Global Gardening with a Leaky Bucket:
Addressing climatic catastrophe through Article 3.3 of the UNFCCC.

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1. Background and introduction

Reviewing the Stern Report (Stern, 2006), Martin Weitzman notes "public policy on greenhouse warming needs desperately to steer a middle course, which is not there yet, for dealing with possible climate change disasters" and "The overarching concern is having some semblance of a game plan for dealing realistically with what may be coming down the road …cutting CO_2e emissions drastically" (Weitzman, 2007).

That this desperate need exists may come as a surprise to readers of "Some Economics of Global Warming", Thomas Schelling's 1992 Presidential Address to the American Economists Association. He argued that the sole economic reason for industrialized countries (who could afford it, but had little to fear from gradual climate change) to take costly action in response to global warming was as insurance against some unexpected high cost climate system behaviour. Those readers might have supposed that economists would not, during over a decade since, have focused on the subsidiary problem of consumption smoothing, but rather on Schelling's main problem.

But he also said that he would like to know more about the possible nature of such a threat before embarking on costly actions. It is shown below that, while still clouded with uncertainty, advances in climate science since the mid-1990's tell us quite enough about the nature of the threat for Article 3.3 of the UN Climate Change Convention to be invoked. This provides a legal basis for Weitzman's game plan and subsequent Sections of this paper outline a new architecture that takes Article 3.3 as the basis for addressing his "desperate need". However, rather than "cutting CO_2e emissions drastically", an approach that is both inadequate to the task and geo-politically fraught, this involves a strategy of biosphere carbon stock management (BCSM – Read, 2008).

The new architecture is a modernization of "Responding to Global Warming" (Read, 1994) of which Schelling commented "'A skilled attempt at fashioning policy and a deep foundation for thinking on the subject.". Michael Grubb said it "points towards a key strategy in efforts to limit global warming - one which links energy and forestry, North and South.", while the late Alan Manne found the book "may be overly optimistic with respect to the potential for biomass fuels". A rather kind review in the Economic Journal concluded "the chances of such a logical system ever being introduced by those engaged in international environmental negotiations are probably negligible." (Beckerman, 1995).

However, the changed scientific understanding since the 1995 Berlin Mandate suggests that civilization's future can no longer afford the luxury of illogicality in the negotiation process and two features of an architecture that invokes Article 3.3 are to be noted. First it makes no call on the Conference of Parties and therefore cannot be blocked by aggrieved Parties taking advantage of the consensus procedures of that Conference. Second, in face of threats of serious or irreversible damage, it calls for cost effective action without delay on account of scientific uncertainty, and without restricting such uncertainty to either the correctness of the climate science or of the efficacy of the action.

After reviewing some aspects of the economics of climatic catastrophe in Section **2** (and two Appendices), and commenting on the Kyoto architecture in that context, **3**, some recent climatic science is noted, **4**, and a metric for climatic danger is advanced, **5**. Consideration of the natural carbon cycle, **6**, points to enhancing emissions reductions efforts with carbon removals activity,[1] **7**. Deploying negative emissions systems in BCSM (or 'global gardening', prominently involving biochar soil improvement) this yields a preferred set of technology types that challenges Manne's skepticism over bioenergy, **8**, and the new architecture is outlined in the remaining Sections.

Through mutual advantage from gains from trade in biofuels, 'global gardening' is geo-politically sweet, in contrast with Kyoto's conflictual burden-sharing of emissions reductions between Parties having widely differing perceptions of responsibility. Building on the comparative advantage in biotic productivity of many land rich but otherwise impoverished low latitude countries, this architecture is shown to be complementary to – indeed supportive of – emissions reductions through continued cap and trade. Thus actions by Parties, or by groups of Parties, that respond to Article 3.3 of the Convention, also facilitate ambitious policy commitments under its Article 4.2, the framework for which is assumed to be in place after 2012.

However, the architecture aims to replace the high transactions costs involved in *post hoc* project based offsets under the flexibility mechanisms – a 'silver teaspoon', costly and not much use for baling large amounts of CO_2 out of the atmosphere – with *ex ante* policies and measures to drive BCSM technologies effectively – a 'leaky bucket' that shifts a large volume of CO_2 into safe storage, without regard to 'additionality'.

Low costs are likely due to an illogicality in Kyoto's architecture, which reflects priorities at odds with elementary economics and leaves 'low hanging fruit' unpicked. Instead of taking up the least cost opportunities first, to yield an upward sloping supply curve, a dogmatic preference for domestic action in reducing energy sector emissions from industrialized countries results in such high initial costs as to inhibit effective action and generate belief that the problem is insurmountable, unless gradual and permitting of long term consumption smoothing. The dogmatism may come from a misunderstanding of CO_2 as pollution (though it is essential to life on earth) or to unawareness of the natural carbon cycle, or simply from an urge to scapegoat some culprit.

Whatever the reason, negative cost options are implicit in the gains from trade available from Grubb's linking of "energy and forestry, North and South" – a linking that is happening, willy-nilly, through biofuels expansion as oil supply proves difficult to sustain. Thus Kyoto provides, ironically, the good news that, if approached logically, mitigating climatic catastrophe is a less daunting task than appears likely from the slow progress experienced with implementing the Protocol, involving no more than the hopefully small costs of imposing sustainability conditions on biofuels trade.

[1] In Biosphere Carbon Stock Management (Read, 2008) and other writing I may have given the impression that carbon removals displaces the need for emissions reductions. However, in the discussion paper where the illustrative calculations that lie behind that essay are presented, out of a total of ~1100 Gt of C kept from the short-term linked atmosphere-ocean system by 2060, about half is fossil fuel left underground (fossil carbon emissions reductions) and about half is in terrestrial storages including new forest plantations (carbon removals). But under BCSM, fossil emissions reductions are secured through sustainable biofuel substitution rather than the gamut of technologies involved in most low emissions scenarios. In this paper, BCSM is used for a combination of emissions reductions and carbon removals achieved through a very large number of community scaled sustainable land use improvements.

2. Approaching the economics of climatic catastrophe

Weitzman concludes his review "… we lack a commonly accepted usable economic framework for dealing with these kinds of thick-tailed extreme disasters whose probability distributions are inherently difficult to estimate… . But I think progress begins by recognizing that the hidden core meaning of *Stern vs Critics* may be about *tail vs middle* and about *catastrophe insurance vs consumption smoothing*".

In the absence of such a framework, the new architecture of this paper takes catastrophe uncertainty as grounds for precautionary action that can be relaxed if resolution of uncertainty shows the action to have been unnecessary (Read and Lermit, 2005). A decision-theoretic approach drawn from business management theorists is used, treating the problem as a game against nature in a matrix of policy options against possible states of nature, with a view to applying a risk-averse decision criterion.

In the simplified matrix below, negative trillions for inaction when nature is 'nice', compared with negative billons with Kyoto style emissions reductions reflects the Stern report, which implicitly assumes not passing beyond a tipping point. With nature 'nasty', negative quadrillions compared to negative quintillions reflects, generously perhaps, the benefit of adaptation activity under the current architecture. Equal cost, under either state of nature, arises with the architecture of this paper, which, by assumption, is successful in averting catastrophe, although possibly more costly than Stern report action as indicated by the + sign[2]. It may be noted that the carbon removals strategy described below is not all that can be done and, in this writer's view, it should be supplemented with precautionary experiments in cloud albedo modification, both in the tropics (Latham and Salter, 2006) and in polar regions (Crutzen, 2006)

	Nature nice (Gradual climate change only – the *"middle"*)	Nature nasty (Abrupt climate change possible – the *"tail"*)
Business as usual	Negative Trillions	Negative Quintillions
Kyoto continued	Negative Billions	Negative Quadrillions
This architecture	Negative Billions +	Negative Billions +

[2] Claims that the costs involved in BCSM would be less than under cap and trade emissions reductions (Read and Parshotam, 2007) have proved controversial – see Appendix 1.

Comment

To the dominant issue of our times the economic profession has (see Appendix 2) generally responded by bending the problem to fit the techniques with which it is familiar – cost benefit analysis, dynamic general equilibrium (e.g. the DICE and PAGE models, *inter alia*) and pollution pricing – without regard to whether they are applicable to the scientific nature of the problem, and putting the key policy area of technological change into a fringe concern of 'complementary measures'. This has placed the policy community in thrall to non-solutions as regards what Schelling identified as the main problem. While there is very little theoretical economics involved in the common sense of a precautionary approach, towards which Weitzman's work steers us, it may be hoped that the policy community can tear itself away from the minutiae of cap and trade schemes for sufficiently long to incorporate a model of the whole carbon cycle into its thinking and to develop policies accordingly.

3. The existing policy paradigm

The Kyoto architecture is based on, by now, out of date climate science and fails to embody an understanding of the natural carbon cycle; it promotes cost-ineffective technology, applies economic theory that is irrelevant to catastrophe avoidance and generates conflictual relations between the Parties. Thus climate change was modeled as a smooth process in the early 1990's; carbon emitted into the atmosphere was taken to remain there for a very long time; technological options prioritized high cost emissions reductions over low cost carbon removals; and optimal policy trajectories appropriate to a future free of uncertainty, and characterized by knowable probability distributions over risky outcomes, were applied under the policy framework of pollution economics.

