Combining Mineral and Geological Sequestration Using TecEco Tec and Eco-Cements and TecEco Tec-Kiln Technology.

Abstract

The Built Environment is potentially a repository for sequestration on a massive scale.

The implications for mineral sequestration and abatement of the new TecEco eco-cement and tec-kiln technologies are discussed in this paper.

Starting with either forsterite or serpentine to produce first magnesite and then tec or 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 the costs and emission of production and disposals. Mineral and geological sequestration are combined resulting in a solution to the carbon balance problem with positive economic outcomes.

Keywords

Mineral, sequestration, forsterite (Mg_2SiO_4), serpentine ($Mg_3Si_2O_5(OH)_4$), abatement, sustainable, sustainability, sequestration, CO_2, brucite ($Mg(OH)_2$), reactive, magnesium oxide (MgO), nesquehonite ($MgCO_3.3H2O$), lansfordite ($MgCO_3.5H2O$), magnesian, magnesia (MgO), magnesite ($MgCO_3$), fly ash, pozzolan, hydraulic cement, Portland cement, concrete, process energy, embodied energy, lifetime energy, magnesite, abatement, magnesia, nesquehonite, lansfordite, amorphous magnesium carbonate, eco-cement, tec-cement, kiln, tec-kiln, calcine, grind.

John Harrison

John Harrison in the managing director and chairman of TecEco Pty Ltd and is known around the world for the invention of eco-cement and other magnesium cement based technologies. John has degrees in science and economics and is best known for the invention of tec, eco and enviro-cements. John is an authority on sustainable materials for the built environment and was a founder of the Association for the Advancement of Sustainable Materials in Construction. He has been the keynote speaker at many conferences and is committed to “materially” finding ways of improving the sustainability of the built environment.

Introduction

Carbon and carbonate sequestration have been the mechanisms through which previous atmospheric global carbon imbalances have been corrected and sequestration still represents the best opportunity for permanent immobilization of atmospheric carbon. Most of the world’s coal and petroleum reserves were formed during previous epochs of volcanic carbon emissions and global warming and around 7% of the surface of the earth's crust above sea level is carbonate.

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. Although promoted by the petroleum industry as a means of extracting remaining reserves of oil "there are significant fundamental research needs that must be addressed before geologic formations can be widely used for carbon sequestration.(NETL, 2004)" 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 (Seifritz, W., 1990; Dahlin, D. C., O'Connor, W. K. et al., 2000; O'Connor, W. K., Dahlin, D. C., Nilsen, D. N., Walters, R. P., and Turner, P. C, 2000; Fauth, D. J., Baltrus, J. P. et al., 2001; Lackner, Klaus S, Grimes, Patrick et al., 2001; NETL, 2004)

Mineral Sequestration

Mineral sequestration is based on one, the other or both of the following exothermic reactions

$Mg_2SiO_4 + 2CO_2 \rightarrow 2MgCO_3 + SiO_2 + 95\ kJ.mol^{-1}$

$Mg_3Si_2O_5(OH)_4 + 3CO_2 \rightarrow MgCO_3 + 2SiO_2 + 2H_2O + 64\ kJ.mol^{-1}$

These reaction occur in nature on geological times scales as chemical weathering and the biological activity of corals and coccoliths (O'Connor, B., 2001). They also occur when carbonated and hence acidic waters percolate through basic magnesium mineral deposits forming silica and stable magnesite as often occurs in serpentized rocks (Yegulalp, T. M., Lackner, K. S. et al., 2001) As a result of these processes eventually all the carbon dioxide in the atmosphere would be safely sequestered (Lackner, Klaus S., Grimes, Patrick et al., 2001) however the process is too slow to prevent global warming as a result of anthropogenic carbon dioxide but has the advantage of permanent disposal of carbon dioxide with no possibility for leakage.

The biggest problem so far with the first stage of a combined process is the reaction rate of the carbonation step. The reaction with forsterite appears to occur more readily and results in greater abatement. The reaction with chrysotile or serpentine as it is sometimes called is however favoured as the mineral is abundant although problems remain to be solved with the kinetics. The most promising method of acceleration appears to be the use of waste sulphuric acid to mobilise magnesium first (Ou, H. X., 2003).

Implications of TecEco Technology

The TecEco technologies interface ideally with mineral sequestration using either forsterite or serpentine as they provide a calcining method whereby the magnesium carbonate produced can be further used to scrub CO_2 from the atmosphere and a way of usefully using the output from this process to sequester carbon as magnesium carbonates in the built environment.

All TecEco processes take advantage of the magnesium thermodynamic cycle (Figure 4 on page 17)

Scrubbing CO2 Using TecEco Tec-Kiln Technology

Although highly confidential and subject to patent applications the TecEco tec-kiln calcines and grinds at the same time in a closed system. Because magnesite can be calcined a relatively low temperatures and as a consequence of certain secret design features variable intensity waste heat or solar energy can easily be utilised. The energy required is also supplemented by the waste heat released during the grinding process.

The CO_2 chemically released by calcining magnesite can be captured and used to replace CO_2 used for other purposes (e.g. carbonated drinks) or geologically sequestered.

The product of the tec-kiln, reactive magnesium oxide, can then be used to “scrub” more carbon dioxide from the air according to the reaction below whereby $MgCO_3$ will break down yielding MgO and CO_2. Equilbrium is at one atmosphere 540 ^{o}C and the reaction will proceed most readily at high partial pressures of CO_2.

