IUCN ACADEMY OF ENVIROMENTAL LAW

Conference on Climate Law in Developing Countries Post-2012: North and South Perspectives

(University of Ottawa, 26 – 28 September 2008)

THE ROLE OF MARINE "FORESTS" AND SOILS AS CARBON SINKS: ENHANCED BIO-SEQUESTRATION AS A MITIGATION STRATEGY

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Introduction

One of the most critical questions facing humankind today is: "What will it take to avoid dangerous climate change"?[1] As negotiations increase in intensity in the lead-up to the meeting in Copenhagen in December 2009 at which it is hoped that a post-Kyoto agreement will be developed, this question acquires greater relevance. The adoption of the UNFCCC in 1992 was a tentative first step towards the development of comprehensive and effective strategies to combat climate change. As a "framework" Convention, it inevitably avoided specific targets. The Kyoto Protocol[2] represented a significant step forward, by establishing initial targets for the reduction of CO2 emissions by some 39 countries listed in Annex 1. These targets were never envisaged to fully address climate change, but rather were developed as a "first step" or interim measure.

Now, the challenge of developing an effective global strategy to combat climate change stares negotiators in the face. Whilst the post-Kyoto agreement is intended to address targets for the period until 2020, there is a growing awareness that the seriousness of the climate change problem demands long-term responses that must be initiated as soon as possible. It is impossible therefore to avoid any longer the "bottom-line" question of what is required to avoid dangerous climate change. The answer to this question has two aspects:

- first, to establish the targets and timetables relating to reductions in the emission of CO2 and other greenhouse gases (GHG's) that can achieve a "safe" long-term level of concentration of these gases in the Earth's atmosphere; and
- second, to identify and implement the specific strategies by which the agreed targets and timetables can be achieved.

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[1] Article 2 of the United Nations Framework Convention on Climate Change, 1992 provides that: "The ultimate objective of this Convention and any related legal instruments that the Conference of the Parties may adopt is to achieve, in accordance with the relevant provisions of the Convention, stabilization of greenhouse gas concentrations in the atmosphere at a level that would prevent dangerous anthropogenic interference with the climate system" : see 38 I.L.M 849 (entered into force March 21, 1994).

[2] Kyoto Protocol to the United Nations Framework Convention on Climate Change, 1997, 37 I.L.M. 32, entered into force on 16 February, 2005.

Each of these two aspects has both a scientific and a policy dimension. Science can offer an analysis of what are the appropriate concentrations/reductions targets, whilst policy - in the form of a new international agreement - will reflect the reductions targets that the negotiating parties are willing to assume. It is quite possible that the scientific assessments may well be overwhelmed by the political, economic and social considerations involved in this process.

Similarly, in terms of strategies to deliver agreed emissions reduction targets, science can perform a crucial role (for example, in demonstrating the viability of carbon capture and storage (CCS) or of alternative forms of renewable energy), but the means actually chosen by each nation to achieve its reduction goals will again be influenced by political, economic and social considerations. As a result, the potentially most effective strategies may be rejected or relegated in priority in favor of others that are less likely to achieve the overall goal.

The gap, or possibly gulf, between science and policy in relation to climate change may be exacerbated by another factor. This is the complexity of climate change science and the rapidly evolving level of understanding of the causes and effects of climate change. Even as negotiations for a post-Kyoto agreement are proceeding, the science concerning the appropriate targets and timetable for GHG emissions reductions is fast developing, in particular through observations that significant and unanticipated "tipping points" may already be being reached in relation to climate change[3]. Science also continues to present new insights with respect to the capacity of various strategies to contribute to the reduction of GHG emissions and concentrations, for example with respect to bio-sequestration options[4]. It is a huge challenge for the negotiators of the post-Kyoto agreement to take into account the rapidly evolving science of climate change as they struggle simultaneously to balance all of the other immediate and pressing considerations before them.

This paper focuses closely on the emerging science of climate change in order to address the legal and policy measures that are required by way of a response thereto. It endeavors to address both elements of the "bottom-line" question identified above – the targets and timetables for GHG emissions reductions and the strategies by which these may be achieved. More specifically, it describes the scientific assessments contained in the IPCC's Fourth Assessment Report in late 2007, and the scientific reports that have emerged since then, which suggest that much more stringent reductions targets are necessary than those canvassed by the IPCC. It also explores how recent scientific understandings of the role of bio-sequestration suggest a critical role for this strategy in avoiding dangerous climate change. In each of these contexts, it will be submitted that the current framework for negotiation of a post-Kyoto

[3] See, in particular, recent papers by the U.S. scientist, James Hansen, discussed further below.

