The science of TecEco binders is continuously changing. Since this paper was written we have determined that the carbonates formed are an amorphous phase, lansfordite and nesquehonite.

Emissions Reduction and other Advantages of TecEco Cements

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Around 98% of the world's energy is derived from fossil fuels that when burnt to produce energy release vast amounts of CO_2. The production of Portland cement clinker, lime and magnesia all require energy and, in addition, result in the release of chemically bound CO_2. The net result is a significant addition to global CO_2 levels.

TecEco cements offer a solution to this problem through improved durability and in the case of eco-cements re-absorption of CO_2. How the new technology cements reduce emissions is discussed in detail in this paper.

Keywords: Abatement, sequestration, CO_2, brucite ($Mg(OH)_2$), durability, reactive magnesium oxide, magnesia, reactive magnesia (MgO), magnesite ($MgCO_3$), hydromagnesite ($Mg_5(CO_3)4(OH)_2{\cdot}4H_2O$), fly ash, pozzolan, hydraulic cement, Portland cement, concrete, process energy, embodied energy, lifetime energy, durability, emissions.

Potential for Change

Underlying sustainability, emissions, pollution and other environmental issues are the material flows through our society that are largely driven by economic factors.

The built environment is, in effect, our footprint on the Earth, it is the accumulation of these material flows and accounts for some 30% of the raw materials we use, 42% of the energy, 25% of water used, 12% of land use, 40% of atmospheric emissions, 20% of water effluents, 25% of solid waste, and 13% of other releases[1,2]. <u>Include infrastructure</u> and the figures quoted would probably <u>double</u>.

Important factors in relation to the sustainability of the built environment are the embodied energies of the materials used and the lifetime energies as a result of their properties and the way they are put together. Also important in relation to the wider environment is the composition of these materials which determines the effects of extraction, how they can be reused and their effects on earth systems on wastage.

To reduce the impact of our take-make-break economic system on the environment, it is fundamental that we think about the materials we use and the molecules they are made of.

John Harrison took up this challenge and in November 1999 established TecEco Pty. Ltd. in Tasmania, Australia with the objective of developing sustainable technologies for the manufacturing and construction industries.

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[1] Australian Federal Department of Industry (1999), *Science and Tourism, Environmental and Economic Life Cycle Costs of Construction*, Detailed Discussion Paper, Section 2, p8.
[2] 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.*

Focusing on reducing the environmental impacts associated with products used in the construction industry, Harrison identified the reduction of carbon dioxide emissions associated with Portland cement as being of fundamental importance and his investigation into the use of reactive magnesium oxides blended with other hydraulic cements (such as Portland cement) and pozzolanic wastes such as fly ash resulted in a series of international patents being filed.

Summary

TecEco cements comprise a range of binders within a system whereby reactive magnesia is blended with Portland cement and usually a pozzolan to remove lime:

Two main formulation groups have so far been defined:

- TecEco modified Portland cements – cements that contain much more Portland cement than reactive magnesia. These cements offer advantages for durability and rheological improvements;
- TecEco eco-cements for significantly lower emissions, fire resistance and a number of other advantageous properties.

In both formulation groups the reactive magnesia firstly hydrates to brucite (magnesium hydroxide) and in eco-cements the reactive magnesia further carbonates to form magnesite and hydromagnesite.

It is the process of carbonation that is the key to TecEco's abatement of carbon dioxide (CO_2) from the earth's atmosphere.

Environmental and other Advantages of Including Reactive Magnesia in Hydraulic Cements such as Portland Cement.

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

Economic Advantages

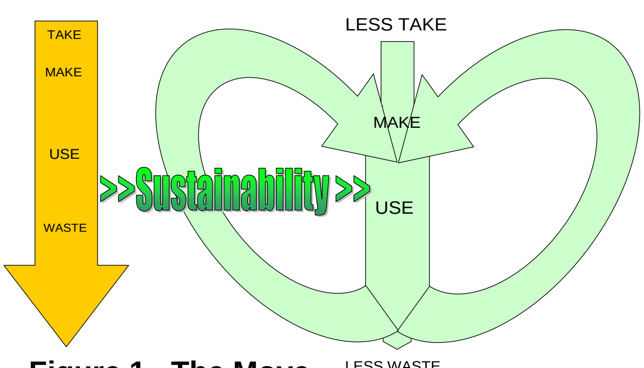

Figure 1. The Move to a More Sustainable Society.