MgO + CO2 → MgCO3- + 118 kJ/mole

The 118 kJ/mole of heat theoretically released will hopefully with some research on the kinetics be sufficient to make it proceed without external energy (Yegulalp, T. M., Lackner, K. S. et al., 2001).

There will of course be inefficiencies, and it would therefore be desirable to exit some MgO continuously from the total process which could be used to make eco-cement concretes to construct the built environment (See Eco-Cements Concretes Containing CO_2 in the Built Environment below).

The Tececo tec-kiln technology is of tremendous importance to the world as combined with mineral sequestration as being developed by others and mineral sequestration in the built environment using eco-cements, one mole of either serpentine or forsterite as a raw materials can sequester many moles of CO_2 from the atmosphere.

A theoretical process diagram of the TecEco total process is shown as Figure 1 below and funds are being sought to develop the process.

Eco-Cements Concretes Containing CO_2 in the Built Environment

TecEco have uniquely demonstrated that eco-cement concretes can sequester massive amounts of CO_2 and use many wastes for their physical property rather than chemical composition and that they are suitable materials for the built environment meeting the various standards as required. Combined with chemical sequestration and TecEco tec-kiln technology based on forsterite or serpentinite the potential sequestration utilising TecEco technology is massive and potentially an economic solution to the problem of global warming facing the planet.

Eco-cement concretes harden and gain strength by absorbing carbon dioxide from the air in accordance with the following reactions.

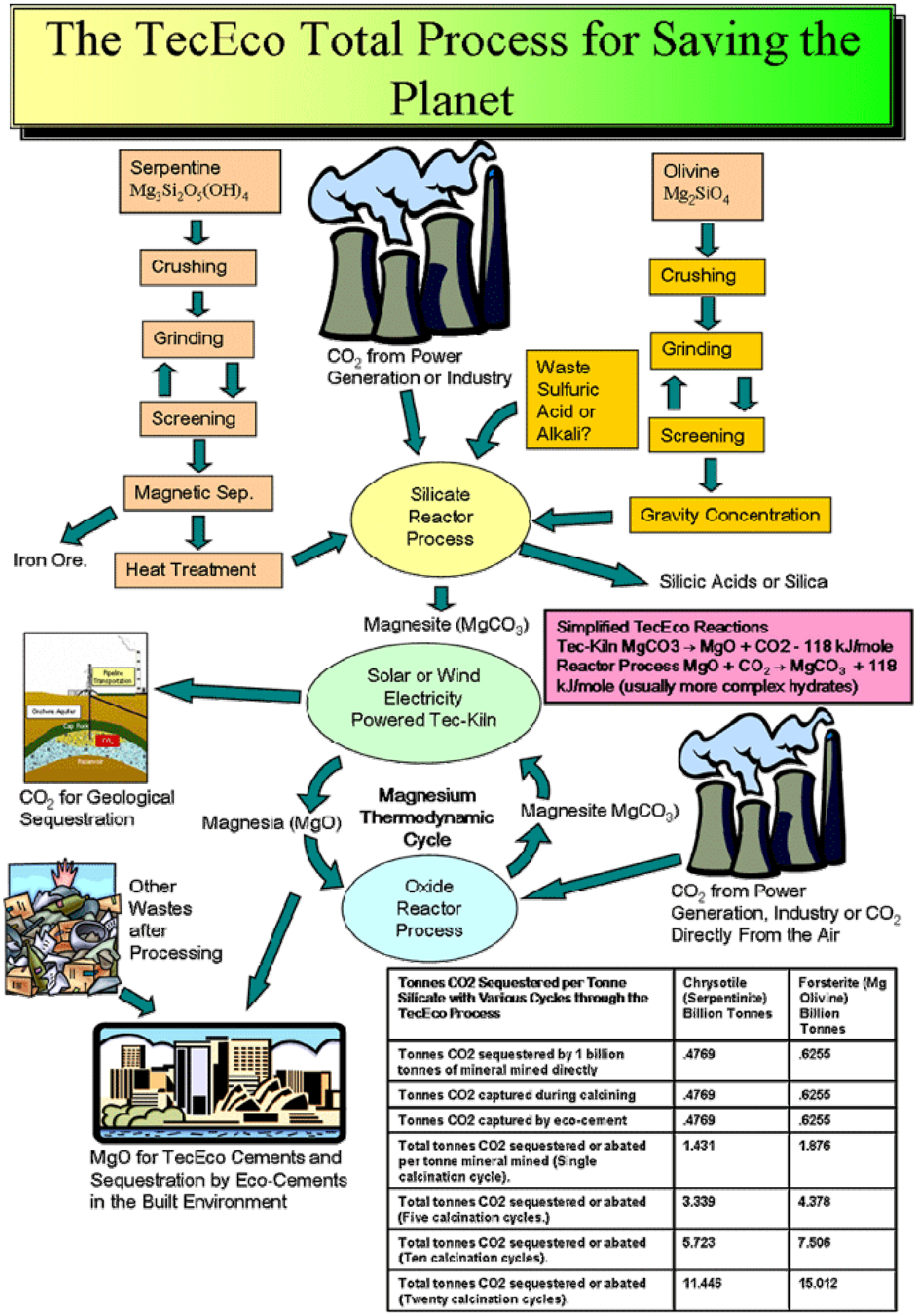
$MgO + H_2O \rightarrow Mg(OH)_2 + 109.19\ kJ.mol^{-1}$ – formation of brucite.

$Mg(OH)_2 + CO_2 + 2H_2O \rightarrow Mg(HCO_3)(OH)\cdot 2(H_2O)$ + 175.59 kJ.mol^{-1} - carbonation of brucite to give nesquehonite.