However, earth's climate and related phenomena is a complex non-linear dynamic system, prone on theoretical grounds to abrupt jumps from one attractor state to another and, from paleo-climatological research, known to so behave (Ankin *et al*, 1993). Also, any given molecule of CO_2 remains in the atmosphere for about four years on average, not 150 as widely believed, though for practical purposes fourteen years is relevant. And CO_2 is not pollution – it is a desirable trace gas of which there is an excess stock in the atmosphere. As noted in Appendix 2, carbon pricing, prescribed by the economic theory of moderately damaging pollution to secure the efficient level of mitigation by penalizing emissions, fails in the case of catastrophic outcomes. Moreover, emissions reductions have a logical limit of zero which, even if reached implausibly soon, seems likely (when assessed with an appropriate metric, Section 5 below) to fail to avert imminent danger.

Nevertheless the new paradigm advanced here to promote negative emissions systems is designed to be complementary to a strengthened cap and trade regime, continued after 2012, both because that provides the stick to incentivize the carrot of the new architecture, and because its early abandonment, without demonstration of a better alternative, is politically unimaginable. Rather is it envisaged that BCSM will prove itself in use, initially by those Parties that first see its merits, and will become more widely adopted as it is seen to work, eventually leading to the consensus adoption of a second protocol addressed to the threat of climatic catastrophe and based on Article 3.3 – perhaps the Wellington Protocol after the city where the idea was first floated.

4. The threat of climatic catastrophe

As was shown by the 'ozone hole' experience, what we don't know may be more important than what we do know. Only after the damage was done was theory put together to explain why, at the end of Antarctic winter, ice crystals formed in very cold conditions at high altitudes over Antarctica could catalyze the action of CFC's in destroying ozone. Reports from British Antarctic scientists that ozone was depleting fast over their heads were dismissed as instrument error by the NASA coordinators of the global ozone monitoring programme, whose theoretical understanding was of a possible uniform world-wide effect of CFC on ozone (Pearce, 1989). So for decades we must endure a much more severe ozone depletion than would have occurred had the evidence of the British scientists been given credence over NASA's incorrect theory.

Currently we don't for certain know why (Witze, 2008) – and it may be unwise to await full scientific certainty – but the evidence is before our eyes (Revkin, 2007) that Arctic Ocean ice cover is disappearing fast and may be gone in less than a decade, contrary to expectations in the IPCC's 2007 fourth assessment report. Of course floating ice

Figure 1. Surface meltwater descending into a crevasse on Greenland, 2004.

displaces its own weight of water so that its melting creates just sufficient water to fill the hole left by the ice, and its disappearance has no immediate effect other than a prospective rush to exploit the oil believed to lie under the Arctic Ocean. But exposed ocean absorbs solar radiation, whereas the ice-covered ocean reflects, so the disappearance results in an increased inflow of heat in summer into the polar region. With this additional warming comes increased surface melt on Greenland (Figure 1). And with disappearance of ocean ice comes the loss of its buttressing effect on Greenland's glaciers, where there are reports of increased ice-quake frequency (Tarko, 2006).

What happens to the meltwater? Maybe it flows away through some unknown channel to Greenland's coast and into the ocean. But maybe it collects in some hollow on the bedrock. Or maybe it freezes up from contact with the underside of the cold ice sheet. For the last two there is a cumulative effect – as the level rises in the hollow with successive warm summers, it lifts the ice sheet off its contact points with the bedrock. Or, as the meltwater freezes, it warms the bottom of the ice sheet till it eventually goes mushy and can slide more easily over the bed-rock. So the threat is that the increased frequency of ice-quakes that has been observed may mean that pieces of Greenland's ice sheet have become unstuck and are trying to move down towards the ocean, bumping up against other pieces that are still stuck, causing the icequakes. Paleo-climatological studies show that warming phases of the glacial-interglacial cycle do not run smoothly but in a series of sudden changes of global temperature, linked to ocean level jumps of a few meters at a time (Hearty, 2007). If all of Greenland's ice were to disappear, the ocean level would jump about seven meters, requiring the evacuation of populous river deltas such as the Ganges, the Yangtse, the Nile, the Mississippi, the Rhine, etc.

Similar story lines for cumulative build up and eventual catastrophic release can be developed for other potential runaway processes such as the release of methane from frozen tundra and the collapse of methanic clathrate deposits located on the inclines of the continental shelves. These processes, like the behaviour of land based ice masses in Antarctica and Greenland, are poorly understood and fall well short of the scientific certainty that might lead to consensus action by the Conference of Parties. However, the precursor signs are such that an effective group or groups of Parties to the Convention may deem that a threat exists sufficient to warrant cost-effective action under Article 3.3.

5. A metric for climatic danger

A novel metric[3] for climatic danger arises from consideration of the cumulative processes described above (Read, 2007a). It may be not the rate of temperature change (0.2 degrees Celsius per decade has been proposed) nor the temperature increase – 2 degrees has been widely canvassed and a lower figure recently (Hansen *et al*, 2008). Intuitively it would appear to be the cumulative warmth injected into the climate system in general, and into Arctic regions in particular, that matters if year after year meltwater accumulation is the mechanism that drives the threat of ice sheet collapse. Given an anthropogenic flux of a few watts per square meter and with a billion seconds every 30 or so years, the unit of measurement would be GJ/m^2 for cumulative heating, say since WW2, when emissions began increasing rapidly. With net thermal flux roughly proportional, over the relevant range, to the level of CO_2 above pre-industrial, the cumulative metric can be gauged from the area under the CO_2 profile (Figure 2). Note that the relevance of the cumulative metric to the threat of ice sheet collapse is hypothetical and uncertain, and thus – to the extent it is intuitively plausible – potentially appropriate to action under Article 3.3 even though not adequate to motivate consensus action by the Conference of Parties.

[3] Lenton *et al* (2008) note the relevance of the cumulative metric to long term ocean thermal expansion, but it is believed that its more urgent significance in relation to the basal lubrication, and potential imminent collapse, of land-based ice masses was first proposed in Read (2007a).

In relation to this metric, first consider the emissions reduction paradigm, pointing to a direction for action that is proving difficult to achieve – for instance Kyoto's commitment to demonstrable progress by 2005 (Protocol Article 3.2) was observed entirely in the breach. However, even a wholly unexpected success with emissions reductions completely fails to contain the cumulative metric, as may be seen from Figure 2.

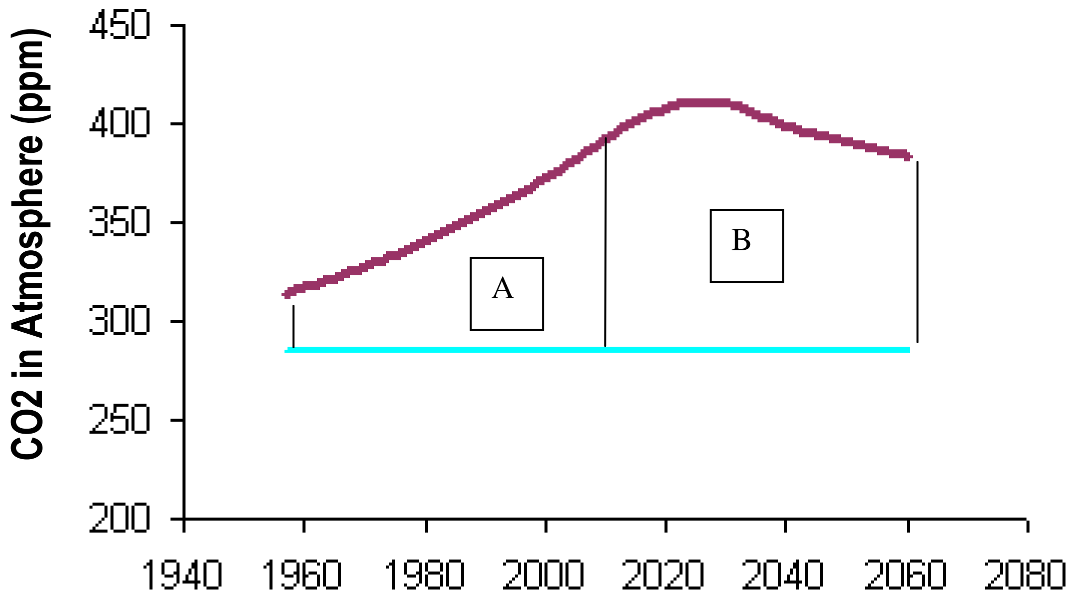


Figure 2 Excess CO_2 over the preindustrial level for the last 50 yrs. and, <u>assuming emissions fall to zero by 2035 and remain zero thereafter</u>, for the next 50 yrs.

