Gaia Engineering - An Economic Approach to solving Climate Change, Water and Waste Problems

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Abstract

Gaia Engineering involves building with man made carbonate to solve the problem of global warming. The technology platform is potentially profitable because it utilises carbon dioxide as a low cost resource to produce cement and aggregates for concretes and other building components and has as a by product fresh water. Importantly there are no legacies for future generations to deal with and the solution does not depend on a high long term price for carbon or carbon trading, both so far not delivered by an arguably failed Kyoto process.

Gaia Engineering has tremendous potential for the concrete industry and given a high level of support would most likely attract significant government funding as it is a superior alternative to geosequestration. As it involves education and leadership there is a strong role for the Concrete Institute of Australia and Cement Industry Federation and possibly a large credible scientific organisation.

Background

There are few that doubt that when the ice stops melting that temperatures will rise rapidly. If the methane clathrates[1] also melt we are heading for a global catastrophe on a major scale and perhaps the end of civilisation.

It should by now be obvious that doing things in the same old way will not solve our climate problems. Politically driven process such as Kyoto that rely on promises, international co-operation and legal pricing in artificial markets to implement constraints on emissions and thus on the real economy are understandably treated with scepticism by many, particularly in business and so far they have not worked. We need to think outside the square and this paper will demonstrate that this is as simple as learning from nature and changing the way we do things to make a living.

Kyoto is obsessed more about numbers than means and mechanisms. It does not address how to get there, has no thought of the strategy or technology platforms. It is a system of promises about the quanta of emissions that so far few have shown they can keep. It is possible that all the actions to date have merely been for political feel good reasons and in the pursuit of profit through efficiency gains. The Kyoto processes process has been almost totally ineffective. A long term view is required with appropriate technologies and strategies for their implementation for the continuance of civilisation.

The problem of global warming must and can be solved. To exist in harmony with the planet in the future we just have to change the way we do things now and the cement and concrete industry have a major role to play.

Understanding the Problem

The problem is not carbon; it is the amount of it in the atmosphere. As carbon sinks go very little is present in the air compared to elsewhere but the natural migration of the excess we have put there to other more permanent sinks is not happening quickly enough. A short term perturbation sufficient to tip the world's climate into another state which may not be suitable for us to live in is occurring. This state could include a vastly different atmospheric composition that may not be suitable for human life if the methane clathrates melt as is ultimately possible.

There are two basic strategy alternatives to solve the problem:

1. Emissions Reduction

Emissions reduction is essential but useless alone now without efforts to actively remove CO_2 from the air (See 2 below). The reason is that there is already enough CO_2 in the atmosphere to cause significant temperature rises and the gas does not dissipate quickly[2].

[1] Also referred to as methane ice or methane hydrates

Emissions constraint without alternatives is also politically and economically not achievable because it involves actions that reduce profitability. Profitability is linked to the survival of individuals, companies and governments and none survive long without. It is no wonder Kyoto type processes have so far failed and are unlikely to succeed.

The Kyoto treaty was flawed from the start in many ways and particularly because it did not provide sufficiently for the development of vital technical alternatives. Both carbon tax and cap and trade systems are based on legal rather than real market forces and somehow global warming was to be solved by using them to reduce emissions in spite of a 100% correlation between them and real world industrial product[1].

Kyoto will not work. It has no technical plan, and no plan at all to address the dependence on energy[1]. It is a highly inequitable and inefficient agreement which will do little to curb greenhouse gas emissions. Carbon trading if implemented successfully is supposed to attach legal costs to emissions that will help the required migration to non fossil fuel energy sources and other green alternative technologies without carbon costs attached. The trouble is that the success of the mechanism depends on the unpredictable and uncertain politics of the future and given the non performance by global governments to date lacks credibility. That there will be a certain and sufficiently high future cost for carbon cannot be relied upon by big business so they have not and are unlikely to invest in alternative green technologies. In the meantime the obvious need for such alternatives remains unattended to because investors are not supporting them given the uncertainties of the Kyoto process and in particular the lack of a long term certain future price of carbon[3]. Development and deployment costs are high and carbon trading is a fickle instrument of governments they do not trust reducing the effectiveness of offsets as a driver. The 'we will if you will' political show continues.

So far we are tracking on worse than all IPCC alternatives [2] Assuming Kyoto commitments are met (which is very unlikely) one estimate is that in spite of Kyoto global emissions will be 41% higher in 2010 than in 1990 [3]

Whilst the debate continues and action lags behind it is becoming increasingly obvious that the rate of onset of major climate change has been underestimated and so we are in a double whammy. An environmental and economic crunch. Many including Lord Stern and the Greens here in Australia have called for a Green revolution to lead us out of the malaise. All the way to the United Nations[4] there are initiatives and calls backing green innovation but ever more cautious investors who have already received a bludgeoning are not putting their money behind green technologies.

Times are tough and possibly going to get tougher before world economies recover from the worst recession since the great depression and in spite of calls for the opposite to occur, big business are understandably walking from anything to do with carbon trading. World industrial product and fossil fuel use and thus emissions are 100% correlated and cannot be decoupled in a hurry without causing further economic stress even with increasingly unlikely world co-operation [1]. In the authors view and alternative strategy is required that involves leapfrogging technology.

