

The Role of Concrete Post Kyoto – The Unrecognized Sequestration Solution?

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Executive Summary

The Kyoto treaty came in to force on the 16th February, 2005 and member nations are wondering how they can meet their objectives.

This paper demonstrates the potential of the concrete industry to deliver a large proportion of the emissions reduction required.

With production at over 14 billion tonnes concrete is the largest material flow on the planet. It is also already a very sustainable material with relatively low embodied energies. The challenge is to develop manufacturing technologies to capture chemically released CO₂ during manufacture and usage technologies that encouraged carbonation as a strength giving process.

It points out that doing so is easier with TecEco kiln and binder technologies, and profitable, particularly under Kyoto.

Keywords

Built environment, carbon credits, economic, emissions, trading, sequestration, mitigation, abatement, sustainable, sustainability, CO₂, capture, concrete, waste, embodied energy, lifetime energy, eco-cement, Kyoto, tec-cement, tec-kiln.

Background

We have a major problem to address. Life on this planet may not be very tenable in a few hundred years if global warming occurs as predicted.

The first to seriously point out the ramifications of continued high use of Portland cement as it is formulated today and global warming was probably Prof. Joseph Davidovits in his paper published in World Resources Review in 1994 (Davidovits 1994). His writings attracted the attention of Fred Pearce, a renowned writer with New Scientist Magazine who wrote an article in New Scientist with the attention getting title of “The Concrete Jungle Overheats”(Pearce 1997). Fred’s article caught the attention of the world and was one of the influences that inspired me to research more sustainable cement technologies. Later Fred was to publish the article “Green Foundations” about the ramifications of our eco-cement concretes for global warming (Pearce 2002).

The Kyoto Treaty

On the 16th February 2005 the 1997 Kyoto Protocol, drawn up in Kyoto, Japan in 1997 to implement the United Nations Framework Convention for Climate Change, finally became international law.

Signatory countries are legally bound to reduce worldwide emissions of six greenhouse gases (collectively) by an average of 5.2% below their 1990 levels by the period 2008-2012.

For the protocol to become law it needed to be ratified by countries accounting for at least 55% of 1990 carbon dioxide emissions. The key to ratification came when Russia, which accounted for 17% of 1990 emissions, signed up to the agreement on 5th November 2004. Ratification of the agreement means Kyoto will receive support from participating countries that emit 61.6% of carbon dioxide emissions.

Member countries have developed their own methods to meet targets. The EU for example has established quotas and a market to buy and sell credits. Unfortunately however some major emitters have not joined making it difficult for resident companies to trade their credits. The official view in the US and Australia is that it would ruin their economies. The Australian government has developed its own scheme called "The National Greenhouse Strategy" that will attempt to reduce emissions by only 10.1% by 2012, which is an 8% increase on 1990 levels. Only in April, 2005 the combined Australian states defied the Federal government and announced they were developing a scheme. They could yet independently as a confederation of labour states join Kyoto.

It will be a difficult task for most of the member countries to meet their Kyoto targets and already nations are falling behind. Spain and Portugal in the EU were 40.5% above 1990 levels in 2002. Canada, one of the first countries to sign, has increased emissions by 20% since 1990, and they have no clear plan to reach their target. The Japanese are also uncertain about how they will reach their 6% target by 2012.

Concrete - Potentially Very Sustainable

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

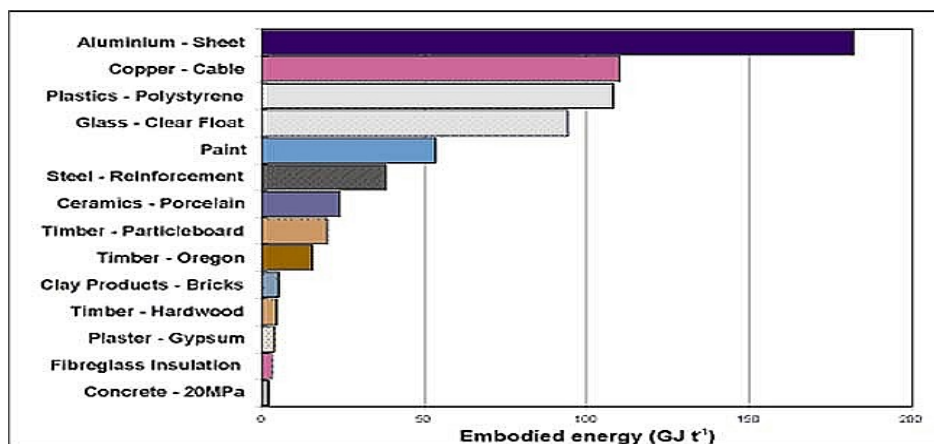


Figure 1 - Embodied Energy of Building Materials (Tucker 2000)

What Matters is Impact

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

As of 2005 some 2.00 billion tonnes of Portland Cement (OPC) were produced globally (USGS 2004) (see Figure 2), enough to produce over 7 cubic km of concrete per year or over two tonnes or one cubic metre per person on the planet.