We are still to work out the thermodynamics for the formation of lansfordite and an amorphous phase of magnesium carbonate still poorly characterised.

The generally fibrous and acicular magnesium mineral carboantes formed add microstructural strength and are ideal binders as well as repositories for carbon dioxide.

On hydration of magnesia to form brucite there is a 117% expansion. On carbonation to nesquehonite further expansion of 307% occurs. Nesquehonite is 71 mass % and lansfordite 77 mass % water and CO_2. The high volume of cement binder formed from water and CO_2 adds to the potential cost effectiveness of eco-cements.



Tonnes CO2 Sequestered per Tonne Silicate with Various Cycles through the TecEco Process	Chrysotile (Serpentinite) Billion Tonnes	Forsterite (Mg Olivine) Billion Tonnes
Tonnes CO2 sequestered by 1 billion tonnes 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
Total tonnes CO2 sequestered or abated (Twenty calcination cycles)	11.445	15.012

Figure 1 - TecEco Tec-Kiln and Eco-Cement Technology Additions to the Mineral Sequestration Process after Goldberg (Goldberg, P., 2001).

Process Economics

The cost of mineral sequestration even without the advantages added by TecEco technology is predicted to be quite reasonable.

Assuming thermodynamically efficient processes, a cost including rock mining, crushing and milling, of around $ US 30/tonne of CO_2 is suggested (Herzog, H., 2002). For a 66% efficient power plant this would add less than 1-2 cents to the cost of a kilowatt hour of electricity.

Should a price of carbon under the now legally binding Kyoto protocol be anything over $ US 30/tonne of CO_2, the process would be economic once kinetic issues for chemically processing magnesium silicates are overcome.

The key to matching the lower cost of geological sequestration of $ 1-5/tonne is to leverage the process using solar or solar derived energy and the TecEco kiln technology/MgO scrubbing process is uniquely capable of doing this.

A combined process involving TecEco tec-kiln technology would sequester much more carbon dioxide and involve the eventual production of eco-cement concrete components that also sequester the gas to create the built environment and is potentially very profitable even if an even lower price for carbon of say less than $ 10.

The use of TecEco eco-cements concretes would also be favoured as magnesite, the raw material, would not have to be mined.

The Kyoto protocol will also encourage the development of other technologies whereby CO_2 becomes a resource and as a result the process will eventually be supported by an economically driven price for CO_2

Process Sequestration and Abatement

Sequestration possible in tonnes CO_2 per tonne of raw material with and without TecEco technology is shown in Table 1 – Tonnes CO2 Sequestered per Tonne Silicate with Various Cycles through the TecEco Process below. It can be seen that with the introduction of the TecEco process 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, five or ten calcination cycles is shown[1].

	Chrysotile (Serpentinite) Tonnes	Forsterite (Mg Olivine) Tonnes
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

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[1] 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.

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 – Tonnes CO2 Sequestered per Tonne Silicate with Various Cycles through the TecEco Process

The graphs on page 7 Table 3 through Table 5 illustrate the massive sequestration available[2] even with only one cycle of calcination. More cycles would result in greater sequestration.

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 10,000,000 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 for serpentine and forsterite are respectively $ 313, 563 and 429 million dollars, and definitely 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
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[3].

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

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. Leveraged by solar or solar derived energy with more cycles of calcination/MgO CO_2 scrubbing using TecEco tec-kiln and tec-scrub technology - much less.

The process scenarios depicted by the graphs would also involve the production of 8.8, 5.9 and 5.5 billion tonnes of eco-cement for magnesite, forsterite and serpentine respectively which would contain 66.6% magnesia. As the global demand would not exceed say 2 billion tonnes (eco-cements could replace potentially around 80% of the concrete used which is not structural and some other materials such as bitumen which may be carcinogenic) an economic maximum of sequestration with only one cycle of calcination would be in the order of a very significant 4 – 5 billion tonnes of CO2 sequestered. Again, leveraged with more kiln cycles much more.