Because of the constraint principle is inherent in the response of many countries to Kyoto many view implementations of the treaty as just another layer of tax. Some go so far as to suggest that the protocol was conceived to shift wealth from developing nations to the third world[5] which in effect it does through the CDM. No wonder the Kyoto process is resisted by many countries and big business.

All the Kyoto process has done is provide a useful forum for negotiation regarding its all important replacement. A replacement that must adopt a new direction as there is little doubt that we have wasted the years since 1997 when the Kyoto treaty was signed as we are now tracking worse than all IPCC scenarios [2].The debate rages as to whether it will cost more to implement constraint or adjust to climate change. The fact that there are profitable technical alternatives like Gaia Engineering is being lost in the heat of the argument.

2. Active Removal from the Atmosphere or Point Sources

Geo engineering active removal from the atmosphere creating man made carbonate building components as in Gaia Engineering will be more effective than emissions reduction as it does not involve the politics of

[2] The residence time of CO_2 is thought to be between 100 and 200 years.
[3] The removal of support for "Greenhouse Friendly" credits recently by the Australian government has resulted in much greater distrust of government backed carbon securities.
[4] The UN Green Economy Initiative to pull us out of the recession
[5] We suggest the reader just google this. When the author did many articles on the subject were found.

'we will if you will'. In the case of Gaia engineering the only involvement from government need be financial support to develop the component technologies and legislation to mandate use in exchange for building permits. This will not happen unless the cement and concrete industry get behind the proposal. They will be supported as there are increasing calls for technical fixes.

As far back as the 2007 Bali conference the World Business Council for Sustainable Development and the International Chamber of Commerce issued a Communiqué that at point 4 stated "Technology is key, for addressing the climate challenges. There is a need for scaling up of R&D jointly between Governments and Business as well as accelerating the deployment of technologies"[6].

In January 2009 the Independent Newspaper in the UK published a survey of 80 international specialists in climate change who made it clear that "an emergency plan B using the latest technology was needed [4]. The call has been repeated by economists Gwyn Prins [5] [6] and Steve Rayner [6] who confirm that "The Kyoto Protocol is a symbolically important expression of governments' concern about climate change. But as an instrument for achieving emissions reductions, it has failed". According to these authors target based emissions reduction was not going to work and what we need to do is make supply side change requiring a shift from the politics of restriction to the politics of opportunity.

What is alarming are the many mostly wacky technical alternatives that are being proffered and the author has covered most of them in the paper "The Implementation and Advantages of Carbon Trading in the Concrete Industry" also presented at this conference.

A change in the technical basis of our economies in favour of using carbon dioxide as an input resource must be profitable otherwise it will not occur or if it did it would not be sustained. By internalising CO_2 in the economy we can harness human psychology dominated by selfish desire and get it working for our long term survival. We can deal with technical challenge and opportunity rather than suffer constraint. A real price on carbon investors can trust will emerge as a result of which people would invent all sorts of way of capturing the gas.

Unlike natural economies found in climax eco-systems we are not using as much CO_2 as we produce. In the past, before humans began interfering with and now controlling the climate, if the CO_2 level was high it would eventually in a self regulatory way be taken up first by plants (on land as well as in the sea) in soils and eventually as solid carbonate rock. That is why over 4.5 billion years some 40 million gigatonnes of carbonate rocks covering some 8% of the crust has been formed. Emissions are not new phenomena either. Carbon dioxide has for many years been added to in the atmosphere by off gassing from the deeper earth. Life has continued as we know it because there is a natural progression in the permanence of carbon fixed in the crustal zone as depicted in Figure 1.

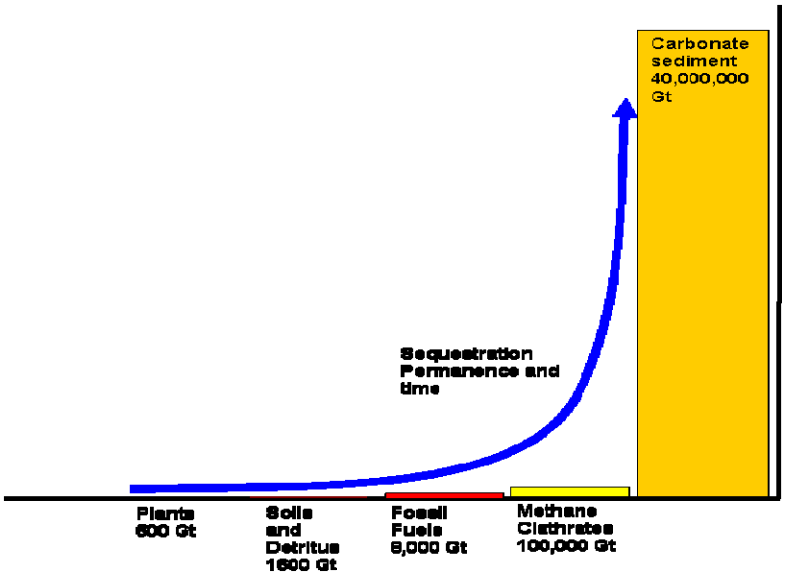


Figure 1 - Carbon Sinks with Increasing Permanence and Time to form to the Right

[6] http://www.tececo.com/files/newsletters/Newsletter75.htm

To survive we must accelerate the rate of change in the direction of the blue arrow in the above diagram. Any other strategy such as currently pursued Kyoto constraint processes will not hold off inevitable failure given population growth that is rising exponentially. Constraint is a negative economic force and cannot harness human endeavour the same way as a technical challenge that all can profitably participate in.