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 produce less waste, slow down and consume less.

Achieving this should be the prerogative 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 of themselves be recycled or reused have substantial economic advantages and TecEco cements have been designed with these desirable characteristics in mind.

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 at which it is calculated.

Table 1 on page 4 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 1 are however still 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 2, and on this basis the hydrated product, brucite, has a lower embodied energy.

Table 1. 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 2. 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

Cost

In terms of 3D space, the use of magnesia results in less embodied energy per hydrated cubic metre of building material[3] 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.

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 means results in reduced emissions.

The possibilities for widespread abatement and solving global climate change issues are enormous and these are discussed in detail under the heading Environmental Advantages on page 6.

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 they will be discussed below in terms of technical advantages.

Existing plant and equipment can also be used for the production of TecEco cement reducing costs of entry, however such equipment would not be as cost effective as the new TecEco kiln.

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

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 of course 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 modified Portland cement concretes tend to resemble margarine more than traditional concretes with a low slump yet excellent workability. As the hydration of magnesia appears to take up water that would with Portland cement concretes tend to bleed, the evidence so far indicates less or no shrinkage in some formulations.

Other properties become more apparent on setting such as a usually higher strength than would be expected from the amount of Portland cement added and 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 and less corrosion, iron stains etc. as TecEco cements are much more durable.

It also takes some time for problems due to alkali aggregate reaction to emerge and with TecEco cements they will most likely never emerge.

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 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 and are usually 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 3. 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 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.

Sequestration and Abatement in TecEco Cements

TecEco cements and in particular eco-cements have received tremendous publicity for the sequestration and abatement possibilities[4].

How abatement occurs varies with the type of TecEco cement

TecEco Modified Portland cements

TecEco modified Portland cements are much more durable because brucite is so much less soluble, mobile or reactive than Portlandite. TecEco modified Portland cements are not attacked by salts, they maintain the passivity of steel and can be used with a wider range of aggregates. As a result concrete structures built using modified Portland cement containing a small proportion of reactive magnesia as well as fly ash should last a lot longer and need replacing less often using less energy to remove them, less energy to

[4] 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.

waste them (a high proportion of urban waste is discarded building materials) and less energy to reconstruct them. Because energy is directly related to CO_2 emissions, net emissions are lower.

TecEco Eco-Cements

Perhaps 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 carbonate to completion in porous materials, absorbing much more CO_2. A typical eco-cement formulation for masonry products for example would contain 50 - 85% material that will carbonate in the cement component compared to 20-25% in the cement component of concrete masonry units (CMUs) containing Portland cement only. There is therefore approximately 50 - 85 % more carbonation in an eco-cement block compared to an ordinary concrete block.

The easiest way to understand them is to think about a 1:1:7, opc, lime and sand mortar in which there is a little less Portland cement and in which the lime is replaced with a bit more reactive magnesia which first hydrates and then carbonates. Toss in a bit of fly ash for good measure, and the nuisance waste consumes the lime. Magnesite is a strong often fibrous and acicular mineral and definitely worth encouraging in a binder. What follows is a more scientific explanation about carbon dioxide CO_2 releases.

Energy Related Emissions

Process emissions for cement manufacture are the emissions from the energy used in mining, transport, mixing, homogenising, grinding, preheating, calcining, finish inter grinding, packaging, transport and warehousing etc. Process energies from the production of reactive magnesia, lime and Portland cement were considered under the heading "Energy" on page 3 and are less for reactive magnesia when measured relative to the materials that are incorporated in a cement once set. On a per mole basis the production of magnesia is also more efficient. 98% of the worlds energy is derived from the use of fossil fuel. Assuming natural gas is used and an average emissions factor of .0640 Kg.Mj-1[5] it is possible to calculate process emissions as in Table 3 and Table 4 on page 10.

Chemical Release of CO_2

A mole of both magnesite and limestone will, on calcination, chemically release a mole of carbon dioxide and a mole of the respective oxides and hydroxides will reabsorb a mole of the gas. Table 3 and Table 4 demonstrate that more CO_2 is chemically released on a CO_2/tonne product basis for both the calcination of magnesite and limestone than the production of Portland cement clinker and this is because the share of lime in Portland cement is only 65.5%. It is also true that on a mass basis, more CO_2 is also chemically released by the calcination of magnesite than limestone, and this is because of the lower molecular weight of magnesium.