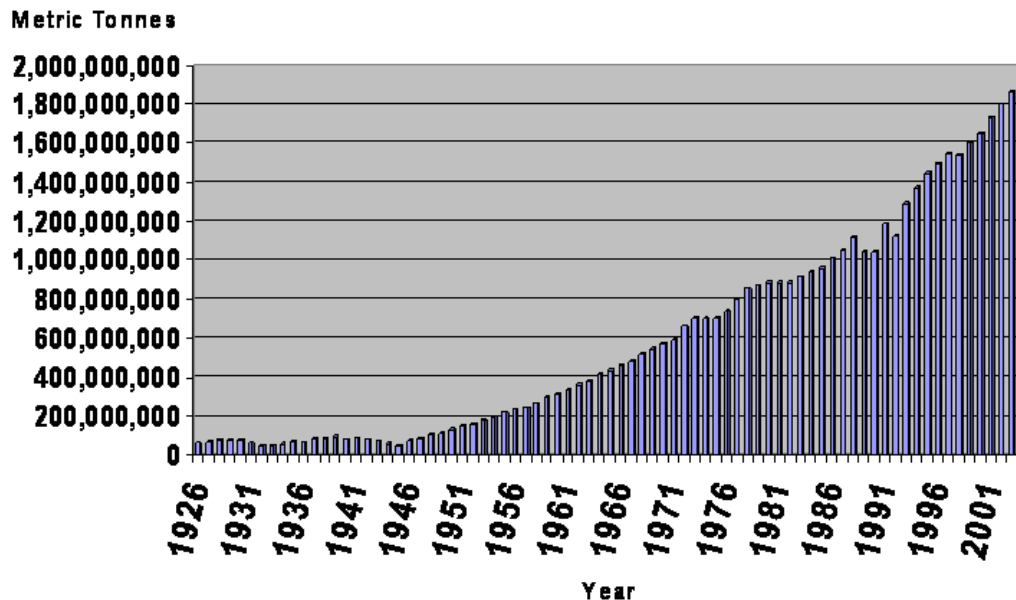


Figure 2 - Cement Production = Carbon Dioxide Emissions from Cement Production 1926-2002 (Van Oss, Hendriks et al. 2003)

As a consequence of the huge volume of Portland cement manufactured, considerable energy is consumed (see Figure 3 - Embodied Energy in Buildings (Tucker, S., 2000)) resulting in CO₂ emissions. CO₂ 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 CO₂/ tonne cement (Hendriks, Worrell et al. 2002) to as high as 1.24 tonne determined by researchers at the Oak Ridge National Laboratories (Wilson 1993) and 1.30 tonne (Tucker 2002). The figure of one tonne of carbon dioxide for every tonne of Portland cement manufactured (Pearce 1997) given by New Scientist Magazine is generally accepted accept in the concrete industry.

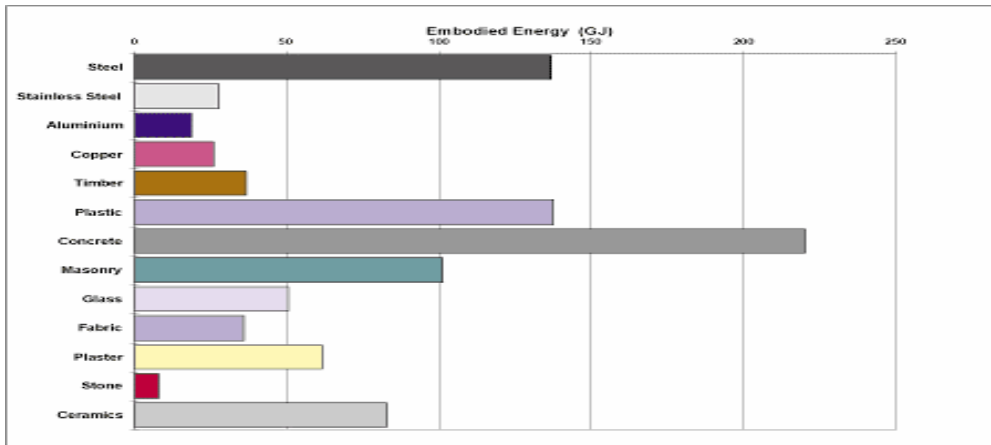


Figure 3 - Embodied Energy in Buildings (Tucker 2000)

Because of the huge volume used, Portland cement concrete is the biggest single contributor to embodied energy in most buildings. As a consequence Portland cement concretes account for more embodied energy than any other material in the construction sector (Tucker 2000).

The manufacture of Portland cement is one the biggest single contributors to the greenhouse effect after the burning of fossil fuels, accounting for between 5% (Hendriks, Worrell et al. 2002) and 10% (Pearce 1997) of global anthropogenic CO₂ emissions.

Why Concrete in the Built Environment is so Important

When trying to solve a problem of immense proportions a good strategy is to first assess the solution, the means of applying it and the outcome from the effort of applying it. Put simply the input/outcome ratio or “bang for buck” is important for success. The obvious place that seems to have been missed by just about everybody to focus sustainability efforts is the built environment¹. Given the size of the built environment there are huge opportunities for improving the techno-process and whilst doing so solving pollution and climate change problems.

“In 1999, construction activities contributed over 35% of total global CO₂ emissions - more than any other industrial activity. Mitigating and reducing the impacts contributed by these activities is a significant challenge for urban planners, designers, architects, engineers and the construction industry, especially in the context of population and urban growth, and the associated requirement for houses, offices, shops, factories and roads (UNEP 2001).”

According to the Human Settlements Theme Report, State of the Environment Australia 2001(CSIRO 2001), “Carbon dioxide (CO₂) emissions are highly correlated with the energy consumed in manufacturing building materials.”

There is huge scope for emissions reduction and conversion of waste to resource given the massive size of the materials flows involved in the built environment of which concrete is around 30%. With the right materials and manufacturing technologies, because of its

¹ Only on 21 February 2006, in Paris, France did the United Nations Environment Programme (UNEP) launch the Sustainable Building and Construction Initiative (SBCI)

sheer size, concrete could be a big part of the solution to global warming and other environmental problems.