There is no strategy in place anywhere in the world that currently recognises that there are barriers to the invention of new technologies including economies of scale, patent costs, early unfair competition and business practices and that can provide the massive R & D and procurement support required. In another paper to be presented at this conference titled "The Implementation and Advantages of Carbon Trading in the Concrete Industry" the restrictions imposed on innovation by our standards and permissions systems is discussed.

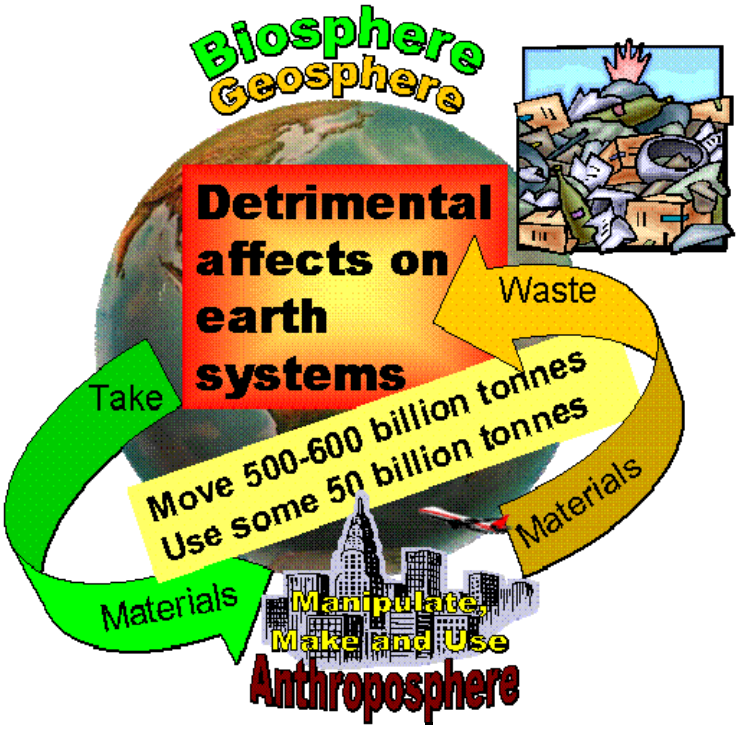


Figure 2 -The Techno-Process

To change the balance of carbon in the atmosphere and achieve long term stability we must actually change the materials flowing through the techno-process[7].

The problem of global warming is so urgent that governments, as well as interfering in the market place (rules, regulations, taxes, tariffs, subsidies etc.) must also foster new technology paradigms that can convert carbon dioxide to a resource. They will do this with the support of industry associations like the cement and concrete industry as it is easy to demonstrate the superiority of Gaia engineering over geosequestration which governments around the world are already supporting.

With the adoption of Gaia engineering the materials flow in the supply chain can be changed in favour of utilising man made carbonate. The underlying molecular flow including the emission of CO_2 and other greenhouse gases will then change and could even reverse.

The sequestration as a result of using man made carbonate in the next ten years or for that matter one thousand years will depend on the take up of the technology. It is important to note that there is plenty of scope as materials flows in the built environment are some 75 billion tonnes and only some 23 billion tonnes of solid man made magnesium carbonate a year is required to equate to annual anthropogenic emissions[8].

[7] The techno-process can be considered as the technical interface of the economy, it involves the flow of materials through the supply use and waste chain stages of their life. Underlying this flow are molecular flows including the flows of carbon dioxide into the atmosphere. See http://www.tececo.com/sustainability.techno-process.php