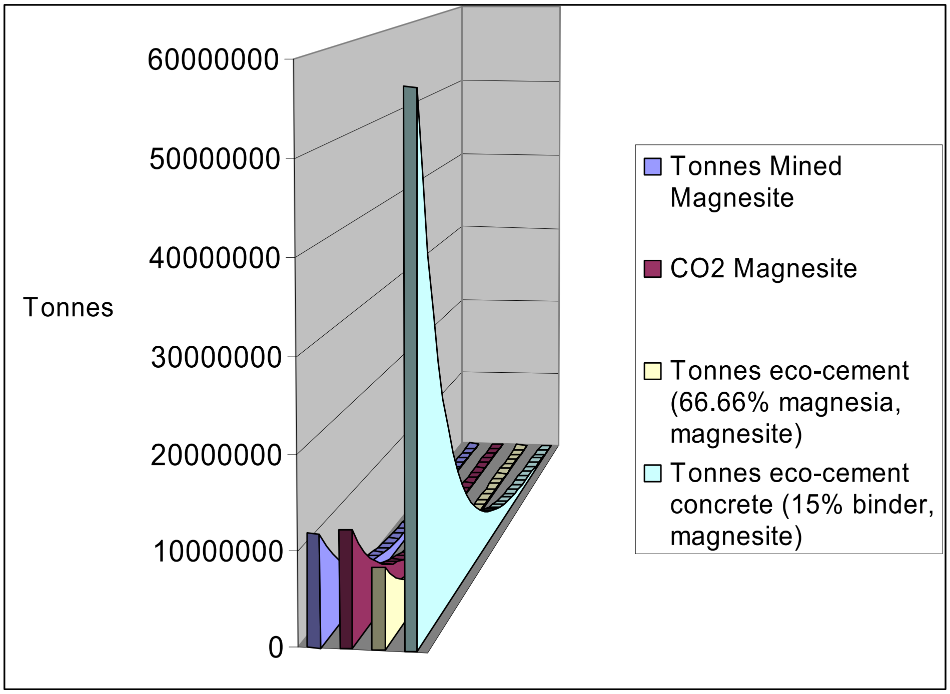

Table 3 – Graph Showing Sequestration and Output Eco-Cement (66.66% Magnesia) and Eco-Cement Concrete (15% Eco-Cement) per Tonne of Magnesite Mined and Processed.

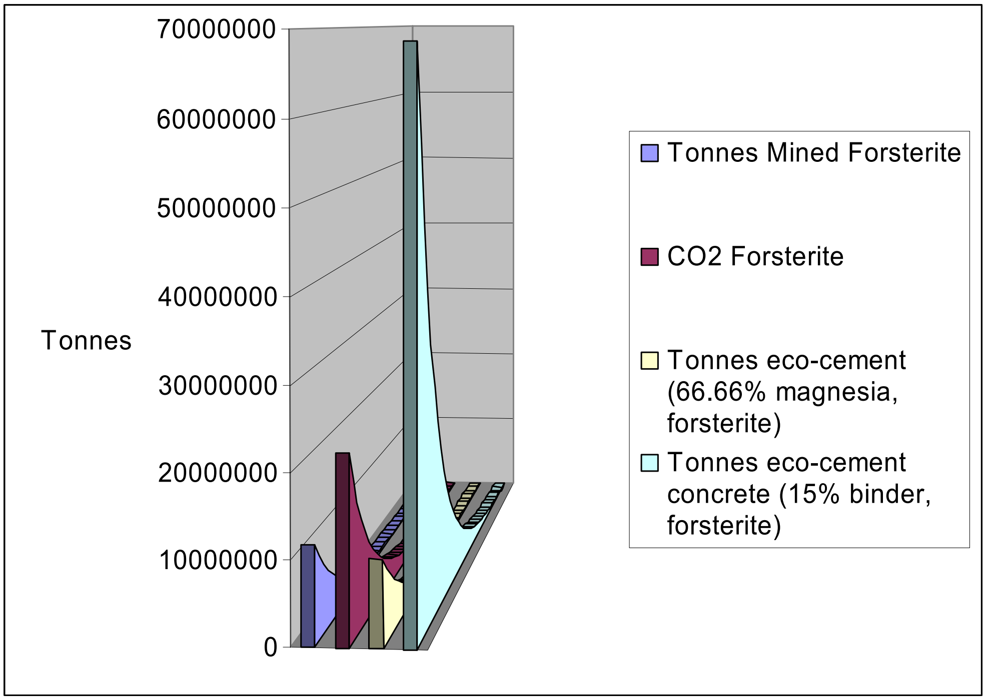

Table 4 – Graph Showing Sequestration and Output Eco-Cement (66.66% Magnesia) and Eco-Cement Concrete (15% Eco-Cement) per Tonne of Forsterite Mined and Processed.

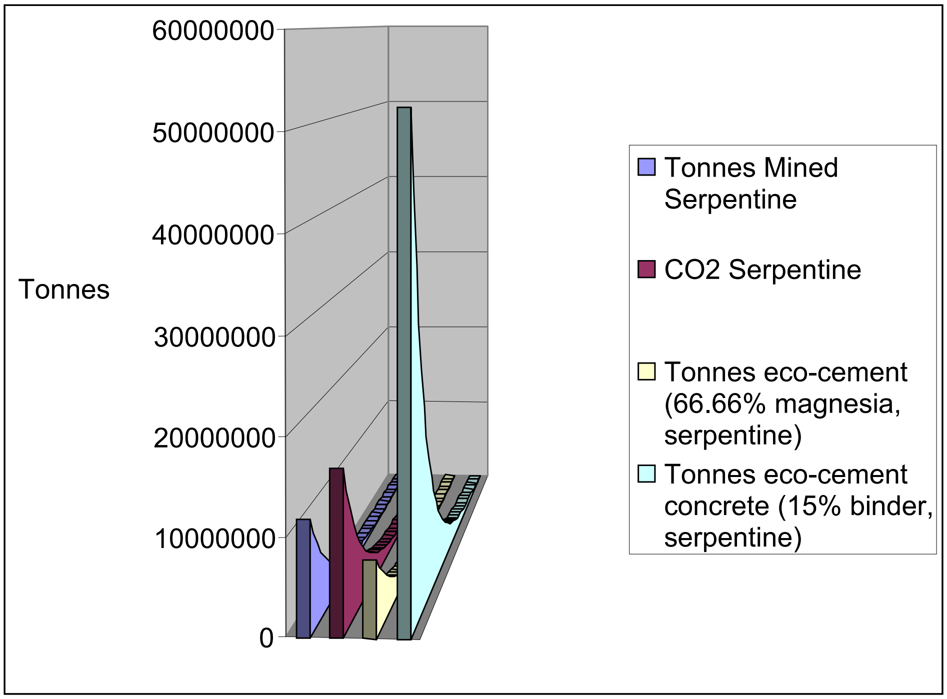

Table 5 – Graph Showing Sequestration and Output Eco-Cement (66.66% Magnesia)and Eco-Cement Concrete (15% Eco-Cement) per Tonne of Serpentine Mined and Processed.