Greening Concretes

The challenge is to reduce the impact of concrete production and usage and there are several ways this could be done.

1. Reduce chemical emissions during the manufacture of cements
2. Reduce the process emissions (resulting in embodied energy) during the manufacture of cements.
3. Change building technology and practice towards carbonating concretes.
4. Use carbon in concrete.
5. Introduce properties to concretes that would result in reductions in the lifetime energies and emissions of structures.
6. Include more supplementary cementitious materials.
7. Change concrete placement practices.
8. Transport Energies

Reduce chemical emissions during the manufacture of cements

Alkali metal oxides are the basis of Portland, TecEco and most other hydraulic cements. Alkali metals like calcium and magnesium release a large amount of chemically bound CO₂ when their oxides are made from their carbonates. If this chemically released CO₂ could be captured during manufacture there would be significant net reductions in emissions and an opportunity for sequestration.

The capture of CO₂ at source during the manufacturing process is easier and more efficient for the calcination of magnesium carbonates than any other carbonates mainly because the process occurs at relatively low temperatures.

TecEco Pty. Ltd. own intellectual property in relation to a new tec-kiln in which grinding and calcining² can occur at the same time in the same vessel for higher efficiencies (grinding releases heat) and CO₂ is easily captured. It is hoped to use geopolymers to make the new kiln, making it easy to mass produce. The new kiln will at first be used to calcine magnesite and make reactive magnesia. When materials improve sufficiently to withstand 1500 deg C the technology may be able to be used for the manufacture of Portland cement. Unfortunately considerable funds will be required to develop the technology beyond the resources of existing shareholders.

Geopolymers are also of relevance in the as they are essentially made from fly ash and other pozzolans and caustic alkalis. To the extent that fly ash remains a waste they are therefore more sustainable. Unfortunately metakaolins and other kandoxi also generally required, are not wastes and require energy to make.

² Calcining in the context of this document refers to the heating of limestone or magnesite to drive off CO₂ and produce the oxide.

Reduce the process emissions (resulting in embodied energy) during the manufacture of cements.

It is important to not just improve the efficiency of producing cement as is being done. Sources of energy also need to be considered.

Use of alternative “waste” fuels.

The use of “waste” streams as sources of energy is a major direction for the industry however I question whether wasting molecules such as rubber or plastics is a good thing particularly if their value as a molecule can be utilised. Using “waste” fuels is certainly adding to pollution, but is better than using “virgin” fuels. As the use of alternative fuels has been discussed in detail elsewhere it will not be in this paper.

Use of Non-fossil Fuel Energy

As can be seen from Table 1, fossil fuel energy is only a very small fraction of total energy on the planet.

Table 1- Different Energy Fluxes on The Planet³

10¹³ Watts	Total	Heat	Wind	Evaporation	Photosynthesis
Solar	12100	8000	37	4000	4
Earth Heat	3.2				
Tidal	0.3				
World Techno-Process Energy Demand	1.5				

Cement could be made using non fossil fuel energy. There are several enticing possibilities – tapping deep geothermal energy or using direct or indirect energy from the sun.

TecEco’s new kiln is designed to utilise direct solar energy in a solar concentrator or waste heat. It can also be powered using electricity from intermittent sources such as wind or wave. The new kiln combines calcining and grinding in a defined path and will capture the CO₂ released. With the development of new and better thermal materials it will eventually be able to be used for the manufacture of Portland cement.

The use of non fossil fuel energy and capture of chemically released CO₂ would be a giant step towards sustainability for the industry.

Change building technology and practice towards carbonating concretes.

Carbonation is the basis of strength gain in carbonating lime concretes. Unfortunately insufficient strength gain occurs for use other than in mortars and renders. It is also well known that carbonation of the Portlandite produced on the hydration of Portland cement increases strength. The disadvantage is that The pH drops to below about 8.9 and steel reinforcing rusts.

³ Estimated from various sources



The alternative that works most efficiently is that proposed by TecEco. Reactive magnesia incorporated in hydraulic cement in porous materials will first hydrate and then carbonate producing large quantities of strength giving minerals. The main reason for the incredible efficiency of this process is the huge volume of binding material produced essentially out of water and CO₂.

When magnesia in eco-cements re-carbonates, more CO₂ is captured than in calcium systems because magnesium has a lower molecular weight as in the calculations below show.

Figure 4 - The World's First Eco-Cement Porous Pavement, Windsor Park, Glenorchy, Tasmania

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

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

There is even more volume of solid material produced by the chemically included water. Consider the volume changes that occur when magnesia hydrates to Brucite and then carbonates to nesquehonite:



11.2 + (l) → 24.3 + (g) + (l) → 74.77 molar volumes.

Overall, the molar volume expansion (11.2 to 74.77 molar volumes or 568%) is significant. Considerable quantities of binding material are produced. Even more is produced for the formation of Lansfordite (MgCO₃·5H₂O).

Absorbing CO₂ out of the air attracts carbon credits. The amount of water used will hardly impact on fresh water shortages.

Kinetically the carbonation of eco-cements in the built environment will only proceed rapidly in porous materials such as bricks, block, pavers, mortars, porous pavement etc., which, fortunately, make up a large proportion of construction materials. All these materials, including mortars, require the use of appropriately coarse and essentially mono graded aggregates for carbonation to occur efficiently.

