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Biosphere carbon stock management: addressing the threat of abrupt climate change in the next few decades: an editorial essay

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"Il faut cultiver notre jardin" (Voltaire, *Candide or Optimism*)[1]

1 Introduction

Climate change is taking place, and fears of triggering abrupt climate change (ACC) are rising. This is mainly because of an excess stock in the atmosphere of otherwise benign CO_2. That can be remedied by beneficial changes in the ways we manage the biosphere.

But first, imagine 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 linear reduction in man-made emissions to zero over a 25 years period, starting in 2010.[2] Then the profile of CO_2 levels

[1]Candide's final comment has been variously interpreted – I take it as Optimism's call to act locally after a travail of thinking globally in the face of Panglossian denial and miserable experience. "'We must work without arguing' said Martin; 'that is the only way to make life bearable.' The entire household agreed to this admirable plan... Small as the estate was, it bore heavy crops." (translated John Butt, Penguin Classics).

[2]I.e. emissions in 2011 are 96% of SRES A2 for that year; in 2012 they are 94% of SRES A2 for 2012; and so on until they are 4% of SRES A2 in 2034 and zero from 2035 onwards.

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would be line Z in Fig. 1 (relative to the IPCC's economically bullish SRES A2 baseline scenario – line A). That is a much greater success than global emulation of the British target, widely regarded as very ambitious, of a 60% reduction by 2050.

Alternatively, imagine that a programme of biosphere carbon stock management (BCSM) is implemented over the same period, yielding worldwide improvement, *à la Candide*, in the ways we use land, raising its sustainable productivity through investments on the scale of current global investments in getting oil and other fossil fuels. And, with enhanced photosynthesis thus taking more CO_2 out of the atmosphere than under current land management practice, the carbon fixed thereby is conserved carefully through large-scale deployment of bio-based negative emissions systems. While using products of the land for food, fibre and fuel, a large part of the carbon-rich wastes would then be stocked somewhere safer than in the atmosphere.

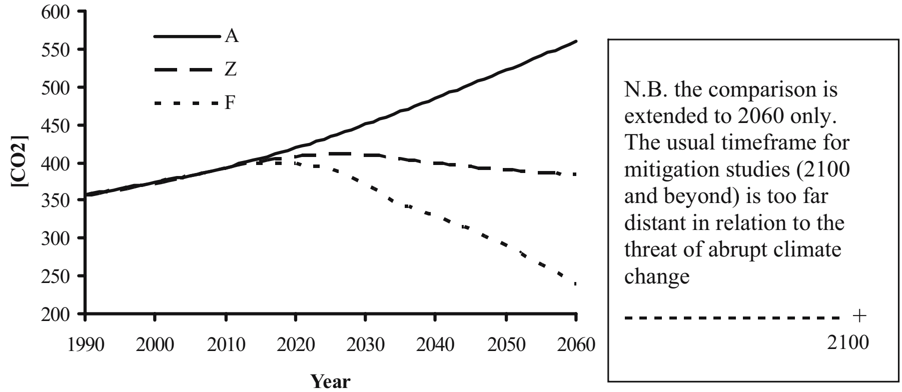
Under an illustrative characterisation of this alternative programme, the resulting profile of levels is line F in Fig. 1. Line Z is, by definition, the best that can be done by emissions reductions under the 25 years linear assumption. However, deploying more biosphere carbon management activities could, imaginably, yield lower profiles than F.

2 Background

The contrast between lines F and Z is the principal result in a discussion paper that also carries rejoinders to the comments of its most recent referees (Read and Parshotam 2007). How the policy process came to overlook BCSM has been attributed to a false vision[3] of CO_2 as contamination, resulting from failures of communication between the disciplines involved (Grover 2007). Climate models mostly projected very long-term slow change due to an excess stock of a naturally occurring non-pollutant – CO_2. But misapplied 'pollution economics' led to the rhetoric of 'emissions reductions.'[4] So technologists addressed emissions reductions in the very long term (IPCC Third Assessment Report, Contribution of Working Group 3, Chapter 2 2001) through advanced zero emissions technologies (e.g. photo-voltaics). And thus scenario builders (IPCC Third Assessment Report, Contribution of Working Group 3, Chapter 3 2001) overlooked the nearer term potential of BCSM, and

[3] Not in the connotation of 'visionary' but the more prosaic 'concept of the world' conveyed by the German *weltanschauung*, for which there is no precise English equivalent. In a world of excess information and bounded rationality it is such vision that guides our selection of information, thus creating and reinforcing the knowledge, possibly false, which informs our actions. Fransman (1998) cites IBM management in the 1980s (having better information than anyone about the potential of the PC but with its vision wedded to the mainframe computer) as the classic case of false knowledge leading to commercial disaster. In this essay I contend that climate change mitigation is in jeopardy because CO_2 has been wrongly envisioned as contaminating pollution, for which the only feasible mitigation is costly emissions reductions.