The projection in Figure 2 for the next 50 years assumes that everything that could go well with the Kyoto process after 2012 does go well. That not only do the Parties find a way of ensuring that all the major emitting nations – USA, China, India, etc. – reduce their emissions, but that successive agreements under extensions of the Kyoto Protocol result globally in a reduction in man-made emissions to zero in a linear trend over 25 years, starting in 2010. That is a much greater success than global emulation of the British target, widely regarded as very ambitious, of a 60 per cent reduction by 2050. By inspection, it is apparent that the cumulative heating increase with this implausible success, to be added to what has cumulated in the last 50 years during which emissions have mainly taken off (area A), is roughly twice as great for the next 50 years (area B) increasing the quantum of the cumulative metric to roughly three times its present value ((A+B)/A) by 2060 and with no ending in sight then.

6. The carbon cycle

It therefore appears necessary, given the pre-cursor signs noted above, to supplement emissions reductions with large scale carbon removals – getting carbon out of the atmosphere and stocking it somewhere safer. That such negative emissions activity is possible at low cost – or possibly negative cost, with oil prices over $100US/bbl – arises from a feature of the natural carbon cycle that appears to have been little appreciated by the policy community, where the folklore is that, once emitted into the atmosphere as CO_2, carbon stays there for a very long time – say a half life of 150 years.

But this is very far from the case since about 110 Gt of carbon is absorbed by the terrestrial biosphere annually (IPCC, 2000) as a consequence of the photosynthetic activity of the plant kingdom which supplies the energy requirements of almost all life on earth. A slightly larger quantity is absorbed by cold oceans (and re-emitted in warm ocean regions) so that, with around 800 Gt of carbon in the atmosphere, it is simple arithmetic to see that, for every ton of carbon that enters the atmosphere as CO_2, another is exchanged with ocean or terrestrial biosphere in less than four years.

However it is no easier to extract CO_2 from the oceans than it is from the atmosphere. Also, half of what is transpired by terrestrial plants is rapidly lost through the plant respiration that results from meeting the plants' own energy requirements, pumping water from its root structure up to the green leaves where the sun's energy is used for the photosynthesis of the carbohydrates which are the building blocks of biomass formation. So we are left with about 60 Gt of carbon fixed annually by the plant kingdom as plant biomass, about eight times fossil fuel related emissions. Equilibrium is reached in nature, between plants (that photosynthesize CO_2 from the atmosphere with H_2O from the soil into complex carbohydrates) and the animals, bugs and fungi, which oxidize the carbohydrates to H_2O and CO_2, which is then respired back to atmosphere (with a delay that is short in the case of annual plants that rot away when they die back, to many hundreds of years in the case of long lived tree species).

If we liken the atmosphere-ocean to a bathtub that is overfilled with CO_2, then emissions reductions constitutes turning off the taps and waiting for the overflow outlet to slowly lower the level. The overflow outlet may be likened to the leakage of carbon from oceans and terrestrial biosphere into long term storage on the ocean bed and in mineralized soil carbon, a slow process which, in natural equilibrium around 280ppm, gives the aforementioned roughly 150 year half-life. There is no low cost bung for this bathtub that can be pulled out to speed up this process, although high cost proposals for mechanical absorption of atmospheric CO_2 have been made (Keith and Ha Duong, 2003).

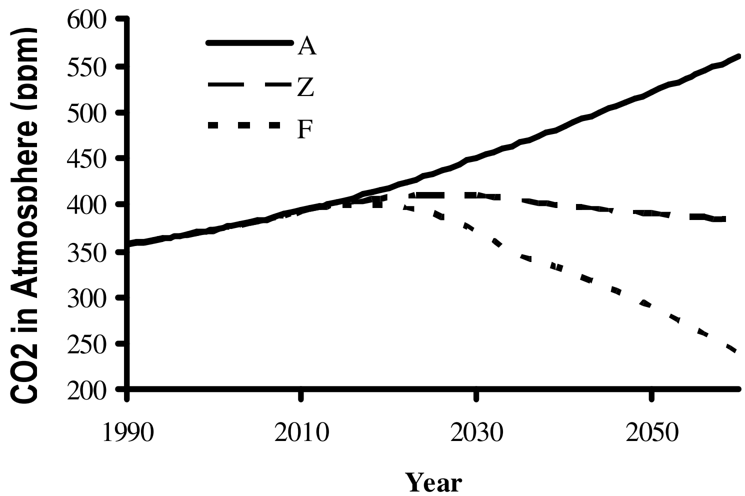
However, understanding of the role of the terrestrial biosphere shows that we have not a bathtub but a jacusi, with CO_2 being continuously removed from the atmospheric pool, and returned to it, by the biotic pump. Each time carbon goes through the biotic pump presents an opportunity, through management of the terrestrial biosphere, to siphon some of it off, and to store it safely on, in, or under, the soil. It is this that makes feasible the deployment of negative emissions systems based on managing biotic flows of carbon and augmenting terrestrial storages (Obersteiner *et al*, 2001). Additionally, it may be noted that the power of these systems is much greater than might be imagined from the 60 Gt of carbon fixed annually in nature. This is because natural evolution secures survival by resilience to natural variation, not by the efficiency that is targeted by good management. Thus well watered commercial eucalypts have fixed 50 tC/Ha year, which would double global net productivity using only half the potentially available land noted in section **8** (though, as discussed there, large scale monocultural forestry in not global gardening).

7. Carbon removals and biosphere carbon stock management (BCSM)

We may deduce that biosphere carbon stock management involving carbon removals is a possible strategy and that the threat of climate catastrophe thrusts this approach (including, as we shall see, most promisingly biochar technology) into a key role in mitigation, rather than being just one amongst the several ways illustrated by Socolow's 'wedges' (Socolow, 2005) of reducing net emissions. It is interesting to note that, as scenarios get to aim for lower targets for CO_2 levels, they display an increasing role for negative emissions systems involving land use change (Azar *et al*, 2003). This is not surprising given the limitation of emissions reductions noted in section 5 above. The most recent work of Hansen *et al* (2008), aiming for 350 ppm CO2, shows a much larger role for land use change than their previous work, aiming for 450 ppm (Hansen *et al*, 2007)

The superior effectiveness of BCSM involving carbon removals with emissions reductions, relative to the emissions reductions orientation that is embedded in the cap and trade framework created by the Kyoto Protocol, is illustrated by comparing its achievement on an ambitious scale with the quite implausible success with emissions reductions mentioned above.

Figure 3:Comparison of zero emission systems and negative emissions systems in mitigating the level of CO_2 in the atmosphere



N.B. the comparison is extended to 2060 only. The usual timeframe for mitigation studies (2100 and beyond) is too far distant in relation to the threat of climatic catastrophe

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<u>Legend</u>

A	SRES-A2 business as usual
Z	SRES-A2 with a transition to zero emissions technologies between 2011 and 2035
F	SRES-A2 with a transition to negative emissions technologies over the same period

So, assume that an ambitious programme of biosphere carbon stock management (BCSM – Read, 2007/8) is successful over the same 25 year period as above, yielding worldwide improvement in the ways we use land and raising its sustainable productivity. This involves financial investments on the scale of, firstly, prospective global investments in getting oil and other fossil fuels, added to, secondly, large scale willingness to pay for avoiding catastrophic climate change threats[4]. With enhanced photosynthesis thus taking more CO_2 out of the atmosphere than under current land management practice, assume also that the carbon fixed thereby is conserved carefully through widespread deployment of carbon storage systems such as biochar soil improvement. With enhanced productivity of the land yielding increased supplies of traditional food and/or fibre, together with biofuel, a large part of the carbon-rich residues would then also be stocked safely, out of the atmosphere.

It has been shown (Read and Parshotam, 2007) that a trio of BCSM technologies that are available, or within reach of straightforward engineering development, could return CO_2 levels to ~300ppm by around 2040, if pursued on an ambitious scale as illustrated by line F in Figure 3. It may be noted that line F is controversial and this matter is discussed in Appendix 1. Line Z (which is identical, after 1990, to Figure 2) is, by definition, the best that can be done by emissions reductions under the 25 years assumption. However, deploying more BCSM could, imaginably, yield lower profiles than F.

In essence, BCSM means worldwide deployment of technologies that get carbon out of the atmosphere and stock it in reservoirs located in the biosphere or lithosphere. It involves enhancing natural aggregate planetary photosynthesis by the plant kingdom and delaying, or in part wholly preventing – e.g. through pyrolysis of biomass residues and dispersing the resulting long-lived biochar in the soil – the return of carbon to atmosphere that, in nature, results from respiration by the animal kingdom and from wildfire. It implies 'global gardening' – taking the same care of soil, at the farm and plantation scale, as is natural to a good gardener.

8. Negative emissions systems

The potential of this strategy has been illustrated by a thought experiment simulating the deployment of three land using technology chains over 25 years on very large areas of land totaling 2.38 billion hectares (GHa.). This area is reported by the FAO (Bot *et al*, 2000) to be potential arable land not in commercial use. By a land use technology chain is meant the choice of planting, the management of growth and harvest, the transport and processing of the crop, and the disposal of residual biotic material (biomass). The three selected chains were eucalypt plantation forestry over 1.0 GHa, mainly in low latitudes (Read 1998); cane sugar plantations over 0.43 GHa, wholly in low latitudes (Moreira, 2006); and switchgrass plantation over 0.75 GHa in temperate latitudes (Greene *et al*, 2004). The technology chains all yield synergy with food supply or (in the case of forestry) fibre, along with liquid fuels and electricity co-produced respectively from the cellulosic and ligneous biomass residues from supplying the high value co-product.