The effect of the substitution of Portland cement with MgO in a simple concrete brick formulation containing 15% cement with and without capture of CO₂ during manufacture of magnesia is depicted in Figure 5 below.

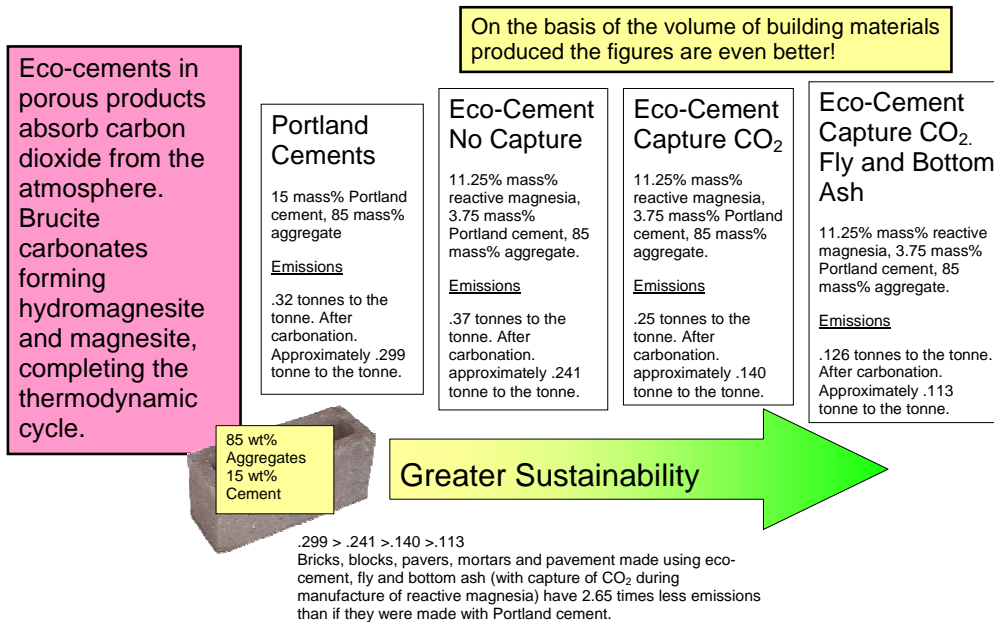


Figure 5 - Abatement in a Concrete Brick Containing 15% Eco-Cement

From Figure 5 it can be deduced that with the formulation specified almost 2/3 of the CO₂ that would have been produced is potentially abated if substituted by eco-cement in porous products such as bricks, blocks, pavers, mortars etc. With CO₂ capture or the inclusion of organic fibre materials and fillers for strength and insulation or both, cementitious building materials that act as net carbon sinks are feasible.

Use carbon in concrete

Not only could carbon be used as part of the binder system as in eco-cements discussed above, it could be used as a reinforcing element or aggregate.

As a reinforcing element

Carbon containing fibres including wood fibre, straw, sugarcane, bagasse, kenaf, hemp, guayule, shredded plastic, carpet clippings etc. have tensile strength and often go to waste. The use of fibre in concrete, and especially waste fibre is one way to add strength without using steel and other reinforcing elements that have high embodied energies and emissions. Apart from adding strength carbon is permanently encapsulated.

As an aggregate or filler

There are many carbon containing materials that go to waste that can add value to concretes as a composite because they have desirable physical properties. For example plastics are generally light in weight and have tensile strength. With the introduction of robotics to construction all sorts of material composites that have the flow characteristics of concretes will be required. Incorporating carbon containing materials as aggregates would convert wastes to resources and also permanently encapsulate carbon.

Introduce properties to concretes that would result in reductions in the lifetime energies and emissions of structures.

Concrete is a self setting solid. The self setting solids industry needs to evolve by vertical integration – to not just supply concrete but complete walling and flooring solutions⁴. To vertically integrate cost effectively the industry need to undertake proper market research and by doing so will discover that strength is not all that is demanded. Other properties in a material that transforms from easily placable to solid will be required including insulation, sound proofing and weight reductions. The introduction of robotics to construction will help drive this.

Architects are pushing the boundaries of design to reduce the lifetime energies of structures. As the physical properties of the materials they use have a strong influence on lifetime energies further improvements will mainly occur as a result of paradigm shifts in the materials technologies they use and if the concrete industry wish to remain in the mainstream, they will have to evolve to supply the properties required in settable solids. Such evolution also implies vertical integration and product differentiation with an increasing range and value of properties.

Use more supplementary cementitious materials

Using more supplementary cementitious materials is a major objective of the Portland cement industry and widely documented as such as for example in “The cement sustainability initiative, our agenda for action”(WBCSD 2002). Fly ash (pfa) and ground vitrified blast furnace slag (gbfs) are mainly used and are wastes from other industries. Pfa by itself does not have cementing properties whilst gbfs does.

To the extent to which less PC is required and no further energy is used because of their use they are more sustainable. The use of Tec-Cements not only results in more rapid strength development with a high proportion of supplementary materials but easier finishing and less binder being required.

Change concrete placement practices

One of the major problems in the industry is the fact that finishers are getting lazier and want to do as little work as possible to place concrete. Because there is a direct relationship between the water/binder ratio and strength and they virtually always add water on site, a correspondingly higher percentage of cement is used than would be required if less water were added. All this extra cement used produces emissions.

I have been experimenting with Roman methods of placing concrete. The Romans tamped a dry concrete mix into place and the result was not only strength but extreme durability (Herring 2002). The Pantheon for example was built in 118-35 AD, and still stands today as testament to the quality of their work. The nearest equivalent today is roller compacted concrete which is laid relatively dry.

