, greater access to social services, and cultural, political and religious participation. Democratisation has enhanced such access and meaningful participation and involvement for civil society actors, for public-private partnerships, and for decentralized, participatory planning and management, which are important features of a successful urban future. Cities and towns have been engines of growth and incubators of civilization and have facilitated the evolution of knowledge, culture and tradition, as well as of industry and commerce. Urban settlements, properly managed, hold the promise for human development and the protection of the world's natural resources through their ability to support large numbers of people while limiting their impact on the natural environment."

The Habitat Agenda further points out that "Increasingly, cities have a network of linkages that extend far beyond their boundaries. Sustainable urban development requires consideration of the carrying capacity of the entire ecosystem supporting such development, including the prevention and mitigation of adverse environmental impacts"

Materials are the linkage between the environment (the biosphere) and us (living in our "technosphere"). At the micro level the molecules we use and at the macro level the way we put them together control the impact on the biosphere during their production, time they remain in the technosphere and impact when they eventually exit as waste back to the biosphere (See also Materials - The Key to Sustainability on page 29).

The use of TecEco cement technology to reduce the environmental and social impacts of cement and concrete

TecEco have developed a cement technology that can partially replace and substitute conventional OPC cement with a more sustainable and environmentally friendly but complementary binder based on magnesium minerals.

The Magnesium based technology works well with existing OPC cements based on calcium and can enhance many of the properties of concretes. The

[28] http://www.unchs.org/habrdd/global.html

main sustainability consequences of blended cements containing magnesium compounds are:

- Reduced emissions of CO_2 and toxic gases. Reduced kiln temperatures and energy input required during manufacture resulting in reduced CO_2 emissions.
- Potential CO_2 capture during manufacture.
- Higher CO2 absorption in porous eco-cement formulations
- The ability of magnesium – Portland cement blended cements to use higher proportions of waste material (e.g. fly ash, ground iron slag and other industrial wastes).
- The use of less total cement to produce the same quality concrete.
- Increased service life of the built environment as a result of increased durability.
- Increased potential for the use of decentralized and smaller cement manufacturing plants having a lower localised impact.

"Complementary to traditional areas of energy research, such as improving energy efficiency or shifting to renewable or nuclear energy sources, carbon sequestration will allow (the) continued (inevitable) use of fossil energy, buying decades of time needed for transitioning into less carbon-intensive and more energy-efficient methods for generating energy in the future.[29]"

The built environment offers tremendous opportunities for abatement and sequestration achievable only by a focus on new materials such as TecEco cements.

Combined with chemical sequestration based on forsterite or serpentinite and geological sequestration techniques the potential sequestration utilising TecEco technology is some three times greater than using either method on its own (See SEQUESTRATION FROM MAKING ECO-CEMENT 33)

Reactions with forsterite appear to occur more readily and result in greater abatement. Reactions with chrysotile or serpentine as it is sometimes called are however favoured as the mineral is abundant although problems remain to be solved with the kinetics.

It is economically feasible and technically viable for the built environment to holistically become our largest CO2 repository.

Conclusion

The built environment is our footprint on the globe and because of the high volume of materials involved represents huge opportunities for sustainability.

The development and appropriate selection of new environmentally friendly materials will be crucial in reducing the detrimental impacts of continuing urban expansion.

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[29] *Chemical And Geologic Sequestration Of Carbon Dioxide*, at http://www.netl.doe.gov/products/r&d/annual_reports/2001/cgscdfy01.pdf , page 7 valid 28/12/03.

Materials are in fact the key to our survival on the planet. The choice of materials controls emissions, lifetime and embodied energies, maintenance of utility, recyclability and the properties of wastes returned to the biosphere.

Materials should ideally exhibit the following properties:

- Limited amounts of embodied energy associated with manufacture.
- Low net emissions and preferably sequestration.
- Economical to produce and use.
- Fit for purpose with appropriate maintenance free service life.
- Re useable/ re cycle properties.
- Minimal environmental footprint.

The use of magnesium-based cements in combination with OPC based concretes and supplementary materials offer an economically achievable solution to reduce the environmental, social and economic costs of continuing urban expansion

5. Mechanisms for the Commonwealth to bring about urban development reform and promote ecologically sustainable patterns of settlement.

Many countries in the world such as Canada, the UK and the US have targeted research as means of priming the pump to address sustainability, climate action and other environmental concerns of urban development. In spite of much rhetoric, the reverse has been the case in Australia. Research funding is driven by market forces and abatement for example blatantly market driven with the Australian Greenhouse Office doing little more than buying emissions reductions.

A genuine national carbon trading system would be better than the fragmented one that is currently evolving and the Federal government should as a priority introduce such a system to add confidence to the carbon dollar.

Although it makes sense economically to reduce emissions (given scale, emissions = energy = money (and with carbon trading, more money)), less obvious changes necessary such as materials research require more subtle government intervention and funding. Market forces alone will not be enough to drive important research into the fundamental behind sequestration which is materials science.

In January 2002, four priority areas were identified for ARC funding: Complex / Intelligent Systems, Genome / Phenome Research, Nano- and Bio-materials and Photon Science and Technology. As of January 2004, the funding agencies have still not caught up with the importance of funding materials science as the key to the changes in our usage patterns required for sustainability.

Fundamental changes are necessary to achieve real sustainability and if these are to occur without economic disruption, as the materials we use control the sustainability of the systems we proliferate, the materials paradigm we live in will also have to change.

The mechanisms available to the Commonwealth Government to bring about change, particularly in the built environment where ecologically sustainable patterns of settlement are required include:

1. Research and Development Funding Priorities to included the funding of research development and deployment of new materials technologies.
2. Procurement policies:
   Government in Australia is more than 1/3 of the economy and can strongly influence change through:
   - Life cycle purchasing policy.
   - Funding of public projects and housing linked to sustainability
3. Intervention Policies
   - Building codes including mandatory adoption of performance specification.
   - Deposit legislation on not just packaging, but a wide range of goods including whitegoods and motor vehicles. (legislation whereby manufacturers have to accept back their products is proving very successful in Germany as a method of forcing greater recycling)
   - Mandatory use of minimum standard materials that are more sustainable
4. Taxation and Incentive Policies
   - Direct or indirect taxes, bonuses or rebates to discourage/encourage sustainable construction etc.
   - A national system of carbon taxes.
   - An international system of carbon trading.
5. Sustainability Education

1. Research and Development Funding Priorities to included the funding of research development and deployment of new materials technologies.

The main change required is to bring national priorities of for research up to date with the urgent requirements of climate action is to include materials science, energy and sustainable technologies. Such changes should urgently reflect in ARB funding policy.

To “prime the pump” and get urgent research development and deployment happening direct funding as a matter of national importance of promising new materials science breakthroughs should be considered. TecEco as one of the lead companies in the race for more sustainable materials would be prepared to negotiate a share in royalty income with the government in return from potential huge global returns.

2. Procurement policies:

Life cycle purchasing policy.

The development of purchasing procedures that are governed by life cycle performances will be a strong tool for the government to assess and adopt materials that will have an overall minimal impact on the environment, society and economics of the nation.

Funding of public projects and housing linked to sustainability

Prescriptive specifications detail the material to be used for a project. If the Commonwealth Government specified the use of new more sustainable materials such as TecEco's magnesium-based cements in appropriate construction projects (following verification research), it would know that certain measures to bring about urban development reform were being met.

In order to bring this about is will be necessary to employ sustainable champions. Akin to a quantity surveyor, such champions would have the role of keeping the project on track to ensure that material selection and procedures have minimal detrimental impacts.

3. Intervention Policies

Building codes including mandatory adoption of performance specification.

Current outdated formula based standards supported by the industry because of vested interests and fear of change should be required to follow the modern trend of performance based specifications giving suppliers criteria to adhere to. As a matter of urgency the Commonwealth Government could adopt performance-based specifications for cement /concrete that:

- restrict the amount of embodied energy,
- restrict the associated emissions of greenhouse gases and
- detail the durability characteristics of the finished product.

Concretes of the future logically will become more composite in composition and current formula based standards are now actually holding up the development of much better materials directed towards existing market demand from more than just strength. Other desirable properties such as durability, insulating capacity, light weight and so on can only be introduced by innovation currently throttled by formula based standards. Given the volume of materials flows the sustainability outcomes of a shift to performance based standards will be significant.

National Deposit Legislation.

Deposit legislation for some packaging is active in South Australia which as a result has far less urban pollution and lower costs to councils of collection and obvious benefits in terms of tidiness. There is no reason why such legislation could not be introduced on a national scale with resulting efficiencies in collection and reuse systems. Extension to include white goods, motor vehicles and many other consumer items would be a logical step to a more sustainable urban environment as such items that could substantially be recycled are currently a major proportion of waste streams. A novel idea and world first would be to include bricks, blocks, glass, metal roofing iron and many other recyclable building products. Savings in landfill costs alone would make the proposal worthwhile.

Mandatory use of Minimum Standard Materials that are more Sustainable

As the need is urgent it may be necessary to ensure the changes required come about to develop legislation requiring the mandatory use of more sustainable materials such as the calcium magnesium cement blends proposed by TecEco.

4. Taxation and Incentive Policies

Direct or indirect taxes, bonuses or rebates to discourage/encourage sustainable construction etc.

Taxes and rebates are a powerful tool in the hands of governments to direct expenditure in perceived desirable directions.

A National System of Carbon Taxes

The proliferation of various state run systems such as in Queensland and NSW should be superseded as soon as possible by worthwhile national carbon trading legislation secured by agreement with the states.

Such as step may be difficult to implement, but should not cost the public purse much. A significant outcome would be the leverage to market forces already in present that will bring about quantum improvements in sustainability at little overall net cost, but much required reallocation of capital.

An International System of Carbon Trading

Joining Kyoto would internationalize and legitimize carbon trading and would be worth if for the carbon credits attached to multiple cycle TecEco sequestration technology if for no other reason.

4. Sustainability Education

An emphasis needs to be given to the education across all disciplines as to the importance of sustainability. The sustainability of the built environment is influenced by a wide range of professionals including investors, developers, local governments, clients, accountants and many more. An understanding of sustainability needs to be fostered from a young age in everyone.

It should be mandatory for engineers to include more materials science in their courses as many have little understanding of the environmental impact of the materials they use. The education of professionals into the consequences of using different materials and the benefits of using sustainable materials is a high priority and should be linked to higher education funding.

Conclusion

The role of governments is to ensure that public need is addressed even if the public do not understand that need. Action is required to address climate change and the more subtle detrimental affects of sprawling urban settlement. Policies and actions are required that do not impinge too heavily on budgets and several such legislative and policy opportunities to bring about the changes required have been suggested in this section.

If all Australian governments committed to building social, environmental and economic sustainability into every element of governance, we could be an example to the rest of the world.

The manufacture and use of low energy, low emissions cements has been demonstrated by TecEco to be technically feasible and should be encouraged as a matter of national importance utilising policies such as those suggested.

OVERALL SUMMARY

The problems of urban growth are manifest, but because of the size and impact, opportunities are also available to bring about change required in pursuit of genuine sustainability.

Many of the materials used in the construction and the development of the built environment have associated detrimental environmental effects. This submission demonstrates that better materials selection is crucial to ensure the built environment 2025 will realise the potential of a truly sustainable relationship with the environment on which the people living in it depend. Materials used should:

- be suitable for purpose and have
- low embodied energies,
- low lifetime energies,
- low associated greenhouse gas emissions considered on a life cycle basis, and
- incorporate wastes that add to properties.

The government has a role in ensuring the new materials technology developed by TecEco is:

- Properly tested
- Readily available
- An economic and cost effective substitute for existing materials such as OPC.
- More sustainable with less lifecycle greenhouse gas emissions, greater utilisation of waste and easier recycling.

The detrimental environmental consequences of the use of cement and concrete have been clearly identified. Used in large quantities cement as it is today produces substantial quantities of carbon dioxide, which are emitted to the atmosphere. This is clearly not sustainable.

Government money and intervention in many different ways is required to bring about the changes necessary to prevent further decay of the support systems of the biosphere on which we depend.

Formula based standards have no relevance in a world where there is an urgent need for new and better materials that reduce our take from the environment by for example being more durable and by incorporating many wastes in their composition, have lower embodied energies and reduced emissions and higher performance over a wider range of criteria.

Leading the field in new sustainable materials are magnesium based cements TecEco have developed that demonstrate many properties that are essential for a sustainable built environment of the future.

Magnesium based cements generally reduce the amount of emitted greenhouse gases during the manufacturing process, have less embodied energy and have the ability to sequester atmospheric carbon dioxide. The products produced by using this technology exhibit enhanced durability and subsequence longer service and life cycles reducing the need to manufacture as much product and can accommodate many wastes.

The development of the TecEco technology was recently advocated by the recent ISOS conference communiqué which can be downloaded in an electronic form from the conference web site, www.isosconference.org.au.