[8] See http://www.tececo.com/sustainability.carbon_cycles_sinks.php

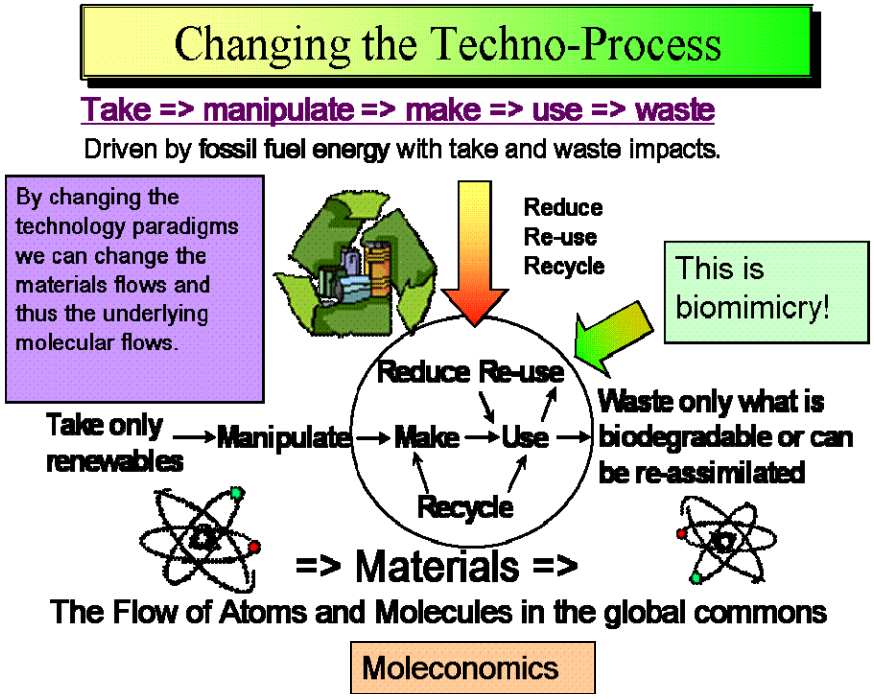


Figure 3 - Molecular Flows Underlying the Techno-Process

Modelling indicates that if 50% of all building and construction were man made carbonate as advocated, then the required reduction in atmospheric carbon dioxide would be achieved by 2030 and the problem of global warming solved. Around 2/3 of materials used in building and construction are mineral based and changing 50% of this proportion to man made carbonate is not impossible to achieve. On the contrary, it is potentially profitable.[9]

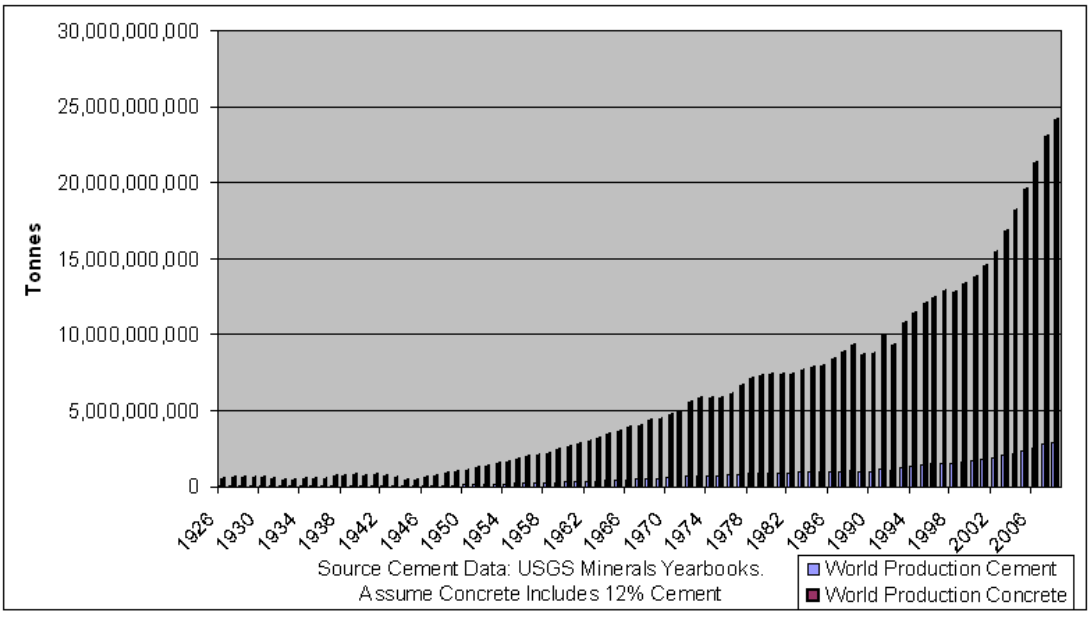


Figure 4 - World Production of Cement and Concrete[7]

This statement has been challenged however the correctness can be understood by considering the orders of magnitude of the flows involved. The annual net increase of carbon into the atmosphere is around 3.2 billion tonnes[8] which using molar proportionality equates to 11.72 billion, say 12 billion tonnes of CO_2. This

[9] Downloadable from the TecEco web site at http://www.tececo.com/files/spreadsheets/GaiaEngineeringVGeoSequestrationV1.3_5May09.xls

equates to 37.728 billion tonnes of nesquehonite, 22.99 billion tonnes of magnesite or 27.29 billion tonnes of calcite (limestone) compared to current annual production of concrete of around 25 billion tonnes. As concrete represents about half of mineral based building materials, clay and mud bricks making up the major proportion of the other half, it can be seen that replacing around 25 billion tonnes of such mineral based building materials with man made carbonate will consume more than all of the current annual increases in atmospheric CO_2. A complete proof has been uploaded to the author's company web site[10].

Once stability is achieved this percentage will of course have to be monitored and adjusted depending on for example the carbon intensity of energy to avoid bringing on an ice age. Following this strategy other problems such as that of waste and the supply of fresh water are incidentally solved as a bonus as will be further explained.

Summary of Gaia Engineering

Gaia Engineering[11] involves changing the way we do things by building with man made carbonate and wastes and involves a group of individuals and companies including the author's company. So far there is a pilot plant working for the production of man made carbonate from seawater and a number of carbonating Eco-Cement concrete exemplars that set by absorbing CO_2 and bind to almost anything[12] which together are proof of concept. The author has also invented a kiln for making the binders required without releases and a number of other enabling technologies.

