Global Warming Solutions

Global atmospheric concentrations of greenhouse gases such as carbon dioxide could be reduced by reducing the burning of organic matter (CH_2O).

$$CH_2O + O_2 \rightarrow H_2O + CO_2$$

Or by sequestering carbon.

$$CO_2 + X \rightarrow XCO_2$$

Natural sinks for carbon such as the photosynthetic process are the best as oxygen is also released. Unfortunately natural processes have not been able to take up all the carbon produced through human (anthropogenic) activity and so a focus on technology is required to find ways of evening up the balance

Focusing on Technology

The fact that there is global warming and it has been caused by "greenhouse gases" including carbon dioxide is not disputed by most scientists. That something must be done is also not an issue and very few, even those who claim there is no long term climate change disagree with the objective of sustainability. What is holding up the process is the cost.

Unfortunately economic analyses to date shows that it will be far more expensive to cut carbon dioxide emissions radically than to pay the costs of adapting to the increased temperatures. All current models show that the Kyoto Protocol will have surprisingly little impact on the climate: temperature levels projected for 2100 will be postponed for all of six years. Yet the cost of the Kyoto Protocol will be $150 billion to $350 billion annually (compared to $50 billion in global annual development aid).

With global warming disproportionately affecting third world countries, the question arises as to whether the Kyoto agreement is the best way to solve the economic dilemma. For example, for the cost of Kyoto as it is for just one year we could solve the world's biggest problem: we could provide every person in the world with clean water. This alone would save two million lives each year and prevent 500 million from severe disease. In fact, for the same amount Kyoto would have cost just the United States every year, the United Nations estimates that we could provide every person in the world with access to basic health, education, family planning and water and sanitation services.

So given the current perception that sustainability is at a cost, there does not appear a way out of the dilemma We therefore need to change the paradigm. Ways need to be found to make progress towards sustainability of economic benefit. To get much more out of much less, to produce more with less impact on the greater environment and so on. That more resources are required unless we dramatically reduce our population is difficult to dispute, the need is to produce and consume resources in a sustainable manner. Science got us into the situation and sound science can get us out again.

A good place to innitiate new sustainable technologies is in our own backyards. Our footprint on earth is the built environment and this accounts for around 40% of all materials flows, emissions and energy consumption. Any change toward sustainability in the built environment would therefore have a huge impact without discernable downsides. The carbon based TecEco cements I have invented are a good start as they involve a shift towards using carbon as a building material.

Only when people are rich enough to feed themselves do they begin to think about the effect of their actions on the world around them and on future generations. A way forward is therefore to focus on ways of achieving sustainable development with positive economic outcomes. Helping people in the third world today to achieve a basic standard of living through sustainable technology will create the foundation for an even better tomorrow as they will become much more concerned about the environment.

Current Technical Solutions

Energy Efficiency

It goes without saying that the more efficient the use of energy can become, the less is required for a given outcome. Any advances to efficiency of processes also save money in that the consumption of less energy to achieve a given outcome means lower input costs and a better bottom line.

Renewable Energy

Renewable energy is energy not from fossil fuel sources and involves capturing current everyday energy from the sun such as manifested in solar and wind power.

The more renewable energy can replace the use of fossil fuels the better. The missing factor is technology which can hopefully make such renewable sources of energy competitive.

Modifying the CO_2 Balance through Engineering

According to Dr Ben Matthews[1] current technical proposals fall into three main categories: increasing the reflection of solar radiation back to space, enhancing natural sinks of carbon dioxide, and direct disposal of carbon dioxide captured at source. Except for the section on using carbon in our own built environment, what follows is a summary of Dr Matthews work. Those interested should read the full paper available at http://www.chooseclimate.org/.

Climate engineering proposals involving reflection of incoming solar radiation

General Principles

1 Climate Engineering, A critical review of proposals, their scientific and political context, and possible impacts.compiled for Scientists For Global Responsibility, November 1996, Ben Matthews http://www.chooseclimate.org/

The temperature at the Earth's surface adjusts (slowly) such that the energy from incoming solar radiation (sunlight- ultraviolet and visible) is balanced by terrestrial radiation (infra red) emitted from the Earth. When greenhouse gases reflect back some of that terrestrial radiation, the surface warms and emits more radiation, until the amount escaping the atmosphere balances the sunlight as before.