[4] I recognise that the flexibility mechanisms in the Kyoto Protocol allow for afforestation and reforestation (and deduct for deforestation, if reported) but the much greater potential of "carbon stock management", compared with "emissions reductions," does not occupy the minds of policy makers and commentators. 'Sinks' came late into the negotiation of Kyoto, and were never part of the main game. Indeed they were regarded as a let-out from the costly business of domestic action on emissions reductions in the energy sector, especially by influential European NGO's that were instrumental in 2000, at the Hague COP6, in securing rejection of the Clinton administration's forestry offset proposals (Schneider et al. 2002). At times it seemed as though these NGOs were more concerned to deconstruct the energy sector than to reduce greenhouse gas levels.



Legend

A SRES-A2 [17]

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

Fig. 1 Comparison of zero emission systems and negative emissions systems in mitigating the level of CO_2 (in ppm) in the atmosphere. *A* SRES-A2 (UN 2002). *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

with it the potential of a two-stage strategy to yield multiple benefits – so-called 'win–win–win' – including preparedness for an urgent climatic threat. Hereafter 'the Strategy,' the first stage is a transition to a largely biofuel based energy system (at low cost, given current oil 'peaking'). The second stage follows if needs be – e.g. with rising concern over imminent ACC – by linking bioenergy to carbon capture and sequestration (CCS – likely high cost).

The Strategy was first proposed (Read and Lermit 2005) in terms of a forestry-based process in a paper that involved an incorrect representation of the CO_2 emissions-to-levels process. This led to an over-estimate of the Strategy's effectiveness which is corrected in (Read and Parshotam 2007), where two additional agriculture based processes are included. Further sections of this essay outline the Strategy and its relevance to potential ACC (Section 3), review the illustrative calculations that yield Fig. 1 and contrast them with practical implementation of the Strategy (Section 4), and discuss the environmental sustainability and socioeconomic equity issues that arise (Section 5). Additionally, a strategy to address potential ACC requires both a separate policy instrument – but one that is compatible with the carbon pricing that is the focus of the Kyoto Protocol – (Section 6) and a regime for its international adoption parallel to and complementary with the existing institutions (Section 7). Section 8 concludes.

3 The strategy and the threat of abrupt climate change (ACC)

In the context of a complex and poorly understood non-linear dynamic system removed to a regime of which there is no experience, adverse outcome avoidance is the aim (King 2006). Expert opinion on the rate at which eco-systems can migrate is false guidance if the real danger is a collapse of land based ice masses. This essay argues that (hopefully, but by no means certainly) effective mitigation of such threats is feasible over the next few decades by a 'be prepared' approach – to be ready to achieve whatever profile of greenhouse gases is revealed by future climate science to be needed to avoid ACC, and not to rest content with such targets as ‘0.2 degrees Celsius per decade.’

There is a disconnection between the very long-term scenarios that mitigation analysts present to policy-makers and increasingly ominous climatic symptoms[5] which suggest that a threshold or tipping point for some kind of non-linear, possibly catastrophic climate event may be near. The disconnection may have been ignored so far for want of ideas on how to be prepared to respond urgently, in the event potential ACC becomes imminent.

Consider the effect of ocean thermal expansion on the stability of grounded ice sheets or of higher ocean temperatures on the viability of north polar sea ice. Then it is intuitive that it is the aggregate inflow of thermal energy into the oceans, releasing temperature driven feedbacks, that will turn out to be what is dangerous. If so, the duration of greenhouse gas levels above the pre-industrial, forcing heat into the oceans, is what matters. We can already see ocean warming effects at current levels of only 380 ppm, and after just a few decades of CO_2 levels substantially above pre-industrial. Yet the scenarios portray stabilisation at 450 ppm, or even 550 ppm, to be achieved after a century of levels elevated much more than hitherto and with aggregate thermal input consequently many times what has occurred so far. That is the disconnection.

The Strategy is driven by the hope that large-scale biosphere management that achieves a return to pre-industrial levels of CO_2 within a few decades (Line F of Fig. 1), possibly supplemented by albedo modification to increase earth’s overall reflectivity to solar radiation (Crutzen 2006; Salter and Latham 2007), can be an effective response to threatened ACC. The Strategy addresses uncertainty, as regards what is needed to avoid ACC, with low cost precautionary actions. These are designed to enable subsequent measures, likely costly, to be effective should partial or complete resolution of the uncertainty show a need for much faster reductions in greenhouse gas levels than have so far been regarded as practicable (IPCC 2000).

These initial precautions involve benign interventions in the full range of processes, largely biotic processes, by which greenhouse gases[6] enter and leave the atmosphere. They take advantage of natural photosynthesis of the carbohydrates that energize most life on earth and by which the terrestrial biosphere fixes about six times as much carbon as is anthropogenically emitted. It is *prima facie* technologically much easier to get CO_2 out of the atmosphere by improvements in the ways we manage land, that raise biotic fixation and yield biomass fuels (de-fossilization), than it is to do without fuel (decarbonisation).[7]

[5] See (Grover 2007) for a brief survey of these, (Schiermeier 2007) for a more extensive discussion and (Wasdell 2007) for how reportage of such risks has been systematically downplayed in the IPCC’s 4th Assessment Report.

