Gaia Engineering – Solving Water, Waste and CO2 Problems

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About the Author

John Harrison has degrees in science and economics and apart from running a large accountancy/consulting practice (John Harrison Accountants) he has had experience as a geologist (exploration and minerals separation) and in engineering and has been responsible for a number of innovations including the tech tendon method of pre stressing. John is managing director and chairman of TecEco Pty. Ltd. and best known for the invention of Eco-Cements which have attracted significant global interest because of their improved sustainability and potential to provide significant sequestration. John is an authority on earth systems science and sustainable materials for the built environment and was the founder of the Association for the Advancement of Sustainable Materials in Construction (AASMIC) and is their current chair. He has been the keynote speaker at many conferences and recently co-chaired the successful SMB2007 conference. John is committed to finding ways of profitably reversing damaging materials flows. In recent times he has concentrated on the research and development of Gaia Engineering including TecEco Cements and Tec-kiln technologies.

Abstract

There is an urgent need to reduce the CO_2 in the air. With their huge volume and existing chemistry concretes contribute around 10% to global warming (Pearce 1997). The current approach in the industry is top down and involves little change. In contrast the author advocates radical changes in the composition not only of cements but aggregates and building components as only by doing so can we change the underlying molecular flows in a way essential for survival.

The invention of TecEco Eco-Cement proves that this rock could be man made carbonate and geo sequester significant amounts of carbon dioxide. As stated by Fred Pearce in the article on Eco-Cements published in the New Scientist magazine (Pearce 2002) “There is a way to make our city streets as green as the Amazon Forest. 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 it is the change the way we make cement.”

This paper goes further and outlines a radical proposal to substitute carbonate for silicate in the Pareto proportion of mineral building materials used in the built environment whereby, with no emissions manufacturing methods, the whole built environment could potentially become one giant carbon sink. Included are cements, aggregates as well as building components.

The proposal it is part of a more holistic solution and certainly easier than achieving the massive emissions reductions called for by politicians all over the world the logical extension of which will be carbon rationing (Hillman and Fawcett 2004) with the associated dangers of such a difficult to implement policy option.

Introduction

Gaia engineering addressed the fundamental issue of the molecular flows underlying what the author refers to as the techno process.

In Gaia Engineering several breakthrough technologies in solution chemistry and materials science working together like a giant ecological pump we call a tececology that can turn the construction industry from a net emitter of greenhouse gases into a net carbon sink on a potentially massive scale.

Gaia Engineering envisages a built environment that is made of man made carbonate and that can be recycled indefinitely. Because it sequesters carbon and delivers fresh water and other commodity salts profitably Gaia engineering is the ultimate solution to the many of the world’s problems. It is the same solution as has been adopted by nature for billions of years.

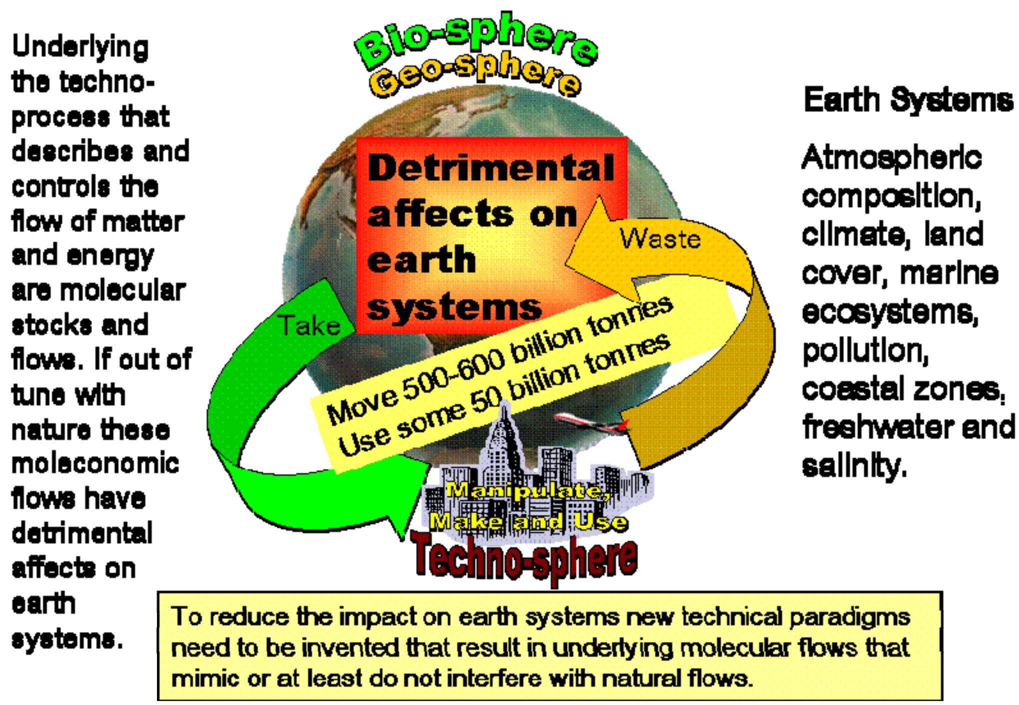


Figure 1 - The Techno-Process

Natural sequestration which has resulted in 7% of the crust being carbonate is supplemented by Gaia engineering which geomimics in an accelerated way the sedimentation of limestone, magnesite and dolomite that has occurred for billions of years to the extent necessary to turn global warming around.

By geomimicing nature's two greatest CO_2 sequestering agents, the oceans and the geophysical environment, the Gaia Engineering tececology can safely and permanently fix CO_2 as building materials which given the flows involved are the logical target for CO_2 and other wastes.

The process is simple and involves producing magnesite and limestone blocks and other artificial stone or "concrete" products directly from seawater and then using TecEco Eco-Cements to mortar them together.

Relevance to Concrete

According to Dr John Phair (Phair 2006) "Concrete is in desperate need of revitalisation in the 21st century due to growing durability, maintenance and environmental concerns. Improving the cement within concrete is an essential part of addressing these concerns. While Portland cement manufacture and use can still undergo slight environmental improvements, great opportunities lie in the utilisation of cements based on alternative compositions, binding-phases and green chemistry. This allows cement to be synthesised from a variety of materials including recycled resources and mineral wastes, which reduces the energy demands during production."

The Gaia Engineering proposition goes beyond concrete, beyond sustainability in the built environment; rather than tinker with the problem it describes a solution that has no downsides unlike some of the whacky alternatives[1]. The Gaia Engineering tececology[2] for the carbonisation of the built environment if implemented could reverse the rise of carbon dioxide in our atmosphere and solve many other problems including that of the supply of fresh water and conversion of waste to resource. Humans and their entourage of rats' mice and cockroaches would not notice the difference in the functionality of their surroundings. Is it not therefore better to adjust our backyard before we meddle on a large scale with nature in some other way?

Gaia Engineering targets at least the whole mineral component of the built environment. Given the huge flows involved the main target material for conversion to carbonate is concrete. The author has demonstrated with

[1] Such as pumping CO2 underground (so called "geosequestration"), pumping it into the deep oceans, fertilizing the oceans with iron or sending sulphur dioxide into the stratosphere.

[2] Tececologies could be thought of as open technical ecologies that are designed to reverse major damaging moleconomic and other system flows outside the loop.

his Eco-Cement invention that this can occur in the built environment without loss of functionality in at least the Pareto proportion of suitably permeable concretes.

A major problem with concretes as we know them today is that they are thermodynamically unstable. Because of a high proportion of tri calcium silicate in cements they have a correspondingly high proportion of Portlandite in them, are very alkaline and prone to carbonation or reaction with chloride and sulfate.