According to the conference communiqué "the present trajectory of planetary human civilisation is unsustainable. Our children face an uncertain future as a result of human "planetary overload". The most urgent challenge of our time is to discover humanity's path to a sustainable future[31]".

There were specific recommendations on each of the nine themes considered by the conference and a set of overarching recommendations in the concluding section of this communiqué. The findings of theme 9, Transport and Urban Design had the following to say about the TecEco technology

"At least five per cent of global anthropogenic greenhouse gas emissions are attributable to the manufacture and use of Portland cement[32]. Eco-cement, an Australian innovation, not only releases less CO_2 during its manufacture, is also capable of sequestering CO_2 and of recycling industrial waste."

"A sustainable future global society is technically possible, economically feasible and socially desirable, but we need the political will to manage the transition. Our science gives us better understanding than ever before of the natural world and our impacts on it. Technology gives us unprecedented

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[31] ISOS Online Conference Communiqué at www.isosconference.org.au/
[32] The figure is more like 10%!

capacity to change the world to meet our needs and suit our desires. Humanity requires us to use that scientific understanding and technological capacity to develop as a sustainable society. That is a moral responsibility to future generations as well as to the other species with which we share the planet.[33,34]

It is important to assess:

- The extent to which choice of materials influences sustainability outcomes
- How then to influence the choice of materials to encourage sustainability.

The case for more sustainable building materials including concrete, which is used the most widely, is overwhelming

National Benefit

A focus on materials as a means of meeting sustainability objectives including emissions reductions, will address the following national issues:

1) An environmentally sustainable Australia:

- Transforming existing industries
- Reducing and capturing emissions
- Providing a way forward for the Kyoto process without economic downsides.

2) Frontier technology:

Australia has an opportunity to lead the world in advanced sustainable building materials offering huge opportunities for abatement.

The magnesia based cements discussed will result in increased durability of concretes and steel reinforcement. Longer term benefits will include a lowering of CO_2 emission through partial replacement of conventional Portland cements by magnesia cements and substantial savings in the cost of infrastructure replacements through improved durability of both concrete and the associated reinforcement throughout Australia.

The technology will also form the basis of a new industry based on magnesite or magnesium silicates, ores available in abundance in Australia.

[33] ISOS Online Conference Communiqué at www.isosconference.org.au/
[34] The ISOS conference was organised by three non government organisations: Australia 21, Nature and Society Forum and Sustainable Population Australia. Sponsors included the CSIRO, Australian National University, ACT Government Office of Sustainability and Land and Water, Australia.

Environmental Benefits

The use of more environmentally friendly materials, including low energy/emission cements proposed by TecEco, will help to minimise the consumption of energy and natural resources by:

- Significantly reducing energy consumption in manufacture in comparison with Portland cements.
- Helping to conserve resources and reducing landfill through the possible use of waste materials in manufacture and as cement replacements.

Their use could enhance and protect the environment by:

- Reabsorbing CO_2 released during manufacture more rapidly than concrete products made with Portland cements
- Providing a means of immobilising toxic and radioactive wastes.
- Providing a more durable built environment requiring less repair and replacement.
- Reducing the consumption of total binder for a given volume of concrete.
- Allowing a wider range of aggregates including aggregates manufactured from wastes to be used.

As Fred Pearce reported in New Scientist[35] Magazine, "There is a way to make our city streets as green as the Amazon rainforest. Almost every aspect of the built environment, from bridges to factories to tower blocks, and from roads to sea walls, could be turned into structures that soak up carbon dioxide- the main greenhouse gas behind global warming. All we need to do is change the way we make cement".

Standing out as easily achieved with the most beneficial outcome is the TecEco cement technology which therefore merit serious attention by industry and governments.

INTERESTED READERS ARE INVITED TO OUR WEB SITE AT WWW.TECECO.COM WHERE MANY OTHER DOCUMENTS ARE AVAILABLE

[35] Fred Pearce, *Green Foundations*, New Scientist, vol 175 issue 2351, 19 July 2002, page 39.

APPENDIX 1 - IMPORTANCE OF THE BUILT ENVIRONMENT FOR SUSTAINABILITY

The built environment offers immense potential for sustainability. According to the Australian Federal Department of Industry, Science and Tourism[36][37], buildings are responsible for some 30% of the raw materials used, 42% of the energy, 25% of water, 12% of land use, 40% of atmospheric emissions, 20% of water effluents, 25% of solid waste and 13% of other releases. Include infrastructure as well and the figure is likely to be double.

To be sustainable buildings should not only be designed to minimise lifetime energies but also be made of relatively inexpensive materials that have low embodied energies. Total emissions should be as low as possible and the materials themselves should not only provide strength, 3D space that insulates and holds heat or cold as required, but have a minimum impact on the environment on extraction and on eventual return.

Many researchers in many nations and are examining alternative building products as a means of improving recyclability, reducing sick building syndrome, sequestering carbon and encapsulating industrial wastes.

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[36] Australian Federal Department of Industry, Science and Tourism, Environmental and Economic Life Cycle Costs of Construction, 1998, Detailed Discussion Paper, Section 2, p8.
[37] The reference given by Industry Science and Tourism was David Malin Roodman and Nicholas Lenssen Worldwatch paper 124 *How Ecology and Health Concerns Are Transforming Construction.*

APPENDIX 2 - GAINING CONTROL OF THE GLOBAL CARBON BALANCE

There are only a limited number of ways to dramatically change the status quo and improve sustainability on a large scale and many have attached costs that are unpalatable to governments.

Reduce Fossil Fuel Consumption

A reduction in fossil fuel consumption is a difficult to achieve, particularly in the developing world as standards of living are related to consumption.
Moves towards greater energy efficiency with for example hybrid vehicles, hydrogen vehicles or the use of sustainably generated electricity are occurring but only very slowly.

Reduce deforestation

The large forests of the world such as in Brazil, Africa, South East Asia and some parts of Australia are being removed at an alarming rate severely impacting on global oxygen production in the biosphere. The key is to reduce the demand for timber as a building material and source of fibre for paper and composites. Improvements in substitute materials will make this possible

Improve the Sustainability of the Built Environment

There is a challenging opportunity to improve sustainability in the built environment and because of the size of the materials flows concerned, significant outcomes through:

Minimising Lifetime Energies

Architects engineers and designers are very involved in the effort to minimise the lifetime energies of buildings. So far design improvements have proved relatively easy to implement using building codes and approvals regulations. There is however a limit to how much further improved design can minimise lifetime energies. In the future building products, including for example phase change materials and a better balance between properties such as insulation and heat capacity, will be required.

Reducing Embodied Energies

Embodied Energies in the built environment are highest for aluminium followed by copper used in wiring, plastics, glass, paint, steel then ceramics. Concrete has an embodied energy of only 2.7 $Gj.tonne^{-1}$ (See APPENDIX 8 - EMBODIED ENERGY & CO2 EMISSIONS on page 62) however is used in quantities as high as 6 cubic kilometers per annum globally and therefore has an enormous impact. Concrete also has high thermal capacity and great compressive strength and these properties explain its widespread use. Ordinary Portland cement concrete is not however a good insulator.

Improvements in manufacturing and the properties of concretes demonstrated by companies such as TecEco will enable lower embodied energies and greater sustainability to be achieved.

Improving Properties

Improvements in the properties of materials will enable less to do more better. As an example, better quality durable materials maintain utility longer, require manufacture less often and are therefore more sustainable. By improving durability, insulation and other properties of concrete and by lowering the embodied energy, substitutable steel, aluminium and other higher embodied energy materials are likely to be used. As a result forests are less likely to by cut down and the sustainability of the built environment will substantially improve.

Reducing Emissions and Releases

Two kinds of gaseous emissions are of concern.

- Many modern building materials release gases trapped in their structures or as they breakdown. Examples are vinyl and urea formaldehyde glues. These gases result in what is known as “sick building syndrome.”
- Most building materials release greenhouse gases during manufacture and the CO_2 equivalent of many common building materials is shown in APPENDIX 8 - EMBODIED ENERGY & CO2 EMISSIONS on page 62. Other gases such as nitrous oxides produced at the high temperatures in a cement kiln are also of concern.

Magnesium compounds are very safe and commonly ingested without problem in for example cabbages. A reduction in net greenhouse gas emissions will occur with adoption of TecEco kiln technology and re-absorption of CO_2 by eco-cements.

Materials - The Key to Sustainability

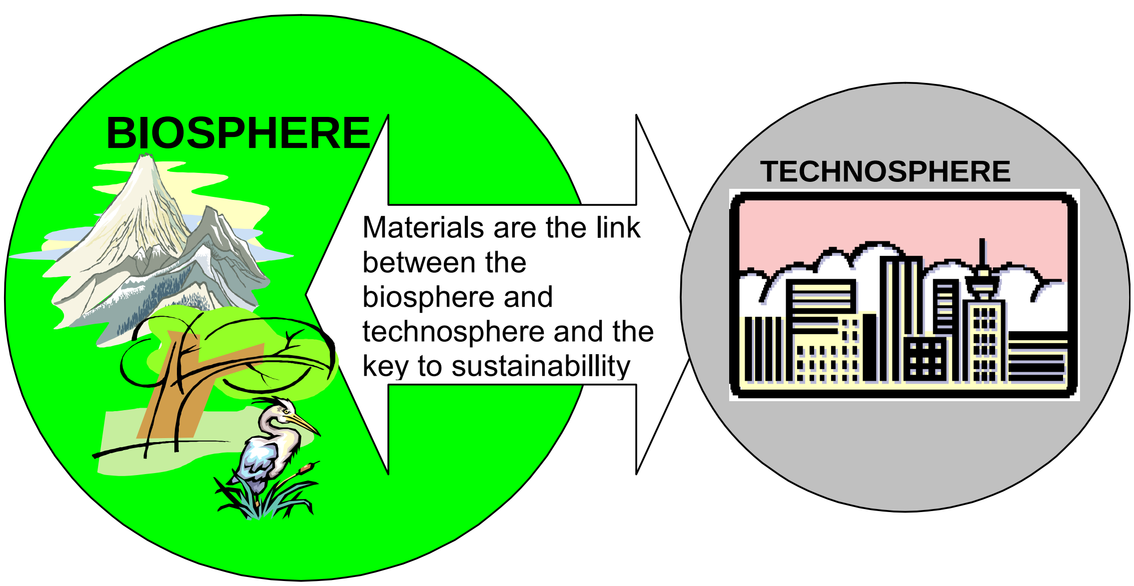

Figure 4 – Materials - The Key to Sustainability

In the take-make-use-waste society that we have created on this planet what we take from the "biosphere" to sustain ourselves and create and power our "technosphere" eventually ends up as "waste" that must be assimilated by the "biosphere". By carefully selecting what we take we can control how long utility is maintained and therefore how long these resources are kept in the technosphere rather than being returned to the biosphere in an altered and often polluting form. In this sense the materials we use and the molecules that comprise them are the key to a more sustainable environment (See Figure 4 on page 29).

Using more of the right inputs in a sustainable manner and manufacturing with final use or wastage in mind will reduce outputs the biosphere can no longer handle without undesirable consequences such as global warming and pollution.

The built environment is our footprint, a major proportion of the technosphere and our lasting legacy on the planet. In this dominant proportion of all materials flows unsustainable practices abound from the logging of old growth forests to the high volume of wastage at landfill.

The challenge embraced by TecEco is to create materials that have comparable if not superior properties, that maintain greater utility longer, that do not have to be down or out cycled, and that result in less outputs to the biosphere that cannot naturally be re assimilated.

According to a recent RMIT university (Australia) press release "new research is showing that careful materials selection can reduce the energy required to construct buildings by more than one third and that materials specification is crucial to indoor air quality, well being and productivity".

Materials are the key to our survival on the planet. The choice of materials controls emissions, lifetime and embodied energies, maintenance of utility, recyclability and the properties of wastes returned to the biosphere.

The built environment is our footprint on the globe and because of the high volume of materials involved represents huge opportunities for sustainability.

APPENDIX 3. - THE BUILT ENVIRONMENT AS A REPOSITORY FOR SEQUESTRATION ON A MASSIVE SCALE

The Built Environment is potentially a repository for sequestration on a massive scale. Starting with either forsterite or serpentine to produce eco-cements the total sequestration is much more than any other method, and the solid output a useful product for constructing the built environment saving on alternative production and disposal costs. Mineral and geological sequestration are combined resulting in a solution to the carbon balance problem with positive economic outcomes.

"Complementary to traditional areas of energy research, such as improving energy efficiency or shifting to renewable or nuclear energy sources, carbon sequestration will allow continued use of fossil energy, buying decades of time needed for transitioning into less carbon-intensive and more energy-efficient methods for generating energy in the future.[38]"

Carbonate sequestration has been the mechanism through which previous atmospheric global carbon imbalances have been corrected and still represents the best opportunity for permanent immobilization of atmospheric carbon.