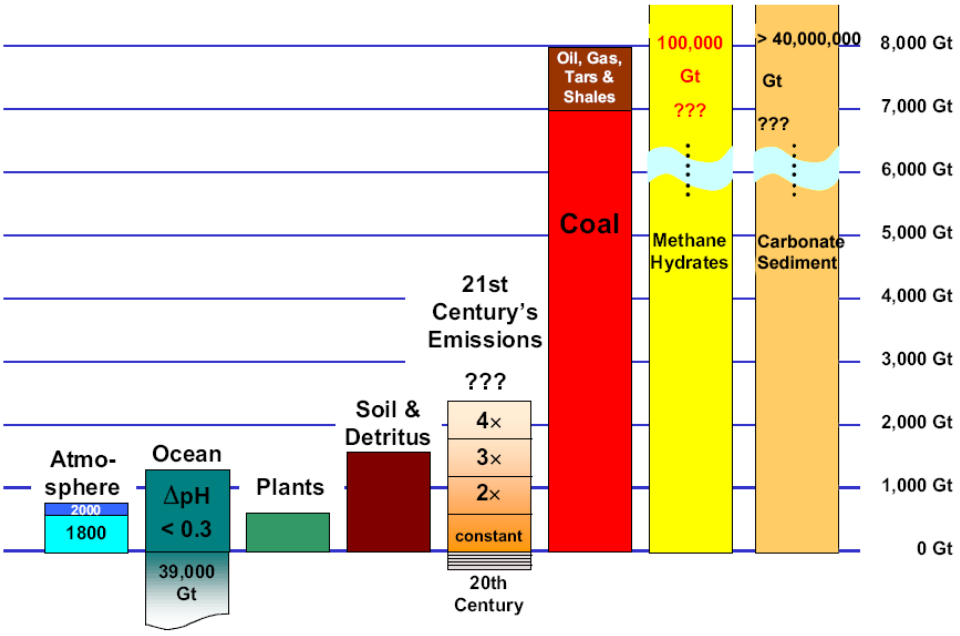


Figure 5 - Carbon Sinks and Anthropogenic Actual and Predicted Consumption of Carbon (after Ziock and Harrison [9] [13])

Although the Gaia Engineering process is simple in concept the detail is more complex and a flow chart is included as Figure 6. A more technical explanation follows.

Gaia Engineering[14] starts with a front end process to capture carbon dioxide using the magnesium contained in bitterns, seawater or brine and to date there are several promising candidate methods that all require further research and development. They include the Greensols[15] process which involves chemical

[10] http://www.tececo.com/sustainability.carbon_cycles_sinks.php
[11] http://www.gaiaengineering.com
[12] Magnesium compounds bind well because of their strongly polar surfaces to any other surface that is or is potentially differentially charged.
[13] Modified from Figure 2 in Ziock by the inclusion of a bar to represent sedimentary sinks. A gigaton (or gigatonne) is a metric unit of mass, equal to 1,000,000,000 (1 billion) metric tons, 1,000,000,000,000 (1 trillion) kilograms, or 1 quadrillion grams.
[14] http://www.gaiaengineering.com
[15] http://www.greensols.com.au

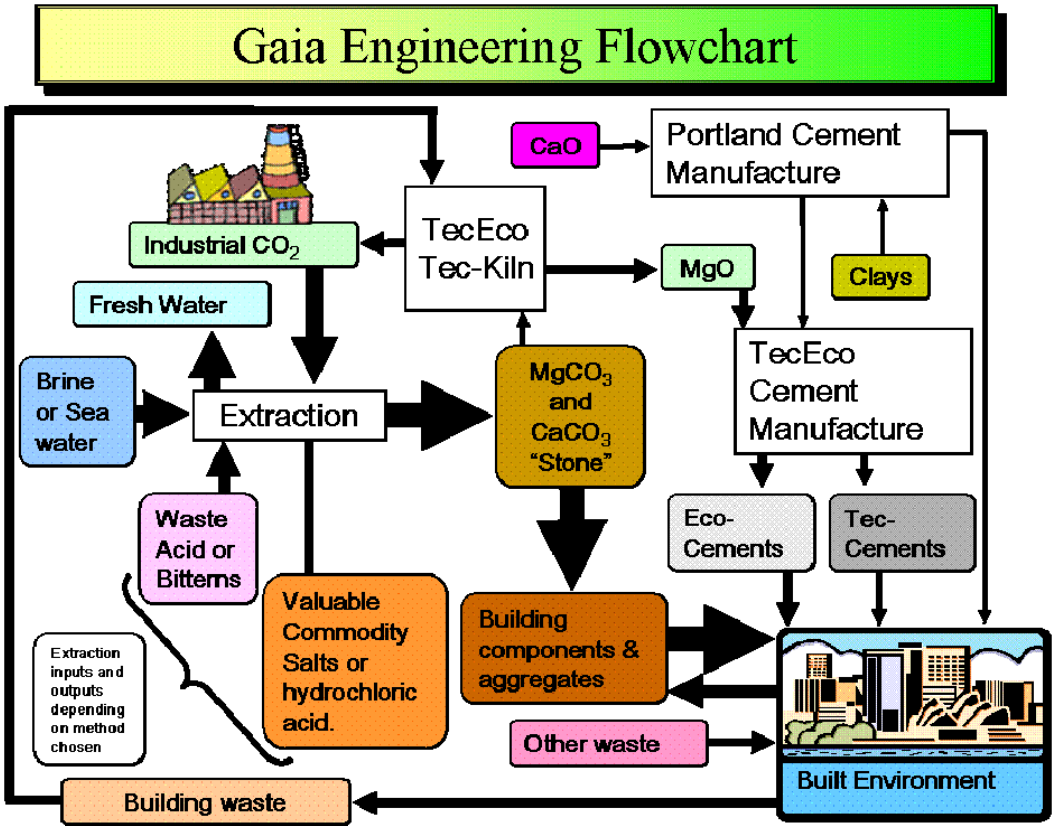
precipitation, the Calera[16] process, a cavitation process, a pyrohydrolysis process that can be run in association with salt manufacture, a ultra high speed centrifuge process and several catalytic processes.