Much of the OPC-based concrete used in the construction of infrastructure during the 1950's and 1960's has deteriorated to the point that extensive repair and replacement is required (Neville 1997).

Carbonation of concrete has been considered previously in numerous papers as a means of achieving sequestration however we question the sense in carbonating a strong silicate after going to the expense both in energy and real terms of making it. A switch to carbonates formed directly from constituent components as advocated by the present paper is also a switch to a thermodynamically stable mineral assemblage of CSH and brucite or carbonates of magnesium.

Although there are many technical errors in his understanding of our cements[3] we agree with Phair that "magnesia carbonates and OPC/magnesia carbonate composite cements are the most likely large-scale magnesia cement alternatives to Portland cement."(Phair 2006)

Global Mass Flows and the Importance of the Built Environment in our Solution to Global Problems

The built environment encompasses in the order of 70 % or 31.5 billion tonnes of all materials flows that are not immediately wasted[4] comprising some 40 - 50 billion tonnes[5]. Of this concrete is the major proportion at around 17 billion tonnes[6] or over 2 tonnes per person per annum and the most widely used material on earth next to water. Concrete is made with cement which has a current production rate at over 2.3 billion t/a (USGS 2005). Although a far more sustainable material than any other used in construction, given the flow it is obviously very important to achieve sustainability within the industry.

Concrete masonry and precast componentry are ideal candidates for a sequestration role in Gaia Engineering because of the huge tonnage involved and because they are easily changed without technical, functional or economic downsides. Given this potential these industries are missing a huge opportunity by remaining polarised in the current paradigm.

[3] Contrary to what Phair states in his paper accelerators are not required to form brucite from MgO. What is required is low lattice energy or reactive MgO. Furthermore the stable phases when brucite carbonates under most conditions are nesquehonite and to some extent lansfordite and possibly an amorphous phase. The latter does not show under XRD. The author admits that he first stated that magnesite and hydromagnesite would form but this was corrected by at least 2002. The lansfordite formed slowly changes to nesquehonite. In the very long term they all may progress towards magnesite but only very slowly.
[4] e.g. mining wastes etc.
[5] A guesstimate by the author based on information from various sources
[6] Assuming a conservative 13% cement on average in concrete the figure is just over 17.69 billion tonnes.

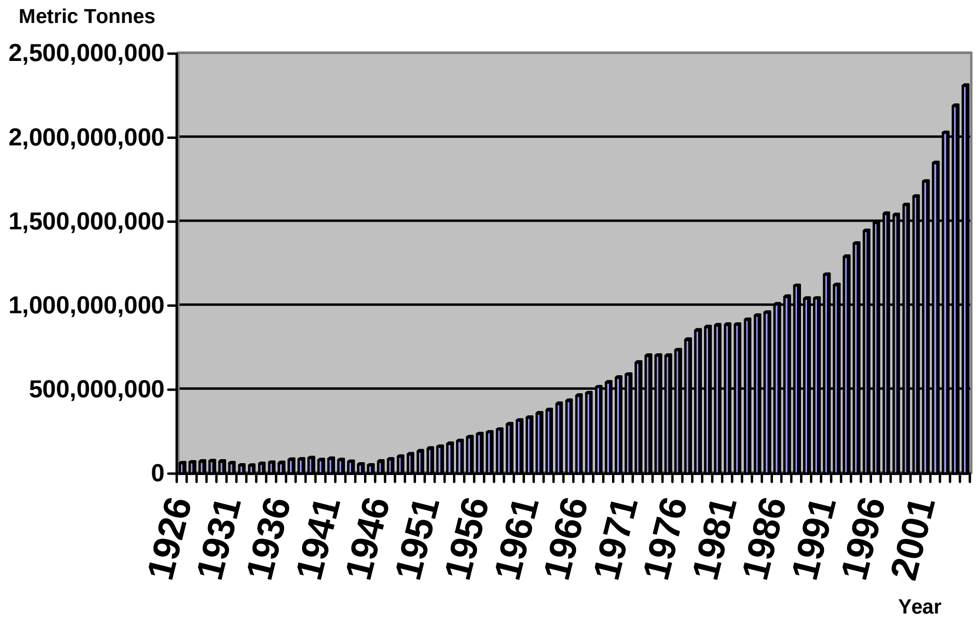


Figure 2 - Cement Production and CO_2 Emissions

Because the Pareto proportion of concretes in the built environment are not usually structural (house slabs, road paving, curb and gutter, walling etc.) the composition or formulation for these uses is relatively easy to adjust. We believe that change will also stimulate those businesses and countries involved.

Consequences of a Switch to Carbonates as a Main Building Material

More CO_2 is captured by magnesium carbonates used in Gaia Engineering than in calcium systems because magnesium has a low molecular weight. There is more CO_2 content per tonne as the calculations below show.

$CO_2/MgCO_3$ = 44/84 = 52 %
$CO_2/CaCO_3$ = 44/101 = 43 %

Lime also requires higher temperatures in manufacture than magnesia (magnesium oxide) and TecEco have produced a range of new, easy to make cements based on using magnesia.

Eco-Cements

The opportunities presented by the re-carbonation magnesium oxide in cement used to make concrete will now be considered.

According to Richard Haughton at the Woods Hole Institute (Haughton 2005), total global carbon cycle flows are:

Table 1 - The Carbon Cycle (tonnes C)

Atmospheric increase	=	Emissions from fossil fuels	+	Net emissions from changes in land use	-	Oceanic uptake	-	Missing carbon sink
3.2 (±0.2)	=	6.3 (±0.4)	+	2.2 (±0.8)	-	2.4 (±0.7)	-	2.9 (±1.1)

Table 2 - The Carbon Dioxide Cycle (Converted from Table 1 to tonnes CO_2)

Atmospheric increase	=	Emissions from fossil fuels	+	Net emissions from changes in land use	-	Oceanic uptake	-	Missing carbon sink
11.72 (±0.2)	=	23.08 (±0.4)	+	8.016 (±0.8)	-	8.79 (±0.7)	-	10.62 (±1.1)

If concretes were held together by nesquehonite as in Eco-Cement concrete, how much would be required to reverse global warming?

$MgO + H_2O \rightarrow Mg(OH)_2 + CO_2 + 2H_2O \rightarrow MgCO_3 \cdot 3H_2O$
40.31 + 18(l) → 58.31 + 44.01(g) + 2 X 18(l) → 138.368 molar masses.
44.01 parts by mass of CO_2 ~ 138.368 parts by mass $MgCO_3 \cdot 3H_2O$

1 ~ 138.368/44.01 = 3.144

12 billion tonnes CO_2 ~= 37.728 billion tonnes of nesquehonite binder in concrete

This is much more than the current production of cement, so if all binders used in concrete were nesquehonite, the problem would be mitigated but not solved.

Including Carbonate Building Aggregates and Components as Well

Fortunately seawater has an almost unlimited supply of magnesium in it so how much magnesium carbonate would have to be man made to solve the problem?

Could we take on the “permanent lifelong job of planetary maintenance engineer”(Lovelock 1979).

$MgO + H_2O \rightarrow Mg(OH)_2 + CO_2 + 2H_2O \rightarrow MgCO_3$
40.31 + 18(l) → 58.31 + 44.01(g) + 2 X 18(l) → 84.32 molar masses.

CO_2 ~ $MgCO_3$

44.01 parts by mass of CO_2 ~= 84.32 parts by mass $MgCO_3$

1 ~ 84.32/44.01= 1.9159

12 billion tonnes CO_2 ~ 22.99 billion tonnes magnesite, with a density of 3000 kg/m^3.