The deposition of carbonate sediments is a slow process and involves long periods of time. Ways of accelerating sequestration using carbonates include geological sequestration and mineral carbonation. "there are significant fundamental research needs that must be addressed before geologic formations can be widely used for carbon sequestration.[39]" "Mineral carbonation, the reaction of CO_2 with non-carbonated minerals to form stable, benign mineral carbonates, has been identified as a possible safe, long-term option for storing carbon dioxide by many authors[40][41][42][43][44][45][46][47]"

The TecEco eco-cement technology involves mineral carbonation with the added benefit of an end product of the process that is of value and made of eco-cement concrete. Products manufactured using the TecEco eco-cement technology to date include include bricks,

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[38] *Chemical And Geologic Sequestration Of Carbon Dioxide,* at http://www.netl.doe.gov/products/r&d/annual_reports/2001/cgscdfy01.pdf , page 7 valid 28/12/03.
[39] *Chemical And Geologic Sequestration Of Carbon Dioxide,* at http://www.netl.doe.gov/products/r&d/annual_reports/2001/cgscdfy01.pdf , page 1 valid 28/12/03.
[40] *Chemical And Geologic Sequestration Of Carbon Dioxide,* http://www.netl.doe.gov/products/r&d/annual_reports/2001/cgscdfy01.pdf at page 8 valid 28/12/03.
[41] Seifritz, W. (1990). Nature, 345, 486.
[42] Lackner, K., Wendt, C., Butt, D., Joyce Jr., E., and Sharp, D. (1995). Energy, 20, 1153-1170.
[43] Walters, R. P., Chen, Z. Y., Goldberg, P. M., Lackner, K. S., McKelvy, M. J., and Ziock, H. (1999). Mineral carbonation: A viable method for CO_2 sequestration.
[44] Morgantown, WV: National Energy Technology Laboratory, US DOE: http://www.fetc.doe.gov/products/ggc
[45] Dahlin, D. C., O'Connor, W. K., Nilsen, D. N., Rush, G. E., Walters, R. P., and Turner, P. C. (2000). A method for permanent CO2 sequestration: Supercritical CO_2 mineral carbonation. 17th Annual International Pittsburgh Coal Conference.
[46] O'Connor, W. K., Dahlin, D. C., Nilsen, D. N., Walters, R. P., and Turner, P. C. (2000). Proceedings of the 25th International Technical Conference on Coal Utilization & Fuel Systems, 153-164.
[47] Fauth, D. J., Baltrus, J. P., Knoer, J. P., Soong, Y., Howard, B. H., Graham, W. J., Maroto-Valer, M. M., and Andrésen, J. M. (2001). Prepr. Symp. Am. Chem. Soc., Div. Fuel Chem., 46(1), 278.

blocks, pavers, mortars, renders and potentially porous pavement and are distinguished in that they can sequester carbon dioxide whilst providing the fabric for the built environment.

Combined with chemical sequestration based on forsterite or serpentinite which is carbonated in accordance with the following reactions the potential sequestration utilising TecEco technology is massive:

$½Mg_2SiO_4 + CO_2 \rightarrow MgCO_3 + ½SiO_2 + 95\ kJ.mol^{-1}$

$^1/_3Mg_3Si_2O_5(OH)_4 + CO_2 \rightarrow MgCO_3 + 2/_3SiO_2 + 2/_3H_2O + 64\ kJ.mol^{-1}$

The first reaction with forsterite appears to occur more readily and results in greater abatement. The second reaction with chrysotile or serpentine as it is sometimes called is favoured as the mineral is abundant although problems remain to be solved with the kinetics.

At low partial pressures of CO_2 and relatively low temperatures, $MgCO_3$ will break down yielding MgO and CO_2[48].

$MgCO_3 \rightarrow MgO + CO_2 - 118.28\ kJ.mol^{-1}$

Utilising a closed system such as with TecEco Kiln technology the CO2 re-emitted can be captured for industrial use (replacing alternative production) or direct sequestration.

The MgO can then either be re carbonated for further capture for as many cycles as required or used to make eco-cement products.

$MgO + H_2O \rightarrow Mg(OH)_2 + 109.19\ kJ.mol^{-1}$

$Mg(OH)_2 + CO_2 \rightarrow MgCO_3 + H_2O + 37.04\ kJ.mol^{-1}$

Sequestering even more CO2

Total sequestration is two, three or many times that possible with direct mineral sequestration of forsterite or serpentinite alone, depending on whether the CO_2 produced during calcination replaces or abates other production or not and how many cycles of calcination are rolled over. Sequestration possible with one one, five or ten calcination cycles is shown in Table 1 - Silicate Molar Tonne Equivalents on page 33.

Note that the above analysis has not been carried out on a complete life cycle basis and hence emissions as a result of mining and processing etc. have not been accounted for.

[48] Equilbrium at one atmosphere is 540 ^oC. Waste heat could be used.

	Chrysotile (Serpentinite)	Forsterite (Mg Olivine)
Tonnes CO2 sequestered by 1 tonne of mineral mined directly	.4769	.6255
Tonnes CO2 captured during calcining	.4769	.6255
Tonnes CO2 captured by eco-cement	.4769	.6255
Total tonnes CO2 sequestered or abated per tonne mineral mined (Single calcination cycle).	**1.431**	**1.876**
Total tonnes CO2 sequestered or abated (Five calcination cycles.)	**3.339**	**4.378**
Total tonnes CO2 sequestered or abated (Ten calcination cycles).	**5.723**	**7.506**

Table 1 - Silicate Molar Tonne Equivalents

SEQUESTRATION FROM MAKING ECO-CEMENT

The following graphs illustrate the massive sequestration available[49] even with only one cycle of calcination. More cycles would result in greater calcination.

It can be seen from the graphs that starting with either magnesite, forsterite or serpentine the amount of eco-cement or eco-cement concrete that can be produced is about the same, in that around 10 million tonnes will give a similar amount of eco-cement of around 6.6 to 8.7 million tonnes – roughly the capacity of the Australian cement industry.

The total sequestration however is very different depending on the starting mineral. For one cycle of calcination only for each 10 million tonnes mined, forsterite gives the best result at 18,766,257 tonnes of CO_2 sequestered, starting with serpentine the figure is 14,307,916 tonnes of CO_2 sequestered and with magnesite 10,438,805 tonnes CO_2 are sequestered. At $ 15- 30 dollars per tonne for carbon credits the values are respectively $ 313, 563 and 429 million dollars, and inventive worth considering by the concrete industry.

Summary totals presented by the Wood's Hole Institute for carbon in the carbon cycle during the decade ending 1990 (in billion metric tonnes or petograms) are as in Table 2 below:

Table 2 - Summary totals presented by the Wood's Hole Institute for carbon in the carbon cycle during the decade ending 1990 (in billion metric tonnes or petograms)

Atmospheric increase	=	Emissions from Fossil fuels	+	Net emissions from changes in land use	-	Oceanic uptake	-	Missing carbon sink

[49] Note that as yet a full life cycle analysis has not done. As a result CO_2 process emissions have not been taken into account.

3.3(±0.2)	=5.5(±0.5)	+1.6(±0.7)	-2.0(±0.8)	-1.8(±1.2)

Converting to tonnes CO_2 this is:

Atmospheric increase	= Emissions from Fossil fuels	+ Net emissions from changes in land use	- Oceanic uptake	- Missing carbon sink
12.07 (±0.73)	=20.152 (±0.1.83)	+ 5.86 (±2.56)	- 7.32 (±2.93)	- 6.59 (±4.39)

In general agreement with other research there appears to be a discrepancy which is believed to be because there has been a greater than measurable amounts taken up by living plant sinks[50].

By extrapolation, and without taking into account process emissions, given only one cycle of calcination it would roughly take the mining and processing of 12.2 billion tonnes of magnesite, 6.8 billion tonnes of forsterite or 8.9 billion tonnes of serpentine to sequester 12.7 billion tonnes of extra CO_2 put into the atmosphere every year. With more cycles of calcination using TecEco kiln technology less. This would also involve the production of 8.8, 5.9 and 5.5 billion tonnes of eco-cement containing 66.6% magnesia. As the global demand would not exceed say 1 billion tonnes an economic maximum of sequestration with only one cycle of calcination would be in the order of 2 – 2.5 billion tonnes. A very significant figure.

The process is at this stage confidential as it relies on a confidential kiln technology however Dr J P Brouwer of the TNO in Holland will confirm the large tonnages involved.

The combined method presented by TecEco is by far the best solution on the planet so far enunciated. To hope with the massive work load as a result of it's significant discoveries for the benefit of all, TecEco are looking for government support around the world to develop the technology.

It is hoped that as a result of this enquiry the technology will remain the prerogative of Australia to develop and sell.

[50] We may also be increasing the overall size of our atmosphere!

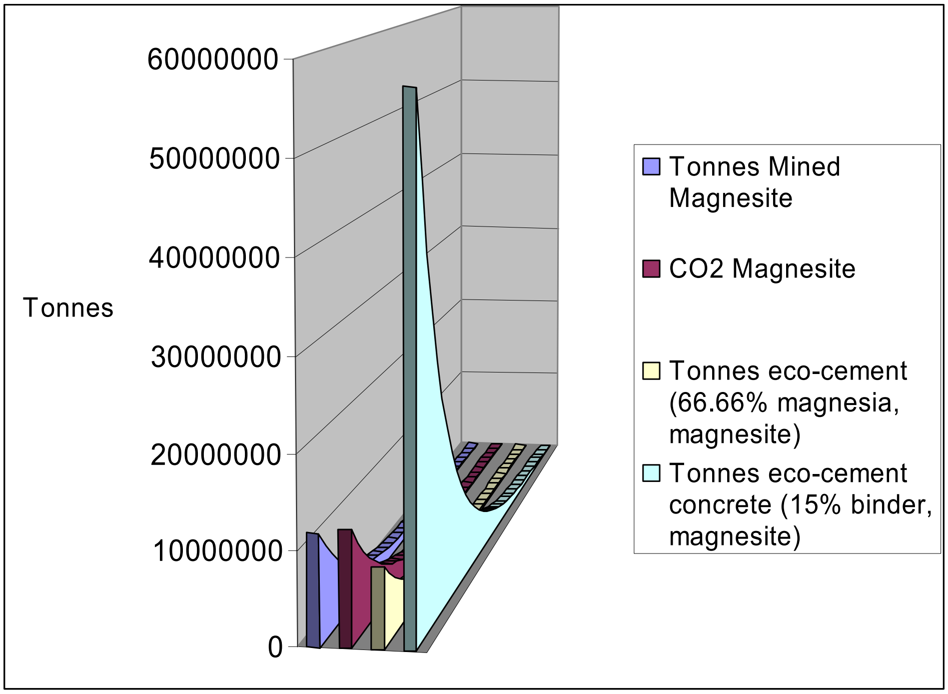

Table 3 – Graph Showing Sequestration and Output Eco-Cement (66.66% Magnesia)and Eco-Cement Concrete (15% Eco-Cement) per Tonne of Magnesite Mined and Processed.

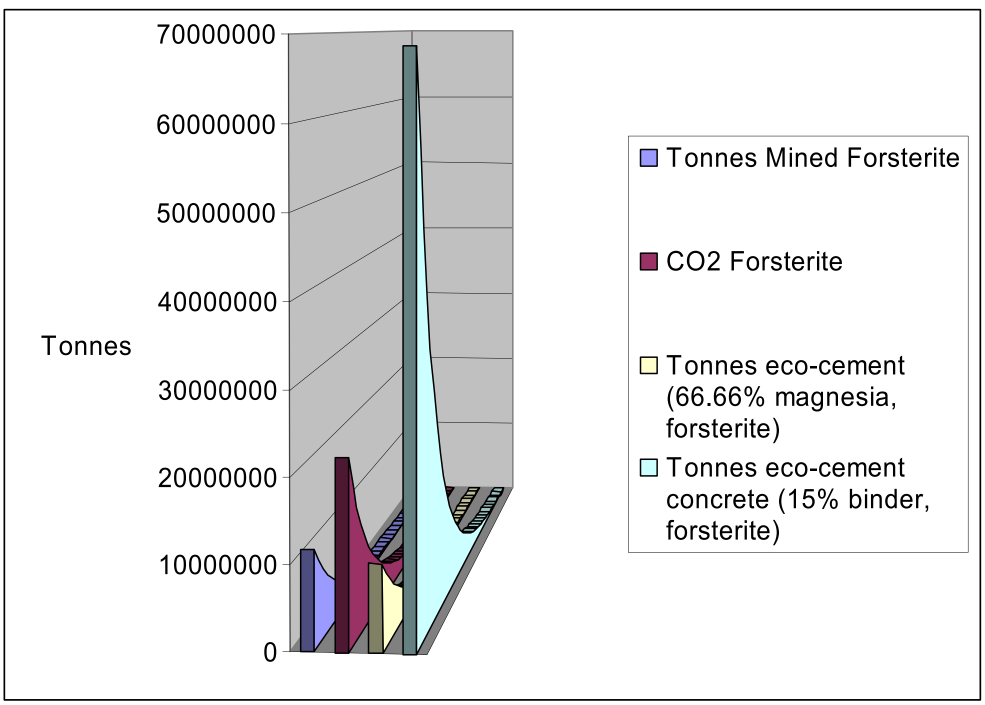

Table 4 – Graph Showing Sequestration and Output Eco-Cement (66.66% Magnesia)and Eco-Cement Concrete (15% Eco-Cement) per Tonne of Forsterite Mined and Processed.