Portland cement as it hydrates produces around 24 mass% lime (often referred to in the cement industry as Portlandite $Ca(OH)_2$). In eco-cements relatively large proportions of reactive magnesia are blended with Portland cement and pozzolans and the magnesia hydrates first to become brucite ($Mg(OH)_2$) and in porous materials like bricks, blocks, pavers, mortars and possibly even highway and footpath pavement (for which it is

[5] This is an average figure from the Australian greenhouse office.

suggested eco-cements should be used[6]), virtually all of the brucite and lime (unless the latter is consumed by a pozzolan) will reabsorb CO_2 out of the atmosphere and eventually reconvert to their respective carbonates completing what are thermodynamic cycles. As a result net emissions are less.

The proportion of materials, and in particular reactive magnesia in eco-cements that will carbonate in eco-cements is much higher, so much more CO_2 is reabsorbed.

[6] There is considerable merit to the argument that road and footpath pavement should be made porous. See newsletter 29 on the TecEco web site.

Table 3. CO_2 Emissions from energy calcining compared on a mass basis.

Relative to Raw Material Used to make Cement	From Manufacturing Process Energy Release 100% Efficient (Tonne $CO2.tonne^{-1}$)	From Manufacturing Process Energy Release with Inefficiencies (Tonne $CO2.tonne^{-1}$)	Relative Product Used in Cement	From Manufacturing Process Energy Release 100% Efficient (Tonne $CO2.tonne^{-1}$)	From Manufacturing Process Energy Release with Inefficiencies (Tonne $CO2.tonne^{-1}$)	Relative to Mineral Resulting in Cement	From Manufacturing Process Energy Release 100% Efficient (Tonne $CO2.tonne^{-1}$)	From Manufacturing Process Energy Release with Inefficiencies (Tonne $CO2.tonne^{-1}$)
$CaCO_3$ + Clay	.10	.18	Portland Cement	.12	.21	Hydrated OPC	.08	.15
$CaCO_3$	.11	.17				$Ca(OH)_2$	.15	.23
$MgCO_3$	.09	.11	MgO	.19	.23	$Mg(OH)_2$	.13	.16

Table 4. CO_2 Emissions from energy calcining compared on a volume basis.

Relative to Raw Material Used to make Cement	From Manufacturing Process Energy Release 100% Efficient ($Tonne.metre^{-3}$)	From Manufacturing Process Energy Release with Inefficiencies ($Tonne.metre^{-3}$)	Relative Product Used in Cement	From Manufacturing Process Energy Release 100% Efficient ($Tonne.metre^{-3}$)	From Manufacturing Process Energy Release with Inefficiencies ($Tonne.metre^{-3}$)	Relative to Mineral Resulting in Cement	From Manufacturing Process Energy Release 100% Efficient ($Tonne.metre^{-3}$)	From Manufacturing Process Energy Release with Inefficiencies ($Tonne.metre^{-3}$)
$CaCO_3$ + Clay	.27	.49	Portland Cement	.38	.67	Hydrated OPC	.22	.40
$CaCO_3$	.27	.41				$Ca(OH)_2$	.34	.52
$MgCO_3$	.27	.34	MgO	.60	.75	$Mg(OH)_2$	.31	.39

Table 5. Total emissions summary.