Thus 22.9/3 billion cubic metres ~ 7.63 cubic kilometres of man made magnesite in the form of aggregates and building components will be required each year.

Summary

Compared to the over seven cubic kilometres of concrete we make every year, the problem of global warming looks surmountable. If magnesite and Eco-Cements were our building material of choice and we could make them without releases (as in Gaia Engineering) we would have the problem as good as solved.

By also using carbonate as a binder as in Eco-Cements we can totally turn the problem of global warming and waste around!

Suitability of Concrete and Masonry as a Candidate for Sequestration of CO_2

Eco-Cement Concretes

There are few technical, mainly conceptual reasons for resisting a fundamental change in the chemistry of cements and the concrete made with them.

When any alkali carbonate is de-carbonated or calcined as in cement production, CO_2 is produced. This release is an inevitable consequence of the stoichiometry of the de-carbonation reaction and it is essential therefore to consider how to capture the gas preventing it entering the atmosphere when making cement. This issue has been addressed for the manufacture of Eco-Cement which is made in the Tec-Kiln described below.

On the other hand when decarbonated metal oxides re-carbonate, they absorb equally significant amounts of CO_2 presenting significant opportunities for sequestration.

Carbonate Building Components

Masons have for many millennia have used limestone, dolomite and huntite as building blocks. For this industry the only difference is that these materials would be man made as part of the Greensols process at the front end of the Gaia Engineering tececology.

Gaia Engineering

Gaia Engineering is a group of new technologies including TecEco's Tec-Kiln technology and Eco-Cements, carbon dioxide scrubbing technologies, a seawater separation technology from Greensols Pty. Ltd. that can produce fresh water, and a number of industrial commodity products including gypsum, sodium bicarbonate and various other salts as well as building materials based on magnesium carbonates.

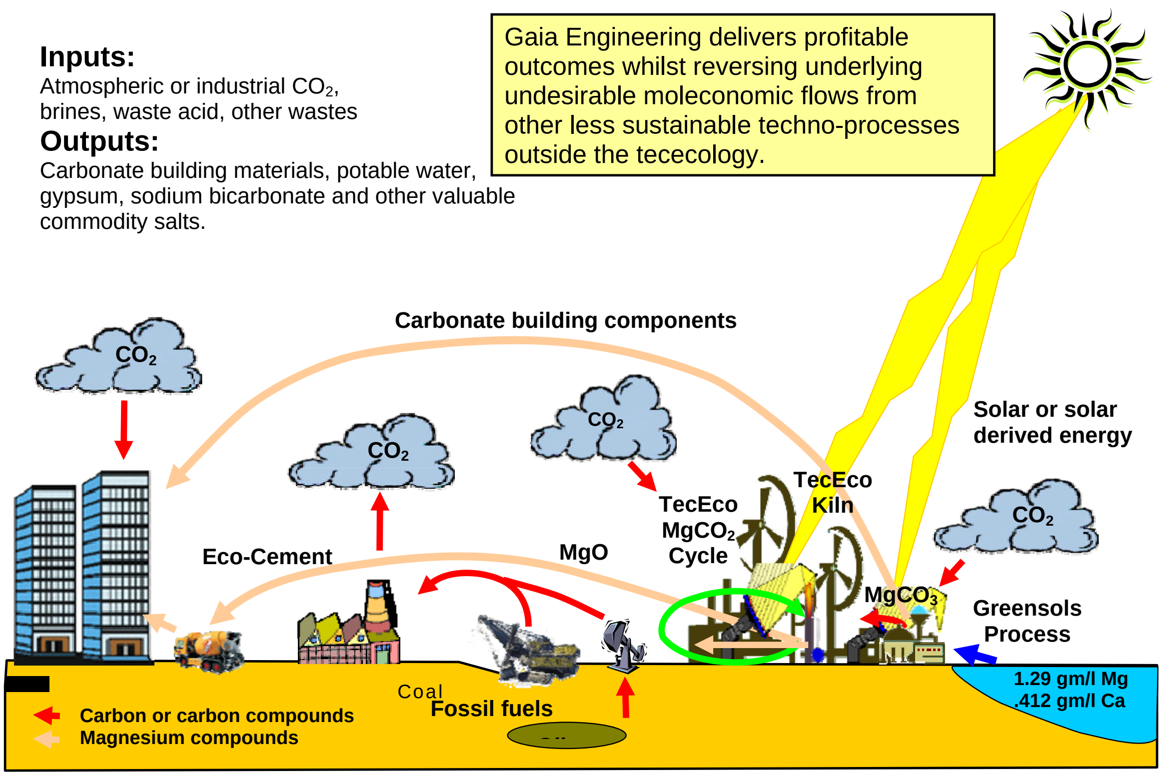


Figure 3 - Gaia Engineering

The Gaia Engineering process starts with the Greensols process which uses carbon dioxide from for example power stations and waste acid to extract magnesium carbonate and valuable salts from seawater or suitable brines and produce potable water as a by-product. The magnesium carbonate from this process can then be used directly as building products such as bricks or block or calcined in the TecEco Tec-Kiln which removes and captures carbon dioxide (ready for incorporation into cellulose, other compounds or for other uses and produces magnesium oxide. The magnesium oxide can either be used to make TecEco cements which utilise other wastes and in the case of Eco-Cement absorb more atmospheric CO_2 as they harden or alternatively can be used to sequester more CO_2 in a hydroxide/carbonate slurry capture process.

The hydrated carbonates produced by the hydroxide/carbonate carbon capture cycle can be de-carbonated and cycle around that process indefinitely as in the diagram below.