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.

Why Sequester Carbon in Concrete?

According to the Australian Federal department of Industry Science and Tourism (Roodman, D. M. and Lenssen, N., 1995; Various, 1998) buildings are responsible for some 30 % of the raw materials we use. At TecEco we suspect the figure would more than double to 70% if infrastructure were also included but recognise more research is required.

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

Contrary to lay understanding Portland cement concretes have low embodied energies compared to other building materials such as aluminium and steel, have relatively high thermal capacity and are therefore relatively environmentally friendly.

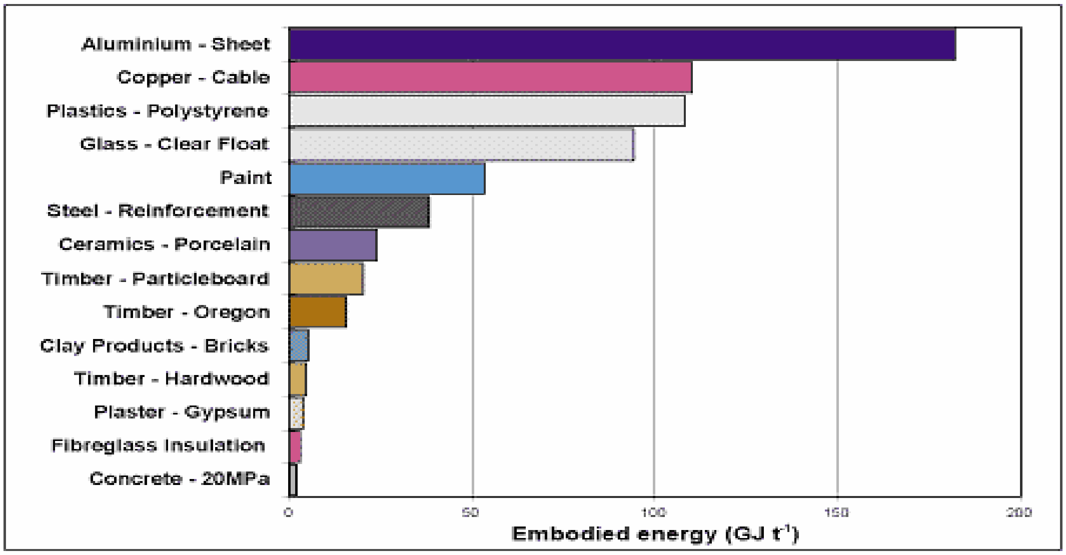

Figure 2 - Embodied Energy of Building Materials (Tucker, S., 2000)

However concrete, based mainly on Portland cement clinker, is the most widely used material on Earth.

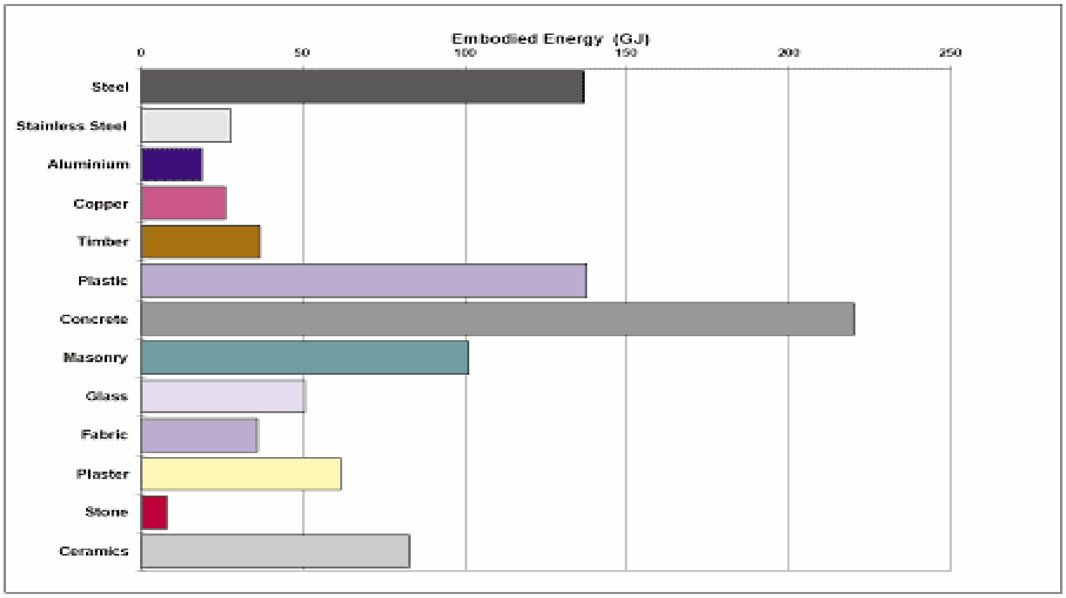

Figure 3 - Embodied Energy in Buildings (Tucker, S., 2000)

The manufacture of Portland cement 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 and energy consumption as fuel and electricity are therefore high, currently representing about 65-70% of the variable costs (Livesey, P., 1996; Cembureau, 2000).

Considerable energy is consumed (See Figure 3 - Embodied Energy in Buildings on page 12) resulting in carbon dioxide emissions. Carbon dioxide is also released chemically from the calcination of limestone used in the manufacturing process.