In the thought experiment, terrestrial safe storage of carbon – safer at least than a continued excess stock as atmospheric CO_2 – mainly involved fossil fuel left in the ground and CCS (the capture of CO_2 and its storage in deep strata, such as saline aquifers – Haszeldine, 2006) with both CO_2 emissions from fermentation (low cost) and from power generation flue gas (high cost). BECCS, linking BioEnergy with CCS in this way,

[4] The World Energy Council has proposed $30 trillion over 30 years to end 'energy poverty'. Adding as much again for sustainability costs would yield $10,000 per Ha over 6 bHa of managed landscape globally.

results in a negative emissions energy system that takes carbon out of the atmosphere whilst providing energy carriers, such as electricity and liquid fuels. That is providing the carbon balance of the bioenergy system is itself sufficiently negative (i.e. displaces sufficient fossil fuel use in the energy sector to strongly exceed any fossil fuel involved in the bioenergy production chain, *per contra* the 'bad' biofuels discussed below).

Since the illustrative calculations for the thought experiment were done, attention has swung to biochar (Lehmann *et al*, 2006) – that is to say charred biomass, such as charcoal from wood, that has been pyrolysed to drive off volatile fractions (which can be condensed to yield bio-oil, a crude liquid fuel that can be processed to a diesel fuel substitute). Biochar has been found in pre-historic sites and evidently is a long-lived way of storing carbon in the soil. But the interest arises particularly because biochar has beneficial properties as a soil conditioner, raising fertility, improving water and nutrient retention and thereby reducing both fertilizer requirements and the runoff that pollutes streams and rivers under modern intensive farming systems. Thus the prospect is that the communities living where the 2.38 GHa of potential arable land exists can gain income from both carbon credits and sales of bio-oil, together with improved yields from the soil.

Six types of reservoir have been suggested for stocking more safely than in atmosphere the carbon or CO_2 flows that arise with negative emission systems:

- New forestry plantations: this is well understood and, with prospective sales revenue at harvest, low cost. It can therefore provide a jump start to reservoir filling. However it reaches a limit imposed by land availability after which, under commercial management, it acts as an ongoing sink supplying (in parallel with other crops, annual and perennial) the biomass raw material for technology chains leading to other reservoirs.

- BECCS – bio-energy with CO_2 capture and storage supplying reservoirs in deep geological strata, mentioned above,

- Biochar storage in soil reservoirs with co-produced bio-oil and enhanced productivity of conventional agricultural outputs, as just mentioned,

- Pickling logs i.e. simply storing biomass anaerobically in pits in the soil[5] in ways that emulate the long term preservation of logs found in swamps .

- New timber structures and other harvested wood products. This provides a reservoir that can grow indefinitely but at a rate which is limited to substantially less than energy sector emissions by the finiteness of demand for new structures and by the shortness of the useful life of much harvested wood product in the form of pulp for paper.

- Existing fossil carbon reservoirs maintained *in situ* through technology chains that involve bio-energy, to the extent this substitutes for fossil fuel.

- Labile in-soil and above-soil carbon resulting from soil improvement and productivity increases under bio-char soil conditioning

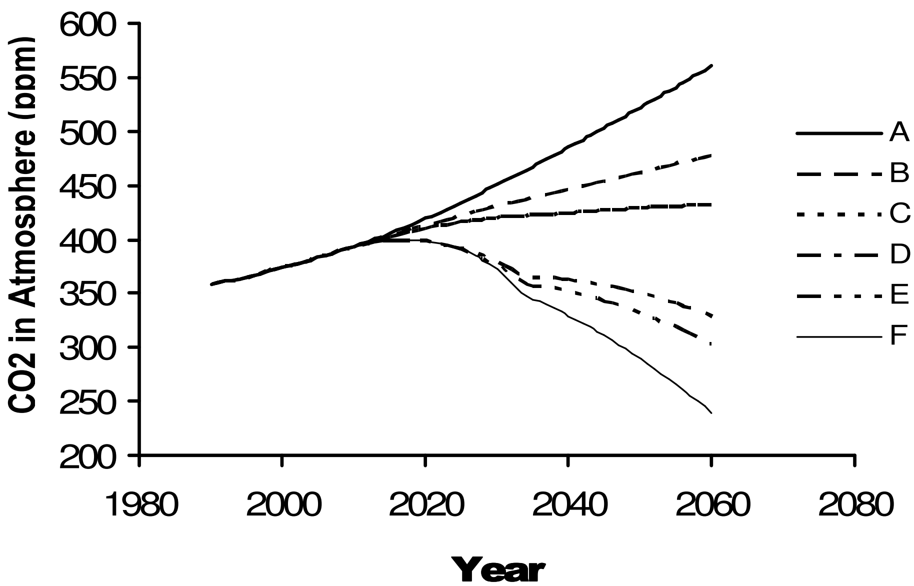
[5] A recent paper (Ornstein, 2008) suggests that the dead and rotting wood of fallen trees in forests worldwide, that will otherwise be oxidized to CO2 within a decade or so, could be buried at low cost, safely storing carbon that will otherwise be emitted to atmosphere.

As discussed elsewhere (Read, 2007/8), the deployment of the three illustrative technology chains over vast horizon to horizon forestry and sugar plantations, and monocultural grasslands, is very far from a practical implementation of global gardening. That is because global gardening must proceed on a scale related to the needs of the communities living where the relevant technologies are deployed and have regard to environmental desiderata embodied in the various multilateral environmental agreements.

For this, BCSM activity, funded ultimately by the energy consumer, needs to be constrained by conditionality based in sustainability criteria being developed in various frameworks (Best, 2007; Morrison and MGhee; 2008; Zarrilli, 2008; Roundtable on Sustainable Biofuels, 2008) from which best practice will emerge through experience.

The most immediate impact of global gardening on the CO_2 level comes from creating new forestry plantations on previously unforested or deforested land, as can be seen from Figure 4 where this major early impact comes as the difference between line D and C.

Figure 4. Simulated carbon removals strategy using three technology chains



Legend

A SRES-A2
B SRES-A2 with sugar cane land use change activity [lower case refers to figure 3 with land areas halved]
C SRES-A2 with sugar cane and switch-grass land use change activities
D SRES-A2 with sugar cane, switch-grass and forestry land use change activities
E SRES-A2 with three land use change activities and low cost capture and storage (CCS) of fermentation CO_2
F SRES-A2 with three land use change activities CCS of fermentation and flue gas CO_2

The top line, A, is a business as usual scenario which, as it has turned out since the scenario was published, substantially underestimated the rate at which emissions would grow after 2000. Thus the adoption of a carbon removals strategy on the scale assumed would result in outcomes somewhat above the set of lines in the diagram. Line B and line C show the impact of first introducing the sugar cane technology chain and then the switchgrass chain, while lines E and F show the additional impact, relative to D, of, first, low cost CCS related to fermentation CO_2, and then high cost CCS related to flue gas CO_2, both processes initiated some years into the simulation, by when it is assumed increased policy urgency will have arisen.

With the exception of forestry, all of the crops are taken annually from perennial plant species and thus provide an immediate supply of food and/or fibre plus bio-energy raw material. But, as a consequence of their year by year cropping and use, the CO_2 absorbed by photosynthesis is partly re-emitted in the same year, depending on the details of the technology chain, so that their effectiveness in carbon removals is partial. However, with the forestry based technology chain (line D minus line C), no crop is taken until the maturity of the first planted stands, with an assumed rotation of 25 years. At the time of the first harvest of the oldest stand, the area occupied is replanted, and so on in successive years to create a 'normal' forest with equal areas of all ages in the rotation and an average age of half the rotation length. Thus provides a permanent storage of half the potential storage were the whole forest area grown to maturity and conserved in that state. As permanent, that is, as the policy that drives the BCSM strategy. Of course, forest fire hazard needs to be guarded against by planting a small additional area as insurance.

During this initial period, the whole of the photosynthesized carbon is locked up in growing forest biomass and stored out of the atmosphere, thus accounting for the greater initial effectiveness of plantation forestry in removing carbon from the atmosphere. In this way, forestry was, a decade ago, seen as a low cost buffer between the initiation of effective policy and the need for costly energy sector investment in then immature technologies (Read, 1996). While the worsening climatic situation, and the lack of such action in the interim, may have removed the luxury of such a breathing space, forestry's effectiveness in a carbon removals strategy places new forestry plantations at centre stage in addressing climatic catastrophe. In a precautionary approach (Read and Lermit, 2005) it has the merit, in the event of good climate science news, of a having valuable alternative use as harvested timber, taking pressure off the harvesting of natural forests and supporting REDD efforts to preserve biodiverse rain forests. And in the event of worsening news it provides a ready stock of biomass raw material as the basis for rapid diffusion of BECCS and/or biochar technologies, with the cleared land being used more intensively for short rotation forestry or quick growing grasses.