To offset the warming effect of the predicted rise in greenhouse gases in the atmosphere it has been suggested that we could reduce the incoming solar radiation by intercepting about 1% of sunlight.

Giant reflectors in space, and stratospheric dust or aerosols are two such methods proposed. The problem is however that such schemws would unevenly affect climate on earth.

Sulphate aerosols or Dust in the stratosphere.

Aerosols or dust in the stratosphere survive much longer than in the troposphere, and are already known to cool the planet, as observed following large volcanic eruptions. In the early 1990s, dust from mount Pinatubo checked global warming, and the observed cooling effect matched well with the most recent model predictions.

It has been suggested that we could deliberately inject either sulphate aerosols or dust into the stratosphere. One idea was to modify jet airplane fuel to do this.

Besides being cheap, the aerosol fix is also promoted as "reversible", i.e. you can easily stop if it doesn't work, and within a few years the dust would fall out. On the other hand, most greenhouse gases have a much longer lifetime so if they are to be offset with stratospheric aerosols, we would have to rely on the ability of future generations to keep flying those planes, to keep repairing the shield or be faced with sudden warming. Even if we are content to pass on that burden, we would also be cutting the amount of sunlight reaching plants on the surface, and presumably also changing its spectral composition. Perhaps the plants would take up less CO_2? And do we really want to live under a constant haze in the sky to keep us cool? Do a few scientists and policymakers have the right to impose this on all other life on the planet? Another obvious objection is that the injected particles might provide a very efficient surface for ozone destruction, as polar stratospheric clouds already do every spring. It seems the engineers have not yet looked at this in any detail.

Giant Reflectors orbiting the earth

This idea is to put gigantic foil sheets up in orbit around the earth to reflect sunlight. They would periodically cast a shadow, intercepting incoming light about 1% of the time, and would be assembled in space because such things couldn't be launched from down here.

Other ways to reflect solar radiation

Solar radiation might also be deliberately reflected locally by altering the surface "albedo" however the effect of such schemes would probably be small compared to natural feedbacks.

<u>Climate engineering proposals involving removal of CO_2 from the air by enhancing natural sinks</u>

Ocean sink proposals: general principles

The deep ocean has an enormous capacity to store carbon dioxide. This is principally due to the high alkalinity of seawater, such that for every 100 molecules of CO_2 stored in it, roughly 98 of these are found as bicarbonate ions, 1 has been converted further to a carbonate ion, and only one remains as CO_2.

The problem is that most of the ocean water is not in contact with the atmosphere. Transfer of CO_2 between the surface ocean and the deep ocean is slow, and occurs by two main processes: subduction of cold salty waters, particularly in the North Atlantic , and the biological "pump" whereby organic particles sink below the mIxed surface layer.

Only a small fraction of these particles eventually reach the sediment, the longest-term sink of carbon, but on the timescale of a thousand years or so removal to the deep water itself is sufficient. If this happened faster, the pulse of CO_2 in the atmosphere from fossil fuel burning would be much smaller, and thus the greenhouse warming less dramatic, although the long-term equilibrium climate change would be unaffected.

So climate engineers want to get CO_2 into the deep ocean faster. There are various proposals: CO_2 could be pumped there directly, soaked up by changing the alkalinity of the water, or absorbed into an enhanced biological pump by "fertilisation" of the ocean with nutrients.

Surface seawater is also typically supersaturated with respect to calcium carbonate, and it might be expected that precipitation of this solid (directly, or into shells or corals etc.) would be a good way to remove CO_2 from the system. Paradoxically, it actually does the opposite, by decreasing the alkalinity. While ocean chemists have long understood this, it seems that some engineering consultants have yet to work it out, proposing, for example, to increase the growth of calcareous seaweeds. Governments who prefer to trust such private consultants may be wasting their money.

Another related effect of the seawater carbonate chemistry is often ignored by the engineers. For every ten units of CO_2 you remove from the surface ocean, about 9 are replaced from the vast pool of bicarbonate ions in the water, and only about 1 would be replaced from the atmosphere. So if, for instance, seaweed was used as a fuel, the main effect would be to shift CO_2 temporarily from the ocean to the atmosphere. It may be better than burning fossil fuel, but is not an efficient way to solve the problem!