Outputs will vary according to the ultimate process selected for the concentration of CO2 needed and are as hereunder:

- Greensols - sodium bicarbonate, mineral salts, carbonate building materials and aggregates, Eco-Cements and fresh water.
- Calera Process – a different process with similar outcomes to the Greensols process
- Cavitation process – relies on mechanically reducing the polar bonding of water.
- Hydropyrolysis - magnesium oxide and hydrochloric acid. The magnesium oxide can be used for Eco-Cements and hydrochloric acid in the Greensols process or industry.
- Ultra Centrifuges - provided materials can be found to withstand the forces involved, potentially similar outputs as the Greensols process.
- Catalytic Routes – calcium and magnesium carbonates can be precipitated using catalysts like carbonic anhydrase or even carbonic acid.

These "front end" processes are being researched by the author and others and will use carbon dioxide from for example power stations and cement kilns or even out of the air to produce man made carbonate utilising the naturally occurring calcium and magnesium found in seawater, suitable brines or bitterns left over from the manufacture of table salt. The man made carbonate produced is converted to building materials and used in the construction industry which is a large insatiable market of the order of size required.

As there are 1.29 grams of magnesium and around .41 grams of calcium in every litre of seawater there is enough of both to last billions of years if not indefinitely with natural replenishment given current needs for sequestration.



[16] http://www.calera.biz

Figure 6 - Gaia Engineering[17] Flow Chart

A proportion of the calcium and magnesium carbonates produced by one of the front end processes will be calcined in the authors Tec-Kiln in a closed system without releases using non fossil fuel energy in a combined calcining and grinding process which removes and captures the CO_2 for recycling in the front end processes and produces quicklime and magnesium oxide. The quicklime can be used to make Portland cement in an exothermic reaction with a source of silicon, aluminium and iron. The magnesium oxide produced will be used as an important component of blended Portland cement – magnesium oxide Tec, Eco and Enviro-Cements also developed by the author as it forms strong minerals in a carbonating system[18]. Eco-Cement is a blend of Portland cement and reactive magnesia. In permeable substrates the lime component of Portland cement and magnesia carbonate by absorbing CO_2 to harden and together with other wastes used also for their physical as well as chemical properties, will be used to make composites.

In this manner huge quantities of CO_2 can be sequestered as artificial carbonate stone, cast components and aggregates as well as concretes poured in situ.

Funds are required for further analysis, however the preliminary graphs produced by a modelling tool available on the TecEco web site[19] demonstrate the potentially enormous sequestration Gaia engineering technologies can provide.

A built environment of man made carbonate and waste materials could be recycled indefinitely and would store a massive amount of CO_2 and other wastes, more than enough to solve the global warming and waste problems if compulsorily adopted by all nations[20]. Implementation merely requires modifying the building approvals process to make it compulsory to use a percentage of man made carbonate and would be more acceptable than forced carbon constraint or rationing.

Alternatives to Gaia Engineering

The main contender is the coal industries answer to the climate change dilemma. So called "clean coal" involves pumping CO2 underground (usually with the co-operation of the oil industry as the gas is used to force up more oil.) Much work over many years during the cold war and later has established that the risks of “geosequestration” as it is called are far too high given the fractured unstable nature of the crust. This risk the fossil fuel industry are keen to ignore and transfer to future generations.

The Climate Action Network Australia (CANA [10]) which is an alliance of environmental, public health, social justice and research organisations working together to fight Global Warming produced an interesting graph in a 2004 media briefing which supports the authors own modelling of geosequestration[21]. The output of the author’s model varies depending on the emissions, response and leakage scenarios adopted but importantly prove that with even with small amount of leakage, which will be inevitable, that geosequestration is only a very short term solution and that it is essential we adopt a permanent sequestration technology such as Gaia Engineering.

The safety and efficacy of geosequestration depends on the leakage rate which of course can never be determined given the lack of stability of the curst. Although researchers vary greatly in their assumptions and conclusions regarding a likely level of leakage[22], whatever the scenario, undeniably some leakage will occur because geological formations are just not completely stable. They are for example disturbed by earthquakes caused by the movement of plates or upwelling of magmas. Another source of leakage could also be the instability of injection points over time [11].

Dooley and Wise [12], Hawkins [13], and Hepple and Benson [14] find that the annual leakage rate must be lower than 0.1% if geological storage is to be safe. The problem is that if the leakage rate is higher, targets for atmospheric greenhouse gas stabilization in the range of 450 to 550 ppm become unattainable in the long term.