My suggested method is as follows. Deliver concrete as a very dry mix similar to what is produced for making concrete blocks, move it about with bobcats, mini bob cats or “Kangas” as they are called in Australia and finally rakes. For a slab shave the surface

⁴ This would help get over a lot of other problems in the industry

level using long sharp cutting edges and then tamp down with a vibrating compactor. Finish by using a finishing slurry or topping coat over the top to any colour and you have it – approximately 20 – 30% less cement for the same strength and potentially lower cost. It takes no longer and costs less so why are we not doing it? Worse still why aren't people researching such methods?

Transport Energies

There are only two ways to reduce the emissions associated with the transport energy component of concrete: change the source of energy away from fossil fuels (as with hybrid and electric vehicles) and/or use less energy by incorporating locally sourced materials as aggregates requiring less transport. Tec and Eco-Cement binders are uniquely less reactive, making the latter more feasible.

Concretes of the future will contain more local, low impact materials that have not been transported.

Sequestration on a Massive Scale

The current price of carbon dioxide is around €26 per tonne⁵. Why not use the built environment as a giant repository for carbon and earn carbon credits at the same time? TecEco have spent the last couple of years developing a technical paradigm for doing so economically. Major outputs of this paradigm include TecEco Eco-Cements that set by absorbing CO₂ out of the air. The new process is called CarbonSafe and readers are directed to the web site of TecEco at www.tececo.com for more information.

CarbonSafe Technology

If adopted on a large scale the CarbonSafe process would sequester significant amounts of atmospheric CO₂ and convert significant wastes to resources. CarbonSafe is an agglomeration of new technologies including TecEco's kiln technology and cements, carbon dioxide scrubbing technology, a seawater separation technology from [Greensols Pty. Ltd](#) and heat at transfer and desalination technologies that can produce fresh water, a number of industrial commodity products including gypsum, sodium bicarbonate and various other salts as well as building materials based on magnesium carbonates that also utilize wastes. Each of these outputs uniquely provides revenue to help make the overall process economic.

⁵ Settlement price March 16, 2006 on the ECX was €26

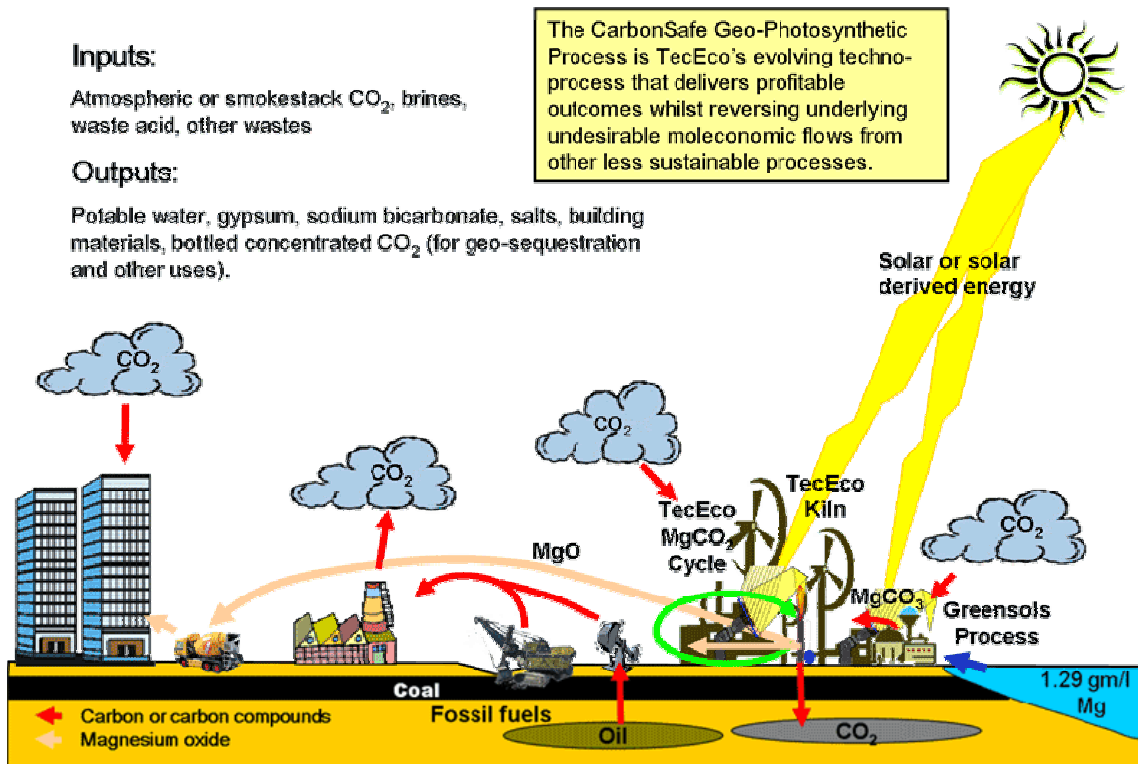


Figure 6 - Graphic Illustration of the CarbonSafe Process for Seawater

The CarbonSafe process starts with either magnesium silicates or the Greensols process. In the case of silicates, magnesium carbonates are produced using proven mineral sequestration technology and then transferred to the MgCO₂ cycle. The Greensols process on the other hand uses carbon dioxide from power stations and waste acid to extract magnesium carbonate and other salts from seawater or suitable brines and producing potable water as a by-product. The MgCO₃ from either process is then calcined in the TecEco kiln which removes and captures carbon dioxide (ready for incorporation for example into cellulose or fuel or other compounds or for geo-sequestration) and produces magnesium oxide. The magnesium oxide can either be used to make TecEco cements which utilize other wastes and in the case of eco-cement absorb more atmospheric CO₂ as they harden or alternatively used to sequester more CO₂ in a hydroxide/carbonate slurry capture process.