Ocean fertilisation: general points

The principle nutrients limiting the growth of ocean algae are nitrate, phosphate, and in some places, iron. To some extent we are already increasing the nutrient supply to coastal waters, through agricultural and sewage runoff. However, further from shore the nitrate and phosphate are supplied mainly by up welling of deep water. Over much of the ocean, where warm surface water rests stably above cold deep water, the nutrient supply is poor and little grows.

So there have been many proposals to grow more algae by augmenting the nutrient supply. Not only might this enhance the biological carbon pump, but it might also provide a fuel or even food for fish.

On the other hand, our ability to predict the many feedbacks intrinsic to marine ecology is still very poor. For instance, the important role of bacteria in recycling nutrients is just beginning to be uncovered. Plankton may also produce other gases which affect climate: notably nitrous oxide and methane which are much more potent greenhouse gases than CO_2, dimethyl sulphide which oxidises to form sulphate aerosols which seed clouds (see above), and also smaller quantities of hydrocarbons and halocarbons which affect atmospheric chemistry.

At least in surface waters you could easily measure some effects of a perturbation. However, once the surplus algae sank deeper, there is little consensus as to their fate. One concern is that the extra supply of organic carbon could use up all the oxygen in parts of the deep ocean and this might lead to the production of a lot of methane, or nitrous oxide

Furthermore, there has been little consideration of the effect on any life in the sea bigger than algae. As a general rule, biodiversity in the sea decreases in highly productive algal blooms. And suppose we really could predict the effect on all the plankton, krill, fish, whales: how then would this help us make a decision whether to go ahead or not?

In any case, the science is very far from making such predictions. Consider, for example, the failure of the scientific management of fish stocks, or the poor understanding of toxic algal blooms. Marine ecology is a complex non-linear system that behave chaotically, with many surprises in store.

Early proposals: Seaweed.

Seaweed dominated the early ocean-algae climate engineering proposals. The idea was to set up kelp farms, eventually covering tens of thousands of square kilometres of the open ocean, originally with the intention of producing methane. In the 1970s $20 million of research was funded by the (then) American Gas Association, only to find that it would cost them 6 times more than the energy they would gain. The vast cost comes from the need to supply nitrate and phosphate to the surface ocean. Either you can add man-made chemicals, in amounts well exceeding the total world production of fertiliser, or use a lot of energy to pump up nutrient rich water from the sea floor. It has also been pointed out that such water is usually supersaturated in CO_2, which would then be released to the atmosphere.

Nevertheless, in the heat of the greenhouse effect and with Carbon taxes/credits in sight, the seaweed idea has been revived, mainly by the US Electric Power Research Institute. They say it would cost about $200/tonne C sequestered. Engineers have devised grand schemes with diagrams showing the tracks of supertankers moving about the farms harvesting the seaweed.

Recent nitrate/phosphate fertilisation proposals

Both the European Community and the Japanese have recently supported research investigating coastal fertilisation to increase both the biological carbon sink, and the supply of fish. Such projects have received much scorn from academic marine biologists, who say they are simplistic and may do far more harm than good, for instance encouraging jellyfish, anoxia or toxic algal blooms. Nevertheless they have found support due to commercial backing. Norsk Hydro (one of the world's biggest manufacturer of fertilisers, incidentally) wishes to add nitrate and phosphate to the Norwegian sea and is already experimenting in fjords. Meanwhile Mitsubishi is funding a similar proposal off Japan, claiming it might not only capture carbon dioxide, but also produce a lot of sardines.

Others are more ambitious still. Jones (1996) calculates the nitrogen needed to soak up the entire projected anthropogenic global CO2 emissions. He also claims to get 260 kilos of fish per tonne of nitrogen.

Iron Fertilisation of the Oceans

Of all climate engineering proposals, fertilisation of the Southern Ocean with iron has raised the most controversy. Perhaps this is because experiments designed to investigate whether iron is the key limiting nutrient are already underway and well publicised.

The idea has been around for about 7 years, and is credited to John Martin who first developed the clean laboratory techniques to measure how little iron there was dissolved in open seawater. The concentration is low because it falls out as a precipitate from alkaline seawater, so the only supply to the open ocean is atmospheric dust. This led him to suggest that iron might be the limiting nutrient, which would explain an old puzzle: Why, in the Southern Ocean and the Equatorial Pacific, is the algal growth much less than would be expected from the supply of nitrate and phosphate? If iron was the answer, as suggested by bottle incubations of the algae in these waters, it might also be a feedback controlling ice ages. Atmospheric dust increases during glacial periods. This dust could fertilise the Southern Ocean and the algae would soak up enough CO2 to reduce the greenhouse effect, enhancing the ice age.