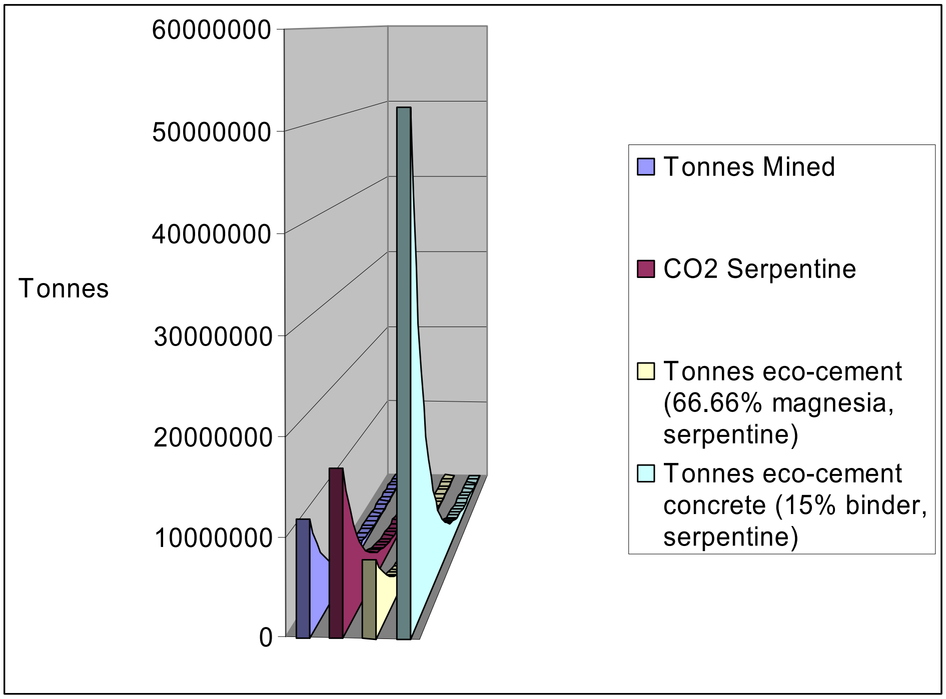

Table 5 – Graph Showing Sequestration and Output Eco-Cement (66.66% Magnesia)and Eco-Cement Concrete (15% Eco-Cement) per Tonne of Serpentine Mined and Processed.

Tonnes Mined Magnesite, Forsterite or Serpentine	CO2 Magnesite	Tonnes eco-cement (66.66% magnesia, magnesite)	Tonnes eco-cement concrete (15% binder, magnesite)	CO2 Forsterite	Tonnes eco-cement (66.66% magnesia, forsterite)	Tonnes eco-cement concrete (15% binder, forsterite)	CO2 Serpentine	Tonnes eco-cement (66.66% magnesia, serpentine)	Tonnes eco-cement concrete (15% binder, serpentine)
10000000	10438805	7243330	48288866	18766257	8681083	57873885	14307910	6618696	44124640

Table 6 – Comparative Table Showing Sequestration and Output Eco-Cement (66.66% Magnesia)and Eco-Cement Concrete (15% Eco-Cement) per 10,000,000 Tonne of Magnesite, Forsterite or Serpentine Mined and Processed with One Calcination Cycle.

APPENDIX 4 - CARBONATE SEQUESTRATION IN THE BUILT ENVIRONMENT

Concrete the Largest Factor

Concrete is the primary volume construction material and its use is likely to grow in future. Current estimates suggest that global cement production is 1.5 billion to 1.8 billion tonnes per annum[51][52]. Global production is likely to increase significantly over the coming decades as the global population grows and the developing world becomes increasingly industrialised.

Seven million tonnes per year which equates to approximately $ 900 million dollars worth[53] of Portland cement concrete (PCC) produced annually in Australia accounts for more embodied energy than any other material in buildings (See APPENDIX 8 - EMBODIED ENERGY & CO2 EMISSIONS on page 62)[54]. Due to growing environmental concerns and the need to use less energy-intensive building products, alternatives and improvements to Portland cement (PC) are being actively researched worldwide. In recent years the use of supplementary cementitious materials such as fly ash, blast furnace slag and alkali activated slag to produce blended PC, has increased worldwide. In Australia, supplementary cementitious materials now account for 20% of all cementitious materials sold[55]. The increased interest in the use of supplementary materials is largely due to the fact that manufacture of PC is one the biggest single contributors to the greenhouse effect accounting for between 5%[56] and 10%[57,58] of global anthropogenic[59] CO_2 emissions.

Cement manufacture is energy intensive, but not as energy intensive as the manufacture of many other building materials such as steel and aluminium. In order for the compounds responsible for strength development in Portland cement concrete to be formed, the raw materials need to be heated to about 1450^{o}C. Energy consumption as fuel and electricity consequently represents about 65-70% of the variable costs associated with Portland cement manufacture[60][61]. As a result of high energy consumption by cement manufacture large amounts of CO_2 are released.

CO_2 is also chemically released as part of the reaction:

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[51] World business council for sustainable development, "Toward a sustainable cement industry", www.wbscd.org/sectoral/cement, 2000

[52] US Geological Survey, Mineral commodity summaries, minerals.usgs.gov, 2002.

[53] Email communication, Tom Glasby, Manager - Construction Solutions, Cement & Concrete Association of Australia, 02/05/2003

[54] Dr Selwyn Tucker, CSIRO on line brochure at http://www.dbce.csiro.au/ind-serv/brochures/embodied/embodied.htm valid 05/08/2000

[55] Civil Engineers Australia, November 2002, 67-69

[56] Hendriks C.A., Worrell E, de Jager D., Blok K., and Riemer P. *Emission Reductions of Greenhouse Gases from the Cement Industry.* International Energy Agency Conference Paper at www.ieagreen.org.uk.

[57] Davidovits, J *A Practical Way to Reduce Global Warming* The Geopolymer Institute info@geopolymer.org, http://www.geopolymer.org/

[58] Pearce, F., "The Concrete Jungle Overheats", New Scientist, 19 July, No 2097, 1997 (page 14).

[59] Anthropogenic – human produced

[60] P Livesey, Challenges for the cement industry, p321 Concrete for environmental enhancement and protection, ed. RK Dhir and TD Dyer, Spon, London (1996).

[61] European cement association (Cembureau); "Energy is a sensitive factor in cement manufacture"; www.cembureau.be, 2000.

$CaCO_3 \rightarrow CaO + CO_2$

About 1.2 tonnes of limestone ($CaCO_3$) are required to produce a tonne of Portland cement). Around 1 tonne of CO_2 is produced for each tonne of Portland cement manufactured[62]. The emissions from Portland cement manufacture are the third highest source of CO_2 emissions after fossil fuel combustion and deforestation[63]. Projected growth in global cement manufacture, especially in developing countries, indicates that energy consumption and CO_2 emissions could double by the middle of the century[64].

A number of novel cements with intrinsically lower energy requirements and CO_2 emissions than conventional Portland cements have been developed including high belite (C_2S) and calcium sulfoaluminate (C_4A_3s) type.

Table 7 - CO2 Released by De-carbonation during the manufacture of Cements and Components

Compound	CO_2 released through decarbonation in producing 1 tonne (tonnes/tonne)
MgO	1.09
CaO	0.78
C_3S	0.578
C_2S	0.511
C_3A	0.594
PC	0.54
PC with 50% addition	0.27
PC with 75% addition	0.135
1PC:2MgO	0.99
1PC:2MgO:3pfa	0.445
C_4A_3s	0.216

Of the materials listed in the table, CO_2 emissions are lowest for blended Portland cements (although this assumes that no CO_2 is produced in the manufacture of the addition and clearly depends on the level of addition[65]). Calcium sulfoaluminate (C_4A_3S) also produces significantly less CO_2 than Portland cement.

Merits of a Carbonate Binder System for Sequestration

From Table 7 it can be seen that magnesium based cements involve the release of large amounts of chemically bound CO_2. If this chemically released CO_2 could be captured

62 T*he European Association (Cembureau) estimate 0.83 tonnes of CO_2 are produced for every tonne of cement produced.*

63 IUCC. 'Why cement-making produces carbon dioxide, Climate change Fact sheet 30, (1993). http://lacebark.ntu.edu.au.j_mitroy/sid101/uncc/fs030.html

64 G Idorn, Concrete progress, Thomas Telford, London (1997).

65 The availability of suitable amounts of addition are also an issue in reducing global CO_2 emissions from cement manufacture.

during manufacture and reabsorbed during setting forming a strong binder, huge opportunities for abatement would result.

Carbonates formed in seawater are the natural, large scale, long term sink for carbon dioxide and is a process that takes over 1000 years to equilibrate. Good evidence of the enormous volumes of CO_2 that have been released from the interior of the earth during many volcanic episodes over the last few billion years is that 7% of the earths surface is covered in rocks such as limestone, dolomite and magnesite.

Of the more common carbonates magnesium carbonates are the most efficient because of the low molecular weight of magnesium resulting in a higher CO_2 content per tonne.

$$\frac{CO_2}{MgCO_3} = \frac{44}{84} = 52\,\%$$

$$\frac{CO_2}{CaCO_3} = \frac{44}{101} = 43\,\%$$

Magnesium can fix carbon dioxide and therefore act as a concentrator and Figure 51 - The Magnesium Thermodynamic Cycle on page 41 depicts what is referred to by TecEco as the magnesite cycle.

If carbon dioxide is captured during manufacture of reactive magnesia then it can be recaptured by hydration and subsequent carbonation in porous cementitious materials with the formation of magnesite and hydromagnesite.

TecEco also have intellectual property in relation to a new kiln in which grinding and calcining[66] can occur at the same time in the same vessel and CO_2 captured for alternative use.

Provided sufficient uses can be found for pure CO_2 produced during manufacture whereby it is also permanently sequestered, a system for sequestration on a massive scale using carbonates as building materials is very promising. Possibilities are in materials such as plastics or deep underground where CO_2 reacts with country rock forming more carbonate.

[66] Calcining in the context of this document refers to the heating of limestone or magnesite to drive off CO_2 and produce the oxide.

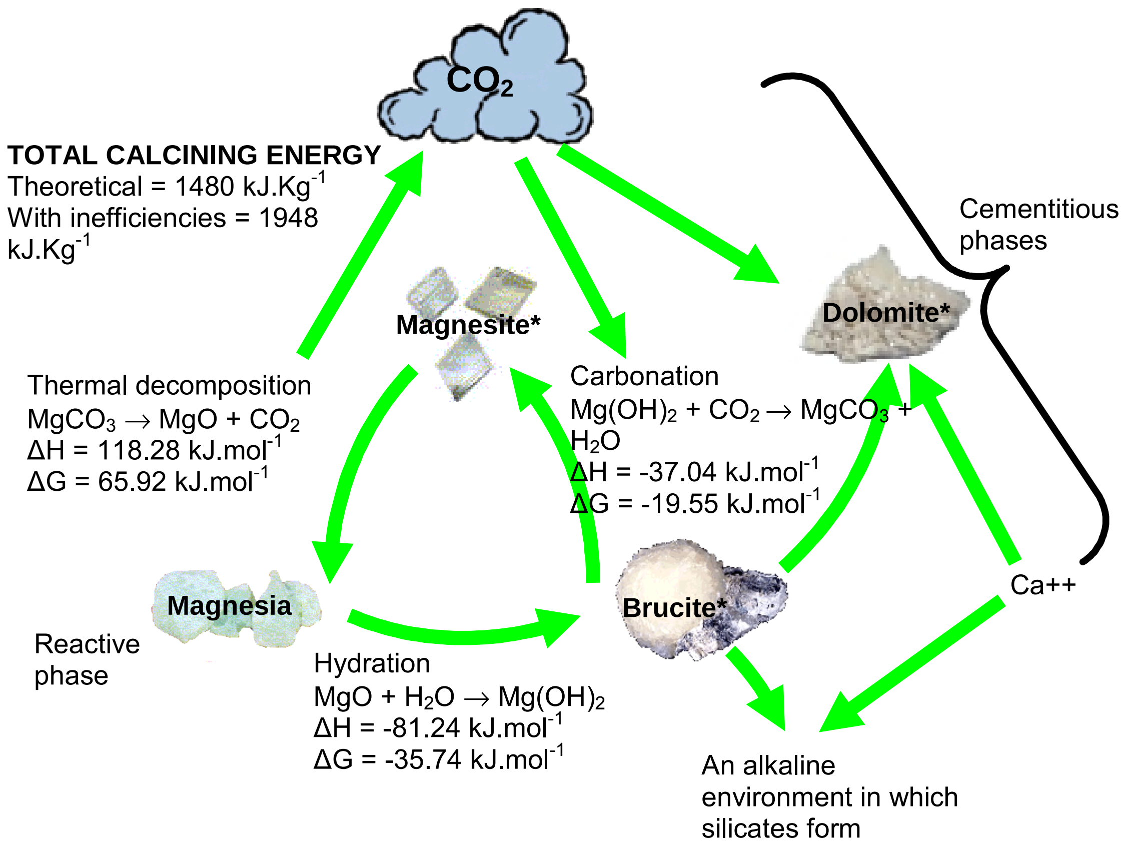

Figure 5 - The Magnesium Thermodynamic Cycle

Table 7 on page 39 shows that the CO_2 produced through calcination of various materials used in binders including MgO as proposed by TecEco.