[4] See discussion below re role of both marine plants and soils alongside forests as carbon sinks.

agreement is out of touch with the scientific realities and that more radical responses than those currently in contemplation are required.[5]

Part I: Establishing Targets and Timetables to Avoid "Dangerous" Climate Change

(i) The IPCC's Fourth Assessment Report (2007)

The most obvious scientific frame of reference for the negotiators of the post-Kyoto agreement is the Fourth Assessment Report of the IPCC, released in November 2007 just prior to the United Nations Climate Change Conference in Bali[6]. Its principal conclusion is not qualified in the same manner as were earlier reports by the IPCC:

> "Warming of the climate system is unequivocal, as is now evident from observations of increases in global average air and ocean temperatures, widespread melting of snow and ice and rising global average sea level.[7]"

The IPCC's 2007 Report also concludes that: "Most of the observed increase in globally-averaged temperatures since the mid-20th century is *very likely* due to the observed increase in anthropogenic GHG concentrations."[8]

In assessing the likely impacts of projected climate change, the IPCC canvasses six scenarios for GHG emissions from 2000 to 2100 and projects the likely temperature change associated with each scenario. These indicate potential increases of between 1.8 -4.0° C from 2000 levels by 2001 as a "best estimate", but within a "likely" range of 1.1-6.4° C.[9] Based on these estimates, the IPCC predicts that sea-levels may rise by somewhere between 18 and 59 centimetres by 2100[10]. The report virtually excludes the

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[5] This is the first of a two-part analysis of how to address climate change; in the second part, to be presented in a paper to the IUCN Academy of Environmental Law Colloquium in Mexico City in November 2008, I will analyze the underlying "drivers" of climate change, which I identify as over-consumption of natural resources; the paradigm of economic growth; and population growth, in order to suggest that no solution will be effective unless it incorporates strategies that are related to these three elements.

[6] The full report of the IPCC comprises the reports of its 3 Working Groups and an over-arching Synthesis Report, all of which are available at www.ipcc.ch/ . Also, a short Summary for Policymakers provides a succinct overview of the key findings of the full report: see http://www.ipcc.ch/pdf/assessment-report/ar4/syr/ar4_syr_spm.pdf (hereinafter cited as "IPCC SPM").

[7] IPCC SPM 2007, at 12.

[8] Id., at 5.

[9] Id., at 7 (Figure SPM.5). These estimates are based on a scenarios developed in 2000 for the IPCC Report on Emissions Scenarios, and include ranges from about 600 ppm (Scenario B1) to 1550 ppm (Scenario A1F1) CO2-eq.

[10] Id., at 8 (Figure SPM.1).

possibility of significant melting of the Antarctic ice sheet[11] and does not envisage an immediate, major threat from the melting of the Greenland ice sheet:

> "Current models suggest virtually complete elimination of the Greenland ice sheet and a resulting contribution to sea level rise of about 7m if global average warming were sustained for millennia in excess of 1.9 to 4.6° C relative to pre-industrial values".[12]

It does however acknowledge the possibility that sea-levels could rise more rapidly over the coming centuries:

> "Partial loss of ice sheets on polar land could imply metres of sea level rise, major changes in coastlines and inundation of low-lying areas, with greatest effects in river deltas and low-lying islands. Such changes are projected to occur over millennial time scales, but more rapid sea-level rise on century time scales cannot be excluded".[13]

For the purpose of considering targets and timetables for GHG emissions reductions, the most relevant information is provided in the final section of the IPCC's Summary for Policymakers, which addresses the "long-term perspective". A specific link to Article 2 of the UNFCCC is provided at the commencement of this section through the observation that determining what constitutes "dangerous anthropogenic interference with the climate system" involves value judgments (whilst also noting that "science can support informed decisions on this issue…").[14] This is an important caveat inasmuch as it concedes that the ultimate choice of mitigation targets and strategies will be a subjective, political decision rather than one based solely on the scientific evidence.

This section of the Summary employs six "stabilization scenarios", each of which constitutes a range for the concentration of CO2 at long-term, stable levels. Category I represents the lowest mitigation scenario (350 – 400 ppm), and essentially constitutes the status quo, given that CO2 levels were measured at 384 ppm in 2007[15]. The highest mitigation scenario envisages a future concentration of CO2 between 660-790 ppm (Category VI).