This led to his famous quote at a conference, "give me half a tanker of Iron, and I'll give you an ice age". It was a joke. But once this idea was out, for the "biggest manipulation of nature ever attempted by man", it seemed inevitable that scientists would want to try it out, albeit on a small scale. The proposal briefly caught the attention of the US media, with portrayals of irresponsible mad scientists in white coats about to take over the world. It was feared especially that the possibility of a technofix to global warming would weaken resolve to reduce CO2 emissions. To calm the uproar the scientists adopted a resolution, including "The American Society of Limnology and Oceanography urges all governments to regard the role of iron in marine productivity as an area for further research and not to consider iron fertilisation as a policy option that significantly changes the need to reduce emissions of CO2".

Prof Andy Watson does not rule out the possibility that this could one day lead to a climate engineering fix ."We are interested in the possibility that something as relatively simple as this could be used." But his model predicts that even a continuous widespread iron fertilisation could only reduce atmospheric CO2 by 60ppm by 2100, a tenth of that needed to offset "Business-As-Usual" fossil fuel emissions.

Iron Fertilisation is cheap, perhaps as low as 5$ per tonne of Carbon fixed, compared to $200 for many other proposed sinks. You need to add iron continuously, but not much. Aeroplanes could deliver dust, or rusting tankers or discarded oil rigs could produce it in situ. A more sophisticated approach might employ purpose-designed slow-release floating granules.

Scientists are however far from being able to predict the effect on the ecology, as already noted in the general points on ocean fertilisation (above). It has been also suggested, that iron fertilisation could alter the dynamics of the Southern Ocean to increase the natural flux of Iron-rich water from depths to the surface, resulting in a runaway iron fertilisation. This physical feedback might be initiated by a decrease in sunlight penetration through the algae. So it is quite possible, that we could underestimate the feedbacks and go too far, creating another ice age after all.

It is not surprising that iron fertilisation has raised so much controversy. Of all climate engineering proposals, it is perhaps the easiest and cheapest to carry out, very elegant, and yet it carries the most unpredictable consequences. It also involves the pristine ocean around Antactica, the part of the world least affected by our pollution so far. Experiments have already been "successful", and the organisers need to publicise the results to help secure more funding, for they have so far avoided commercial sponsorship and rely on research council funds. Perhaps because it is investigated openly by independent ocean scientists, the idea retains more credibility than it would if backed by industry. Some claim that we should push ahead with research, to ensure the results are open for the world to judge, before any commerical venture can get established. There is already an international race among oceanographers to get the money for the next experiment. But the Southern Ocean belongs to none of us, perhaps more rightly to whales, krill, penguins, algae, all life on earth. Respect for this seems to have been lost in the race to be first with clever science.

Greening the Deserts

People have always dreamed of greening the world's deserts. Their potential as a CO2 sink as well as a food source has revived interest in such grand schemes. One such proposal from the Japan Gas Association and RITE includes generation of clouds by evapotranspiration from coastal mangroves and lagoons, and artificial mountains to promote rainfall, along with underground dams and new cities. They even provide an "artists impression" of this new landscape.

A slightly less ambitious scheme involves using halophytes. These are plants, usually found in salt marshes, that thrive in saline conditions. The idea is that, perhaps with a bit of genetic engineering, they could be adapted to desert lands irrigated with seawater, or lake/river water that has become too salty for any other purpose. Glenn estimated that world-wide there are 130million hectares of suitable land, and that this could sequester about 0.7 billion tonnes Carbon annually, at a cost of about $200/tonne. It is suggested that some of the crop could be ploughed back into the "soil", the rest could be buried dry. He also recommends a particular oilseed crop, that is edible, tasty, nutritious, and could also be a fuel. The main problem is that you need a lot of excess irrigation to leach out the salts that would otherwise build up. Presumably you also leach out nutrients at the same time, so where do you replace them from? This question is not addressed.

Some other obvious points seem to have been overlooked. If you make the desert wet (or even just grow trees on it), it becomes darker, thus absorbing considerably more sunlight and warming the planet. There would also be very high evaporation, and water vapour itself is a greenhouse gas. On the other hand, if more clouds formed as a result, they reflect sunlight. We should also recall, that rice paddy fields are a very large source of methane, and these salt marshes might be likewise.