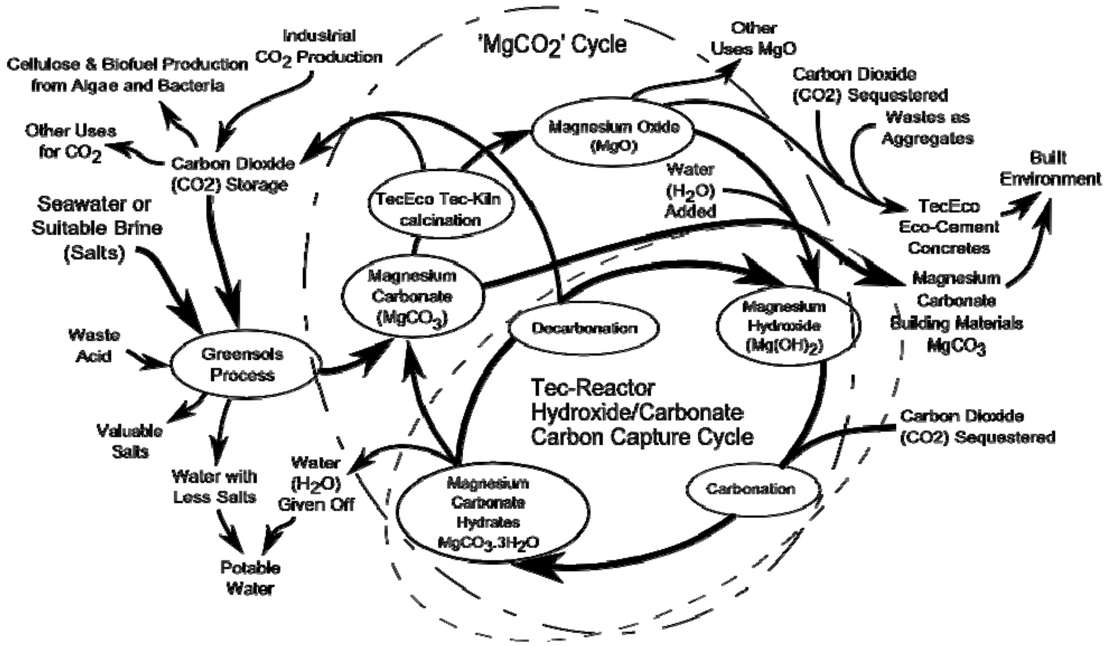
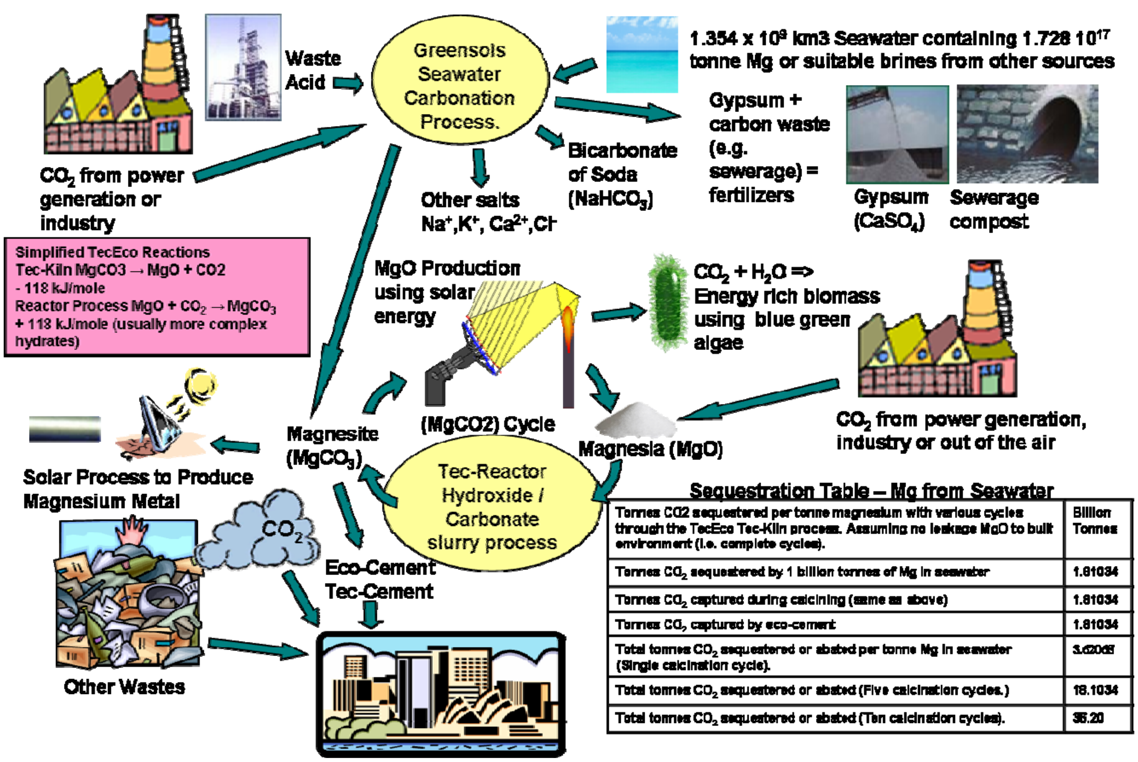


Figure 4 – Gaia Engineering Process Vectors

At the present time our planning is that the carbon dioxide produced during the calcining phase for the manufacture of reactive magnesia used in Eco-Cements will be recycled into the Greensols process to make more cement and building components. Other technologies are still evolving to use the CO_2 produced by Gaia Engineering. A particular future use that we are monitoring is to force rapid growth of algae able to convert CO_2 and water into oxygen and energy rich biomass.



Tonnes CO2 sequestered per tonne magnesium with various cycles through the TecEco Tec-Kiln process. Assuming no leakage MgO to built environment (i.e. complete cycles).	Billion Tonnes
Tonnes CO_2 sequestered by 1 billion tonnes of Mg in seawater	1.81034
Tonnes CO_2 captured during calcining (same as above)	1.81034
Tonnes CO_2 captured by eco-cement	1.81034
Total tonnes CO_2 sequestered or abated per tonne Mg in seawater (Single calcination cycle).	3.62068
Total tonnes CO_2 sequestered or abated (Five calcination cycles.)	18.1034
Total tonnes CO_2 sequestered or abated (Ten calcination cycles).	36.20

Figure 5 - Gaia Engineering Process Diagram

The Greensols process is very efficient because it does not work against the hydrogen bonding of water and it can deliver massive sequestration at low energy cost. The magnesium thermodynamic cycle (MgCO2 cycle) and Tec-Reactor hydroxide/carbonate carbon capture process mimic photosynthesis using the same central atom (magnesium). They can go around and around like a bicycle wheel as together, mass and energy are neither created nor destroyed, energy is only lost outside the system through inefficiencies.

There is an exothermic part of the MgCO2 cycle where heat is required and an endothermic part where heat is released. To make the process as efficient as possible it is desirable to capture the heat from the exothermic parts and as efficiently as possible transfer it to the endothermic parts of the cycle and new technologies are evolving rapidly for the capture of low grade heat.

Components of Gaia Engineering

Gaia Engineering combines a number of lead technologies in a total process we call a tececology defined earlier[2]

The Greensols Process

Greensols Pty. Ltd is an Australian company with an economic technology to precipitate carbonates and other valuable compounds from sea water and brines thereby producing fresh water and in the process and sequestering significant amounts of carbon dioxide.

The Greensols Process is our preferred option for producing the magnesium carbonate required for the Gaia Engineering tececology due to fact that it uses industrial CO_2 from power stations and from the manufacture of reactive magnesia used to make Eco-Cements and waste acid as inputs and is potentially low cost. Potable water and a number of commodity salts are other outputs which can be sold to help fund the process.

The Greensols Technology modifies volumes of seawater[7] or brine to promote the inorganic precipitation of calcium carbonate or other carbonate mineral phases such as magnesium carbonate. The process permanently fixes CO_2 as mineralogically stable calcium carbonate or magnesium carbonate. There can be minimal change to the overall chemical composition of seawater with the discharged water being within the compositional range of normal coastal waters. Alternatively water with significantly less salt can be further purified to make drinking water. No nutrients are added.

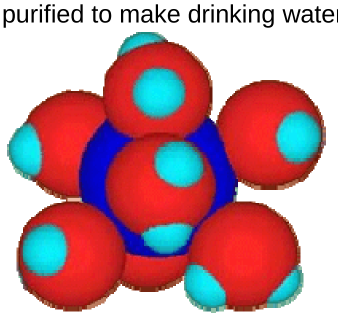


Figure 6 - Hydration Shelling Around Calcium and Magnesium Ions

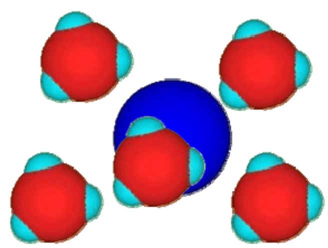


Figure 7 - De Orientation and Departure after Depolarisation

The Greensols Technologies differ from sequestration projects involving vegetation as the sequestering agent, in that the removal of atmospheric CO_2 during the precipitation of the carbonate mineral is permanent. The extraction of CO_2 from the atmosphere and the production of calcium carbonate results from a one-way exchange between atmospheric carbon dioxide and seawater. Additionally, the leakage and stability problems currently associated with in-ground geo-sequestration technology are avoided, as are the nutrient enrichment problems associated with ocean nourishment with for example iron.

Waste acid is used to de polarise a statistical proportion of water molecules by attaching a proton whereby positively charged sodium, calcium or magnesium ions as well as negatively charged ions including carbonate ions are released, can combine and then precipitate.