Conditionality

However, as is increasingly being found from experience with some first generation biofuel technology chains, embarked on for reasons of farm support, or in response to looming peak oil, 'bad' biofuels can have negative environmental and social impacts, resulting in minimal or even negative carbon removals and competition for land with food supply systems. The distinction between 'good' and 'bad' biofuels is made in the Sustainable Biofuels Consensus (Trindade *et al*, 2008) arrived at by a group of experts meeting in April 2008, in the context of rising concerns regarding the sustainability.of many biofuel systems.

The Sustainable Biofuels Consensus distinguishes such 'bad' biofuels from 'good' biofuels, including second generation bioenergy technologies (Faaij, 2006) and bio-fuel co-product of biochar land use improvement. Ethanol produced from sugar cane, using the modern fermentation and crop management systems developed in Brazil, is the main 'good' biofuel that is currently in substantial use. In a recent initiative, this technology is being transferred to Ghana (Dogbevi, 2008) one of the sub-Saharan African countries where it can advance the Millennium Development Goals through economic growth led by exports of 'good' biofuel. Such sugar cane expansion occurs on cerrado land in South America (miombo land in Africa – Morrison and McGhee, 2008) that is not used for food production and that is plentifully available. It does not occur in rain-forest since sugar cane requires a dry season, but can happen on biodiverse wetlands, as reported in Kenya (Mongabay.com, 2008) where it may breach future sustainability conditions.

In reaching the Consensus it was noted that biofuel obligations in Europe and the USA could well be met by imports of 'good' sugar cane ethanol from Brazil and sub-Saharan Africa. So the impact on food prices of such obligations arises entirely from the trade barriers to ethanol imports into just those countries that have imposed the obligations, thus providing protection to 'bad' domestic biofuel production from fodder corn and rape seed (canola) crops. In reality, higher food prices result from a variety of factors including • high fuel prices (which biofuel supplies serve to ameliorate); • the shift in developed countries' farm support from production subsidies, with a view to raising the viability of food production elsewhere and supporting sustainable rural development in many of the world's most impoverished regions; • and adventitious extreme weather events that, to the extent they are related to climatic warming, stand to be limited through success with BCSM, with biofuels as the channel for accessing energy sector finance.

9. Energy sector financing and effective policy

It is for reasons of effectiveness discussed above that a global BCSM strategy would initially focus on stimulating the worldwide development of the vast forestation program implicit in Figure 4. How such global cooperation might be brought into being in parallel with, and complementary to, the continuation of Kyoto-style cap and trade action to reduce emissions is the crux of the new architecture discussed below. Here we briefly discuss a policy instrument that can bring about the financing of this development, with funds derived ultimately from the energy consumer.

Such an instrument will not be a price on carbon both for the reasons of effectiveness discussed in Appendix 2, and because that instrument is assumed already being used to drive cap-and-trade emissions reductions. The prices that matter, for an investment in forestry related to carbon removals, are the prices on carbon in each year of growth, yielding a cash flow related to the growth pattern of the planted trees, together with the prices at maturity on carbon (a debit on felling) and on timber and residual woody biomass. Today's prices for carbon, timber and biomass are a poor guide to such future prices, creating risk and leading to underinvestment. As is becoming increasingly recognized in policy formation, mandates or obligations on fuel suppliers, such as renewable portfolio standards, are needed to create investment certainty – for instance the biofuel mandates adopted in a number of countries in the face of risky oil supply prospects, and increasingly relevant to climate policy objectives as sustainability criteria come to be applied to these mandates.

Thus mandates that result in planting 40mHa on a 25 year rotation that reaches 400 tons biomass per Ha (~200 t C)[6] at maturity would absorb 8 Gt C, broadly in line with projected fossil carbon extraction, so that a simple mandate on extractors of fossil fuels to invest in projects that absorb the fossil carbon they extract over a 25 year time-span could build up to forestation over 25 years on the 40 mHa x 25 = 1 GHa scale implied by Figure 4. Alternatively they may opt for burying forest wastes (footnote 5 above) or for biochar soil amendment using, for instance, biotic urban wastes as feedstock. For efficiency, the mandate would both be tradable, so that the obligation could be contracted to the most cost-effective operator, and, within the broad area of carbon removals, be technology free. So, if burying forest wastes (low cost, but with no saleable co-product) were lower net cost than forestry options with prospective sales of timber and biomass, then plantation forestry would wait its turn, after all burying of forest wastes options had been taken up.

It is also to be noted that proportional obligations have the same effect as the recycling into desirable technologies of carbon tax revenues, or permit auction revenues, but avoids the problems that arise from channeling cash flows through governments or international bureaucracies (Read, 1998a).

10. The UNFCCC and the Kyoto architecture

The Kyoto cap and trade regime was conceived as a framework for achieving gradual and accurately accounted for emissions reductions by a group of industrialized countries that had, in the Climate Change Convention, accepted responsibility for taking the lead. These reductions were to be from the well defined fossil fuel sector that has conveniently available data. Burden sharing was negotiated through tough bargaining between countries, each concerned, as is the way with international negotiations, to minimize its own burden, regardless of the negotiation's ultimate objective. Differing perceptions, as between developed and developing countries, of past and future responsibilities for excess atmospheric carbon, compounded the difficulties, which were eased by flexibility mechanisms. These permitted the trading of allocated emissions reductions and, as offsets against commitments to domestic emissions reductions, the use of tightly defined emissions reducing projects in other Parties' territory – joint implementation in the case of other developed countries, and through the clean development mechanism (CDM) in the case of developing countries not included in the cap.

For such a framework, there could hardly be a more awkward concept than a technology based approach that promises large but uncertain carbon removals projects, mostly arising in countries outside the cap, and mainly involving non-energy sector activities. Thus the need, under threats of catastrophic climate change, to realize the potential of negative emissions systems, points towards a different architecture post-2012.

Note that the Kyoto Protocol is subordinate to Article 4.2(d) of the UNFCCC which obliged the first Conference of Parties (COP1, Berlin,1995) to consider whether the commitments under the UNFCCC itself were adequate. Note also that the processes of

[6] At 500m on moderate soil ~40° South in New Zealand, Pinus Radiata yields 156.1 above ground live biomass, 34.1 below ground live biomass, 7.3 dead woody litter, 11.9 fine litter = 209.3 tC/Ha total after 20 years (Beets, 2007). Faster growth rates are achieved with eucalypts and other fast growing species in tropical and sub-tropical conditions.

the COP's are by consensus. Thus Parties that regard their interests as prejudiced by a proposed new commitment are able to block progress – a course of action adopted frequently by Saudi Arabia and Kuwait in particular – leading to tortuous negotiations that resulted in the details of the Kyoto Protocol not being finalized until the Marrakesh Accords of 2001. However no such requirement for collective agreement exists under Article 3.3, leaving the way open for those Parties or groups of Parties that perceive a serious threat to set an example that may be followed by other Parties later and, in doing so, to enable their entrepreneurs to get ahead with, and to develop technological superiority in, the carbon management and sustainable bioenergy technologies of the future.

Measurement problems

Aside from these procedural aspects, there is a further difficulty facing the deployment of negative emissions systems within a cap and trade framework like Kyoto. This derives from the very effectiveness of land use change activities linked to the difficulties of accurate measurement that are intrinsic to any biotic process. For instance, it may be easy enough to know that a ton of biochar is put on the soil, but its rate of decay, though very slow, is uncertain, as is the increase in labile soil carbon that results from the soil improvement yielded by the biochar. Also the above-ground carbon in consequent greater vegetative growth, presents a difficulty, especially with annual crops which, depending on season, will be standing in North or South hemispheres, but on average how much, and where, is hard to account for.

This is at odds with the conceptual basis for Kyoto that treats carbon as a contaminating pollutant which must be remedied by emissions reductions – cutting off the flow of contamination. Thus the main game in the 1995-2001 Kyoto negotiations was domestic action to reduce emissions from the energy sector in the developed (Annex B) countries that the Convention requires to be taking the lead (Convention Article 4.2(a)). Note that such energy sector emissions reductions can be measured accurately using information derived from commercial contracts that is aggregated in the construction of published energy statistics. However they are difficult to achieve and this caused Parties to undertake commitments limited to quite small percentage reductions, which, on account of the difficulty, were jealously guarded against possible leakage, e.g. by forestry offsets.

Along with other offsets under the flexibility mechanisms, land use change was regarded by many as a let-out from the main game (Grubb *et al*, 1999). Since their objective was to reduce compliance costs they were regarded by some as cheating, a view that carried weight because all such offsets do in reality contain an incentive to cheat. Both the buyer (say an energy firm seeking a low cost way to offset its emissions) and the seller (say a farmer seeking carbon credits from spreading biochar) have an incentive to exaggerate the size of the offset – e.g by exaggerating emissions, or downplaying absorption, under the counter-factual baseline scenario. This is *per contra* a conventional contract where the buyer, say of a cabbage, has an incentive to check on the quality of the goods and will decline to buy if it is poor value for money.