Planting trees

There are plenty of good reasons to plant trees, and carbon storage is but one of them. Although reforestation might be considered climate engineering, it takes place within national boundaries rather than exploiting the "global commons", and also it can hardly be considered a new unknown technology! Trees can be planted by people locally and they know what to expect as a result.

However, there are a few common misconceptions. For instance, mature forest does not take up carbon, only young forest is a net sink. As the forest matures, it approaches equilibrium where growth equals decay. So this is only a long term solution, if you continually harvest the wood and then store it somehow. It has also been suggested that we fertilise existing forests to maximise carbon uptake, this would likwise provide only a temporary sink.

On the other hand, some grasslands or peat bogs in particular, can be a permanent sink for carbon, as more accumulates on top each year. Recent reports suggest that this carbon sink may be equal or greater in magnitude than the world's trees. Also, if a peat bog is dried out by planting trees, the previously anaerobic peat becomes accessible to soil micororganisms, which release it as CO2, or worse, as methane. So it is not always wise, from a climate perspective, to put trees where there were none recently before.

Proposals involving direct disposal of anthropogenic CO2

Pumping liquid CO2 into the bottom of the ocean.

According to Dr Ben Williams more research money has been poured into this topic than all of the others here put together. It attracts funding because a company could dispose of just its own CO2, and thereby avoid taxes or emissions quotas. I'm not sure whether this strictly counts as "climate engineering". However, it is usually placed in comparison with the other proposals here, and discussed in the same journals. The deep ocean is also a "global commons" rather than the property of the company, and as such we all have a right to be concerned with its use. And this topic raises many of the same ethical and scientific dilemmas, as do the proposals above.

A lot of technology has been developed, to separate CO2 from stack gases, on the assumption that this is the key to the pollution problem. But burning fossil fuel produces so much CO2, that really the major problem is where to put it afterwards. As mentioned above, the deep ocean has an enormous capacity, and is the natural medium-term sink for carbon. Note that the best long-term sink is not in seawater, but fixed by photosynthesis back into the oil and coal from which it came. Unfortunately these take millions of years to form.

The gas would first have to be liquefied, and then pumped down pipelines (for which the technology doesn't exist yet) to below 1500m depth (for environmental reasons -see below). It would then mix with seawater, forming a very acidic plume which would spread out across the sea floor.

Originally it was thought 3000m was necessary, because above this height the pressure is insufficient to keep the CO_2 as a liquid. However, various groups then claimed shallow injection was possible because, so long as you could get enough CO_2 to dissolve before the bubbles rose to the air, then the resulting dense CO_2 solution in seawater would sink naturally. They looked for sites where ocean currents already descended continental slopes.

A complicating factor is that when concentrated CO_2 and water are mixed, they react to form solid compounds known as clathrates. In trial experiments, the clathrates blocked the end of the CO_2 pipe. A lot of research then followed on this topic. Indeed, it has been proposed that the clathrates may be useful, because they sink rapidly, so this helps to solve the depth problem. The Japanese are particularly keen on the idea of deliberate clathrate formation as clathrates are being considered as a fuel.

CO_2 is an acidic gas, and the liquid CO_2/seawater mixture would be highly acidic. It could therefore kill most marine life, perhaps over a large area of the sea floor. Usually the chemistry of the benthic environment changes very little, so even a small perturbation may have disastrous effects (for pH tolerance see IEA 1996). Perhaps the engineers view the deep sea as worthless mud with a few worms in it. However, marine ecologists have recently estimated that there are so many different species of benthic organisms, that the biodiversity is comparable to the tropical rainforests. We just don't know much about it yet. Again, does this give us a right to destroy such life to satisfy our thirst for burning oil?

Finally a few of these questions are being considered, for instance at an International Energy Agency Workshop on environmental impacts (IEA 1996). The marine biologists came up with some fairly restrictive criteria, such as "no species should be driven to extinction" and "no significant destruction of ecological processes at basin scales", for which there must be no acidic strata which could form a barrier to migration. To be sure of that, and to protect diversity of shelf slopes, CO_2 should be released below 1500m. On the other hand, a pure "CO_2 lake" sitting on the sea bed (it's denser than water) would be disastrous for life in the sediment.