Various figures are given in the literature for the intensity of carbon emission with Portland cement production and these range from 0.74 tonnes coal/ tonne cement (Pearce, F., 1997) to as high as 1.24 tonne (Wilson, A., 1993) and 1.30 tonne (Tucker, S., 2002). The figure of one tonne of carbon dioxide for every tonne of Portland cement manufactured (Pearce, F., 1997) given by Fred Pearce in New Scientist Magazine is generally accepted and has been used in this paper.

The production of cement has increased significantly since the end of World war II and rate of production is accelerating.

As of 2004 some 2.00 billion tonnes of Portland Cement (OPC) were produced globally[4], enough to produce over 7 cubic km of concrete per year or over two tonnes or one cubic metre per person on the planet. This accounts for more embodied energy than any other material in the construction sector (Tucker, S., 2000). Using Fred Pearce's figure of 1 tonne

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[4] USGS figures extrapolated to 2004

of CO_2 per tonne of cement produced above this amounts to two billion tonnes of CO_2 emitted per annum or a significant 15.7% of the net annual increase of 12.7 billion tonnes in carbon dioxide in the atmosphere given the Woods Hole figure cited above.

The emissions from Portland cement manufacture are the third highest source of CO_2 emissions after fossil fuel combustion and deforestation (IUCC, 1993) accounting for between 5% (Hendriks, C. A., Worrell, E. et al., 2002) and 10% (Davidovits, J. A.; Pearce, F., 1997)' of global anthropogenic[5] CO_2 emissions. 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 (Idorn, G., 1997).

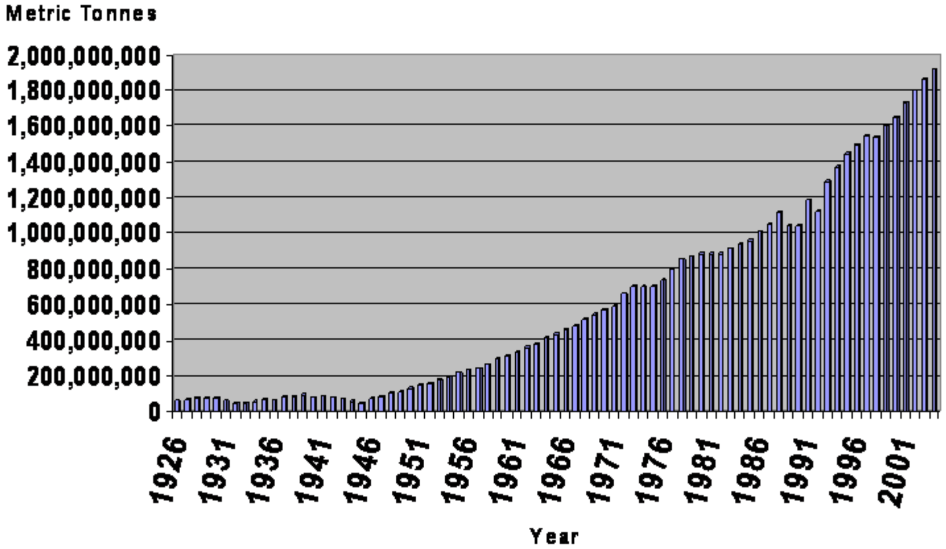

Table 7 - Cement Production = Carbon Dioxide Emissions from Cement Production 1926-2002[6] (Van Oss, H., G., Hendriks, K. et al., 2003)

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 and growing demand is the associated enormous potential for environmental benefits and improvements in sustainability.

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[5] Anthropogenic – human produced

[6] Cement production = Carbon dioxide emissions at 1 tonne cement= 1 tonne CO_2

Supplementary Cementitious Materials as Extenders

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 (CEA, 2002). The increased interest in the use of supplementary materials is largely due to the fact that better technical performance at a lower price is often the outcome. TecEco tec-cement technology facilitates the use of more supplementary materials without an increase in strength over time performance.

Other than eco-cements a number of other 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) types.

Tec-Cements

TecEco tec-cements include a much lower proportion of reactive magnesia and reduce emissions by further extending supplementary materials and reducing water whereby greater strength is obtained for less total binder. Further details are available from the TecEco web site.

Net Emissions Associated with Various Concretes

Table 8 - CO_2 Released by De-Carbonation during the Manufacture of Cements and Components

Compound	**CO_2 released through decarbonation in producing 1 tonne (tonnes CO_2/tonne produced)**	**CO_2 potentially recaptured in a porous concrete or mortar**	**Net Emissions (if no capture)**	**Net Emissions (if capture for MgO and CaO only)**	**Example of Cement Type**
MgO	1.09	1.09	0	-1.09 (net sequestration)	Eco-cement mortar
CaO	0.78	0.78	0	-.78 (net sequestration)	Carbonating lime mortar
C_3S	0.578	.289	.289	Not feasible technically yet	Alite cement
C_2S	0.511	.255	.256	Not feasible	Belite

				technically yet	cement
C_3A	0.594	0	0.594	Not feasible technically yet	Tri calcium aluminate cement
PC	0.54	.27 (variable)	.27	Not feasible technically yet	Portland Cement
1PC:2MgO	0.99	.817	.173	-.817 (net sequestration)	Eco-cement with no pfa
1PC:2MgO:3pfa[7]	0.445	.367	.077	-.367 (net sequestration)	Eco-cement with pfa
1PC:2pfa[7]	.27	.137	.137	Not feasible technically yet	Very high fly ash cement
.05MgO:.95PC:2pfa[7]	.18	.092	.092	Not feasible technically yet	Tec-cement assuming 1/3 (.334%) less binder required.
C_4A_3S	0.216	0	.216	Not feasible technically yet	Calcium sulfoaluminate cement

Of the cement types listed in Table 8, without capture of CO_2 during the manufacturing process emissions are lowest for eco-cements and calcium sulfoaluminate (C_4A_3S) cements. Obviously blending supplementary materials that extend the binder will also reduce net emissions variably depending on the addition and pozzolanicity without capture[8]. With capture of CO2 during calcination high magnesian TecEco eco-cements excel over all other binder systems and they can also be extended with supplementary cementitious materials.