[7] Very slightly so as to not affect marine life

Strongly charged ions such as calcium, magnesium and carbonate attract hydration shells of water around them. Magnesium and calcium ions polar bond to oxygen and the negative carbonate ion to hydrogen. These bonds can propagate through several layers of water and are strong enough to prevent the formation of calcium and magnesium carbonates even from supersaturated solutions.

The addition of a proton to water using strong waste acid results in its depolarisation whereby it no longer electronically holds as many ions (sodium, calcium, magnesium or carbonate etc.) statistically releasing them and allowing them to combine and precipitate as carbonates and other more valuable salts, leaving behind essentially fresh water.

The statistical release of both cations and anions results in precipitation of for example magnesium carbonate as shown above. Many other earlier authors including Deelman (Deelman 2003) and Lippman (Lippmann 1973) simply got the science wrong.

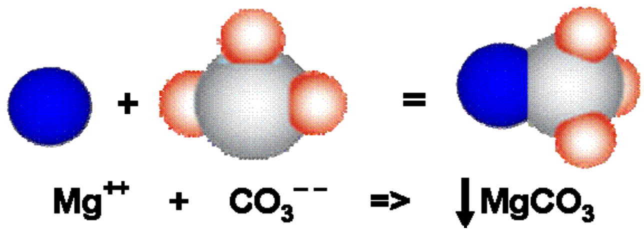


Figure 8 - Precipitation Reaction with Free Ions Combining

The magnesium carbonate produced can remain as such, providing mineral sequestration. Alternatively it can be used as input for the manufacture of magnesium metal or passed to the MgCO2 Cycle component of the CarbonSafe process which removes (and stores) the carbon dioxide, producing reactive magnesia.

Gaia Engineering and Water

Kader Asmal, Chairperson of the 2000 World Commission on Dams (WCD) wrote. “On this blue planet, less that 2.5% of our water is fresh, less that 33% of fresh water is fluid, less that 1.7% of fluid water runs in streams”(WCD 2000). “It is estimated that 1/3 of the world’s population are presently living in water stressed countries. Depending on the emission scenarios, climate scenarios and population change, it is estimated that up to 2/3 of the world’s population will be living in water stressed countries by 2050 as a result of climate change” (Defra 2004)

The Greensols process is much cheaper than current state of t he art reverse osmosis as it does not require energy to work against the hydrogen (or polar) bonding of water to the salts it contains. It relies on the alternative mechanism of chemically depolarising water thereby removing this energy barrier.

Table 3 – The Greensols Process Compared with Reverse Osmosis

Greensols	Reverse Osmosis
Low energy costs - Does not work against the electronic forces in water.	Relatively high energy costs - Works against the hydrogen bonding of water to separate it from its ions
Low maintenance - The plant consists of low cost replaceable pumps	High Maintenance - The membranes need cleaning and changing at regular intervals.
No damaging or dangerous outputs	Highly saline water is potentially damaging
Value adds include fresh water, sequestration, valuable salts and building products	The only value add is fresh water

The Tec-Reactor Hydroxide / Carbonate Slurry Process

The Tec-Reactor hydroxide/carbonate carbon capture cycle technology cannot be patented and several research groups are involved in further developing it including the university of Cincinnati, Ohio (Keener 2001), Los Alamos National University (Butt, Lackner et al. 1996), the university of Barcelonia (Fernandez, Segarra et al. 1999) and Arizona State University (Bearat, McKelvy et al. 2002).

The science behind the process is that depending on temperature and the partial pressure of carbon dioxide, the gas is more or less taken up by a solution of magnesium hydroxide. There details of the system are still being worked out but it looks very promising especially in combination with other Gaia Engineering technologies

A recipe for making a healthy drink used by the Arabs who sell us most of the oil causing the problem serves to indicate the feasibility of this process

The colder the water (as long as it is not frozen) the more CO_2 is will absorb. At say 4 degrees C the following reaction is encouraged

$$Mg(OH)_2 + 2\ CO_2 = Mg(HCO_3)_2$$

At higher temperatures and with a lower partial pressure of CO_2 it can easily be reversed.

The Tec-Reactor hydroxide/carbonate carbon capture cycle process is an important part of the Gaia Engineering tececology. Inputs include fresh magnesium oxide from the Tec-Kiln and low-concentration CO_2 from for example a power station. Outputs include high-concentration CO_2 and magnesium carbonate that requires rejuvenation.

Magnesium oxide from the TecEco Tec-Kiln is dissolved in water to produce magnesium hydroxide slurry. Gas containing CO_2 is bubbled through the slurry, wherein carbonation occurs, creating magnesium carbonate hydrates in solution. The slurry is then heated to cause de-carbonation whereby the CO_2 previously absorbed is driven off and captured, resulting in the reformation of magnesium hydroxide that recycles through the process.

There is a limit to how many cycles can occur before contamination of the magnesium carbonate hydrate needs to be addressed. The rate of contamination by elements like, for example, iron will depend on a number of factors including what is in the flue gasses from for example a power station. It is hoped that processing through the Tec-Kiln will remove most of this form of contamination and at least enable the reprocessed magnesium oxide to be used as inputs to make for example Eco-Cements. Further research needs to be undertaken prior to finalising the design of the process plant to establish the number of cycles that can be run prior to decontamination via the Tec-Kiln.

The MgCO2 Cycle

The MgCO2 cycle is a thermodynamic cycle in which energy is neither created nor destroyed but only lost through inefficiencies.

The reasons why the Gaia Engineering tececology uses the MgCO2 cycle include:

- Magnesium has a low molecular weight as a result of which more CO_2 is captured than in calcium systems as the calculations below show.

  $CO_2/MgCO_3 = 44/84 = 52\%$ whereas $CO_2/CaCO_3 = 44/84 = 43\%$

- Magnesium carbonates can be calcined at low temperatures easily using non fossil fuel energy thereby reducing inefficiencies.

- At 2.09% of the crust magnesium is the 8th most abundant element.

- Every litre of sea water contains about 1.29 grams of magnesium and magnesium carbonate will be abundantly available through the Greensols process.

Magnesium minerals are potentially also low cost and in Gaia Engineering will come from the Greensols process. The new Tec-Kiln technology from TecEco will enable easy low cost simple non fossil fuel calcination of magnesium carbonate with CO_2 capture and re-use.