The high concentration of CO_2 in the seawater would reduce its capacity to hold other gases, particularly oxygen, and therefore the bottom water might become anoxic. Methane could then form, although they assert it wouldn't rise to the sea surface.
But how can we sure that the CO_2-rich water will not return to the surface? Deep ocean currents do change over time, sometimes suddenly, rarely predictably, depending on finely balanced physics. Or instead of up welling slowly to the surface, the CO_2-rich water might become unstable while the CO_2 is still concentrated, rising suddenly as plumes of gas. Methane does this occasionally from the sea bed, indeed, there is a theory that this may account for the mysterious loss of ships in the "Bermuda triangle", which would sink in the froth. And only last year, we may recall the natural disaster of lake Nyos in Cameroon, where a plume of CO_2 that suddenly bubbled up from the bottom, asphyxiated all humans and animals within a few miles of the lake. This CO_2 had been accumulating from quiet volcanic activity in the rocks, but so far nobody can explain why it suddenly destabilised when it did. Pumping liquid CO_2 to the bottom of the sea, could lead to similar disasters; until we understand what triggers them, we cannot deny the possibility.

If that CO_2 that we had stored over several decades, suddenly came back up and into the atmosphere in just a year or two, the effect on the global climate could be catastrophic. For a sudden pulse of CO_2 could cause enough warming, to trigger climate feedback processes that lead to a runaway greenhouse effect. It would have been much better to have put the CO_2 into the atmosphere, year by year as it was produced.

It also takes a lot of energy to pump anything down to such a pressure under the ocean, and you have to burn a lot more fossil fuel to make this extra energy, so this process is extremely inefficient. There seems to be some disagreement in the literature as to exactly how much more energy is needed, but it is at least 30-40% extra. Part of the confusion arises because both CO_2 "capture" from flue gases (essentially an entropy problem) and CO_2 "disposal" (transport, pressurising) cost energy, but where one stops and the other begins is arbitrary. Also, the costs are much higher for conventional power stations than for new ones purpose-designed for CO_2 capture.

Not only is all this expensive to the consumer, but in the long term it also makes the problem worse, because to get that extra energy you have to burn more fossil fuel... So you end up disposing more CO_2 (eg 40%) into the deep ocean than you would have put into the atmosphere if it had gone up in smoke as at present. Over hundreds of years through ocean circulation and diffusion, the CO_2, including that "extra" CO_2, will find its way back into equilibrium with the atmosphere. Effectively this is putting an extra burden on future generations in order to avoid a problem now. This is an issue of intergenerational equity, which wouldn't usually be noticed in any cost-benefit analyses because the future is so rapidly discounted.

As the global climate warms and CO_2 increases in the atmosphere, the deep ocean's buffering capcity for CO_2 uptake decreases, and so deep ocean disposal becomes a less favourable option.

Storing CO_2 under the rocks

Although the ocean is a much bigger sink, some CO_2 might be stored more easily and reliably underground, in aquifers or depleted oil and gas wells. Indeed, such projects are already underway, both in Texas and below the North Sea from a Norwegian platform.

This CO_2 currently being pumped back underground was not captured from power station flue gas: without carbon emission taxes or quotas this process is still too expensive for large-scale operation. It comes from under the rocks in the first place, mixed with the oil and gas deposits. Gas from the Sleipner Vest gas field off Norway contains 9.5% CO_2, most of which has to be separated from the methane before it can be sold. The recent introduction of a carbon tax (180$/t C) in Norway encouraged Statoil to set up an installation to pump the CO_2 (about one million tonnes a year) into a sandstone aquifer 1000m under the platform (see IPCC 1996 (b) and European Chemical News 1996). This is seen as a pilot project, perhaps leading eventually to the burial of up to 1/3 of all Europe's CO_2 emissions. With "enhanced oil recovery" schemes CO_2 is pumped into an oil well such that it's pressure forces out more oil, preferably without the CO_2 and oil becoming mixed together, though this is not always straightforward.

To bury 1/3 of Europe's CO_2 emissions clearly requires much more than separation of the CO_2 initially mixed with natural gas. Yet to separate CO_2 from the flue gases of conventional power stations is very expensive and inefficient. Statoil envisages instead a "hydrogen" economy whereby the fuel is converted into CO_2 and H_2 rather than being oxidised completely in combustion (Kaarstad 1995). The hydrogen (note it's highly explosive!) would be used to power transport, whilst the CO2 could be buried.