The smallness of the Protocol's emissions reductions commitments – no doubt due to the foreseeable difficulty of their achievement – meant that quite easily envisaged land use change projects would have a significant impact on the quantum of domestic energy sector emissions reductions needed – maybe displacing them entirely. The commitments had been negotiated in 1997, before proposals for land use change offsets had arisen, so that such proposals, coming along later, were unwelcome to those who took domestic action to reduce energy sector emissions as the main priority of climate policy. The failure at the 2000 Hague Conference of Parties, in the shadow of US Presidential elections, of Gore's proposals for forestry-based offsets has been attributed (Schneider *et al*, 2002) to the influence of European NGO's which, in this writer's personal experience, seemed more committed to deconstructing the energy sector than to getting CO_2 out of the atmosphere.

Much was made of the uncertainties mentioned above, along with a question of 'permanence' – fossil fuel emissions not emitted stayed not emitted, it was held, whereas carbon absorbed in a forest would be re-emitted if the forest were destroyed by wildfire or harvested for timber. This despite the obvious reality that a policy-induced normal commercial forest would stay in place, on average half grown, as would extractable fossil fuel stay below ground, for as long as policy kept it there. However, the point being made is that negative emissions systems based on land use improvements have a hard row to hoe in securing consensus agreement to a major role in any post-2012 regime that continues to focus on emissions reductions.

Leakage

The threat to the environmental integrity of the Protocol presented by land use change projects is particularly acute in the case of projects to secure credits under the CDM and thus carried out in developing countries (where most of the land is located where biomass production – photosynthesis – could be enhanced). This is because developing countries emissions are not included under the emissions cap for the developed countries listed in Annex B of the Protocol. As a consequence, a defective project under the CDM, which is used as an offset against an Annex B country's commitment, results in a direct loss of the environmental integrity of the Protocol.

This contrasts with the situation for a Joint Implementation project hosted by an Annex B developed country. That is because, although the buyer and seller with a JI project both benefit from exaggerating the size of the offset, the Annex B host country is still obliged to meet its bottom line commitment under the cap, as is the Annex B sponsor country. If the project falls short then the host country will not find its emissions reduced as expected, and will need to take additional measures, e.g. by an extra tax on carbon.

However, it may be noted that the indirect effects of a land use change in an Annex B country can occur outside the set of countries included in Annex B. If, for instance, New Zealand were to convert land from milk production to forestry, it would not reduce demand for milk worldwide – production would shift (and with it enteric methane emissions from cows) to another country, possibly a non-Annex B country. Thus correctly estimating the effectiveness of a project or policy depends on choosing the correct system boundary which, with globalised markets for food, fuel, and timber, needs to take account of possibly very distant indirect effects.

The methodologies approved by the CDM Executive Board to determine the carbon credits related to land use change projects are consequently onerous and impose heavy transactions costs on entities seeking to realize the potential of land-use related projects.

Requirements to prove additionality relative to a hypothetical business as usual situation, and to prove the absence of leakage, involve a major input of professional expertise in countries where that is an extremely scarce resource[7]. Continuous monitoring needs to be provided to ensure that the ongoing mutual incentive to cheat is frustrated.

All this has resulted in a very small volume of land use change projects under the CDM, even though land use improvement has the potential, by orders of magnitude (figures 2 and 3 above), to be the most effective means available for achieving the ultimate objective of the UNFCCC, the avoidance of dangerous anthropogenic climate change. As suggested in our Section **1** introduction, it is as though a perfectly formed silver teaspoon were being used to bale carbon out of the good ship 'Earth's Atmosphere', when what is needed is a bucket – possibly a leaky bucket.

11. The Architecture of Global Gardening with a Leaky Bucket

We can now draw together the threads in this paper to outline a two-part architecture relevant to the bad scientific news of an approaching tipping point, possibly rapidly approaching, and to the good news that a more immediately available set of technologies is applicable under the new BCSM strategy than for the old paradigm of domestic emissions reductions. Growing more biomass is not rocket science, biofuels are easily assimilated into existing energy systems, and carbon conserving process technologies that can return carbon rich residues to soil – biodigestion, pyrolysis, etc. – are well known.

In expounding this architecture we shall be mindful of a concern (Schelling, 1992) that commitments to outcomes are indicative of insincerity. The future is too uncertain for such commitments: the Russian economy may collapse, generating 'hot air', or recover again; production may migrate to developing economies with more emissive plant, largely accounting – along with a prolonged credit-driven boom – for increases in emissions this century ahead of the most pessimistic projections; peak oil may raise energy prices more than any politically imaginable carbon tax; and so on. Commitments to policies and measures is something on which governments can deliver and the adequacy of each others' policies can be a matter for well mannered negotiation in the context of technically expert analysis, as consistently advocated by Schelling (2006) taking note of the model provided by the Marshall Plan negotiators.

No Party to the Convention has yet explicitly addressed the issue of catastrophic climate change, even though their duty under Article 3.3 is clear. As noted in the introduction, Article 3.3 of the UNFCCC commits the Parties individually to take cost effective precautionary action in response to threats of serious or irreversible climatic change with scientific uncertainty not to be used as reason for delay (whether such uncertainty relates to the threat or – see Appendix 1 – to the remedy).

The absence till recently (Lenton *et al*, 2008) of firm opinion in the scientific community on the existence of a threat of passing some tipping point, may have contributed to

[7] I have to hand (CDM – Executive Board, 2007) a forestry project for a Tanzanian location, worked up to the so-called "Gold Standard", which, with Appendices, runs to 176 very dense pages and secures in aggregate less than 2 million tons of CO_2 removals over the years 2008-2012. It reminds me of JM Keynes' "The economic consequences of Mr Churchill" detailing the damage done to the British economy by Churchill's 1920's adherence to the gold standard.

inaction. But more important may have been the hopelessness of the task, given the conventional wisdom that sees CO_2 as pollution, to be remedied through emissions reductions for which the economists' recipe is to charge for the previously free disposal of greenhouse gases to atmosphere. Carbon taxes in the region of $1000 per ton have been modeled (Manne and Richels, 1992) to achieve only the modest reduction below business as usual implied by 'two times pre-industrial CO_2'. No wonder the political process, ignorant of the potential of land use improvement for managing carbon stocks, has so far declined to recognize the possibility of catastrophic climate change.

Part A: Global Gardening through Sustainable Carbon Management Partnerships

Part A reflects the urgency that springs from the threat that the tipping point may be near (Wasdell, 2007) and comprises arrangements for BCSM to go ahead under Article 3.3 independently of whatever consensus on post-2012 arrangements arises from negotiations under Article 4. Then the architecture is very simple. Parties – countries that are party to the UNFCCC – or groups of Parties (e.g. under the aegis of the G8) agree on bilateral or group-lateral Sustainable Carbon Management Partnerships between fuel importing Parties and prospective biofuel exporting Parties.

These Partnerships would commit importing countries to stimulate investments in BCSM activities in producing countries that, along with carbon removal, yield 'good' biofuels plus food and/or fibre co-products. The quantum of biofuels and of carbon removals aimed for would be a matter for negotiation and initially need be no more than 'demonstrable' to borrow a Kyoto Protocol word. But as the number of partnerships expands, negotiations between those involved would work towards agreement on effort-sharing in achieving the scale of BCSM activity indicated in Figure 3.

The implication of 'good' biofuels is that the importers guarantee to provide a market for the exporters' product only on condition that the exporters agree to employ sustainable best practice in land use, based on land use planning for bio-diverse conservation areas and in support of other desiderata of multilateral environmental agreements, and on product processing to biofuel and higher value co-products. This is to introduce objective standards of sustainability into developing country Parties' actions under the Climate Change Convention, *per contra* the current situation. This is that individual Parties determine their own sustainability criteria as a sovereign right – leading to a prospective Dutch auction in sustainability standards as profit-seeking firms shop about for the most advantageous location for BCSM investments.

This state of affairs may be unwelcome to the more perceptive developing country Parties and, subject to their involvement in negotiating their own sustainability criteria (which may need to be location sensitive) a shift towards objective sustainability standards may well be welcomed. Initially, with several group-lateral or bi-lateral partnerships, a variety of sustainability best practice standards would likely be negotiated. In the spirit of 'let 100 flowers bloom' the most effective, subject to locational variation, could be expected to emerge and, when the BCSM strategy achieves consensus, form the basis for a new multilateral protocol under Article 3.3.

Part B: the Leaky Bucket

Desirable though the leaky bucket may be – that is to say a framework that avoids the high transactions costs involved in the Kyoto flexibility mechanisms by substituting *ex ante* policy-based buy out, disregarding additionality, for *ex post* project based offsets – it remains the case that anything done under Article 4.2 is by consensus of the Conference of Parties. For Part B we therefore offer several leaky bucket alternatives, by no means an exhaustive set, each compatible with the carbon removals paradigm embodied in the global gardening of Part A. Which of them may be adopted, or some other variant, depends on the strength of concern over the current high transactions cost *post hoc* offset regime. Should, for instance, the G8 endorse a Global Sustainable Carbon Management Partnership, it could have the weight to demand the most ambitious version of the leaky bucket approach.