[17] Gaia engineering is probably best described as a low energy bottom up economic solution to the world’s most pressing problem that will work because it profitably changes the fundamental flows that are damaging.
[18] Mainly because their shape magnesium carbonates, many of which are hydrated, contribute to microstructure.
[19] http://www.tececo.com/files/spreadsheets/GaiaEngineeringVGeoSequestrationV1.2_5Jan09.xls
[20] It will be necessary for a world carbon regulatory system with Gaia Engineering to make sure too much carbon is not removed.
[21] http://www.tececo.com/files/spreadsheets/GaiaEngineeringVGeoSequestrationV1.2_5Jan09.xls
[22] An sadly their source of funding

The diagram below from CANA [10] illustrates a scenario in which geosequestration is used as the exclusive greenhouse gas emission reducing tool for the next two hundred years and a leakage rate of 0.1% per annum is assumed. The graph shows that by the end of the 22nd century the entire 'carbon budget' of future generations would be consumed by leakage from past underground carbon dioxide storage. This would mean that future generations can not avoid dangerous climate change, even if they reduced their own greenhouse gas emissions to zero.

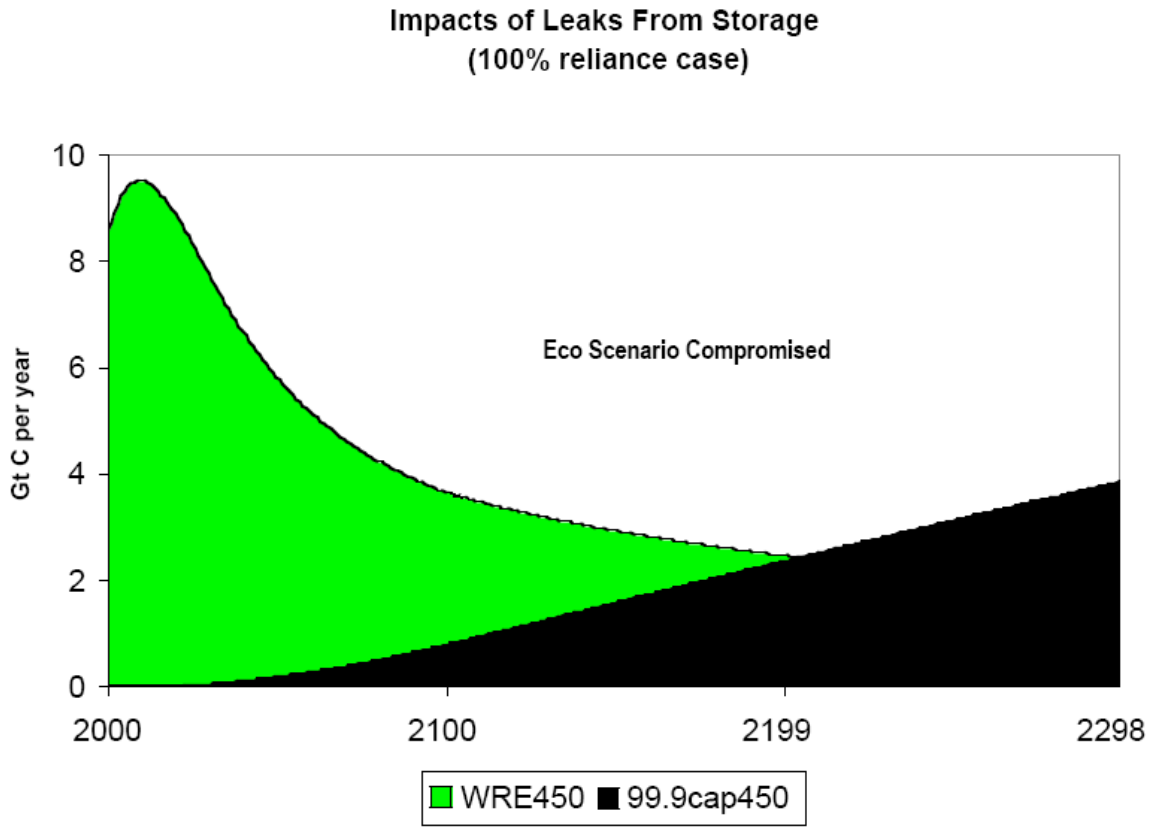


Figure 7 -Impact of a 0.1% Leak Rate from the Underground Storage of Carbon [10]

It is obvious that a more permanent form of sequestration is essential because of the leakage issues associated with geosequestration and the failure so far of the Kyoto process. It will be too difficult given human nature for us to give up the remaining 7,000 gigatonnes of coal left on the planet as a source of energy and the rate of conversion to non fossil sources of energy cannot possibly be quick enough. As Di Fazio [1] has demonstrated - the correlation is just too strong between world industrial product (WIP) and fossil fuel energy and thus emissions.

A priori it is essential that we sequester a large amount of carbon to solve the global warming crisis and the only viable technical solution without legacies and that could potentially be profitable is carbon in soils and Gaia Engineering. A detailed analysis of all the various alternatives is to be found including Gaia Engineering, carbon in soils and geosequestration on the TecEco web site[23]. For the sake of completeness even wackier alternatives such as pumping CO_2 into the deep oceans and putting what amounts to reflectors in the sky are also mentioned!