Perhaps the greatest danger with these schemes is that the pressurised CO2 would not stay in the aquifers under the rocks. If CO2 stored for several decades suddenly re emerged as a sudden pulse to the atmosphere, the resulting sudden greenhouse warming could be catastrophic. On the other hand, perhaps the rocks are slightly more secure than the deep ocean, for which the same applies?

Liquefying the CO2 and pumping it down also requires a lot of energy so the process is once again inefficient, requiring considerably more CO2 to be produced in the first place, as above for ocean storage.

Another concern is that the CO2 could contaminate groundwater in nearby aquifers, making it acidic and unsuitable for many purposes.

Even if these concerns could be met, it is unlikely that enough suitable storage locations are available to remove a large fraction of world CO2 emissions.

CO2 fixation by in-situ lakes of algae

The most seriously considered idea, for on-site treatment of waste CO2, brings us back to the algae again, but this time they would be in vast artificial lakes, covering tens of square kilometres for a medium-sized power station. It's really a form of solar power, which is why you need a large surface area, and uses photosynthesis to convert the CO2 back into organic carbon. This might eventually be recycled as a fuel, chemical feedstock, or even food. They would be very strange algae, thriving on warm CO2-rich stack gases bubbling through the acidic water. Various attempts are being made to culture and genetically engineer algae specifically for this purpose. They also need to be tolerant of sulphate, nitate and other pollution from the fossil fuel combustion. It is reckoned that such frothing pea-soup reservoirs, would be four time more efficient than a tropical rainforest, at capturing solar energy. Maybe, but I know which I'd prefer to have outside my door!

Using Carbon to Build our Own Environment

Figures abound as to the size of our built environment but are in broad agreement. According to the Australian Federal department of Industry Science and Tourism[2] buildings are responsible for some 30 % of the raw materials we use, 42 % of the energy, 25% of water used, 12% of land use, 40% of atmospheric emissions, 20% of water effluents, 25% of solid waste and 13% of other releases[3].

A Tasmanian company, TecEco Pty. Ltd. have patented the addition of reactive magnesia to other hydraulic cements including Portland cement in virtually any proportion. At one end of the scale, with high proportions of Portland cement (modified Portland cements) is higher strength but lower sustainability – at the other end of the

2 Australian Federal department of Industry Science and Tourism, Environmental & Economic Life Cycle Costs of Construction, 1998 - Detailed Discussion Paper, (section 2 - page 8)

3 The reference given by Industry Science and Tourism was Worldwatch paper 124 How Ecology and Health Concerns Are Transforming Construction Worldwatch Paper 124 by David Malin Roodman and Nicholas Lenssen

scale is increased sustainability, increased capacity to utilise wastes of all kinds but less strength (eco-cements). All formulations are more durable.

Because eco-cements are recyclable, low energy, at worst nearly CO2 neutral and at best carbon sinks, if widely deployed the impact on the numbers is huge.

To what extent could the eco-cement technology be deployed? The substitution rate of reactive magnesia in eco-cements is high at around 70% of the binder component, whereas with modified Portland cements the figure is more like 5 – 10%. The analysis of modified Portland cements, which also result in sequestration is much more complex, so, considering only eco-cements which can be used for a wide variety of purposes such as bricks, blocks, pavers, mortars, roads, wharfage, airstrips, floor slabs and possibly even some dams an adoption figure of more like 80% is likely.

Global production of Portland cement is currently around 1.65[4] billion tonnes. Eco-cements can be used for bricks, blocks, pavers, mortars, airstrips, wharfage, roads etc. and at around 80% substitution by eco-cement some 1.32 billion tonnes would be required. As a corollary 1.32 billion tonnes of Portland cement would not therefore be required. For eco-cements it is realistic to assume that 100% of the reactive magnesia component completes the thermodynamic cycle magnesite → magnesia → brucite → magnesium carbonates so using the CSIRO dbce CO_2 equivalent of 1.3 tonnes CO_2 to the tonne of Portland cement[5] the sequestration (before process energies and OPC additions) would be in the order of 1.716 billion tonnes CO_2.