The reaction for calcination of magnesite can be written:

$$MgCO_3 = MgO + CO_2$$

If cements containing carbonating components such as eco-cements proposed by TecEco are to be efficient for sequestration then.

- Considerable carbon dioxide by weight should be reabsorbed.
- Structures and components made using them must be sufficiently porous to allow the re absorption of CO_2 produced during manufacture.

According to TecEco carbonation will only proceed rapidly in porous materials such as bricks, block, pavers, mortars, porous pavement etc., which fortunately make up a large proportion of building materials.

In Portland cement around 75% of the calcium in the limestone calcined during manufacture ends up as silicates which do not readily re-carbonate. 25% ends up as Portlandite ($Ca(OH)_2$) which will carbonate particularly in porous materials. TecEco propose the substitution of Portland cement with magnesia (MgO) which in eco-cements in porous materials fully carbonates. The result is a higher proportion of binder that will carbonate in a porous matrix.

The affect substitution in a simple concrete brick formulation containing 15% cement with and without capture of CO_2 during manufacture of magnesia is depicted in the diagram below.

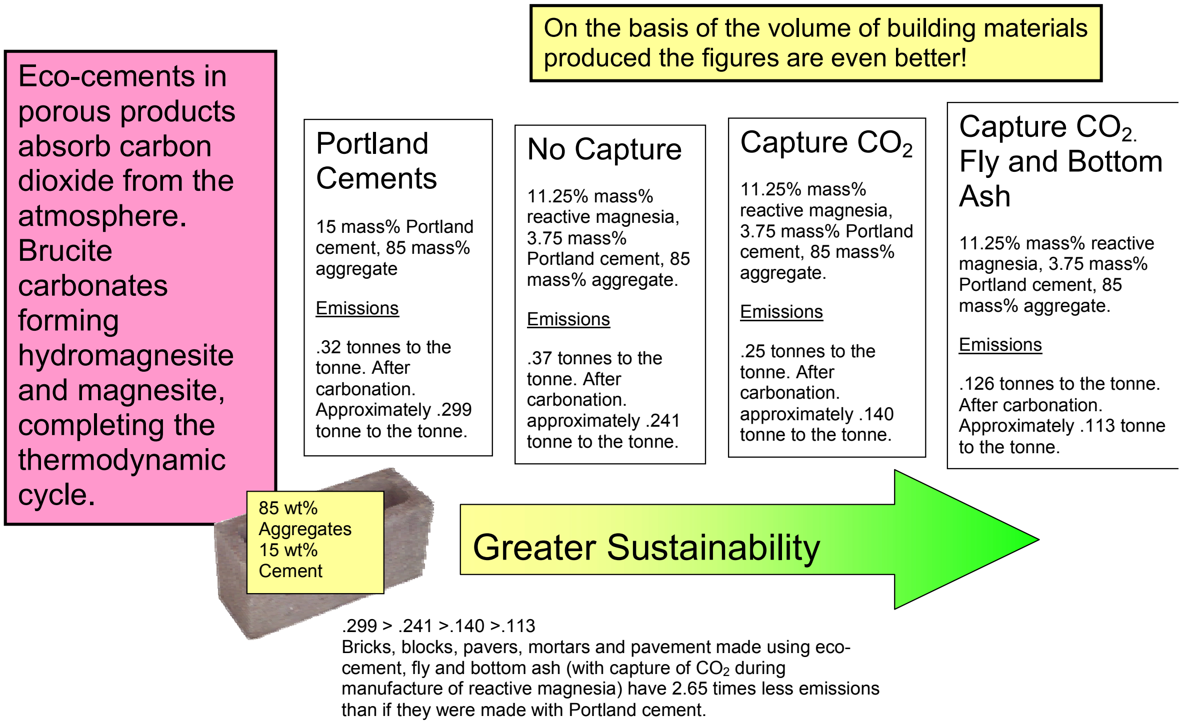

Figure 6 – Abatement in a Concrete Brick Containing 15% Eco-Cement

From Figure 62 it can be deduced that almost 2/3 of the CO2 in concrete is potentially abated if substituted by eco-cement in porous products such as bricks, blocks, pavers, mortars etc. With the inclusion of organic fibre materials and fillers for strength and insulation, cementitous building materials that act as net carbon sinks are feasable.

The above explanation is simplistic. As the energy considerations are complex readers are directed to the web site of TecEco at www.tececo.com where a paper titled Reduction and other Advantages of TecEco Cements can be downloaded and read.

APPENDIX 5 - TECECO CEMENT TECHNOLOGY

The use of magnesia in cements as advocated by TecEco Pty. Ltd. promises to not only lower long run costs but result in superior properties including better insulation with the inclusion of waste materials, abatement with economic benefits, huge opportunities for export and a way forward for the Kyoto process.

TecEco have patented the blending of reactive magnesia with other hydraulic cements such as Portland cement and usually a pozzolan and have received worldwide publicity in the last twelve months[67]. So far three formulation outcomes have been defined:

TecEco cements were invented in response to technical problems exhibited by Portland cement and the need for more sustainable binders.

Technical issues addressed by the new Tececo cement technology include:

- Rheology
  - Workability, time for and method of placing and finishing, stick and rebound with mortars.
- Shrinkage
  - Cracking, crack control
- Durability and Performance
  - Sulphate and chloride resistance
  - Carbonation
  - Corrosion of steel and other reinforcing
  - Delayed reactions (eg alkali aggregate and delayed ettringite)
- Bonding to brick and tiles
- Efflorescence

Concretes are already a relatively sustainable material. With low cost high thermal capacity they supply essential thermal mass to buildings. With the advent of TecEco technology, concretes will offer greater opportunities for sustainability with improved insulating properties as well as:

[67] Articles have appeared in a diverse range of publications including New Scientist (Fred Pearce, Green Foundations, *New Scientist*, vol 175 issue 2351, 19 July 2002, page 39 and Tam Dalyell, Westminster Diary, *New Scientist* vol 176 issue 2368, 09 November 2002, page 55), *The Toronto Star* (National Report, Saturday, July 27, 2002, p. F05), Margaret Vine-Hall, The Next Generation Cement, *Clever Devils, A Mercury Supplement*, The Mercury, Thursday August 22, 2002, and more recently in The Guardian (Owen Dyer, A Rock and a Hard Place, Eco-cement yet to cover ground in the building industry, *The Guardian*, Wednesday May 28, 2003) and Climate Change Management, June 2003 issue.
Electronic Publications have included, John Harrison, *One Way to Make More Environmentally Friendly Housing*, On Line Opinion, 15/03/02, http://www.onlineopinion.com.au/2002/Mar02/Harrison.htm
Elizabeth G. Heij, Green entrepreneur in action: introducing Network member, John Harrison of TecEco, *CSIRO Online Sustainability Network Newsletter 16E*, 14 October, 2002, and many others not as yet catalogued.
A film about block making using the technology has also been shown by Discovery Channel Canada and more recently in the USA. The technology also won the Tasmanian Innovation of the Year Award in 2002 with considerable associated publicity

- Lower binder aggregate ratios
- Greater durability
- Lower embodied and lifetime energies
- Waste utilisation and recycling
- Abatement and sequestration

SUMMARY OF THE TECECO CEMENT TECHNOLOGY

Portlandite (or lime as it is often called) has always been the weakness of concrete as it is far too soluble, mobile and reactive. Scientists and engineers have known this for a long time but have not considered the consequences of replacement. TecEco advocate not just removal with the pozzolanic reaction but replacement with Brucite, a much less soluble and reactive hydroxide of magnesium.

TecEco have demonstrated that reactive magnesia which hydrates in a concrete forming Brucite can be advantageously blended with other hydraulic cements such as Portland cement with demonstrable improvements in properties and that previously reported dimensional distress was because the magnesia present was insufficiently reactive, having been through the high temperature process of Portland clinker production.

A mineral assemblage in a concrete including brucite and carbonates of magnesium and excluding lime is ideal compared to an assemblage including a mineral as reactive as lime (Portlandite). The TecEco technology demonstrates how to achieve this assemblage. International patents[68] have been applied for covering the addition of various proportions of reactive magnesia to cements used in concretes with or without added pozzolans. Lime is removed from concrete by the pozzalanic reaction and replaced with Brucite. Durability, sustainability, corrosion, carbonation, rheological, shrinkage and alkali aggregate reaction problems are substantially resolved and in some cases greater strength can even be achieved.

Many leading scientists and science organisations around the world have endorsed the technology[69], publicly released on a large scale in the New Scientist Magazine of the 13th July 2002 and described variously as a “world first” and “benchmark in materials science” and having enormous medium and long term potential.

Although the capture of CO2 during the manufacture of the TecEco cements is recommended, conventional equipment can be used for all stages of manufacture reducing overheads and the capital cost of entry.

The new materials technology is applicable in a wide range of applications depending on the sustainability, durability, rheology or strength required and three main formulation strategies have so far been defined:

- Tec- cements (eg 10% MgO, 90% OPC.)

  Contain more Portland cement than reactive magnesia.

  Reactive magnesia hydrates in the same rate order as Portland cement forming Brucite which uses up water reducing the water binder ratio, increasing density and

[68] International patent number PCT/AU01/00077
[69] Independent appraisals are downloadable from our website at www.tececo.com

possibly raising the short term pH increasing the effectiveness of reactions with pozzolans. After all the Portlandite has been consumed Brucite controls the long term pH which is lower and due to it's low solubility, mobility and reactivity results in greater durability.

Other benefits include improvements in density, strength and rheology, reduced permeability and shrinkage and the use of a wider range of aggregates without reaction problems.

- Enviro-cements (eg 26-75% MgO, 25-75% OPC)

  In non porous concretes Brucite does not carbonate readily.

  High proportions of magnesia are most suited to toxic and hazardous waste immobilisation and when durability is required. Strength is not developed quickly.

- Eco-cements (eg 50-75% MgO, 50-25% OPC)

  Contain more reactive magnesia than Portland cement. Brucite in porous materials eventually carbonates forming stronger fibrous mineral carbonates adding strength and presenting huge opportunities for abatement.

Tec-Cements

Tec-cements concretes have a relatively low proportion of reactive magnesia that hydrates to form Brucite. They usually also contain a pozzolan which reacts with the Portlandite released as di and tri calcium silicate hydrate and forms more calcium silicate hydrates (CSH).

As a consequence of the removal of Portlandite and replacement by Brucite tec-cement concretes have a different pH curve to Portland cement concretes and Portland cement concretes that have had pozzolans added. As the hydration of magnesia takes up a lot of water (44.65 mass% is water) it is thought that during the early plastic stage the pH may be higher. In the longer term however the pH is controlled by Brucite and is lower.

The equilibrium pH of Brucite in water is 10.38 and it maintains the pH of concretes in that range for much longer periods than portlandite as it is far less reactive. For most kinetic pathways it carbonates much less readily[70] (ΔG_r Portlandite → calcite = - 64.62 $kJ.mol^{-1}$, ΔG_r Brucite → magnesite = - 19.55 $kJ.mol^{-1}$). The equilibrium pH is still however at a sufficiently high level for steel to remain passive[71] and for the stability of calcium silicate hydrates[72]. Dense concretes made using TecEco formulations should maintain reducing conditions and a pH over 8.9 required for the long term survival of steel much longer than Portland cement concretes.

Tec-cement concretes exhibit high and faster development of strength and this is probably due to

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[70] Depending on the kinetic pathway.
[71] As Fe_3O_4 rather than oxides such as Fe_2O_3 or FeO_2 which tend to hydrate and are dimentionally unstable.
[72] The neutralisation of Lime by pozzolans results in a drop in the Ca/Si ratio in CSH and potential brittleness (pers com Prof. Fred Glasser, University of Aberdeen)

- more silicification reactions including a more effective pozzalanic reaction during the early plastic stage whilst the pH is possibly elevated.

- a low water binder ratio as a result of improved rheology due to better particle packing and some surface charge affects.