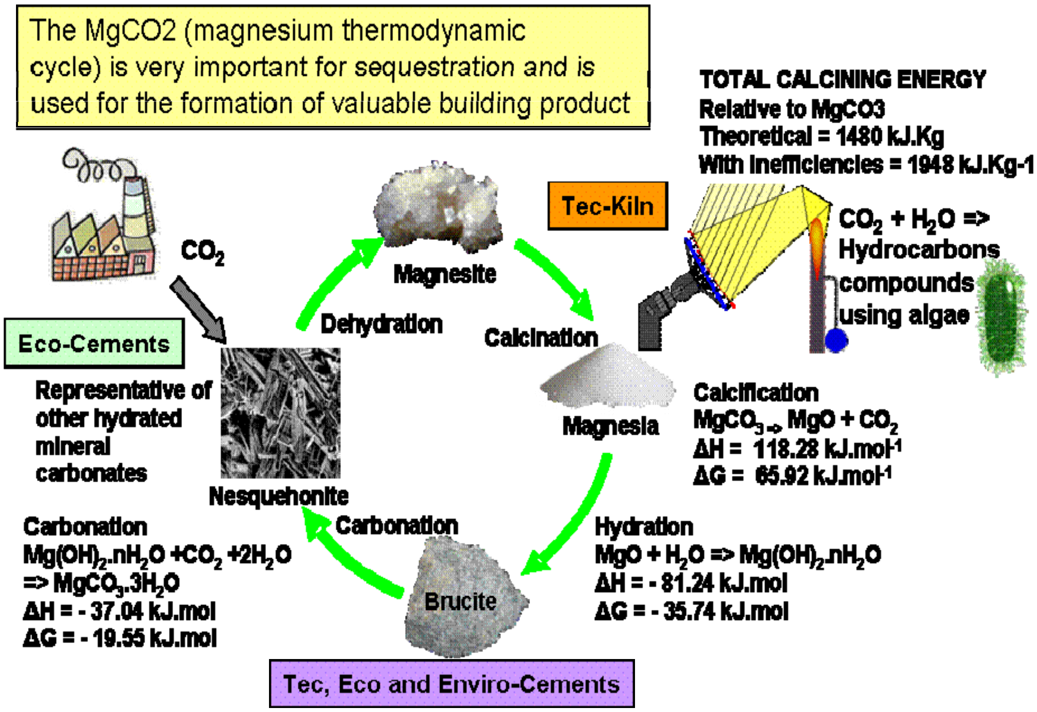
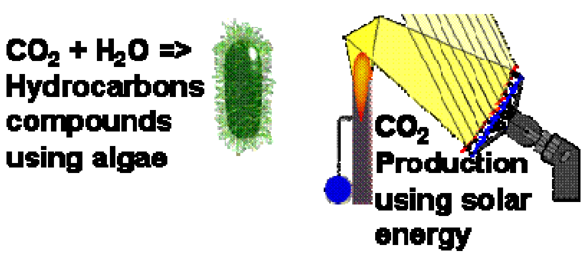


Figure 9 - The Magnesium Thermodynamic Cycle (MgCO2 cycle)

The TecEco Tec-Kiln



The Tec-Kiln was originally designed for low temperature (<750ºC) calcination of magnesium carbonate to produce reactive magnesia[8] for use in TecEco Cements without releases and will be used in Gaia Engineering. The Tec-Kiln can also be used to produce reactive magnesia from other ores such as mined magnesite.

Figure 10 - Conceptual Drawing of the TecEco Tec-Kiln

To reverse the environmentally damaging impact of molecular flows from techno-processes such as too much CO_2 in the air, the TecEco Tec-Kiln will use non fossil fuel energy such as solar or solar derived energy (e. g. wind or wave energy) for producing the magnesia required for TecEco Cements including Eco-Cement that will hold the carbonate building components from Greensols together.

It is unique in that it operates in a closed system whereby the waste energy from grinding is captured and there are no releases to the atmosphere. The CO_2 produced will be used in the Greensols process to produce more magnesium carbonate building components.

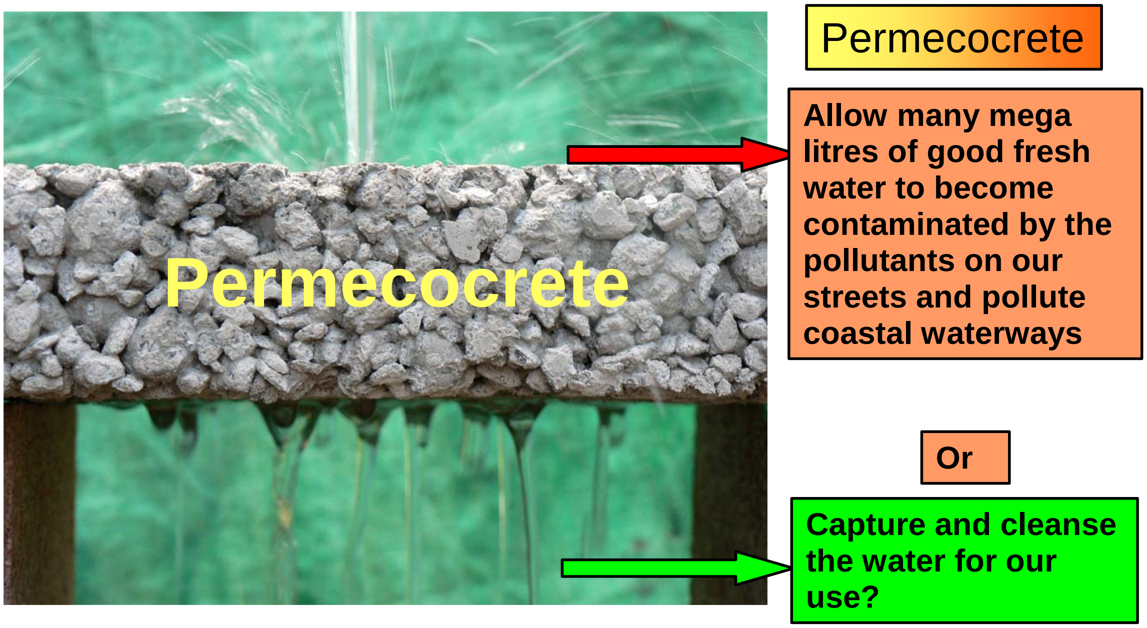
The Tec-Kiln is also distinguished from existing kilns in that it grinds and calcines simultaneously in a closed system, making use of the heat generated by grinding to assist with calcination. The low temperature requirements of magnesia production make it easy for the Tec-Kiln to operate using non-fossil-fuel energy, such as solar power.

[8] Reactive magnesia is magnesia with low lattice energy. See http://www.tececo.com/technical.reactive_magnesia.php

Eco-Cements

Eco-Cements will be used to bind the components such as bricks blocks and tilt panels made with magnesium carbonate from the Greensols sub process together.

Eco-Cements incorporate reactive magnesia and wastes and used to make permeable concretes absorbs CO_2 from the atmosphere to set and harden and in this way mimic nature.



TecEco have now perfected pervious pavements that can be made out of mono-graded recycled aggregates and other wastes and that sequester CO2.

It does not get much greener!

Figure 11 - TecEco Eco-Cement Permecocrete – An Example of a very Sustainable Eco-Cement Product

Wastes such as fly and bottom ash, slags etc. can also be included for their physical properties as well as chemical composition without problems from delayed reactions.

Because the lower process energies of Gaia engineering have not been determined we have in our LCA (life cycle analysis) assume the same energies for making Portland cement. We are able however to incorporate capture and recycling of CO_2 with the LCA for Eco-Cement which is a net carbon sink as shown in Figure 12 and Figure 13.