The process energy of making eco-cements now needs to be considered. There would be some use of energy during the calcining of magnesite, but as TecEco have every intention of using only electricity generated sustainably (the process occurs at a low temperature using only 1480 kJ.Kg-1 for the reactive magnesia component - typically 7% of the total eco-cement proportion) and as in Tasmania where TecEco is located there are ample supplies of sustainable electricity and huge reserves of magnesite, calcining could also be considered to have zero impact on CO_2 emissions. This leaves only the remaining process energies including mining, transport grinding etc. and from additions of OPC. If these are considered to be similar to those for Portland cement but with the use of sustainable electricity for blending, grinding and packaging the total non sustainable energy consumed would be some 1050 kJ.Kg-1 equivalent to some .125 tonnes CO_2[6] to the tonne totalling .165 billion tonnes.

Now if eco-cements are on average 3% Portland cement then a further 51.48 million tonnes of CO_2 would be emitted. Subtracting both the process energy and Portland cement contribution to the figure for chemical sequestration arrived at earlier of 1.716 billion tonnes of CO_2 the net sequestration would be in the order of 1.499 billion tonnes CO_2

Note that we have not included the process energies and CO2 equivalents for wastes used are accounted for in the production of those wastes. For the mathematically minded:

Total Portland cement produced	1.65	billion tonnes

[4] Latest USGS Figure for 2001.
[5] Dr Selwyn tucker, CSIRO dbce. Published figure.
[6] Given the energy intensity for power generation in Australia

80% substitution by eco-cements	1.32	billion tonnes
Chemical sequestration (1.3 tonnes to the tonne)	1.716	Billion tonnes
Less CO2 from process energy (assumed intensity factor for coal)	.165	Billion tonnes
Less CO2 from average additions of Portland cement in formulations	.0515	Billion tonnes
Net sequestration	1.499	Billion tonnes

Substitution Effects.

TecEco eco-cements are the first building materials devised of high thermal mass and low embodied energy. Realistically therefore there will be considerable substitution into the markets for bricks, steel and aluminium used in construction. Leaving out timber used in the built environment because it is a relatively short term sink, the following table sets our estimates of global markets, the percentage substitution and abatement worked out using a similar analysis to the above.

Material	**World Market**	**Substitution**	**CO2 factors**[7]	**Abatement**
Bricks	250 million tonnes[8]	80%	.28 $MtCO_2\ t^{-1}$[9]	38.75 million tonnes[10]
Steel	840 million tonnes[11]	25%	2.38 $MtCO_2\ t^{-1}$[12]	473.55 million tonnes[13]
Aluminium	20.5 million tonnes[14]	15%	18 $MtCO_2\ t^{-1}$[15]	55.35 million tonnes[16]
			Total	567.65 million tonnes

Sequestration from Including waste carbon based materials

The sequestration that would result from the inclusion of waste carbon based matter including sawdust, waste timber shavings and chippings, plastics, rubbers etc, many of which are currently burnt adding to the global atmospheric CO2 level, would be colossal but impossible to calculate because of the variation that may be expected. The amount of sequestration that would result by including waste carbon based materials is unknown but at least in the order of .5 billion tonne and we have used this figure.

Many of these materials will add strength to eco-cement products as they have innate tensile strength. Wood for example is in the order of 250 mpa whilst some waste plastics are closer to 1000 mpa.

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[7] Dr Selwyn tucker, CSIRO dbce. Published figures.
[8] This figure was derived from known figures in some countries.
[9] Dr Selwyn tucker
[10] 80% of 250 mt X (.28-.125) = 38.75 mt
[11] International Iron & Steel Institute figure at http://www.worldsteel.org/article/iisi20020118.
[12] Dr Selwyn Tucker, crosschecked to AGO Australia data.
[13] 25% of 840 mt X (2.38-.125) = 473.55 mt
[14] International Aluminium Institute at http://www.world-aluminium.org/iai/stats/index.html
[15] Alan Pears, RMIT
[16] 15% of 20.5 mt X (11.03-.125) = 33.53 mt

Conclusion

The total abatement from the widespread adoption of Tececo eco-cement technology is 1.499 billion tonnes by direct substitution for cement and by substitution of other building materials by eco-cements a further .568 billion tonnes totalling 2.067 billion tonnes. Including the carbon sequestered from the use of waste carbon based materials as fillers in the cement results in a figure for total sequestration of at least 2.5 billion tonne or over 10% of the annual addition of carbon dioxide.

There do not appear to be any environmental downsides to the technology.