The removal of excess water by magnesia as it hydrates prevents bleeding and the introduction of associated weaknesses such as interconnected pore structures and also tends to dry tec-cement concretes from the inside and combined with a lower long term pH, and the low solubility and reactivity of Brucite, results in improved durability.

The advantages of using Portland cement such as ambient temperature setting and strength are not diminished however shrinkage is reduced if not eliminated due to low water loss and in appropriate proportions the expansion of magnesium minerals balancing the slight shrinkage of Portland cement concrete eliminating cracks and reducing porosity.

Low pH, low porosity, reduced shrinkage cracks, the fact that magnesia dries concrete out from the inside as it consumes water and reduced reactivity result in the virtual elimination of delayed reactions and corrosion as well as resistance to salts.

More flyash can be added to advantage and sustainability is improved by reduced binder/aggregate ratios, longer life and lower emissions ratios.

Enviro-Cements

Enviro-cements differ in that they contain higher ratios of magnesia to hydraulic cement. Chemically and physically they are more suited to toxic and hazardous waste immobilisation than either lime, Portland cement or Portland cement lime mixes and they are more predicable than geopolymers.

In a Portland cement Brucite matrix[73]

- OPC takes up lead, some zinc and germanium

- Brucite and hydrotalcite are both excellent hosts for toxic and hazardous wastes. Brucite has a layered structure and traps neutral compounds between the layers.

Heavy metals not taken up in the structure of Portland cement minerals or trapped within the Brucite layers end up as hydroxides.

The pH which is controlled in the long term by Brucite is around 10.4, and is an ideal long term value at which most heavy metal hydroxides are relatively insoluble.

TecEco cements are also very suitable for immobilising toxic and hazardous wastes because they are more durable, homogenous and do not bleed water, are not attacked by salts in ground or sea water and dimensionally more stable with less cracking.

Eco-Cements

Eco-cements differ in that they contain higher ratios of magnesia to hydraulic cement.

[73] Portland cement minerals and Brucite are the main binder minerals. A host of minor species also form and are also present.

In porous or semi porous materials such as bricks, blocks, pavers, mortars and renders, as there are no kinetic barriers, the magnesia not only hydrates, but carbonates completing the thermodynamic cycle by reabsorbing the carbon dioxide produced during calcining.

Eco-cement concretes are also to some extent recyclable and can have up to around 90% recycled industrial materials such as fly ash included in their formulation and are therefore likely to become the building material of future choice[74][75]. Important uses will include providing a sustainable, low cost building material with high thermal capacity, low embodied energy and good insulating properties for construction in products such as bricks, blocks, stabilised earth blocks, pavers and mortars, wharves and airstrips and in combination with wood waste for packaging. Carbonated eco-cement formulations for the built environment are also strong and resistant to the chemicals that attack Portland cement

Brucite, magnesite and hydromagnesite bond well to many different materials including wood[76] and will hold a large proportion of waste.

RAMIFICATIONS OF THE TECECO CEMENT TECHNOLOGY

The ramifications of the new binder technology are far reaching and potentially include:

Greater Strength:

Significant strength with low binder/aggregate ratios have been observed in tec-cement concretes and this is likely to be a result of low water/binder ratios, increased density and possibly more effective pozzalanic reactions caused by high early pH due to supersaturation of calcium hydroxide as the hydration of reactive magnesia takes up water.

Faster Strength Development

Tec-cement concretes exhibit more rapid strength development even with high additions of pozzolans.

Lower Long Term pH?:

As Portlandite is removed the pH becomes governed by the solubility of Brucite and is much lower at around 10.5 -11, stabilising many heavy metals and allowing a wider range of aggregates to be used without AAR problems. Carbonation is slower and the pH remains high enough to keep Fe, FeO and Fe_3O_4 stable for much longer.

Better Rheology - Easy to Use:

Better particle packing and surface charge affects enable fine magnesia to act as a lubricant for Portland cement improving homogeneity and rheology.

Durability:

[74] 100% utilisation would reduce global CO_2 emissions in the order of 10% - 15%.
[75] With either the collection of CO_2 at source or the inclusion of carbon based fibres or both eco-cements can be net carbon sinks
[76] Hence the contemplated use for lightweight packaging.

TecEco Tec - cements are protected by Brucite, are not attacked by salts, do not carbonate readily and last indefinitely. As tececo cements dry from the inside out, and have a lower long term pH internal delayed reactions are prevented.

Greater Density, reduced permeability?:

Brucite fills pore spaces taking up mix and bleed water as it hydrates reducing voids. (Brucite is 58.3 mass% water!).

Less Shrinkage?:

Internal consumption of water reduces shrinkage through loss of water. Magnesium minerals also expand on formation and take up water, whilst concrete tends to shrink. Blended in the right proportions, concretes can be made that are dimensionally neutral over time.

More Sustainable:

Tec-cements can use less binder for the same strength and all TecEco cements use a high proportion of recycled materials, a wider range of aggregates reducing transport emissions and have superior durability slowing down replacement. Eco-cements reabsorb chemically released CO_2.

Insulating Properties / High Thermal Mass / Low Embodied Energy:

Eco-cement products will be favoured for energy conserving buildings.

Recyclable:

Eco-cement products can be reprocessed and reused, making them more attractive to many users.

A Fire Retardant:

Brucite, magnesite and hydromagnesite are all fire retardants. TecEco cement products put fires out by releasing CO_2 or water vapour at relatively low temperatures.

Low Costs:

No new plant and equipment are required.

Lower materials cost. With economies of scale TecEco cements should be cheaper and less cement is required in some formulations.

Lower usage costs include easier placement and finishing, elimination of shrinkage and bleeding, faster strength gain (in some formulations), use of a wider range of aggregates reducing transport costs, less or no plasticisers, no bleeding and greater durability reducing replacement costs over time and potential carbon credits.

POTENTIAL USES

The new cements are suitable for a wide range of uses including

- As a stabilising agent in the production of earth buildings.

- Mortars, renders, grouts & drill hole cements.
- Controlled low strength materials
- Soil stabilisation/solidification.
- Agglomeration of furnace feeds and pellet manufacture.
- Waste and toxic waste immobilisation/fixation.
- For the production of bricks, blocks and pavers utilising coal combustion by-products including waste heat.
- To manufacture lightweight disposable high thermal capacity insulated packaging
- Blended with Portland cement to improve properties such as strength and durability.
- Where rheology is important such as with gunnite or shotcrete.
- Where fire retarding properties are essential.
- Use in areas of high chloride or sulphate contamination of sand and aggregates.
- Where there are critical resource shortages such as in China.
- Where cost or environmental considerations are important.

The research and development and business plans consider priorites for research, development and deployment.

The Advantages of Including Reactive Magnesia in Hydraulic Cements such as Portland Cement.

The TecEco technology represents a unique way forward for the sustainability process with no known disadvantages.

The economic, technical and environmental advantages of TecEco cements are related and considered below under those headings.

Economic Advantages

In the take-make-waste linear system, which underpins the majority of the world's economies, utility is added until final point of sale and from then on utility generally declines until wastage is complete. If utility can be maintained longer or increased by greater durability or reuse then the system must slow down and consume less and therefore produce less waste.

Achieving this should be the priority of governments around the world. New materials are required that are more durable and that exit the linear system forming return loops eliminating wastes, reducing output and thus input (the take) from natural ecosystems. Materials with a lower embodied energy and that can use waste or themselves be recycled or reused have substantial economic advantages and TecEco cements have been designed with these desirable characteristics in mind.

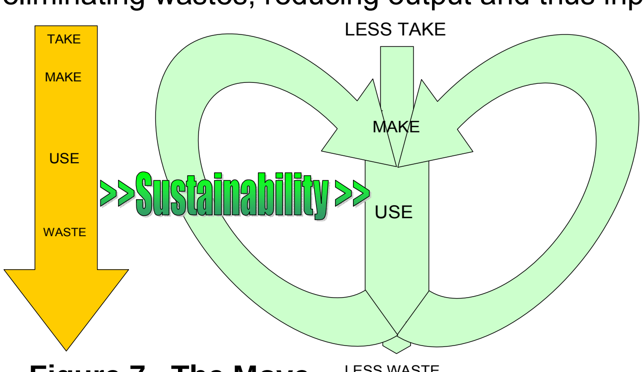

Figure 7. The Move to a More Sustainable Society.

Energy

Energy is the largest cost factor in the production of mineral binders.

Whether more or less energy is

required for the manufacture of reactive magnesia compared to Portland cement or lime depends on the stage in the utility adding process.

Table 8 on page 51 shows that given a take-make-waste system, on a mass for mass of natural materials consumed basis, less energy is required. TecEco argue however that the most valid point of comparison is when the utility is greatest and in the case of TecEco modified Portland cement this is when Portland cement and reactive magnesia have hydrated becoming a binders in concrete. In the case of eco-cements further utility is added when brucite carbonates completing a thermodynamic cycle and become magnesite again.

The mass comparisons in Table 8 are also deficient in that the built environment has most utility when 3D space is created not mass. After all do we purchase 20 tonnes of bricks, timber, nails and tin for a home? The utility argument can therefore be carried further and a better basis of comparison is on a volume of binder material produced basis as in Table 9. In this case the hydrated product, brucite, has a lower embodied energy.

Cost

In terms of 3D space, the use of magnesia results in less embodied energy per hydrated cubic metre of building material[77] and hence potentially lower costs in terms of money spent for built environment constructed.

Given volume production and the development of TecEco cement and associated technologies, even less process energy than in tables 1 and 2 should be required for the production of reactive magnesia because:

- The manufacture of reactive magnesia is a benign process occurring at relatively low temperatures and for which waste energy should be able to effectively be used.
- The manufacture of more durable building materials will mean that less energy is required over time because structures require replacing less often.
- The manufacture of reactive magnesia is suited to new TecEco kiln technology in which 25% greater efficiencies should result due to the capture of waste heat from grinding.

[77] There is a good argument for using volume comparisons as the build environment is composed of 3D space, not mass.

Table 8. Calcining energy compared on a mass basis.

Relative to Raw Material Used to make Cement	From Manufacturing Process Energy Release 100% Efficient ($Mj.tonne^{-1}$)	From Manufacturing Process Energy Release with Inefficiencies ($Mj.tonne^{-1}$)	Relative Product Used in Cement	From Manufacturing Process Energy Release 100% Efficient ($Mj.tonne^{-1}$)	From Manufacturing Process Energy Release with Inefficiencies ($Mj.tonne^{-1}$)	Relative to Mineral Resulting in Cement	From Manufacturing Process Energy Release 100% Efficient ($Mj.tonne^{-1}$)	From Manufacturing Process Energy Release with Inefficiencies ($Mj.tonne^{-1}$)
$CaCO_3$ + Clay	1545.73	2828.69	Portland Cement	1807	3306.81	Hydrated OPC	1264.90	2314.77
$CaCO_3$	1786.09	2679.14				$Ca(OH)_2$	2413.20	3619.80
$MgCO_3$	1402.75	1753.44	MgO	2934.26	3667.82	$Mg(OH)_2$	2028.47	2535.59

Table 9. Calcining energy compared on a volume basis.

Relative to Raw Material Used to make Cement	From Manufacturing Process Energy Release 100% Efficient ($Mj.metre^{-3}$)	From Manufacturing Process Energy Release with Inefficiencies ($Mj.metre^{-3}$)	Relative Product Used in Cement	From Manufacturing Process Energy Release 100% Efficient ($Mj.metre^{-3}$)	From Manufacturing Process Energy Release with Inefficiencies ($Mj.metre^{-3}$)	Relative to Mineral Resulting in Cement	From Manufacturing Process Energy Release 100% Efficient ($Mj.metre^{-3}$)	From Manufacturing Process Energy Release with Inefficiencies ($Mj.metre^{-3}$)
$CaCO_3$ + Clay	4188.93	7665.75	Portland Cement	5692.05	10416.45	Hydrated OPC	3389.93	6203.58
$CaCO_3$	6286.62	8429.93				$Ca(OH)_2$	5381.44	8072.16
$MgCO_3$	4278.39	5347.99	MgO	9389.63	11734.04	$Mg(OH)_2$	4838.32	6085.41

Carbon Credits

There will potentially also be a financial bonus attached to the use of reactive magnesia in TecEco cements in the form of carbon credits:

- CO_2 could be captured at source (as in the TecEco kiln).
- TecEco eco-cements absorb a little less that their own weight of CO_2 in porous materials such as bricks, blocks, pavers, concretes and pavements.

TecEco cement concretes can also contain a large amount of waste materials such as fly ash further reducing the embodied energy per unit volume of building material. Lower embodied energy results in reduced emissions.

The potential for widespread abatement and solving global climate change issues is enormous and is discussed in detail under the heading Environmental Advantages on page 53.

Other Cost Factors

There are other more technical factors that will contribute to the economic advantages of blending reactive magnesia with Portland cement. These include strength, durability and the ability to blend large amounts of waste materials such of fly ash, and these will be discussed below in terms of technical advantages.