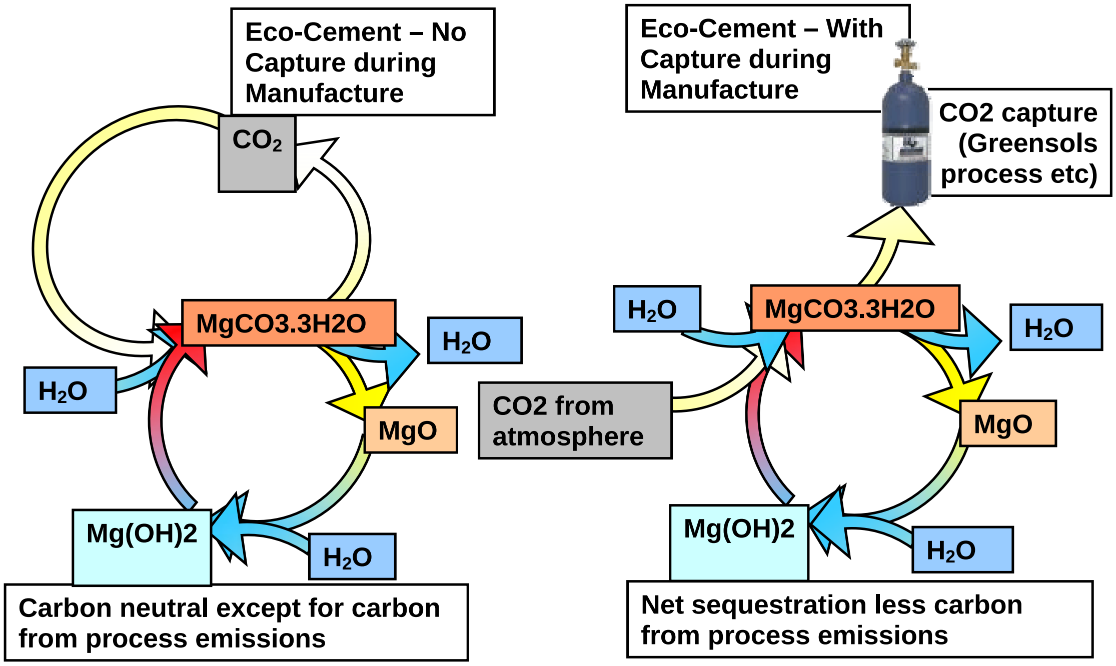


Figure 12 - Carbon Cycles in Eco-Cement with and Without Capture

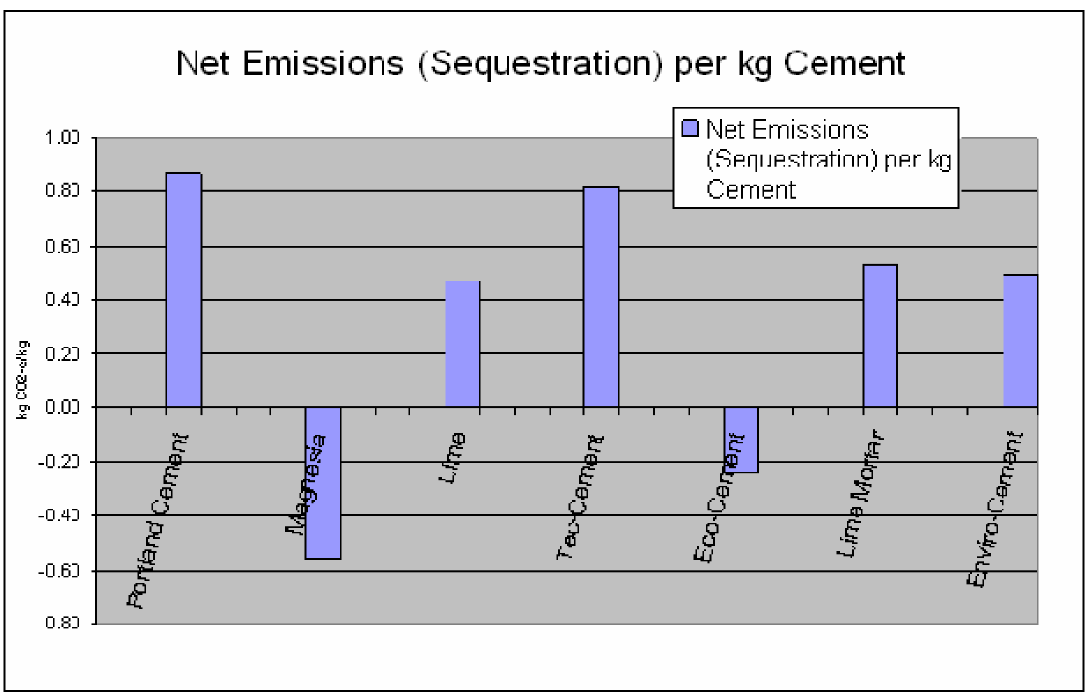


Figure 13 - Net Sequestration Typical Eco-Cement (Assuming Capture during Manufacture)

The more magnesium oxide in an Eco-Cement and the more permeable it is, the more CO_2 that is absorbed. The rate of absorption of CO_2 varies with the degree of porosity. Carbonation occurs quickly at first and more slowly towards completion.

Recycling in Gaia Engineering

Figure 14 below depicts flows in Gaia Engineering specifically relating to the built environment and does not include cycling in the MgCO2 cycle described above. The figure also demonstrates a significant recycling flow of waste carbonate and other wastes being converted to building materials, the latter because of the unique ability of TecEco cements such as Tec and Eco-Cement to bond to them and their low internal reactivity.

When buildings are finished with that are made of carbonate they will either be reused after cleaning (carbonate mortars are easier to remove) or reprocessed to produce Eco-Cement. Carbonate is recyclable to Eco-Cements because it can undergo a full thermodynamic cycle (See Figure 9).

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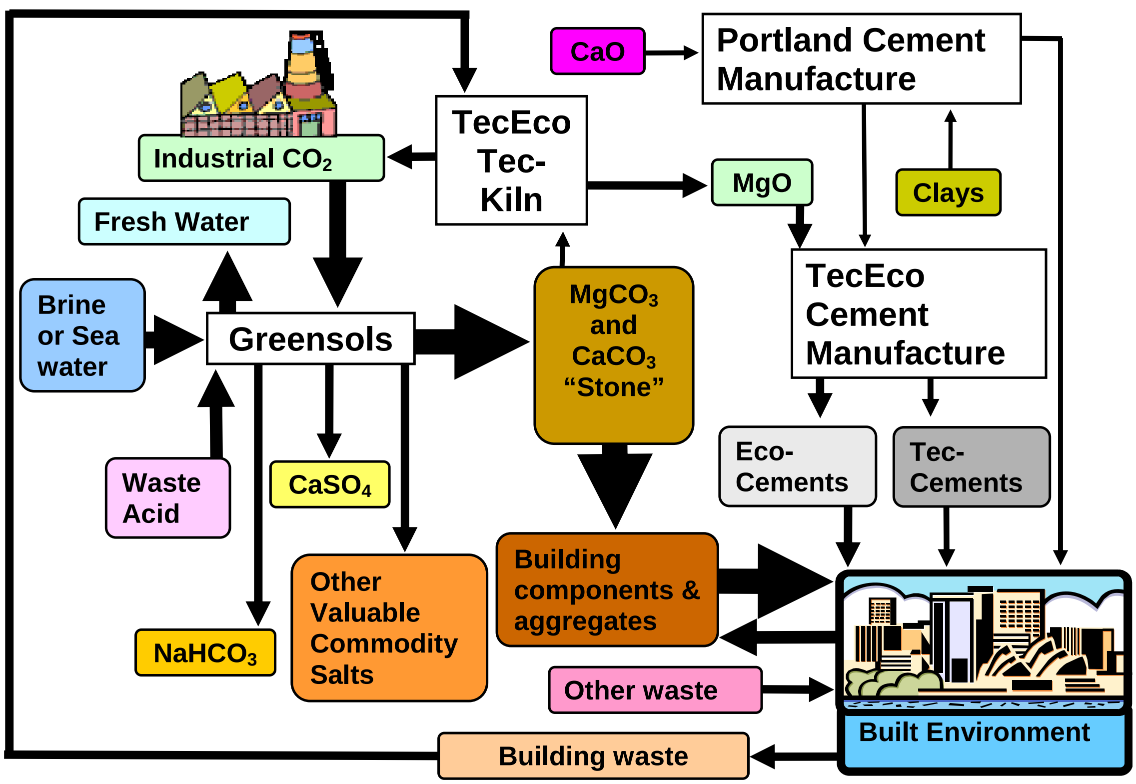

Figure 14 – Building with Carbon pursuant to Gaia Engineering. (The thickness of the arrows roughly corresponds to the size of the flows involved.)