The MgCO₃.3-5H₂O produced by the hydroxide slurry process can be de carbonated and cycle around that process indefinitely as in the diagram below.

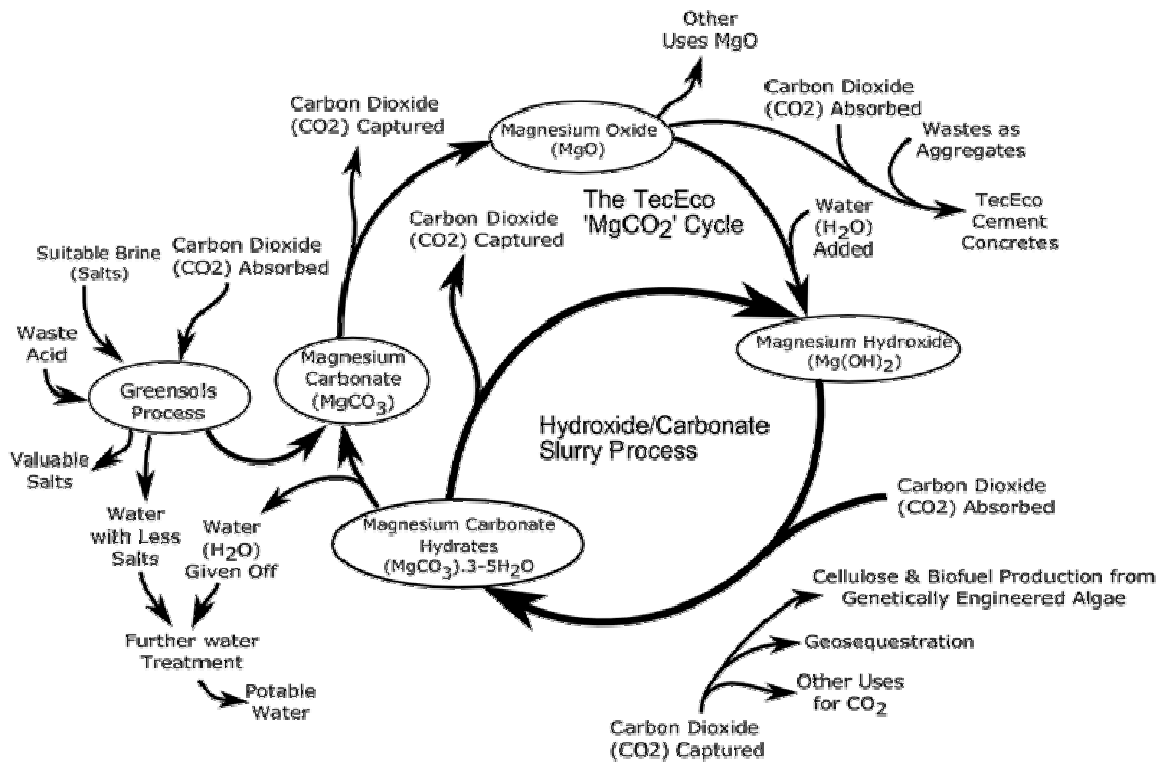


Figure 7 - CarbonSafe Process Vector Diagram for Seawater

Technologies are still evolving to use the CO₂ produced by CarbonSafe. A particular future use of CO₂ that we are monitoring is to force rapid growth of genetically modified algae able to convert CO₂ and water into oxygen and cellulose or oxygen and fuel.

The MgCO₂ and hydroxide/carbonate slurry process cycles 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, 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.