CO_2 EMISSIONS SUMMARY

	Calcination Energy CO2 Release 100% Efficient	Calcination Energy CO2 Release with Inefficiencies	Chemical CO_2 Release	Total CO_2 Release 100% Efficient			Total CO_2 Release with Inefficiencies		
				Raw Material	Product in Cement	Hydrated Cement	Raw Material	Product in Cement	Hydrated Cement
Total CO2 Released (tonnes/tonne)									
Relative to:									
Limestone and Clay	0.10	0.18	0.51	0.61			0.70		
Portland Cement	0.12	0.21	0.51		0.63			0.73	
Hydrated Portland Cement	0.08	0.15	0.36			0.44			0.51
$CaCO_3$	0.11	0.17	0.44	0.55			0.61		
$Ca(OH)_2$	0.15	0.23	0.59			0.75			0.83
$MgCO_3$	0.09	0.11	0.52	0.61			0.63		
MgO	0.19	0.23	1.09		1.28			1.33	
$Mg(OH)_2$	0.13	0.16	0.75			0.88			0.92
CO2 Released (tonnes/cubic metre)									
Relative to:									
Limestone and Clay	0.27	0.49	1.39	1.66			1.88		
Portland Cement	0.36	0.67	1.62		1.98			2.29	
Hydrated Portland Cement	0.22	0.40	0.96			1.18			1.36
$CaCO_3$	0.27	0.41	1.19	1.47			1.60		
CaOH	0.34	0.52	1.32			1.67			1.84
$MgCO_3$	0.27	0.34	1.59	1.87			1.93		
MgO	0.60	0.75	3.49		4.09			4.24	

$Mg(OH)_2$	0.31	0.39	1.81			2.12			2.20
CO2 Released (cubic metres/cubic metre)									
Relative to:									
Limestone and Clay	136.94	250.60	711.54	848.48			962.14		
Portland Cement	186.08	340.52	827.07		1013.14			1167.59	
Hydrated Portland Cement	110.82	202.80	492.56			603.38			695.36
$CaCO_3$	140.13	210.20	608.66	748.79			818.86		
CaOH	175.92	263.88	676.71			852.63			940.59
$MgCO_3$	139.86	174.83	813.14	953.00			987.97		
MgO	306.95	383.69	1784.57		2091.52			2168.26	
$Mg(OH)_2$	159.15	198.94	925.26			1084.41			1124.20

Emissions Abatement and "Closed Loop" Materials Flow: A Recipe for Increased Sustainability.

What is important is that the sequestration by carbonation in the thermodynamic cycle magnesite=>magnesia=>brucite=>magnesite is potentially substantial and therefore represents a very useful way to create more sustainable building materials, particularly if the CO_2 produced during calcining could be captured during the manufacturing process as TecEco propose to do with their new kiln[7].

Given the huge size of the materials flow required to create and maintain the built environment the substitution of pure Portland cements by eco-cements on a widespread scale could result in massive abatement, particularly with capture of CO_2 during manufacture.

To understand the huge scale of possible abatement and sequestration consider a typical concrete made with 15 mass% Portland cement compared to a concrete made with 15 mass% TecEco eco-cement that could be used for porous masonry products such bricks, blocks, pavers and mortars as well as possibly highway and footpath pavement[6] and hence carbonate. Of the TecEco eco- cement 25 mass % is Portland cement, 75 mass % is reactive magnesia as shown in Figure 1. Assume the Portland cement on hydration produces 24 mass % Portlandite.