The Merits of a Carbonate Binder System for Sequestration

From Table 8 it can be seen that carbonating cements also involve the release of large amounts of chemically bound CO_2 when their oxides are made. The table also shows that if this chemically released CO_2 could be captured during manufacture and reabsorbed during setting forming a strong binder, there would be huge opportunities for safe sequestration in the built environment with no possibility of leakage or detrimental affects on a wider scale.

The idea of capturing CO_2 as carbonate mimics what has in fact naturally been occurring for millions of years. Carbonates formed in seawater are the

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[7] Assuming no emissions for pfa or that they are accounted for in the power industry.

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

natural, large scale, long term sink for carbon dioxide, however the process 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 the high percentage (7%) mentioned previously of the earths surface covered in rocks such as limestone, dolomite and magnesite.

Reasons For the Superior Efficiency of Magnesium

The reason magnesium carbonates are so efficient for sequestering carbon are:

- The low molecular weight of magnesium resulting in a higher CO_2 content per tonne.

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

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

- The low equilibrium temperature for the calcination of magnesite to form magnesium oxide.

The capture of CO_2 at source during the manufacturing process is also easiest for the calcination of magnesium carbonates simply because the process occurs at a relatively low temperature. TecEco Pty. Ltd. own intellectual property in relation to a new tec-kiln in which grinding and calcining[9] can occur at the same time in the same vessel for higher efficiencies and easily capture of CO_2.

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 for alternative permanent disposal are in materials such as plastics or deep underground where CO_2 reacts with country rock forming more carbonate (geological sequestration).

Eco-Cements and the Magnesite Thermodynamic Cycle.

Magnesium fixes carbon dioxide and therefore act as a concentrator and Figure 4 - The Magnesium Thermodynamic Cycle on page 17 depicts what is referred to by TecEco as the magnesite Thermodynamic cycle and explains to the technically minded how this is so.

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

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 lansfordite, nesquehonite and an amorphous phase mineral all of which because of their generally acicular shape add microstructural as well as innate strength as binders.

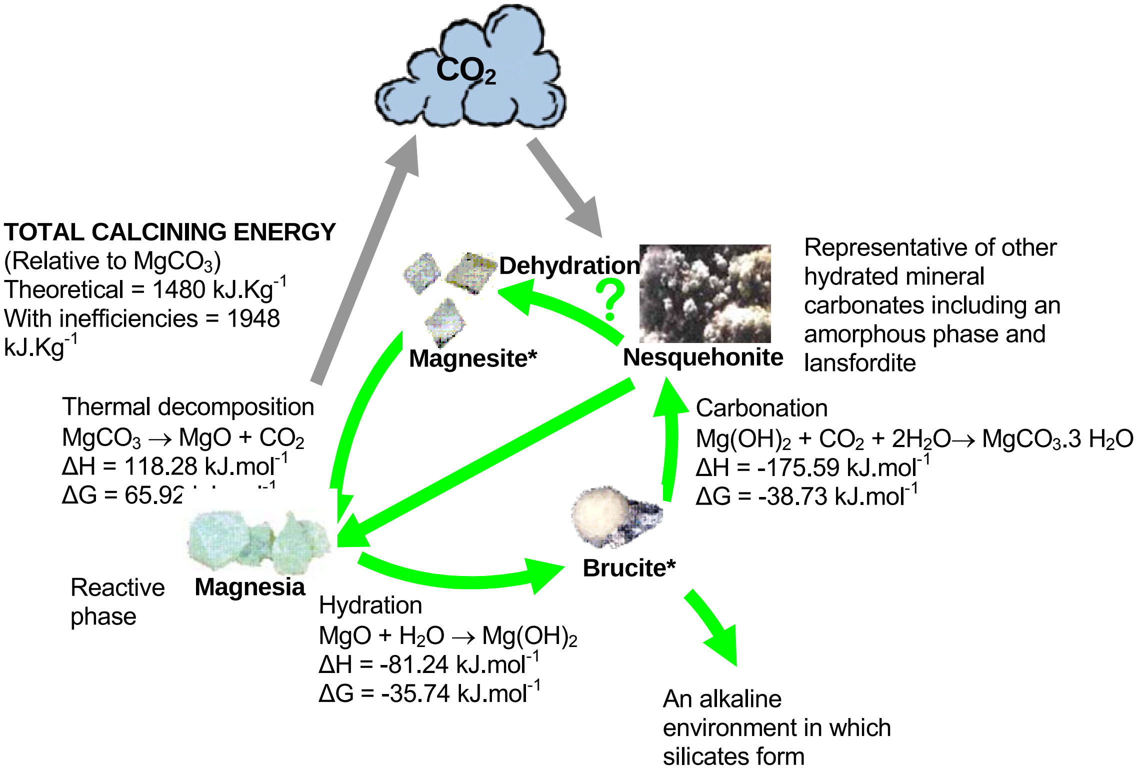
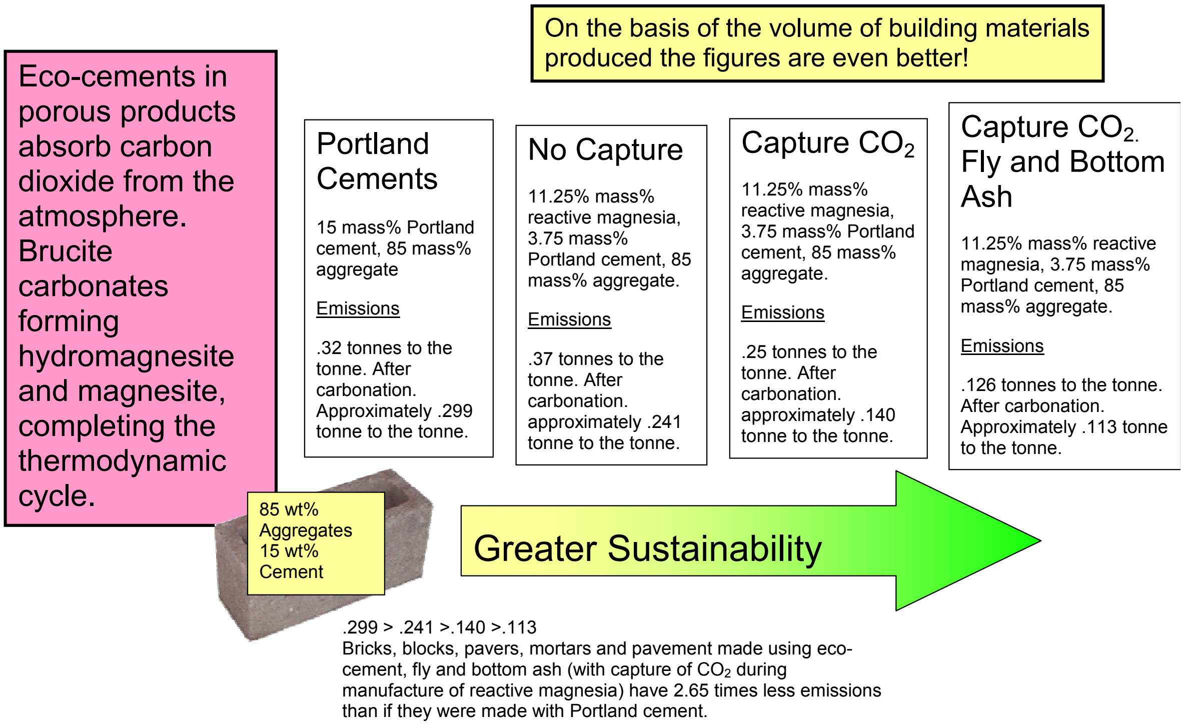