[6] The illustrative calculations relate to reducing the atmospheric stock of CO_2, but implementation would also involve management of CH_4 stocks. As it happens, there is no practical technology for extracting CH_4 from the atmosphere, so management of CH_4 stocks is effectively the same as CH_4 emissions reductions.

[7] This claim is controversial and, more than any other, attracted criticism from referees of (Read and Parshotam 2007) whom, I believe, mistook our illustrative calculations on a small set of technologies applied over very large areas of land for a description of the practicable implementation of the Strategy. Also, we neglected to review the analyses of land-use change mitigation in the literature, e.g. as in (Sands and Leimbach 2003). As discussed in the rejoinders in (Read and Parshotam 2007), these top-down analyses cannot capture the bottom-up technological richness of the modelling that is needed, envisaged in this essay in Section 4, under *Implementation*. Consequently they underestimate, by an order of magnitude, the mitigating potential of land use change strategies, such as the carbon stock management approach advanced in this essay. The situation is reminiscent of that in the mid 1990s, in the early stages of the bottom-up/top-down controversy in relation to energy sector mitigation. In the outcome, the bottom-up estimates of technological potential were largely vindicated.

In modifying the balance of absorption and emissions on managed areas of land, the Strategy aims to realise the potential for socio-economic and environmental benefit that will come from well-conceived investment in under-capitalised, and in many places degraded, land.[8] Thus, the Strategy addresses the need that emerged with the Millennium Development Goals (UN 2002) to link greenhouse gas mitigation with sustainable development, thereby serving other multilateral environmental agreements as well as the UNFCCC. For instance, by growing a very large number of new, community-scaled, plantations (Read et al. 2001) the Strategy meets such concerns as the depletion of natural forests (and hence serves bio-diversity conservation) along with sustainable timber supply for forest product industries.

Negative emissions systems (Obersteiner et al. 2001) are central to the Strategy and crucially different from zero-emissions systems, such as most renewable energy technologies. This is because, in their initial stage (i.e. managing land to grow useful plants) they actively remove CO_2 from the atmosphere, thus enabling storage elsewhere of the carbon in the CO_2.

Zero-emissions systems simply avoid adding to the stock that is already there. As a consequence, even the universal adoption of those systems could achieve no more than an asymptotic process towards the level of CO_2 in the proximate sinks into which atmospheric CO_2 empties, as illustrated in line Z of Fig. 1. These sinks are the biosphere, and the ocean surface layers (where it forms carbonic acid), which, in turn, transfer very slowly into stable soil carbon and the deeper ocean. It may be noted that the terrestrial biosphere may become a net emitter under temperature stresses foreseeable with business-as-usual emissions scenarios (Cox et al. 2006) and that carbonic acid is already at a concentration that is threatening the food chains of ocean eco-systems (Turley et al. 2006).

BECS – bioenergy linked to CO_2 Capture and Storage (CCS, as is promoted in relation to "clean coal" (IPCC 2005)) – constitutes a negative emissions energy system in which the more bioenergy is consumed, the less CO_2 remains in the atmosphere. Using revenues from bioenergy product sales to pay both for the gathering and processing of biomass raw material (co-produced with high value products that pay for cultivation and harvest) and for the safe disposal of CO_2 wastes, BECS actively pumps CO_2 out of the atmosphere. Done on a sufficiently large scale, this results in a reduction in atmospheric CO_2 levels, as in line F of Fig. 1, below the asymptotic path of line Z.

More generally, the stocking of carbon, once fixed by photosynthesis can be:

- pre-combustion – standing forest (Read 1996),
- post combustion – CO_2 capture and sequestration (CCS) (Obersteiner et al. 2001),
- partial combustion – pyrolysis to yield bio-oils plus stable carbon biochar that can be permanently stocked in the soil, raising fertility (Lehmann et al. 2005), or
- nothing to do with combustion – wooden houses and other structures.

These examples show that negative emissions energy systems are a sub-set of the negative emissions systems that yield economic benefits. In turn, a larger set includes systems that yield no economic benefit, such as 'pickling logs' and the direct capture of CO_2 from the air and its storage underground (Keith and Ha-Duong 2003).

[8] For instance, with ecosystem success dependant on resilience rather than efficiency, there is scope to enhance net primary productivity, and hence natural absorption, by simple investments such as, *inter alia*, the fencing in of areas of savannahs to protect tree seedlings from browsing animals, or organic soil improvement, e.g. through bio-char conditioning (Lehmann et al. 2005; Ogawa et al. 2005; Marris 2006).

4 Illustrative calculations: technologies, land and implementation

To illustrate the Strategy, the impacts on net CO_2 emissions were calculated for three negative emissions land improvement technology chains deployed on a very large scale over the 50 years 2011–2060. These impacts were applied as perturbations on the emissions projected in a standard scenario (the economically bullish IPCC SRES A2 scenario (IPCC 2000)) and the resulting net emissions transformed to the profile of CO_2 levels over the period, using an adaptation of the Bern model (Kirschbaum 2003).