Alternatively, the Part B leaky bucket concept may commend itself to the Conference of Parties on merit, regardless of progress with part A global gardening. However, as with any scheme designed to reduce the transactions costs of the current regime, the leaky bucket approach is a threat to the growing bureaucracy and carbon accountancy services industry that has grown up around *post hoc* offsetting[7bis]. Resistances to the leaky bucket approach – possibly covert – may come from these sources, and lead to something close to continuance of the existing architecture. In that event carbon removals activity under Part A can still obtain *post hoc* offset credit, to the extent that it gives rise to projects that fall within the constraints of the Kyoto-style flexibility mechanisms, i.e. afforestation and reforestation under Kyoto Article 3.3 and, under its Article 3.4, maybe other land use change activities post 2012, such as biochar soil improvement.

However, sincere commitments can only be to targets and the purest version of Part B is that future commitments under Article 4.2(d) should indeed be to fossil fuels emissions reductions targets and to negotiating policies and measures designed to achieve them that also yield *ex ante* buy out of targeted emissions reductions. The greater the buy out the more lenient the target, so that difficult emissions reductions would be replaced, in greater volume, by more feasible BCSM activity. A greater volume (implying a lower price for BCSM carbon than for emissions reductions carbon) both because the leaky bucket is explicitly leaky, rewarding good behaviour whether of not 'additional', and because removals, yielding multiple co-benefits, are easier, and involve less sacrifice, in a negotiation over effort sharing.

Besides the large volume of BCSM activity induced by Part A, other *ex ante* policy measures focused on motivating investment in energy efficiency and best practice in different industrial sectors would enable the individual Party's cap to be more easily reached. This incentivizes governments to put such schemes in place, thereby reducing demand to emit, lowering the domestic price on carbon, and reducing the consequential burden on the economy that arises with that type of policy. Ultimately the negotiation of targets, and the *ex ante* agreement of a package of measures, would be an effort-sharing exercise that would take account of the differing circumstances of the various Parties.

Amongst *ex ante* measures could, and very likely would, be cap and trade schemes applying to firms ('entities') under the jurisdiction of each Party (or negotiating group such as the EU) and creating a domestic price on carbon having the important symbolic impact and effect on current behaviour noted in Section **2** above. A uniform price across Parties is not needed for the marginal cost equalization that delivers efficiency in cost effectiveness terms. This would be through activities implemented jointly between Parties, with low transactions cost certification of best practice by verification agencies and the application of rule of thumb quantification of carbon benefits, yielding rewards to the entities involved at their sponsor Party's carbon price.

That some Parties' entities would have greater incentive than others does not diminish the effectiveness of a price in causing entities to seek out least cost options, and merely signifies that their government had, *ex ante,* negotiated a greater role for its domestic cap and trade scheme, and a lesser role for, say, housing insulation policies, than other Parties. Each sponsor Party would have negotiated commitments for some quantum of overseas BCSM sponsorship amongst its policies and measures to be taken into account in setting its target, but the incentive on an entity (firm) to use the flexibility mechanisms would not spring from that quantum but from its domestic carbon price, and from other policies put in place by its sponsor government to secure the negotiated quantum of fossil fuel related emissions reductions.

An alternative and less radical approach to Article 4 would be to retain the insincerity of commitments for emissions reduction outcomes, but with emissions related strictly to fossil fuel use, and to replace the apparatus of *post hoc* offsets (with its burdensome apparatus of additionality and resulting need for strict – and costly – financial and carbon accountancy) with *ex ante* commitments to policies and measures, as just outlined. Then greater policy commitments, including BCSM commitments, leads to more lenient negotiated emissions reductions commitments (greater allocated amounts) until each Party negotiates a technically feasible and, to its voters and other stakeholders, politically acceptable combination (albeit, as is inevitable with commitments to outcomes, subject to the vagaries of circumstance discussed above).

This would be to generalize the precedent of the 'Australia clause' (Grubb *et al*, 1999) under which its very lenient Kyoto commitment was negotiated in recognition of its (claimed) special circumstances in relation to land use change. Different commitments to policies and measures would constitute different special circumstances for different Parties and negotiations around them would hopefully lead to the sophisticated and technically expert conduct of business advocated by Schelling.

Alternatively again, the buy out of emissions reductions targets (or commitments) by *ex ante* commitments to policies and measures could be restricted to policies relating to the difficult-to-measure land use change (land use improvement) activities which are the focus of Part A global gardening. This leaves the (arguably) more easily measured emissions reductions activities (i.e. activities unrelated to land use) to continue to be credited as *post hoc* offsets against emissions reductions, as with Kyoto's existing flexibility mechanisms. This formulation is the original version of the leaky bucket concept (Read, 2008).

12. Concluding comment

This paper has outlined a response to the emerging but uncertain threat of imminent climatic catastrophe – not climate change itself but the effect of climate change upon polar ice and ocean levels. Under Article 3.3 of the UN Climate Convention, the Parties have committed to take action in relation to such a threat despite this uncertainty or uncertainty as to whether the measures taken, such as the BCSM advanced here, can meet the challenge. It was suggested in passing that certain quickly reversible measures of cloud albedo modification, coming under the label of 'geo-engineering', should also be initiated, at least to the extent of trials to see if they would work. Whether BCSM should itself be classified as geo-engineering is unimportant and might turn on whether it was attempted on the unacceptable pattern of mega-scale land use change that provided the basis for the illustrative calculations or took the form of global gardening, adapted to the needs of the communities that occupy the managed landscapes of the world.

The Sustainable Biofuels Consensus stated "Our vision is of a landscape that provides food, fodder, fibre and energy, that displays sustainable rural development; that restores ecosystems, protects biodiversity, and sequesters carbon; and that contributes to global peace by diversifying the energy supply" which vision global gardening aims to secure. That cannot happen until the policy community opens its thinking to the reality that security from catastrophe cannot be achieved by pursuing its current objective of emissions reductions and escapes from the illogicality, which results from that blinkered approach, of ignoring the win-win trade-based outcome that is available. If it does, then the large supply of sustainable biofuel that arises as one of the co-products of BCSM will enable emissions reductions commitments in the post-2012 regime to be more ambitious than currently seems plausible, thus achieving the complementarity signaled in Section **1**

Apart from its potential to support a number of multilateral environmental agreements through effective land use planning and management to secure biodiversity, resist desertification, and preserve wetlands, BCSM provides the only prospect of reversing the ocean acidification of recent decades. Also of supporting sustainable rural development through the deployment of funds over the next few decades on the scale of several thousand dollars per hectare in the process of land improvement, water management and soil restoration that is needed if an improving quality of life is to be available to the projected populations of the decades ahead.

But maybe BCSM will fail, possibly, with dwindling oil supplies, under commercial pressure that cannot be contained by sustainability conditions to accelerate 'bad' biofuels. Or it may transpire that improved scientific understanding of polar ice reveals that threat to be illusory. In that event the process can be stopped. However, time lost in starting the process cannot be recovered, since plants and plantations take time to grow.

Any Party can initiate its response under Article 3.3 and a first step would be for some Party to formally recognize the need – even a small island state, threatened with submergence, could seek sponsors for an experimental Latham-Salter ship. However, effective implementation of global gardening through the leaky bucket approach can more quickly come if an industrialized country Party declines to accept an allocated amount commitment unless its *ex ante* carbon management policies and measures are taken into account, thereby blocking consensus on the post-2012 emissions reductions negotiation. Thus the consensus procedures of the Conference of Parties can serve better purposes than those to which they have so far been put by oil producing countries, in resisting progress towards achieving the ultimate objective of the Convention..

Acknowledgement

I wish to acknowledge my intellectual debt to Thomas C. Schelling, who puts understanding ahead of technique.

Appendix 1 Controversy over the costs of biosphere carbon stock management

While it may be thought that the feasibility of returning to pre-industrial CO_2 levels before mid-century is a research result of considerable interest, even importance, it has been available since mid-2005 and could have been in the peer-reviewed literature assessed in the IPCC's Fourth Assessment Report. However, publication of this leading result from our research has been frustrated by a peer review process of surprising hostility, at the end of which I was invited to write the Editorial Essay for *Climatic Change* (Read, 2007/8) that provides the background to this paper. Contemporary with that essay was published a discussion paper (Read and Parshotam, 2007) carrying the latest version of the submitted article, which, along with our supposedly important leading result, reports the calculations that underpin Figure 4. The discussion paper also carries the comments of reviewers G and H (*sic*) together with my rejoinders.

It may be noted that none of reviewers A to G questioned the leading result, which is unsurprising since it merely brings together and aggregates the results of three previously published peer-reviewed publications (Moreira, 2005, Greene *et al*, 2005, Read, 1998). Reviewer H claimed that one of our assumptions was overly optimistic, despite the fact that it had passed muster with the reviewers of Read (1998) and Read and Lermit (2005), a claim to which I respond in my rejoinder.