Figure 4 - The Magnesium Thermodynamic Cycle

Kinetically the carbonation of eco-cements 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. Note that all these materials including mortars require the use of appropriately course aggregates

Because of the high efficiency of CO_2 capture by magnesium oxide and for a number of other technical reasons TecEco propose the substitution of Portland cement with magnesia (MgO) which in eco-cements in porous materials fully carbonates whereas in tec-cements with a lower proportion the total binder content is reduced. 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.



On the basis of the volume of building materials produced the figures are even better!

Eco-cements in porous products absorb carbon dioxide from the atmosphere. Brucite carbonates forming hydromagnesite and magnesite, completing the thermodynamic cycle.

Portland Cements

15 mass% Portland cement, 85 mass% aggregate

Emissions

.32 tonnes to the tonne. After carbonation. Approximately .299 tonne to the tonne.

No Capture

11.25% mass% reactive magnesia, 3.75 mass% Portland cement, 85 mass% aggregate.

Emissions

.37 tonnes to the tonne. After carbonation. approximately .241 tonne to the tonne.

Capture CO$_2$

11.25% mass% reactive magnesia, 3.75 mass% Portland cement, 85 mass% aggregate.

Emissions

.25 tonnes to the tonne. After carbonation. approximately .140 tonne to the tonne.

Capture CO$_{2.}$ Fly and Bottom Ash

11.25% mass% reactive magnesia, 3.75 mass% Portland cement, 85 mass% aggregate.

Emissions

.126 tonnes to the tonne. After carbonation. Approximately .113 tonne to the tonne.

85 wt% Aggregates 15 wt% Cement

Greater Sustainability

.299 > .241 >.140 >.113

Bricks, blocks, pavers, mortars and pavement made using eco-cement, fly and bottom ash (with capture of CO$_2$ during manufacture of reactive magnesia) have 2.65 times less emissions than if they were made with Portland cement.

Figure 5 – Abatement in a Concrete Brick Containing 15% Eco-Cement

From Figure 5 it can be deduced that almost 2/3 of the CO$_2$ in concrete is potentially abated if substituted by eco-cement in porous products such as bricks, blocks, pavers, mortars etc. With CO$_2$ capture or the inclusion of organic fibre materials and fillers for strength and insulation, cementitous building materials that act as net carbon sinks are feasible.

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 further papers are available.

Summary and Conclusion

Mineral sequestration in for example power stations leveraged using TecEco tec-kiln technology and an MgO scrubbing process and combined with geological sequestration and the manufacture of eco-cement concretes for the built environment is by far the best sequestration solution to combat global warming so far and TecEco are now seeking UN and government support around the world to develop the technology.

As Fred Pearce reported in New Scientist (Pearce, F., 2002) 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”.

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