Existing plant and equipment can also be used for the production of TecEco cement thus reducing costs of entry.

Technical Advantages

Portlandite or as it is sometimes called, lime, has always been the weakness of Portland cement. It is more soluble than brucite, more mobile and more reactive with for example common salts in ground and seawaters. The reason is that the Ca^{++} ion is much larger at 114 picometres than the Mg^{++} ion at 86 picometres and the latter fits better in an atomic lattice with hydroxide anions and is therefore more stable. The essential feature of TecEco technology is replacing lime in Portland cement with brucite. Although it could be added directly as brucite, far more strength is gained through the process of the formation of the mineral from highly reactive magnesia in a manner that densifies Portland strength. Provided there is no delayed hydration this makes sense and technical advantages result.

Noticeable during the mixing and placing stages are a much better rheology and a marked tendency not to bleed. TecEco tec-cement concretes tend to resemble margarine more than traditional concretes and have a low slump yet excellent workability. As the hydration of magnesia appears to take up water that would tend to bleed in Portland cement concretes, the evidence so far indicates less or no shrinkage in some TecEco formulations.

Other properties become apparent on setting such as a usually higher strength than would be expected from the amount of Portland cement added. This is probably due to reduced water cement ratios and less cracking due to reduced shrinkage.

Over time noticeable will be the lack of “crazy” cracking due to carbonation, less corrosion, iron stains etc. as TecEco cements are much more durable.

It also takes time for problems due to alkali aggregate reaction to emerge, and with TecEco cements they will most likely occur.

There are many other technical advantages of TecEco cements. For example magnesite is more resistant to mild acids at low temperatures than calcite, meaning eco-cement blocks will last longer than limestone or Portland cement blocks.

TecEco cements are also fire retardants as brucite breaks down releasing water vapour and magnesite breaks down releasing CO_2 at a relatively low temperatures hence cooling or putting out fires.

No doubt in time more technological improvements will emerge as the properties of the new TecEco cements are determined. What is more noticeable is the lack of problems provided appropriate grades of reactive magnesia are used. The specification sheets from vendors do not convey the full story and people interested in using reactive magnesia should talk to TecEco.

Environmental Advantages

Apart from being much more durable, depending on the formulation and use, eco-cements used to make porous materials such as bricks, blocks, pavers, mortars and pavement re-absorb CO_2, are to some extent recyclable. They can also be made including a high proportion of fly ash and other recycled usually pozzolanic industrial waste materials.

Around 98% of the world’s energy is derived from fossil fuels that when burnt to produce energy releases vast amounts of CO_2. In terms of the volume of built environment and infrastructure that results, less energy goes into making TecEco Cements for the reasons given under the heading Energy on page 49. Materials that have a lower embodied energy are more sustainable.

Lifetime energies are the energies required to heat and cool buildings over time. Building materials that have thermal capacity reduce lifetime energies and are therefore also more sustainable. TecEco cements, being mineral based, have a high thermal capacity and good insulating properties, especially with added waste organic matter such as saw dust and hence result in lower lifetime energies.

Industrial wastes are a major global problem. TecEco cements can accommodate a high proportion of many wastes, thereby reducing their impact on eco-systems.

If materials have closed loops and can substantially be recycled then their impact when they are no longer required is much less. If they can be made of materials more naturally assimilated back into the earth, then nature can very quickly convert them back to its own uses. TecEco cements can be substantially recycled not only into more building materials but for other purposes as well. If wasted, they do not affect natural ecosystems as much as Portland cement because they have a lower pH.

If materials can be made that last much longer and require replacing less often, they are said to be more durable. More durable materials are therefore more sustainable. The durability of TecEco cements also results in greater sustainability.

The most publicised formulations of TecEco cements are eco-cements which contain a much greater proportion of materials such as reactive magnesia (and thus brucite) in the cement component that carbonates to completion in porous materials thus absorbing considerable chemically released CO_2

The use of Calcium sulfoaluminate compound together with belite (C_2S) and reactive magnesia is to be investigated by TecEco at a future date.

Materials availability

The basic ingredients of TecEco cements are:

- Magnesium oxide
- Portland cement
- Pulverised fuel ash or similar pozzolanic material.

Magnesium is the eighth most abundant element in the earth’s crust and the availability of magnesium ores to make magnesium oxide is not an issue in Australia and in most other parts of the world. Furthermore TecEco claim that it is not necessary to use pure magnesite in all applications. Less pure grades could be obtained by decomposing dolomites at temperatures below $900^{o}C$. The remaining limestone could remain as an inert filler. TecEco hope to get over the problem of iron contamination which reduces reactivity using their new kiln.

APPENDIX 6 - REDUCING THE EMBODIED ENERGY OF CONCRETE.

The use of supplementary pozzolanic cementitious materials including: fly ash, blast furnace slag and alkali activated slag, blended with OPC, has increased worldwide. In Australia, supplementary cementitious materials now account for 20% of all cementitious materials sold[78]. The supplementary materials are generally waste products from other industries. Fly Ash, for example, is the resultant product from coal fire electricity generating power stations. It is good practice to use this relatively inert waste product in the manufacture of concrete, as the alternative is generally disposal in landfill. The outcome is that less OPC is used which has high-embodied energy.

To be of use in a concrete mix, the pozzolan requires an alkaline solution, which is present in normal cement mixes. The combination produces a concrete that exhibits good physical properties that is acceptable to the construction industry.

One disadvantage of the use of supplementary materials relates to the slower gain of strength. The maximum proportion of supplementary material to cement is limited and relatively small. Exceeding this proportion can adversely effect the setting time of concrete thus making the mix unsuitable for construction use.

The use of Magnesium based cements in combination with OPC can allow for a higher proportion of fly ash to be used in certain mixes. This increases the opportunities where the use of materials with high-embodied energies can be reduced.

A Magnisium based cement added into a concrete mix will result in the required strength properties being achieved whilst using less OPC. This results in less high embodied energy OPC being required in a mix to achieve the desired strength.

Concrete will be the key material for Mankind to create the built environment in this millennium. The requirements will be both demanding, in terms of technical performance and economy, and yet be greatly varied, from architectural masterpieces to the simplest of utilities.

It has been said that the greatest problem will be what to do with wastes. There is tremendous scope to add strength and improve other properties through the addition of wastes forming what amount to composites. As many wastes have molecular value expressed as strength, insulating capacity or light weight for example, or are made essentially of carbon and would therefore sequester substantial CO_2, they should be used in concretes not just to reduce pressure on land fill but to add desireable properties.

[78] Civil Engineers Australia, November 2002, 67-69

Many wastes such as wood fibre, and various plastics for example were originally manufactured for packaging and have exellent value adding properties for concretes

The manufacturing process of magnesium based cements requires much lower temperatures than those needed to process and manufacture OPC. This allows lower embodied energies cements with greater sustainability to be produced.

The manufacturing process of magnesium based cements will require less transport and energy inputs, thus reducing the associated embodied energies of the material.

APPENDIX 7 - EMBODIED AND LIFETIME ENERGIES IN THE BUILT ENVIRONMENT

The following is an extract from the CSIRO on line brochure at http://www.dbce.csiro.au/ind-serv/brochures/embodied/embodied.htm

Buildings are high consumers of energy and therefore have a significant impact on our environment. The study of embodied energy gives us an understanding of how much and where energy is used in the construction of buildings, and the cost benefits of recycling.

What is Embodied Energy?

Embodied energy is the energy consumed by all of the processes associated with the production of a building, from the acquisition of natural resources to product delivery, including mining, manufacturing of materials and equipment, transport and administrative functions.

How is Embodied Energy Related to Carbon Dioxide Emissions?

CO2 emissions are highly correlated with the energy consumed in manufacturing building materials. Furthermore, cement and aluminium are higher than average and glass is lower. On average, 0.098 tonnes of CO2 are produced per gigajoule of embodied energy.

Why is Embodied Energy Important?

The energy embodied in existing building stock in Australia is equivalent to ten years of the total energy consumption for the entire nation. Choice of material and design principles have a significant, but previously unrecognised, impact on energy required to construct a building. Embodied energy is one measure of the environmental impact of construction and the effectiveness of any recycling, particularly CO2 emissions.

How much does Embodied Energy vary between Building Materials?

The embodied energy per unit mass of materials used in building varies enormously from about two gigajoules per tonne for concrete to hundreds of gigajoules per tonne for aluminium. Using these values alone to determine preferred materials is inappropriate because of the differing lifetimes of materials, differing quantities required to perform the same task and different design requirements.

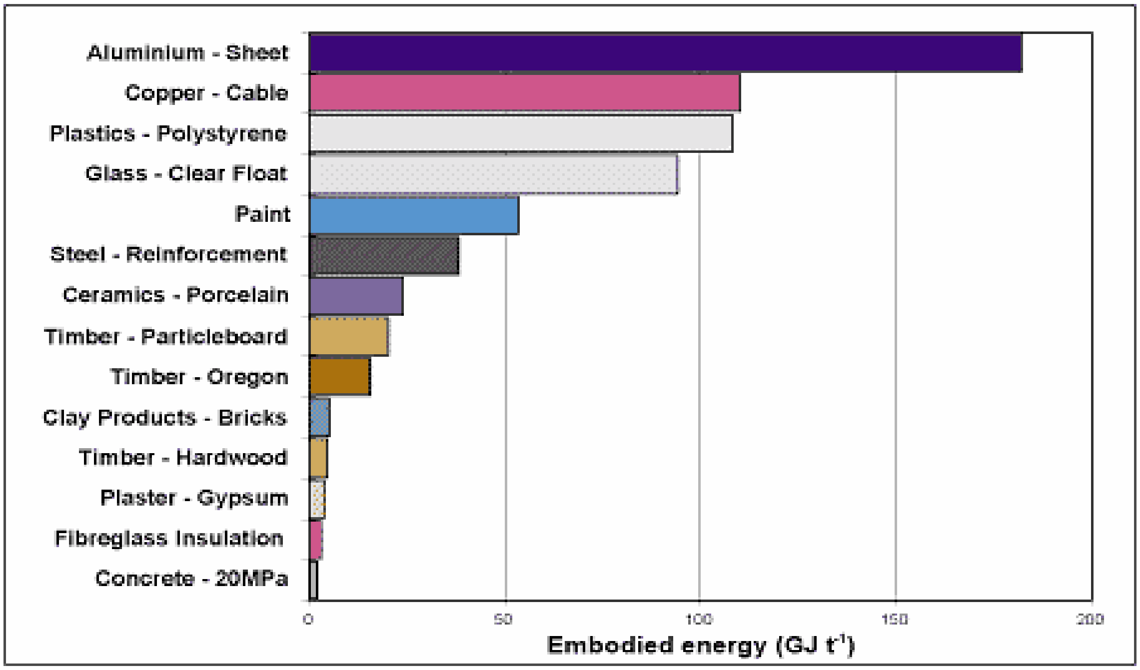

Figure 8 Embodied Energy of Selected Materials

How do we Compare the Embodied Energy Impact of Materials?

In choosing between alternative building materials or products on the basis of embodied energy, not only the initial materials should be considered but also the materials consumed over the life of the building during maintenance, repair and replacement. As buildings are becoming more energy efficient in their operation, the embodied energy is approaching half the lifetime energy consumption.

Does Reuse and Recycling of Materials Reduce Embodied Energy?

The reuse of building materials commonly saves about 95% of embodied energy which would otherwise be wasted. Some materials such as bricks and tiles suffer damage losses up to 30% in reuse. The savings by recycling of materials for reprocessing varies considerably with savings up to 95% for aluminium but only 20% for glass. Some reprocessing may use more energy, particularly if long transport distances are involved.

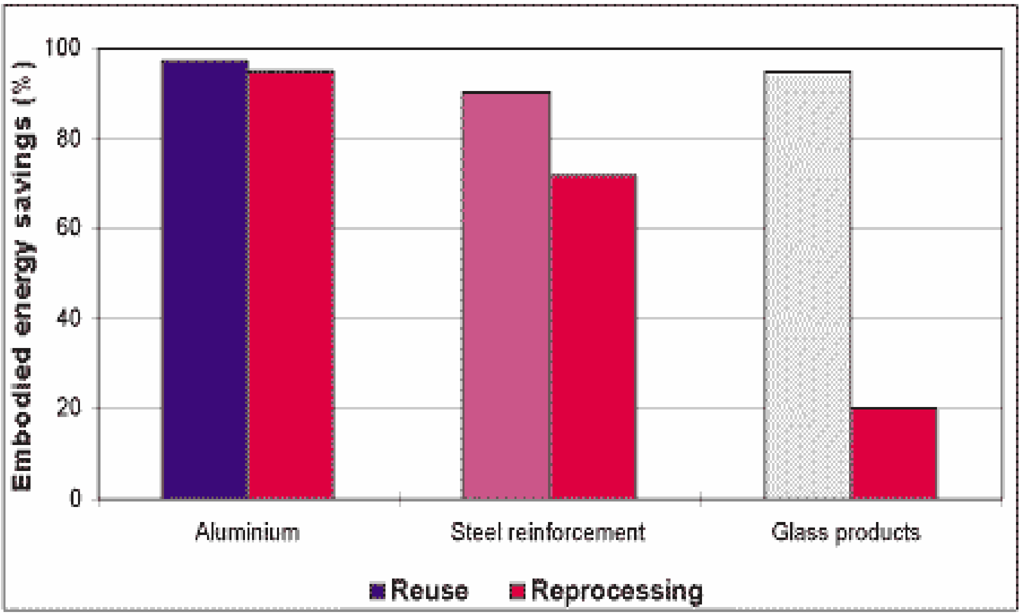

Figure 9- Potential Energy Savings

How does Embodied Energy compare with Annual Operating Energy?