Technologies In deriving Line F in Fig. 1, the three land using technologies chains considered, each yielding commercial outputs in addition to energy supply and carbon benefits, were:

A Co-production of timber and bio-energy [fermentation of cellulosic fractions of woody wastes plus power generation from ligneous residues or pyrolysis to bio-oils with bio-char co-product] from new plantations over an area increasing to 1 Gha by 2035, on mostly non-arable land in temperate and tropical regions, leaving bio-diverse natural forest less disturbed by timber extraction (Read 1998)

B Co-production of animal feed and bio-energy from grass [extraction of protein, fermentation of cellulosic fractions, plus power generation from residues] on existing or potential arable land in temperate regions over an area increasing to 0.72 Gha by 2035 (Greene et al. 2004)

C Co-production of sugar and biomass for bio-energy [fermentation of cane sugar syrup plus power generation from bagasse residues] on potential arable land in tropical regions over an area increasing to 0.43 Gha by 2035 (Moreira 2005)

The estimates of the carbon cycle impacts and energy outputs of these activities assumed an initial 4-year political decision taking and capacity building process – now, 2007, 3 years. Then follows linear growth of the areas that benefit from these land use improvements, from 2011 to 2035, with 1.5% per annum technological progress from 2035 to 2060, but no further increase in the areas of land involved.

The estimates assume the tailing off of tropical deforestation from 2023, by when alternative supplies of timber, and sustainable income generation for those who live by deforestation, are assumed to become available. They also assume increasing concern over potential abrupt climate change, with the ramping up of low-cost sequestration of fermentation CO_2 from 2020 and high cost flue gas CCS from 2025. They assume CCS is 80% effective in temperate regions, where the prospectivity of saline aquifers is high, and 60% in tropical regions, where prospectivity is lower (Haszeldine 2005).

Land availability Potential rain-fed arable land, net of protected land and urban settlement, has been estimated (Moreira 2005) using FAO and IPCC studies (Bot et al. 2000; IPCC 2001), viz:

	Gha	% used commercially	Available (Gha)
Sub Saharan Africa	1.05	15	0.893
North Africa and Near East	0.04	100	
North Asia Urals Eastwards	0.28	64	0.101
Asia and Pacific	0.74	64	0.266
South and Central America	0.98	15	0.833
North America	0.43	54	0.158
Europe	0.32	63	0.118
World	3.82	38	2.38 of which 1.99 tropical and 0.38 temperate

The potentially available land is not unoccupied but represents areas of land on which the occupants are not engaged in economic activity reported to the FAO. Their lifestyles may include hunting and gathering, slash and burn agriculture, warfare, and other forms of subsistence. But the existence of such large areas of which the outputs are unrecorded suggests that there is no shortage of land but of investment in land. Such investment would demand a commercial return that would have entered into economic data available to the FAO. And such investment in the future, under effective sustainable development conditionality, would yield improved quality of life for the people living there, based on raised soil productivity for food and fibre, as well as for fuel and for carbon management.

Implementation These estimates are illustrative of the potential of BCSM and do not represent the envisaged implementation of the Strategy. Formal analysis of the envisaged implementation would require the spatially differentiated modelling of market agents' choices under effective policy measures (see Section 6) over a vast array of potential technology chains for managing land, and for processing the products of the land, that conserve carbon out of the atmosphere. In an era of growing recognition of the critical importance of carbon stock management vis-a-vis simple emissions reductions, adoptions from this array of technology chains would follow a typical S-curve for market penetration rather than the linear pattern estimated here. Their general adoption would yield improved land use over the ~1.5 Gha of current arable production as well as the FAO's 2.38 Gha of 'available' rain-fed arable land, plus carbon-conservative practices on pastoral land and in handling industrial and municipal organic wastes, etc. Some hope that comprehensive research into the vast array of potential technology chains, and the demonstration and rapid deployment in chosen locations of some amongst them, will yield decadal time-scale control over atmospheric carbon may be derived from noting the additional carbon flows involved in implementing the Strategy that have not been included in the illustrative calculations (Read and Parshotam 2007) that yield Fig. 1:

- increased in-soil labile carbon resulting from the growth of new forest plantations and from a change from arable farming to the cropping of perennial grasses;
- increases in both in-soil and above-ground labile carbon stocks resulting from improved fertility due to soil improvement;
- use of biomass residues from all sources outside the 'available' 2.38 b Ha. (crop residues, forest residues, agricultural residues and municipal solid waste) variously estimated at 30–90 EJ/year in medium term and 40–240 EJ by mid-century (Fischer and Schrattenholzer 2001);
- carbon stocked in timber artefacts, with increased timber supplies from the new plantations driving substitution for energy intensive steel, aluminium and concrete;
- increasing use of CCS technology in the declining fossil fuel sector, beyond that included in the baseline SRES-A2 scenario.