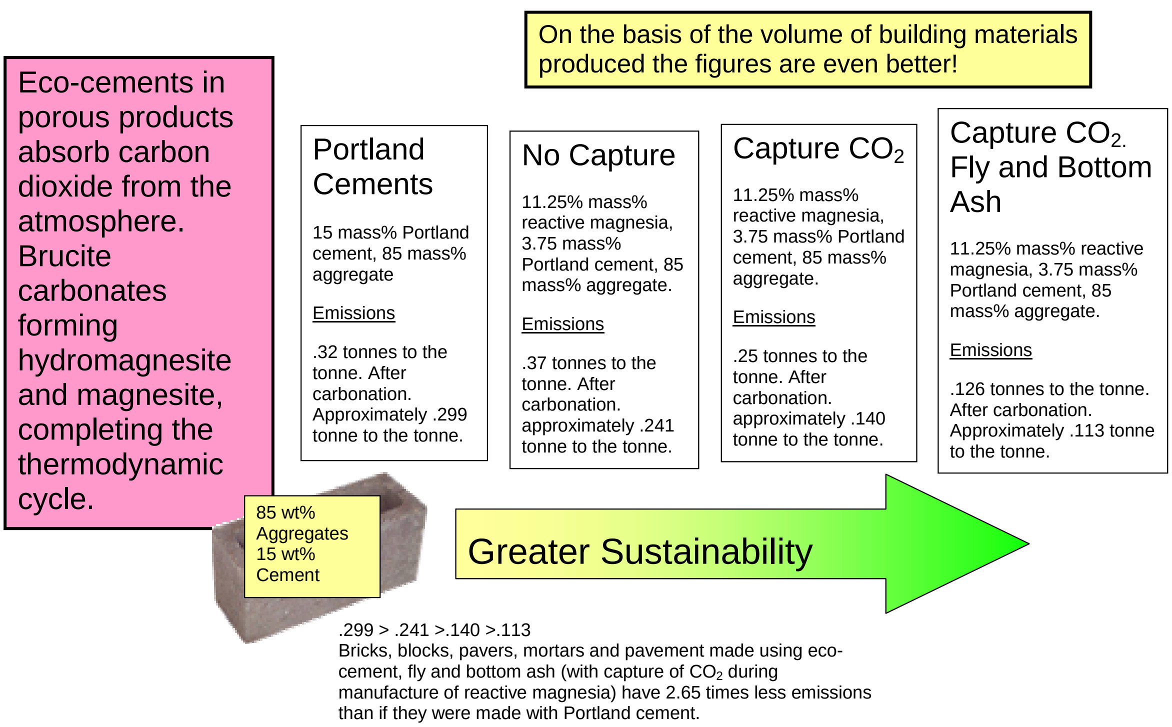

Figure 2. Emissions with and without capture CO2 from Eco-cement compared to Portland cement. The determination of the figures is complex and has been done on the basis

[7] Patents pending.

all factors being the same for the production of magnesia as for the production of Portland cement other than the calcination energies[8].

The figure for the CO_2 emissions from the production of Portland cement blocks used in calculating the numbers shown in Figure 1 of .896 tonnes CO_2 to the tonne of cement is in broad agreement with the figures of Hendriks C.A. et. al. in an IEA paper[9]. The lime produced as Portland cement used in porous materials sets is assumed to totally carbonate and results in net emissions of .78 tonnes CO_2 to the tonne of cement.

Given the above, the 15% Portland cement concrete in the above example has net emissions of .299 tonnes to the tonne. The eco-cement formulation, on the other hand, has lower net emissions of .241 tonnes to the tonne.

With the capture of CO_2 during the manufacturing process which is relatively easy for the production of reactive magnesia, the figure for net emissions drops to a low .140 tonnes CO_2 to the tonne of cement.

A new and 25% more efficient TecEco magnesia kiln is currently being designed (patents pending) in which CO_2 is captured during calcining and grinding. The use of this kiln will become economically feasible in the long run due to the fact that the molecular weight proportion of CO_2 in $MgCO_3$ is so high with correspondingly high carbon credits and the fact that it will be practical to decommission existing cement plants and replace them with new plant as such plants become obsolete. If sustainable energy is used to power the new kiln that does not release CO_2 such as from wind power ***then eco-cements could even become a net carbon sink.***

The use of fly and bottom ash, in which the energy costs are already accounted for in the power industry, would also reduce net emissions because of dilution and because some process energies such as for mining would not be included.

Global Abatement

The potential for greater sustainability by changing the materials flows involved in the construction of our built environment, which represents our footprint on earth, is enormous. Buildings and even roads could be built using eco-cements of similar composition to the above example.

Consider the abatement, if the above formulation of 15 mass% eco-cement was generally adopted for 80 % of construction purposes (With no fly or bottom ash as there would not be enough!). Using similar math the abatement that would result is shown in the following table.

Table 6. Abatement from substitution of Portland Cement by Eco-cement.

	Without CO2 Capture during manufacture (billion tonnes)	**With CO2 Capture during manufacture (billion tonnes)**

[8] Complex spreadsheets are available.

[9] Hendriks C.A. et. al. in an IEA paper, C.A. Hendriks, E. Worrell, L. Price, N. Martin, D. de Jager, K. Blok, and P. Riemer, *Emission Reduction of Greenhouse Gases from the Cement Industry. International Energy Agency Conference Paper* Retrieved from www.ieagreen.org.uk 01/07/02.