The embodied energy of a building is a significant multiple of the annual operating energy consumed, ranging from around 10 for typical dwellings to over 30 for office buildings. Making buildings such as dwellings more energy efficient usually requires more embodied energy thus increasing the ratio even further.

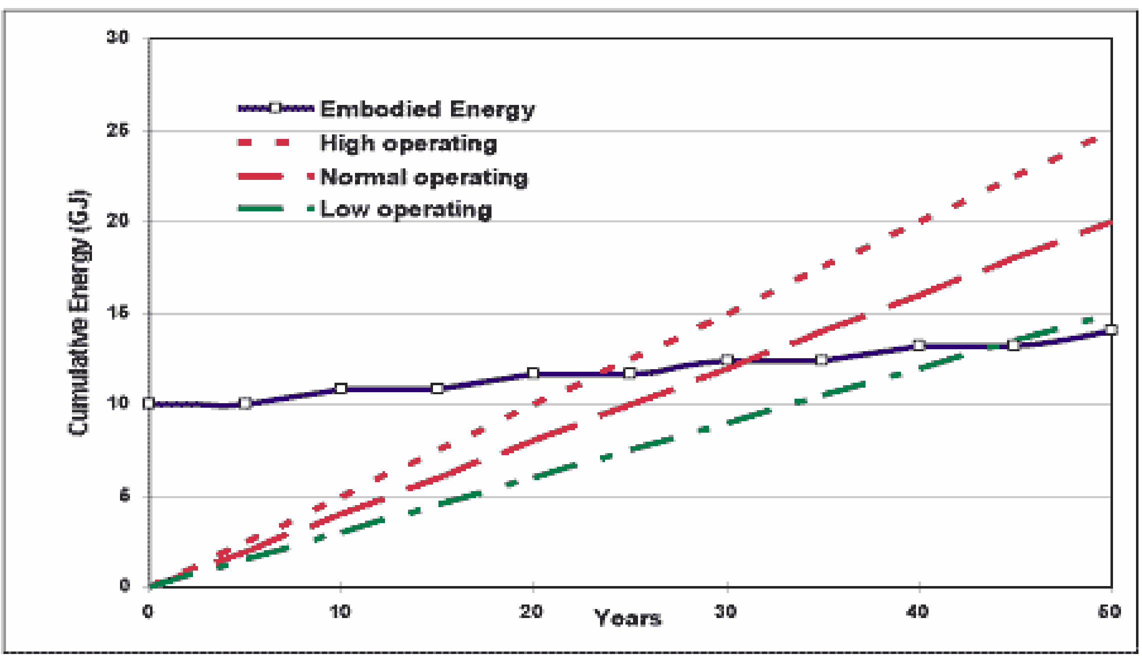

Figure 10 - Cumulative Life Cycle Energy of an Office Building

How much Embodied Energy is there in a House?

Materials such as concrete and timber have the lowest embodied energy intensities but are consumed in very large quantities; whereas the materials with high energy content such as stainless steel are used in much lesser amounts. Thus the greatest amount of embodied energy in a building is often in concrete and steel.

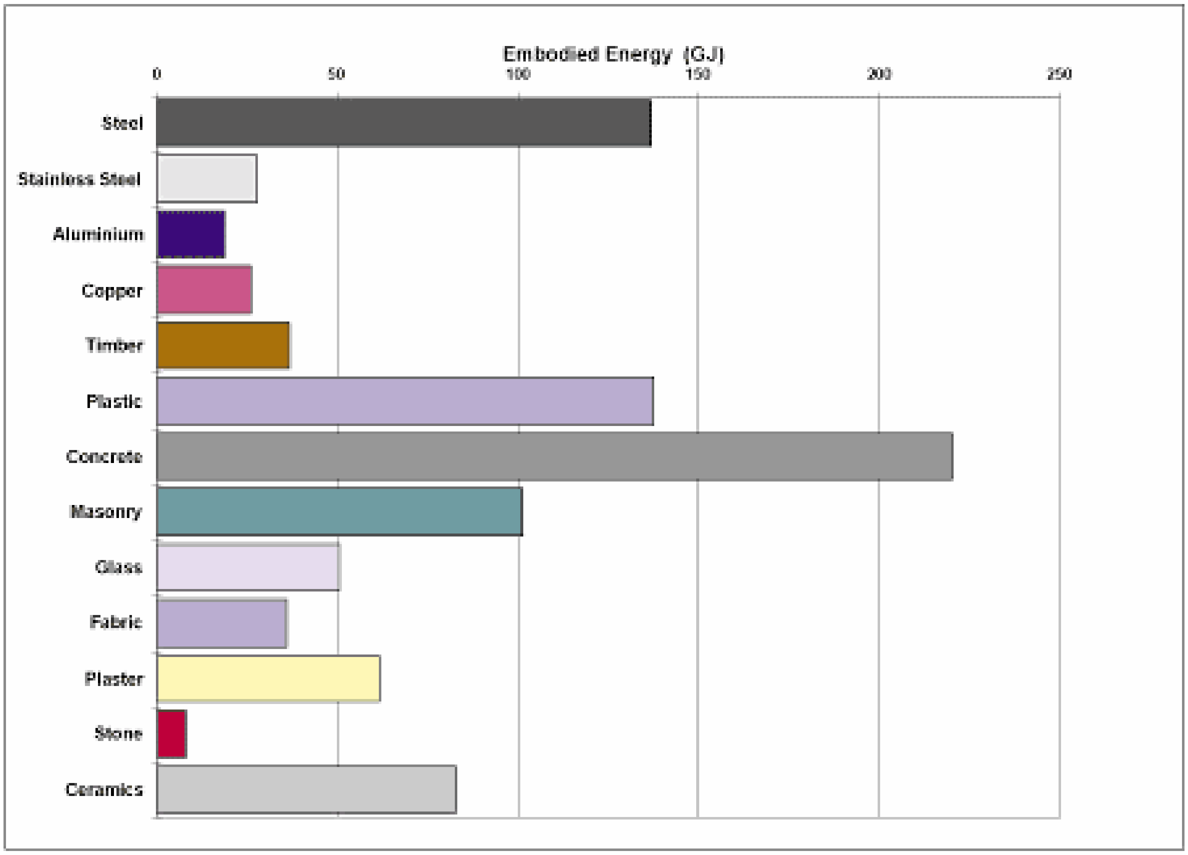

Figure 11 - Embodied Energy in a House by Material Group

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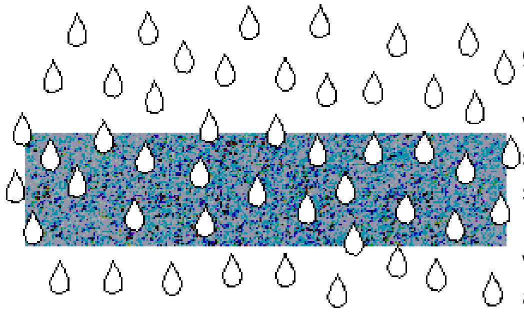
Date last modified: 07 March 2000

APPENDIX 8 - EMBODIED ENERGY & CO2 EMISSIONS

Product	Embodied Energy	Units	Reference	Intensity Factor	Ratio Tonne CO2/ Tonne Product	Units
Clay Bricks	4.7	Gj t-1	CSIRO dbce. Dr Selwyn Tucker	0.0596	0.28	t CO2.t-1
Portland Cement	12.2	Gj t-1	CSIRO dbce. Dr Selwyn Tucker		1.30	t CO2.t-1
Masonry Units	0.4	Gj metre-2	Calculated using this spreadsheet.		0.19	t CO2.t-1
Brick Mortar	1.8	Gj t-1	CSIRO dbce. Dr Selwyn Tucker		0.30	t CO2.t-1
Masonry Mortar	1.8	Gj t-1	CSIRO dbce. Dr Selwyn Tucker		0.30	t CO2.t-1
Readymix Concrete (20mpa)	2.7	Gj t-1	CSIRO dbce. Dr Selwyn Tucker		0.27	t CO2.t-1

Readymix Concrete (30mpa)	3.9	Gj t-1	CSIRO dbce. Dr Selwyn Tucker		0.39	t CO2.t-1
Steel	40	Gj t-1	est CSIRO dbce. Dr Selwyn Tucker	0.0596	2.38	t CO2.t-1
Aluminium	185	Gj t-1	est CSIRO dbce. Dr Selwyn Tucker	0.0596	18.00	t CO2.t-1

APPENDIX 9. POROUS PAVEMENTS - AN OPPORTUNITY FOR SUSTAINABILITY[79]



In years gone by forests and grassland covered most of our planet. When it rained much of the water naturally percolated though soils that performed vital functions of slowing down the rate of transport to rivers and streams, purifying the water and replenishing natural aquifers.

Our legacy has been to pave this natural bio filter, redirecting the water that fell as rain as quickly as possible to the sea. Given global water shortages, problems with salinity, pollution, volume and rate of flow of runoff we need to change our practices so as to mimic the way it was for so many millions of years before we started making so many changes.

Porous pavements are now seriously being considered by enlightened engineers around the world as a way of reducing run-off and improving safety. TecEco believe they are essential for our long term survival on this planet.

Proponents claim that porous pavements reduce the overloading of our present drainage system, cleanse water before it enters aquifers or streams and rivers, improve safety, reduce maintenance on buildings due to seasonal ground movement and reduce the costs of watering street trees.

Ideally a porous pavement should be made with stone aggregates and a cementitious binder and be similar to concrete to handle and install. In cold areas it is important that the pavement should not trap water otherwise in winter the water would freeze and cause cracking. It is also important to detail a porous structural base and sub base for the pavement that has a high void ratio as this acts as a reservoir, and provide underground drainage as required.

TecEco are interested in porous pavements because they would allow access by CO_2 curing eco-cement formulations with all the associated improvements in sustainability including massive waste utilization and large scale sequestration.

The Clogging Myth - Stopping Common Sense to Prevail?

The experience of many engineers is that with relatively minor control and maintenance clogging will not reduce the infiltration rate below a design rate within the lifecycle of the pavement. Like any other kind of surface, porous

[79] Reprint from TecEco Newsletter 28

pavements have to be swept periodically to remove debris and water under pressure can be used.

Advantages

Reduced volume and rate of runoff

Porous pavement would allow the replenishment of aquifers and reduced the cost of infrastructure to carry water out to sea as the volume and rate of flow would be less. Not as many pollutants, rubbish and debris would be transported reducing waterway pollution.

Cleaner water - less pollution

A porous pavement with integral bacteria would improve water quality entering aquifers, streams and rivers. The critical "first flush" of pollutants would be sent rapidly into the cross-section where constantly available sources of bacteria and microbes exist and have sufficient air exchange capability to maintain themselves and perform their cleaning functions. Porous pavements could act as both pavements and bio-filters at the same time.

Improved Pavement Safety

Water penetrates through porous pavements quickly leaving drier and safer surfaces with no standing water.

Drier pavements have the obvious effect of increasing friction between shoes or tyres and the foot, cycle path or road surface in wet weather and at the same time reducing road noise and spray, improving visibility.

Pavements are safer because they are not lubricated with a film of water flowing across the upper surface to the edge drains. As water does not tend to collect, sheet ice problems should be less in colder climates.

Less Maintenance

Aquifers would be more regularly replenished resulting in less variable ground moisture content, reduced ground movement with wet dry cycles and less maintenance on buildings and infrastructure.

Less Watering

A permeable surface will allow water to penetrate to street trees reducing the need for watering during dry periods and saving money.

Durability

Porous pavements made with TecEco eco-cements would not be attacked by salts and would last considerably longer that conventional binders such as bitumen (in some countries referred to as asphalt) and Portland cement.

Sustainability

Porous pavements made with TecEco eco-cements would utilise a considerable proportion of wastes such as fly ash and as they would carbonate, provide substantial abatement. Water entering aquifers, streams and rivers would be of higher quality and carry less macro pollutants. Fresh water replenishment of aquifers would reduce salinity and reverse falling water tables.

Research

TecEco are looking for governments/research institutions around the world interested in laying down experimental roads using eco-cement porous pavements and then monitoring run-off, water quality etc.