Importance and Benefits of the Involvement of the Cement and Concrete Industry

The importance of solving the global warming crisis cannot be underestimated. The Cement and Concrete Industry can be at the forefront of the solution rather than be part of the problem. At the same time taking on such a challenge with government funding would solve their own problems of economic malaise. Imagine what an announcement by a major cement company that Portland cement can be made without releases and that concrete containing man made carbonate can be made would do for share prices. The fact that the

[23] http://www.tececo.com/sustainability.solutions_global_warming.php

whole process can also result in lower costs would, for a while at least, also overcome the thin margin curse of the industry.

Consider a simple model whereby a tonne of cement is sold for $A 200 and costs $A 180 to produce. If there are in total 1 tonne of emissions to be taxed per tonne of cement and if the legal cost of emissions is $A 25 per tonne a net loss of $A 20 results. If the same cement is made without releases and can reabsorb all the emissions that would have occurred, then the net profit is $A 60 per tonne. Build into this simple model lower manufacturing costs and higher prices for carbon and huge profits can be made. Gaia Engineering is the most profitable form of rapid permanent sequestration yet devised.

Huge amounts of money do not need to be found. What is missing is publicity and credibility. If the industry demonstrates strong support the money required for development and deployment will come from governments.

As M K Singhi from India commented at the recent Cement Industry National Conference in Melbourne in relation to his country "we want the concrete industry to be the saviour of the world" [15]. This can indeed be the outcome because the cement and concrete industry is the only industry with sufficiently large markets for man made carbonate to reverse global carbon flows profitably. Because the process is profitable is it infinitely more acceptable than constraint according to Kyoto.

Summary and Recommendations

Geosequestration is considered wacky by most sane scientists yet the lobby group involved are attracting millions from the Australian Federal government. Gaia Engineering is much more attractive because it is potentially profitable, easier to implement and has no associated risks and thus no legacies for future generations. By products include fresh water which is in strong demand and even without, the process is still potentially profitable. Most importantly building with man made carbonate and wastes is the easiest solution to implement quickly and on a scale that our modelling indicates will work. The most formidable obstacle is not the science which is relatively simple but the mindset we are in. We must adaptively change to survive.

For a bunkered down and stressed cement and concrete industry it is worth contemplating what an announcement that cements can be made without releases and aggregates made of man made carbonates would do for share prices and what the use of the author's Tec –Kiln that utilises much less energy by using non fossil fuels and combining calcining and grinding would do for the bottom line.

If we continue to do the same old thing in the same old way then nothing much will change.

References

1. di Fazio, A. *The Fallacy of Pure Efficiency Gain Measures to Control Future Climate Change*. [cited 2008.
2. Whetton, P., *Climate Change: What is the Science Telling Us?* 2008, CSIRO: Presentation for the Australian Cement Federation Conference, 14 September, 2007, Melbourne.
3. Ford, M., et al. *Perspectives on International Climate Change*. in *Australian Agricultural and Resource Economics Society 50th Annual Conference*. 2006. Sydney: Australian Agricultural and Resource Economics Society
4. Conner, S. and C. Green, *Climate scientists: it's time for 'Plan B'*, in *The Independent*. 2009, Independent Newspapers.
5. Prins, G., *The road from Kyoto*, in *The Guardian*. 2008, The Guardian: London.
6. Prins, G. and S. Raynor, *Time to ditch Kyoto.* Nature, 2007(449): p. 973 - 975.
7. USGS, *Mineral Commodity Summary - Cement.* 2009(2009).
8. Haughton, R., *Understanding the Global Carbon Cycle*. 2009, Woods Hole Institute.
9. Ziock, H.J. and D.P. Harrison. *Zero Emission Coal Power, a New Concept*. Available from: http://www.netl.doe.gov/publications/proceedings/01/carbon_seq/2b2.pdf.
10. CANA, *Carbon Leakage and Geosequestration*. 2004, Climate Action Network Australia.
11. Torvanger, A., S. Kallbekken, and I.K. Rypda, *Prerequisites for Geological Carbon Storage as a Climate Policy Option*. 2004, Center for International Climate and Environmental Research: Norway.
12. Dooley, J.J. and M.A. Wise, *Why injecting CO2 into various geological formation is not the same as climate change mitigation: The issue of leakage*, in *Sixth International Conference on Greenhouse Gas Control Technologies*. 2002: Kyoto, Japan.

13. Hawkins, D.G. *Passing gas: Policy implications of leakage from geologic carbon storage sites*. in *International Conference on Greenhouse Gas Control Technologies*. 2002. Kyoto, Japan.
14. Hepple, R.P. and S.M. Benson. *Implications of surface seepage on the effectiveness of geological storage of carbon dioxide as a climate mitigation strategy*. in *Sixth International Conference on Greenhouse Gas Control Technologies*. 2002. Kyoto, Japan.
15. Singh, M.K. *Indian Cement Industry Overview*. in *Australian Cement Industry Driving CO2 Reduction National Conference* 2007. Melbourne.