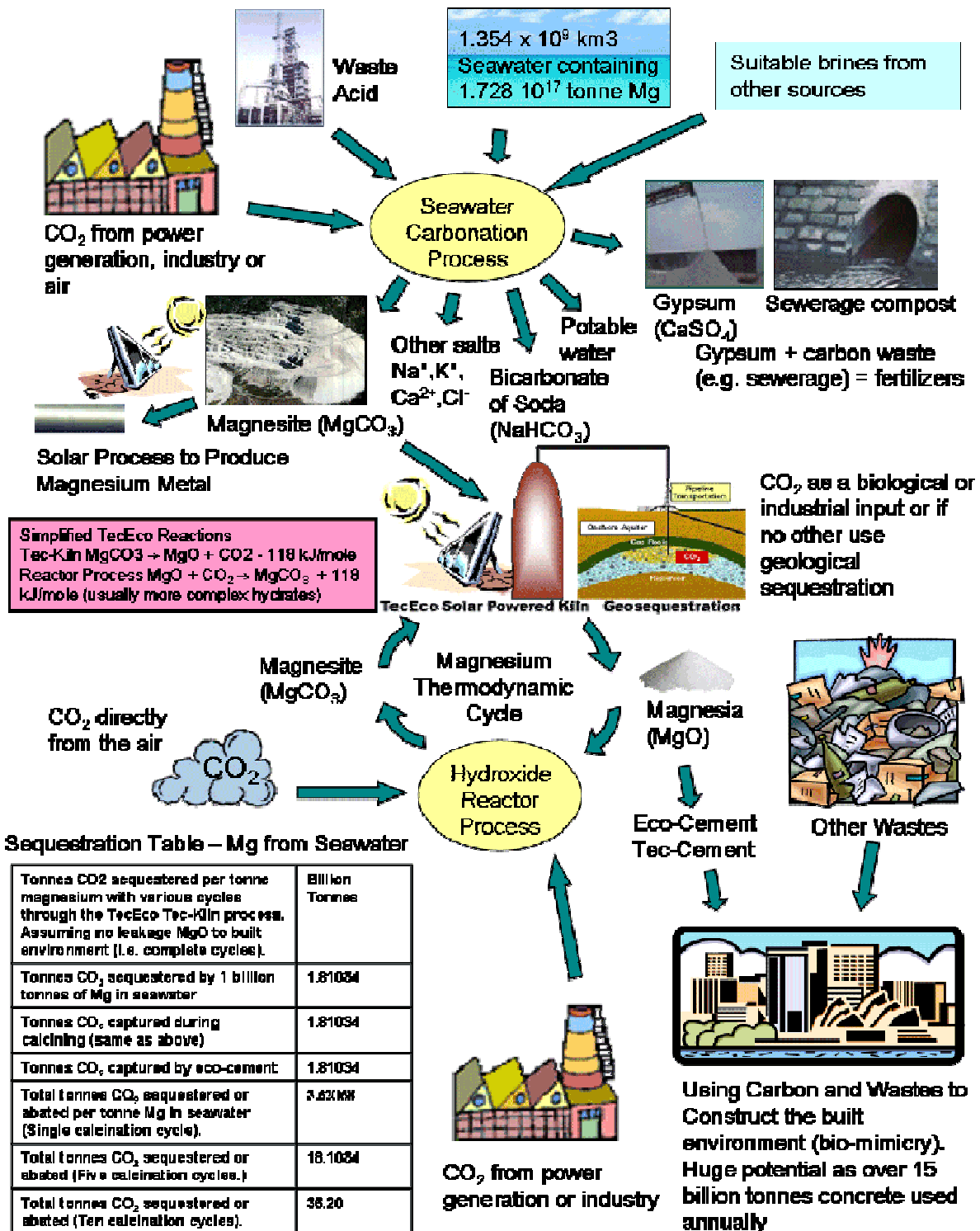


Figure 8 - The CarbonSafe Process for Seawater

The efficiencies of the various sub-processes are fundamental to making the CarbonSafe process economic and minimizing the amount of energy required overall. An important area of research we are engaged in is to develop technologies for the efficient collection, concentration and transfer of heat energy and more information about this is available on the TecEco web site at www.tececo.com.

We call CarbonSafe a geo-photosynthetic process because it mimics the way that plants, algae and some bacteria capture and store carbon using photosynthesis. In 1796, Jean Senebier, a French pastor, showed that CO₂ was the "fixed" or "injured" air and that it was taken up by plants. Soon afterwards, Theodore de Saussure showed that the increase in mass of the plant as it grows could not be due only to uptake of CO₂, but also to the incorporation of water.

It followed that the process of photosynthesis achieves the following:



Basing our industrial ecologies on CarbonSafe will result in sustainable cities that store carbon and are constantly recycled.