How far to go with driving market agents to select carbon conservative technology chains would depend on trends in costs and increasing concerns over ACC. If such chains run up against decreasing returns, e.g. as wider areas of marginal land come to be needed, further deployment would only be pressed under strengthened policy, reflecting concerns over imminent ACC. In that case they would be associated with early deployment of the second, likely costly, stage of the Strategy, i.e. linkage to CCS. However, the literature on competing technologies (Arthur 1990) – and experience with, for instance, wind-power in Denmark – suggests that the current costs of technologies are a poor guide to future relative costs. Alternative decarbonised and carbon intensive scenarios show little cost difference in the long run, allowing for induced technological change (Gritsevskyi and Nakicenovic 2000; Barker et al. 2006), and specialisation into a bio-based scenario may strengthen the benefit from such induced improvement.

Neither is it clear how long the Strategy needs to continue. Land use improvements on the scale envisaged – on average, an area the size of France in warmer regions and of Germany in temperate zones, each year for 25 years – is a daunting organisational prospect. This is so even though the improvements yield raised living standards for the communities that live on the land. And even though the needed technologies exist or, in the case of advanced 'second generation' bioenergy technologies, are well within sight. Described as 'breathtaking' by reviewer H of (Read and Parshotam 2007), it is less so than the consequences of triggering irreversible ACC – literally breathtaking for many unfortunates. And what is assumed for illustrative purposes is not what will happen – once embarked on, BCSM would be accelerated or slowed in response to changing scientific understanding of ACC.

But if the prospect of averting the threat of ACC and of rectifying historic inequities (see below) enthuses a generation appalled by the folly of mine, and of the post WW2 generation, then snowballing success may attend the Strategy. Rapid technological transitions – the shift from inconvenient rail to congested road for instance, and from sea to air for international passenger transport – have taken place in a generation, and can again. Good citizenship could see environmental consciousness spread from the politically correct to become the norm, with waste materials willingly separated at source for recycling and trees planted on every nook of available land – motorway verges, urban wastelands, etc. Carbon-conservative treatment of wastes – municipal, farm, forest and factory organic – extracting energy and enhancing soil quality, could become universal.

So, if the Strategy were to follow the path of line F, then, by 2040, the question would arise whether to proceed to CO_2 levels below pre-industrial – for instance to compensate for still elevated levels of other greenhouse gases, or to cool still dangerously warm oceans – at risk of a CO_2 de-fertilizing effect. Or, with the current excess stock of CO_2 taken out of the atmosphere and deposited safely elsewhere, and with advanced photo-voltaic and hydrogen technologies taking over energy supply, then lands used for a few decades for intensive biofuel production could be restored to their bio-diverse original state, stocking them with species conserved over the meantime in reserve areas.

Without a great deal of further research (and likely, to a lesser degree, even with it) the cost and duration of the Strategy is a matter for speculation. What is clear is that, with peaking oil, any short and medium term costs are associated with securing sustainability, not with expanding the use of bio-fuels, a process that has acquired its own momentum under concerns for energy security. And what is also clear is that, even if the additional costs of sustainability turn out to be substantial, they represent the only insurance policy available against the threat of ACC (short of geo-engineering, Crutzen 2006; Salter and Latham 2007, which conveys no prospect of socio-economic or non-climatic environmental side benefits).

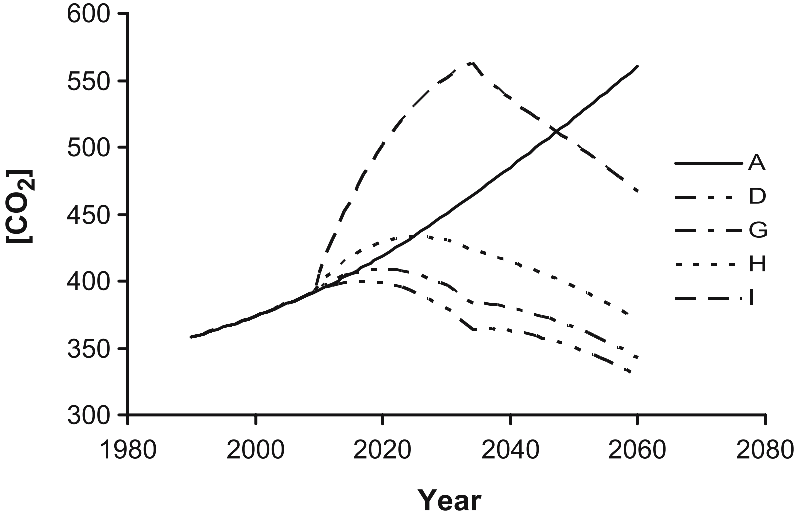
5 Sustainability, equity and capacity building

It is widely recognised that the involvement of developing countries is needed in the post-2012 regime and, less widely – mainly in the South – that the major historic source of emissions, and hence responsibility for the elevated level of CO_2 that now exists, lies with the North. Thus a *sine qua non* for the future regime is an arrangement that delivers to the

South the investments and technology transfers needed to secure its sustainable economic development as well as, to both North and South, effective climate change mitigation. I propose policy measures to achieve that in Section 6. In this Section we note the necessity of securing such sustainability if the ACC threat is to be mitigated.