Total Portland Cement Produced Globally	1.80	1.80
Global mass of Concrete (assuming a proportion of 15 mass% cement)	12.00	12.00
Global CO_2 Emissions from Portland Cement	3.60	3.60
Mass of Eco-Cement assuming an 80% Substitution in global concrete use	9.60	9.60
Resulting Abatement of Portland Cement CO_2 Emissions	2.88	2.88
CO_2 Emissions released by Eco-Cement	2.59	1.34
Resulting Abatement of CO_2 emissions by Substituting Eco-Cement	**0.29**	**1.53**

Abatement without capture of CO_2 during manufacture is .289 billion tonnes and with capture 1.532 billion tonnes. If fly and bottom ash were used the abatement figures would be higher due to dilution as emissions from their production are accounted for in relation to the energy produced by burning coal.

Driving the Growth of the Global Cement Industry Through the TecEco Technology: An Opportunity to be Taken, not a Threat to be Ignored

Realistically there would also be considerable substitution of TecEco eco-cements replacing clay bricks, steel and aluminium used in construction. Driving this would be the fact that TecEco eco-cement concretes would be the first building materials devised of high thermal mass and low embodied energy. The cement industry should therefore see the production of eco-cements as an opportunity, not a threat[10]. Table 7 sets out TecEco's estimates of global markets for construction products, the realistic percentage substitution by TecEco eco-cements (assuming a mass for mass basis) and a total CO_2 abatement worked out using a similar analysis that using in Table 6. (The estimates ignore timber as it is a relatively short term carbon sink).

[10] This is very basic economics. The merit of diversification into eco-cement should be considered.

Table 7. Abatement from substitution ($MtCO_2\ t^{-1}$,millions of tonnes).

Building Material to be substituted	Realistic % Subst-itution by TecEco technology	Size of World Market (million tonnes	Substituted Mass (million tonnes)	CO2 Factors[11]	Emission From Material Before Substitution	Emission/Sequestration from Substituted Eco-Cement (Tonne for Tonne Substitution Assumed)		Net Abatement	
						Emissions - No Capture	Emissions - CO2 Capture	Abatement - No Capture	Abatement CO2 Capture
Bricks	85%	250[12]	212.5	0.28	59.5	57.2	29.7	2.3	29.8
Steel	25%	840[13]	210	2.38	499.8	56.6	29.4	443.2	470.4
Aluminium	20%	20.5[14]	4.1	18.0[15]	73.8	1.1	0.6	72.7	73.2
TOTAL			**426.6**	**20.7**	**633.1**	**114.9**	**59.7**	**518.2**	**573.4**

[11] Dr Selwyn Tucker, CSIRO dbce. Pers. com.
[12] This figure was derived from known figures in some countries.
[13] International Iron & Steel Institute figure Retrieved 08/08/03 from http://www.worldsteel.org/article/iisi20020118.
[14] International Aluminium Institute Retrieved 08/08/03 from http://www.world-aluminium.org/iai/stats/index.html.
[15] Alan Pears, RMIT, Melbourne, Australia

These calculations indicate that if the TecEco technology can succeed in replacing non-cement based building materials, a further 518.21 or 573.42 billion tonnes would be sequestered on top of the figures from table 2 depending on whether CO_2 is captured at source or not. Total sequestration if eco-cements were adopted for 80% of the current uses of Portland cement could therefore be as high as 2.105 billion tonnes.

Further sequestration would result from the inclusion of waste carbon based matter such as sawdust, waste timber shavings and chippings, plastics, rubbers etc, many of which are currently burnt adding to the global atmospheric CO_2 level. Many of these materials also have the advantage of not only adding insulating capacity but strength to eco-cement products as they have innate tensile strength. Wood for example is in the order of 250 MPa whilst some waste plastics are closer to 1000 MPa. The figure is impossible to calculate because of the variation that may be expected, but is likely to be in the order of more than 0.5 billion tonne.

With the inclusion of materials containing carbon the total abatement from the widespread adoption of TecEco eco-cement technology could therefore be more than 2.5 billion tonnes. As the annual atmospheric increase in CO_2 is around 12.7 billion tonnes[16] this would be over 15% of the annual increase.

Conclusion

The case for including reactive magnesia with Portland Cements in concretes is overwhelming and results in potential solutions to many of the problems of the material including greater sustainability.

As Fred Pearce reported in New Scientist[17] 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”

The TecEco cement technologies therefore merit serious attention by industry and governments.

[16] Retrieved 08/08/03 from http://www.whrc.org/science/carbon/carbon.htm.
[17] Fred Pearce, *Green Foundations*, New Scientist, vol 175 issue 2351, 19 July 2002, page 39.