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Modeling the Sequestration Performance of the Gaia Engineering Tececology

The author has developed a crude Excel model of the Gaia Engineering process to work out the plant and process requirements to sequester enough CO_2 to avoid reaching a concentration of 450 parts per million in the atmosphere, considered by many as an upper limit to avoid the most dangerous effects of global warming and irreversible change. It relies on several assumptions, including a forecast for magnesia sales for use in concrete and the extent to which global abatement programs will be successful,. Outputs include the number of plants of a given capacity that will be required as well as the costs and revenues involved in running the process.

The model quite clearly demonstrates that the problem of increasing concentrations of CO_2 in the atmosphere can be solved using Gaia Engineering.

Some governments are in fear of change yet modern economic theory (evolutionary economics in particular) is based on the fact that change is the major driver of economic growth. This process, called creative destruction by Schumpeter (Schumpeter 1954), is whereby new innovation destroys old and less efficient process and is the drive engine of modern economies.

The Economics of Gaia Engineering

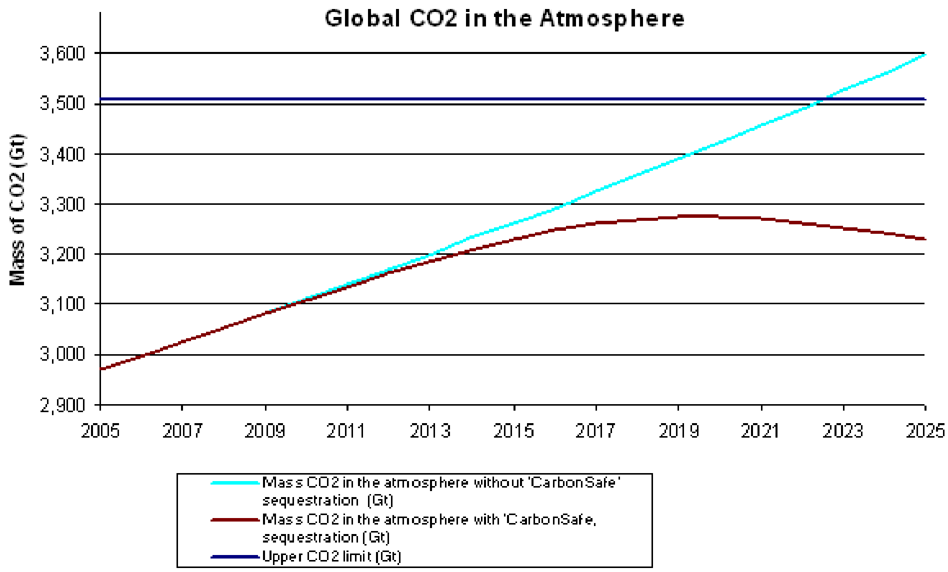

Figure 15 - Gaia Engineering Sequestration

Gaia Engineering is unique in that it can potentially achieve profitability without the economies of scale required for so many other technical solutions to Global Warming and this is because it has other valuable outputs including fresh water and valuable commodity salts and low energy inputs.

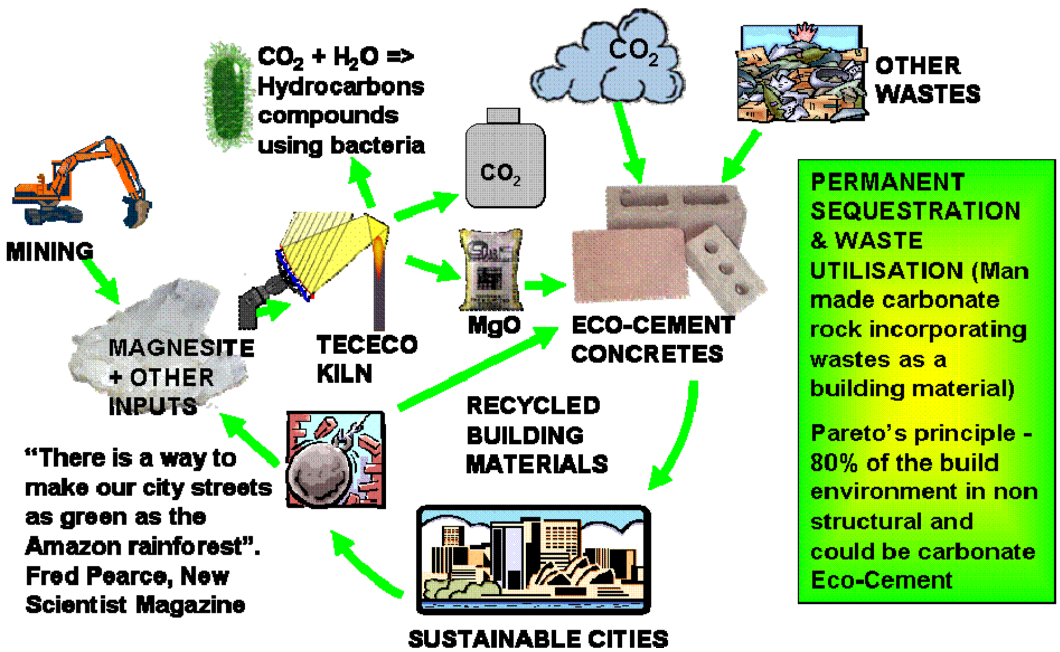

Figure 16 - Recycling Cities of the Future under Gaia Engineering

Summary

The Gaia Engineering tececology will result in sustainable cities that store carbon and are constantly recycled. It teaches us that mimicking nature and using carbon is not only possible, but the logical solution to solving the most pressing dilemmas of the modern era – those of carbon dioxide in the atmosphere and wastes.

References

Bearat, H., M. J. McKelvy, et al. (2002). "Magnesium Hydroxide Dehydroxylation/Carbonation Reaction Processes: Implications for Carbon Dioxide Mineral Sequestration." Journal of the American Ceramic Society **85**(4): 742-748.

Butt, D. P., K. S. Lackner, et al. (1996). "Kinetics of Thermal Dehydroxylation and Carbonation of Magnesium Hydroxide." Journal of the American Ceramic Society **79**(7): 1892-1898.

Deelman, J. C. (2003). Low-Temperature Formation of Dolomite and Magnesite, Compact Disc Publications, Geology Series.

Defra (2004). Scientific and Technical Aspects of Climate Change, including Impacts, Adaptation and Associated Costs. UK, Department for Environment, Food and Rural Affairs.

Fernandez, A. I. C., J M, M. A. Segarra, et al. (1999). "Kinetic study of carbonation of MgO slurries." Hydrometallurgy **53**: 155-167.

Haughton, R. (2005). Understanding the Global Carbon Cycle, Woods Hole Institute.

Hillman, M. and T. Fawcett (2004). How We Can Save the Planet. London, Penguin Books.

Keener, T. (2001). Annual Project Report - CO2 Separation and Sequestration Utilizing FGD

Scrubber By-Products, University of Cincinatti.

Lippmann, F. (1973). Sedimentary Carbonate Minerals. Berlin, Heidelberg, New York, Springer-Verlag.

Lovelock, J. E. (1979). Gaia: A New Look at Life on Earth, Oxford University Press.

Neville, A. M. (1997). " Maintenance and Durability of Structures." Concrete International **19**(11).
Pearce, F. (1997). "The Concrete Jungle Overheats." New Scientist(2097): 14.
Pearce, F. (2002). "Green Foundations." New Scientist **175**(2351): 39-40.
Phair, J. W. (2006). "Green chemistry for sustainable cement production and use." Tutorial Review.
Schumpeter, J. A. (1954). History of Economic Analysis. New York, Oxford University Press.
USGS (2005). "Mineral Commodity Summary - Cement." (2005).
WCD (2000). A New Framework for Decision-making The Report of the World Commission on Dams, Earthscan.