A recent symposium on bioenergy and sustainability (UN Foundation and German NGO Forum 2006) revealed much that is going forward to establish criteria for sustainable bioenergy, while noting that the current growth of biofuel trade is in some cases neglectful of them. For instance, the destruction of native tropical forest in Indonesia to make way for oil palm plantations to supply export biodiesel (Lumuru 2006) does far more harm than good within the next few decades that are of current concern over threatened ACC. This is because uncontrolled soil disturbance and vegetation burn-off at the time of land use change results in the oxidation of soil organic matter, and of above-soil biomass, with CO_2 release that can offset the policy-desirable carbon stock relocations that are the aim of the Strategy.

The effects of such CO_2 release at the time of the land use change are illustrated in Fig. 2 where the SRES A2 scenario (line A) is perturbed (line D) by the three productive technologies only, i.e. without CCS, on alternative assumptions that the release of CO_2 is 30, 90, and 300 tons C per ha (lines G, H and I). We may take these, respectively, to correspond roughly to the conversion of pasture to arable land, to the burn-off of incomplete canopy woodland/scrub in temperate regions, and to the burn-off of dense tropical forest, Indonesia style, to make room for biofuel production.



Legend

A	SRES-A2
D	SRES-A2 with sugar cane, switch-grass and forestry land use change activities but no CCS
G	SRES-A2 with three land use change activities and 30 tC per ha released through land use change
H	SRES-A2 with three land use change activities and 90 tC per ha released through land use change
I	SRES-A2 with three land use change activities and 300 tC per ha released through land use change

Fig. 2 CO2 in atmosphere (ppm) with CO2 release at time of land use change

Such unsustainable management is not implicit in the three land-use improvement estimates used to illustrate the Strategy, nor in the multiplicity of land use improvements that are envisaged for its implementation. Figure 2 is simply to illustrate the need for sustainable best practice at the time of land use change – e.g. ensuring that cleared biomass is used as bio-energy raw material, or that a large proportion of its carbon content is converted to biochar and stored more or less permanently in the soil.

The relevance of socio-economic sustainability, at the micro level implied by project related sustainability criteria, is clear. If biosphere management activity does not deliver improved living standards to the people living on the land, and if they are not committed to project participation and to some degree of proprietorship, then a disaffected population can very easily secure the failure of the project – in the extreme by arson, to which forest plantations, in particular, are very exposed. Thus the success of the Strategy cannot come – at least in developing countries where low-income rural communities are closely tied to the land they live on – from the horizon-to-horizon monocultural dystopias envisaged by some concerned environmentalists. Instead it must come from a very large number of community scaled projects (Read et al. 2001) adapted to the local climatic and other dimensions of the physical environment, and to local customs and culture, including land tenure practices.

For such country-driven sustainable development, there is need to create a corps of trained grassroots entrepreneurs, skilled in the art of engaging the commitment of communities on the ground (Unsigned Editorial 2006), and equipped with the technical expertise and organizing competence to attract investment funding, to access markets for the sale of biofuel and other outputs from the projects, and to secure project related carbon credits. The creation of this corps could come through a GEF funded training programme to develop a network of training centres in developing countries linked to research institutions in both North and South (Haque et al. 1999). The latter would develop curriculum and country-specific training best practice, and provide research backup for responding to problems in the field that are beyond the competence of grassroots entrepreneurs and the community-based managements they set up. Costing ~$50 m.p.a. for 10 years, this programme would add only a few cents per ton of atmospheric CO_2 removal to projects that could not be initiated and sustained without such trained personnel and technical back-up (Read 2001).

6 Policy measures

It is obvious that 100% take-up of zero emissions technologies is equivalent to a zero emissions cap. However, the psychology is quite different. The emissions cap creates an accountants' paradise, setting one firm against another, and one country against another, in a punitive zero sum game, where the more the burden on others, the less is required of oneself. In contrast, a technology oriented measure that obligates a required rate of take up of policy-desirable technology types[9] releases entrepreneurial energy to get ahead with securing market share and competitive edge with the new technology types.

[9] In the ACC context, biotic CO_2 absorption, biomass utilization, and carbon storage elsewhere than in the atmosphere. Note, these technology types are those that are scientifically relevant to the objective of managing the carbon cycle. They do not specify particular technologies, or involve 'picking winners.'

In the competition between business as usual technologies and policy-desirable types of technology, the policy objective must be to progressively squeeze out investments in the most undesirable technologies (such as, for instance, tar sands and coal to gasoline). This can be done by setting clear but flexible obligations for the take-up of the policy-desirable technology types. Clarity comes from a commitment to use long run flexibility to maintain the squeeze on undesirable technologies, progressively raising the obligation so as to take up forecast market expansion in excess of (dwindling) conventional supplies.

Thus policy measures could take the form of rising and tradable proportional obligations[10] imposed through well-designed renewable portfolio standards or through conditionality on the initial issue of emissions permits. For instance, an obligation on transport fuel suppliers (including aviation fuels) for a rising proportion of biofuels in their products. And, on large point source emitters (such as power stations), to offset their emissions with a rising proportion of stored biomass in new standing forest plantations, thus investing in a strategic reserve of biomass raw material (Read 1996), available in the event that bad news of imminent ACC demands an urgent halt to the use of coal.