However, the claim made for biosphere carbon stock management in my Essay is quite robust against minor revisions of the assumptions since, as noted above and in Read (2007/8) the practical implementation of BCSM would not replicate the thought experiment mega-scale land use changes of the illustrative calculations, over 2.38 GHa of 'available' land. Rather would it involve the diffusion, over the whole ~6 GHa of managed landscape worldwide, of the land use improvement technologies implicit in the concept of global gardening. Prominent would be the biochar technology discussed above, of which only notional account was taken in our working paper, since little was known about it at the time of writing.

It may also be noted that none of the Editorial Commentaries published in *Climatic Change* (including one part-authored by a doyen authority in the field – Marland and Obersteiner, 2008) – challenged the leading result, though the commentators were unanimous in their concern that BCSM be conducted sustainably – a concern which I share, as I hope is clear from a casual reading of the Essay or this paper.

But the concern of the reviewers of Read and Parshotam (2007) seemed to be to prevent publication of the leading result. In several cases there were generalized and, save for one, unsubstantiated accusations of carelessness. The one instance was that I had spelled 'principle' for 'principal' – good reason it would seem for preventing the IPCC Fourth Assessment Report from informing policy-makers that – contrary to any previously published analysis – a return to pre-industrial levels of CO_2 in a few decades is feasible.

As regards costs, I declined to be drawn into a numbers game since projections of relative costs are hostage to the fortune of competition between technologies and the lock-in of arbitrary outcomes (Arthur, 1989) and because the implementation of BCSM would, as is made clear, be nothing like the illustrative calculation for three technology chains deployed on a vast scale. But, as regards the three technologies, sugar cane ethanol is commercially viable with oil prices over \$40 /bbl; low latitude plantation forestry sequesters carbon at only a few dollars per ton; and the calculations in Greene *et al* (2004) show their switchgrass based technology, when implemented as a continuing programme, to be viable at oil prices around \$70 /bbl. In the illustrative calculations it is assumed that the forest output will be used in part as biofuel with CO_2 capture and sequestration, a costly technology that will be appropriate if scientific news gets worse. But, if need be, plantations can be felled prematurely and used wholly for bioenergy with CCS. However, that technology chain, as modeled in Read and Parshotam (2007) postpones the costly part of the investment, in CO_2 capture and compression, until maturity of the first rotation, say 2035, and hence is low cost in present value terms.

As noted in Section 7, it is interesting to see that, as scenarios get to aim for lower targets for CO_2 levels, they display an increasing role for negative emissions systems (Azar *et al*, 2003). This is not surprising given the limitation of emissions reductions noted in section 5 above. The most recent work of Hansen *et al* (2008), aiming for 350 ppm CO2, shows a much larger role for bioenergy and forestry than their previous work aiming for 450 ppm (Hansen *et al*, 2007) Indeed their scenario looks a little like a watered down version of BCSM, though with a role for emissions reductions that, in BCSM, takes the form of biofuel substitution for fossil fuels that remain sequestered in the ground, rather than the efficiency gains and non-fuel renewables that are prominent in other low emissions scenarios.

Be that as it may, the wording of Art 3.3 points to the adoption of effective measures even if their quantification falls short of full scientific certainty – as indeed it must in relation to land use change where so much depends upon the behaviour of people living on the ground. So it is hard to understand where this hostility comes from if it is not professional jealousy from mitigation analysts who have for two decades given priority to emissions reductions, under the false assumption that what is a stock management problem should be addressed using traditional pollution policy measures. I am not sure how long civilization can survive continued failure to treat a stock management problem as a stock management problem.

Appendix 2. Towards an economics of catastrophe precaution

Limitations of cost-benefit analysis

Weitzman's *tail* and *middle* language is used in a subsequent article (Weitzman 2008) which provides a theoretical basis to steer attention towards uncertain potential catastrophe. He demonstrates that it is not permissible to leave catastrophic climatic possibilities out of account, as of *de minimis* probability in the long thin tail of an *ex ante* normal distribution of possible climatic outcomes. This is because the frequency of bad outcomes in the distribution of scenarios that have been developed by climate modelers indicates that the real probability distribution function of outcomes is not normal but

Student-T 'fat tailed', leading to the conclusion that the likelihood-weighted pattern of costs is dominated by the costs of catastrophe. However, to steer consideration towards the fat tail is not to provide 'a commonly accepted usable framework', so that Stern's Review, though a *tour de force* exercise in cost benefit analysis, is frustrated in pursuing Schelling's main task by the limitations of that methodology in relation to deep uncertainty.

Thus, the trigger point for a climatic catastrophe, still less the point of no return beyond which no policy measures can rescue civilization from catastrophe, is unknown (Lenton *et al* 2008). So the probability of any particular trajectory for greenhouse gases provoking such an event is also unknown and the calculation of expected values for the outcome of any particular policy choice, and of any particular architecture designed to secure such a choice, is invalid. This makes the application of cost benefit analysis to the selection of an optimal policy problematic and may explain why analysts have stayed in the comfort zone of Weitzman's *middle*, conducting consumption smoothing studies that avoid current sacrifice and rely on technological progress to ease the burden on later generations of rapid adjustment.. That is where Stern's Review is technically located despite his pervasive concern to avoid imposing on future generations a wrecking of the environment incurred on our watch – quoting (Henry, 2006) that 'uncertainty should not be inflated and invoked as an alibi for inaction'. His concern is, however, frustrated by the lack in formal economics of a usable framework for handling uncertainty.

The discount rate

Cost-benefit analysis requires the application of a single discount rate (possibly varying over time) based on an (as discussed above, invalid) subjective probability distribution over possible states of nature. Its selection in the Stern Report (Stern, 2006) has been a matter of controversy, unsurprisingly since, in the uncertain circumstances, it can only be arrived at subjectively. However, the decision matrix approach of Section **2** enables a discount rate appropriate to each scenario to be determined endogenously. Since business as usual and Kyoto continued both involve negative growth (if not the collapse of civilization in the face of armed conflict provoked by famine and mass migration from the many populous deltas round the world) a negative discount rate is applicable until sufficient mitigating activity is done to avert the catastrophic outcome.

Of course this is not to suppose that market agents will adopt such a discount rate in reaching investment decisions: the function of policy is to induce market behaviour in line with the public good determined by applying the appropriate discount rate. This is somewhat more than just saying that policy must make market players do what needs to be done to avoid climatic catatrophe: the appropriate negative discount rate should be applied across alternative policy measures to achieve the least cost avoidance of catastrophe. With that result secured, activities that mitigate residual gradual climate change can then be assessed with normal public good discount rates, or maybe the unusually low kind advocated in the Stern report if the non-catastrophic outcome nevertheless yields a growth rate substantially lower without mitigation than with. Given the 'switching' properties of capital theory (Samuelson, 1966) it is by no means unlikely that some Kyoto-style measures would then become desirable – measures that dominate at negative discount rates, and are implemented to avoid catastrophe, may leave additional options desirable at a positive discount rate.

Deep environmental externalities and the price mechanism

The original statement of the modern economics of environmental policy (Baumol and Oates, 1975, 1988) which formally demonstrated the efficacy of externality pricing, made an exception in the case of deep externalities, such as current emissions provoking a future climatic catastrophe. Such a situation leads to a flattening of the inter-temporal production possibility frontier to the point where it loses its conventional convexity property and the price mechanism leads to a 'corner solution', far away from the optimum (Read, 2007). For that reason, and because the price mechanism is already in use for continued cap and trade, an alternative mechanism of proportional obligations ("mandates") is assumed to be deployed in the new architecture developed in this paper (though, of course, measures adopted by individual Parties are a matter for their sovereign jurisdiction). However, this is not to leave no role for the carbon price: it has an important symbolic role in modifying the current decisions of all market agents and a price determined by cap and trade fulfils that role, though it cannot represent the full social cost of emissions as proposed by Stern, since that is essentially unknowable due to fundamental uncertainty. Moreover it is a poor driver of investment decisions, owing to uncertainty linked to managerial risk aversion, and the proposed new architecture provides more effective signals with a more specific technological direction.

Technological change and the learning externality

Baumol and Oates's theory of environmental policy is comparative static in nature and fails to internalize the inter-temporal beneficial externality that comes from learning by doing. This is a serious lacuna when the objective of policy is to induce appropriate technological change, which is certainly the case for responding either to gradual or to catastrophic climate change. Although exactness cannot be secured owing to uncertainty regarding the rate of induced technical progress with different technologies of the future, it has been shown that an initially small, but increasing, proportional obligation generates a high implicit value on initial investments in the policy-desirable technologies, falling over time (Read, 1999, 2000, 2000a). Since the value of early experience is greater than subsequent experience, because the lessons learned are available sooner, this pattern of incentives broadly corresponds to the initially high and falling value of the learning externality, which is accordingly internalized in an approximate way. Better to be roughly right than certainly wrong, which is the case with cap and trade, which seems likely to generate a rising incentive rather than the high initial incentive appropriate to early learning (and needed to overcome barriers to entry that may face novel technology).

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