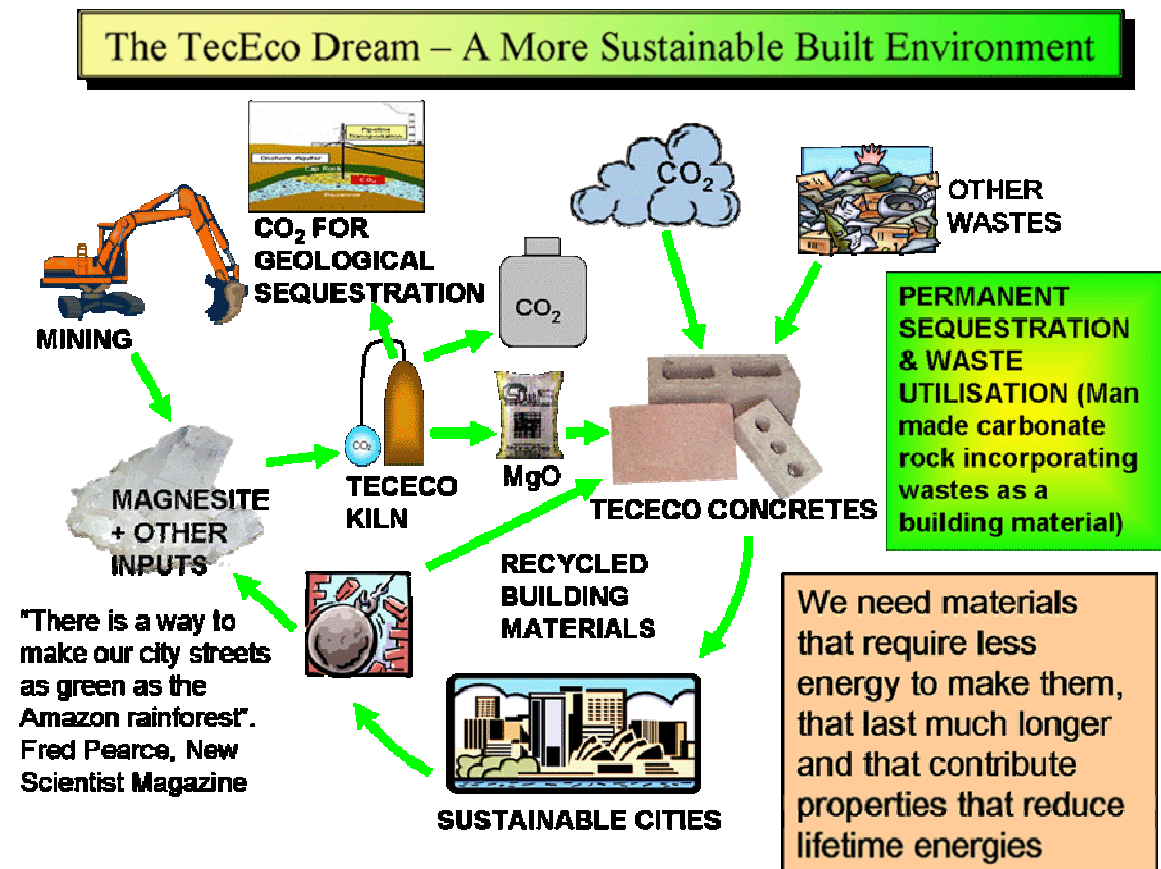


Figure 9 - Sustainable Cities

The TecEco Model of the CarbonSafe Process

TecEco have developed an Excel model of the CarbonSafe process to work out the plant and process requirements to sequester enough CO₂ 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. If you would like to review the model please go to the TecEco web site and look under [tools](#).

The model is designed to work out how we can not reach 450 ppm CO₂, considered a dangerous level by most commentators.

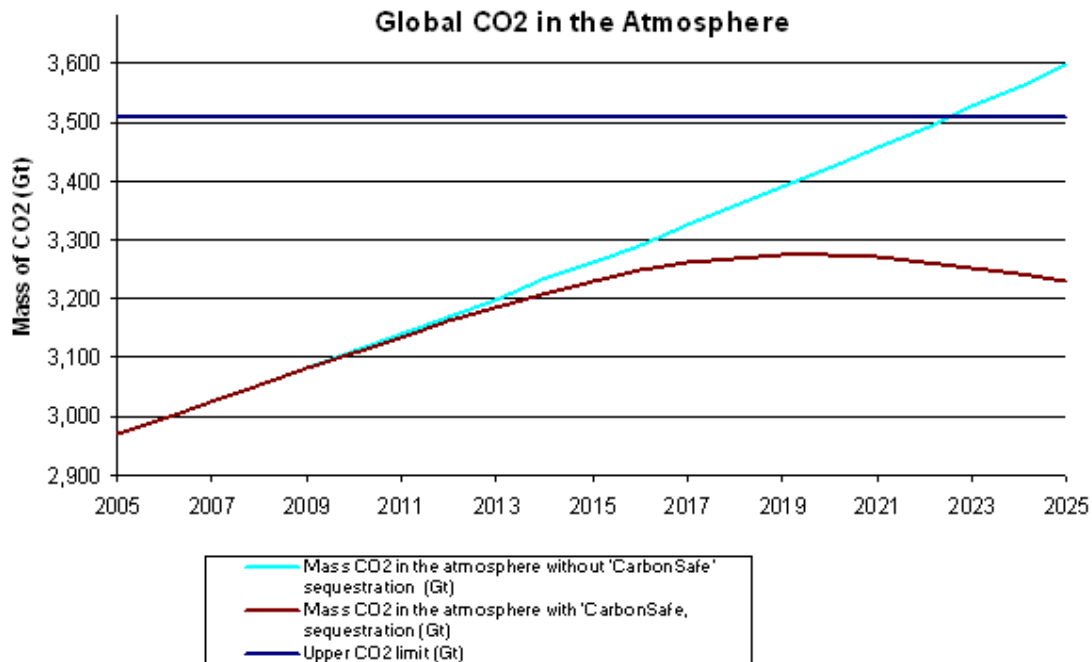


Figure 10 - CarbonSafe Sequestration

The Politics of a Massive Sequestration Process

To achieve the massive sequestration possible it will need the co-operation of governments, the power industry, the cement industry and the construction industry. The incentive is that it could be profitable under Kyoto. As many countries in the world like Japan and Singapore that are signatories to the Kyoto protocol are trading nations and not having natural resources are best able to meet their Kyoto commitments through carbon trading CarbonSafe should be of interest to them.

Sequestration on a massive scale is far more politically acceptable than energy rationing which is currently the only other viable alternative. Practically we should adopt a holistically integrated approach and also work on reducing emissions.

The Economics of a Massive Sequestration Process & Kyoto

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 of around \$ US 20/tonne of CO₂ are suggested. For a 66% efficient power plant this would add less than 1 cent to the cost of a kilowatt hour of electricity (Yegulalp, Lackner et al. 2001).

At the current price of carbon dioxide per tonne Carbonsafe would be even more than economic as it has an inherently lower cost base.

The Kyoto protocol will also encourage the development of other technologies whereby CO₂ becomes a resource and as a result the process will eventually be supported by an

economically driven price for CO₂. The use of TecEco eco-cements concretes would also be favoured as magnesite, the raw material, would not have to be mined. An added advantage would be the permanent disposal of carbon dioxide with no possibility for leakage.

Kyoto member countries have more hope of persuading the US and Australia to join Kyoto if those countries are waiting for a technical solution by developing exemplars of the solution offered by TecEco. Given the options of energy rationing, massive sequestration in the built environment or some combination of both, sequestration on a massive scale is most easily politically implemented. The added benefit of adopting TecEco technology is that it can help convert mountains of waste, arguably the second biggest problem facing the planet, into resource and potentially also produce potable water.

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