Given uncertainty in the long run development of demand, take-up would be a commitment for the near term, a target in the medium term, and indicative for the longer term horizon of investment planning. This because it is possible that expansion of the policy-desirable technology types will run up against obstacles, and BCSM prove infeasible on the scale envisaged here. In that event, any gap between conventional fossil fuel supply and rising transportation demand that is unmet by biofuels would need to be met by the zero emissions technologies that have been the focus of response to Kyoto commitments – e.g. ‘plug-in’ hybrids. Equally, if forest plantation expansion is slow to be achieved, then alternative near and medium term carbon storage could be provided by accelerated application of CCS, retrofitted to existing fossil fuel power stations.

From the perspective of ACC, neither of these zero emissions approaches gets below line Z in Fig. 1, and precautionary policy might need to rely more on preparing to deploy geo-engineering. And, from the perspective of equity, neither of these zero emissions fall-back approaches generates sustainable rural development in the South. So, should the Strategy fail, it may be that something different would need to be done to rectify the historic debt of the North and secure developing country participation. However, on the more hopeful prospect for the Strategy that is advanced in this essay, the expansion of biofuel trade and plantation forestry will be largely based on investments and technology transfer, by energy firms in the North, to secure biofuel supplies based on sustainable rural development projects in the South.[11]

[10] Tradable obligations so as to secure the efficiency benefits that derive from the equi-marginal principle (Kolstad 2000). If, as remarked 30 years ago (Kneese and Schultz 1975), environmental problems are largely resolved by technological innovations, it is deplorable that environmental economists base their policy advice mainly on comparative static analyses of pricing mechanisms rather than the dynamics of fostering desirable technological change. The linking of tradable obligations to emissions permit issue, ‘allocating permits usefully,’ yields lower carbon prices and less market distortion whilst internalizing the beneficial ‘learning by doing’ externality involved in technological innovation (Read 1999, 2000, 2005) and ameliorating the impact of high carbon prices, which bear heavily on the poor (Common 1988). See (Read 2007) for more detail on the merits of proportional obligations and on the infeasibility of addressing severe detrimental externalities, such as ACC, through the price mechanism.

[11] These investments would likely be mostly indirect, with a network of agents and intermediaries providing certificates of sustainably performed carbon-conserving activities to energy supply firms in the North seeking to provide evidence of performance of their obligations.

Whether such a shift would automatically benefit the South on account of its comparative advantage in land and climate, or whether it would be necessary on equity grounds also to include in the obligations that some large proportion of the activities should be conducted in the South, is for future discussion and possible negotiation. What is clear is that the proposed obligations could address two equity issues together, the second being the vast transfer of wealth to firms[12] in the North that comes as a result of 'grand-fathering' emissions permits. Apart from redirecting normal investment flows away from business-as-usual investment in policy-adverse directions, an additional source of funds would thus come from energy price increases that reflect the scarcity value of emissions permits. Under rising proportional obligations, maybe with a minimum (large) South component, funds would be directed towards progressively rectifying the historic inequity. This would, as has been a longstanding concern in the South, be clearly additional to official development assistance, as they would be private sector funds.

7 A way forward

Whatever is done to implement the Strategy, it must clearly be complementary to Kyoto and not pose as an alternative. First, as discussed in Section 4, there must be great doubt as to the effectiveness of the Strategy until it is well on the way to success – the punitive psychology of cap and trade, supplemented by geo-engineering, may be the only response possible to the threat of ACC. And second, there is great momentum in the growth of carbon markets which it would be counter-productive, and in any case politically inconceivable, to impede.

Fortunately, the Strategy both provides additional CDM projects in the South and reduces the propensity to emit in the North. Thus the increasing supply of biofuels due to the Strategy, taken with its new plantation sinks, enables more ambitious commitments to be undertaken after 2012. And using the initial issue of emissions permits, as mentioned above, to lever proportional obligations provides a seamless policy framework, besides driving the equity objective. Thus Protocol and Strategy are potentially synergistic.

No new multi-Party negotiation is needed to initiate the Strategy. Each Party to the Convention has agreed to its Article 3.3, which requires Parties that perceive danger of severe or irreversible damage from climate change to take action without delay on account of scientific uncertainty (either as regards the danger or the efficacy of the action). Thus there is no need to agree on collective action as is required under Article 4.2(d), from which the Berlin Mandate and the Protocol hang.

Parties that proclaim the seriousness of climate change and the nearness of some tipping point, should, under Article 3.3, simply get on with addressing the threat of ACC. In doing so, they will stimulate their businessmen to get ahead with the technologies of tomorrow. Then bilateral bioenergy partnerships could commit South countries to sustainable good

[12] Of course, these are the firms in just those energy intensive sectors where past behaviour is responsible for the present dangerous stock of carbon in the atmosphere. If there seems some justice in denying such grandfathered reward for past misdeeds, it should be noted that the burden falls on consumers of the products of those sectors, and tomorrow's consumers will have this generation to blame. Still, this one-generation transfer, with carbon stocks safely relocated by mid-century, may seem closer to justice than taking the risk of abrupt climate change burdening more distant generations with the permanent cost of abandoning the coastal cities that house much of the world's population, and their surrounding fertile coastal regions (Stern 2006).

practice in relation to biosphere carbon stock management activities in return for becoming a favoured recipient of private sector investments from partner North countries.[13] Then the obligation of energy firms in the North, discussed above, would not simply require a (large) South component, it would be a large component from the specified bilateral partner country. Then also the definition of what is sustainable would cease to be a matter for the host country to decide, but would become a matter for negotiation towards scientifically valid criteria. There is at present considerable debate (Best 2006; www.biofuelswatch.org.uk) as to what such criteria should be, and an initial phase in developing a global framework for the Strategy could simply be to 'let one hundred flowers bloom.' Different bilateral partners could negotiate whatever sustainability criteria seem right for them.

With the passage of time, experience on what works best would emerge, and consensus be reached on best practice, possibly under the aegis of the G8's Global Bioenergy Partnership. A key role for G8 (and maybe a test of its seriousness in addressing the climate change issue) would be to agree on the rate at which the Strategy needs to be ramped up in order to maintain the squeeze described above on policy-undesirable technologies. Ultimately, if it were acceptable to the Convention Parties, then such a global partnership could become formalized into a second Protocol addressed under Article 3.3 at the threat of ACC (maybe the Wellington Protocol, after the city where the idea was first floated). This would leave the Kyoto Protocol intact as the response under Article 4.2.d to long-term climate change – one law for murder, another for manslaughter.

8 Conclusion

At the outset of this essay, and somewhat unusually in a journal of scientific discourse, I invited the reader to engage in two acts of imagination. It is obviously a question of judgment on which others may differ, but, given the inherently punitive and beggar-my-neighbour nature of an emissions cap, given the continuance of entrenched interests that have hindered progress to date, and given its prospective need to impose burdens on the South rather than rectify historic inequity, I regard the first (spectacular success with the Kyoto emissions cap) as entirely implausible as well as (Fig. 1) plainly incapable of an effective response to the threat of abrupt climate change, a view in which I am not alone (Crutzen 2006).

However, others may judge that the second, the Strategy outlined in this essay, is deeply implausible, on grounds of the enormity of the organizational task involved in rapidly transforming and improving the ways in which we make use of the land worldwide – in the spirit of *Candide*, call it global gardening. This despite the win–win–win negotiability of the Strategy, delivering on a variety of multilateral environmental agreement aims (Grover 2007).

Those sharing my view will hope that the vision and rhetoric of policy-makers will augment 'emissions reductions' with 'carbon removals' – getting carbon out of the atmosphere and putting it somewhere safer through biosphere carbon stock management; that they will regulate to squeeze out those technologies that compete with biomass as fuel raw material; and that, driven by clear long-term policies, the vision of energy sector

[13] Such agreements would appear not to fall foul of developing WTO analysis of the relationship between environmental concerns and free trade principles (Singh 2006). For instance, modern bio-energy could come within WTO infant industry provisions for a number of years, while achieving take-off.

players seeking to secure raw material supplies will shift from getting fossilized biomass to growing live biomass.

It is clear that there is great room for doubt as to how far and fast it is possible to go with the Strategy. Certainly it cannot achieve rapid take-off without early implementation of a capacity building programme such as mentioned in Section 5. And a clearer idea of how far and fast can only emerge from a research programme outlined elsewhere (Read 2006).[14] But, however far and fast it is possible to go with the Strategy, Article 3.3 of the Convention makes it incumbent on each Party that takes the threat of ACC seriously to take action individually, without delay on account of scientific uncertainty. Nothing stops any developed country from initiating negotiations for a Bilateral Bioenergy Partnership – guaranteeing a market for biofuel exports in exchange for assured sustainability in their production – with its chosen land-rich partner, or partners, tomorrow.

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[14] A programme that would have included precautionary research into albedo enhancement by injecting aerosols into clouds, had I been aware of that possibility when writing (Read 2006). Crutzen (2006) proposes injecting sulphate aerosols into the tropical upward branch of the stratospheric circulation, but maybe into the sub-polar upward branches would be effective in relation to the polar amplification of climatic change that we are experiencing. Salter and Latham (2007) propose injecting micron sized droplets of seawater into strato-cumulus clouds at low latitudes where avoided insolation is greatest. Crutzen also mentions that forestry, as an alternative to his approach, has its problems, and I hope I have addressed some of these in Section 5. I have not touched on albedo lowering due to forestry, and note here that that aspect is also for research. However, a return to pre-industrial CO_2 levels, along with total global forest coverage still about 1 GHa less than pre-industrial, and with albedo consequently greater than pre-industrial, may, *prima facie*, seem to offer hopes for a return to the climatic quasi-stability of the last several millennia. This, it appears, has resulted fortuitously from anthropogenic emissions due to forest clearances and paddy rice cultivation (Ruddiman 2003).

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