In order to account for other greenhouse gases (methane, nitrous oxide et.al.), each of the stabilization scenarios is converted into a CO2-eqivalent (CO2-eq) concentration. Thus, for Category I, a range of 445-490 ppm CO2-eq is indicated, with the report noting in a footnote to Table SPM.6 that "the best estimate of total CO2-eq concentration in 2005 for all long-lived GHGs is about 455ppm…"[16]. Thus, a

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[11] Id., at 12: "Current global model studies project that the Antarctic ice sheet will remain too cold for widespread surface melting and [will] gain mass due to increased snowfall."

[12] Id., at 12.

[13] Id., at 13.

[14] Id., at 18.

[15] Russell, J., "Climate Change Accelerates" in *Vital Signs Online*, Worldwatch Institute, February 2008 (available at www.worldwatch.org); see Figure 3.

[16] IPCC SPM 2007, at 20.

stabilization target of approximately 450ppm CO2-eq would require a lowering in concentration from current levels (following a temporary higher peak due to the momentum in climate change) and hence very substantial reductions in emissions of CO2 and other GHGs. This is reflected in the following statement in the Summary:

> "In order to stabilise the concentration of GHGs in the atmosphere, emissions would need to peak and decline thereafter. The lower the stabilisation level, the more quickly this peak and decline would need to occur".[17]

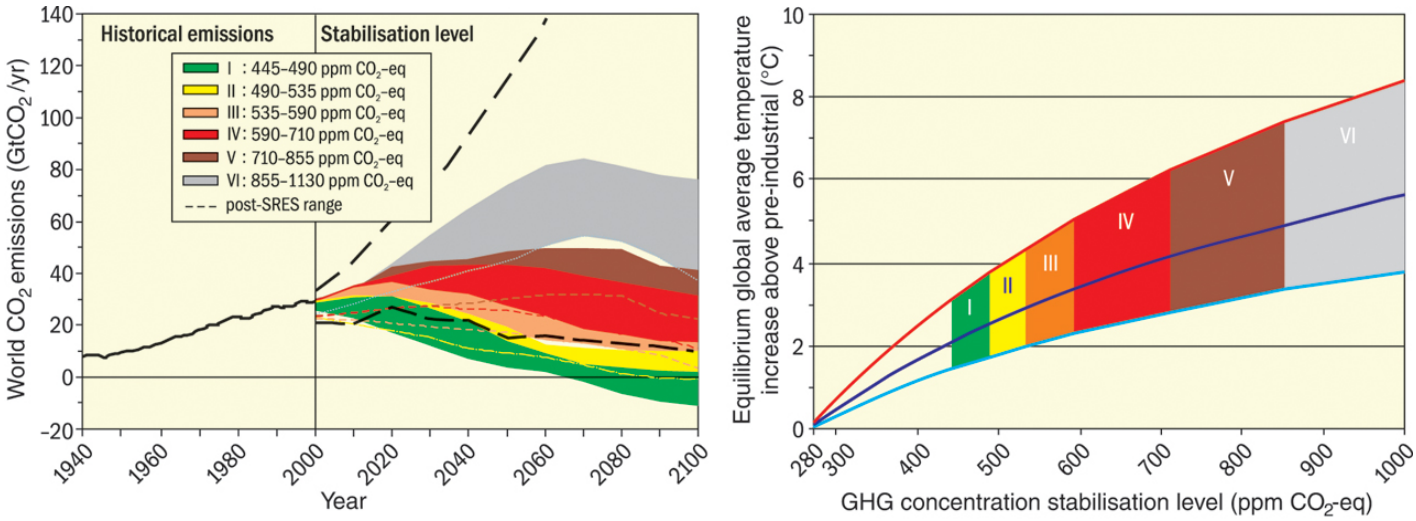
In choosing a particular stabilisation level, the most significant consideration is widely regarded to be the likely average temperature increase that will be associated with such a level. Figure SPM.11 of the Summary for Policymakers provides an illustration of the relationship between the six stabilization targets and the likely equilibrium global average temperature increase above pre-industrial levels. It suggests that the "best estimate" for Category I is an average increase of just over 2° C; for Scenario 2, which assumes a concentration of about 550ppm CO2-eq, the best estimate is in the vicinity of 3° C.

It should be noted that there is a much wider range of temperature increase indicated in Figure SPM.11, reflecting the upper and lower bounds of "likely" temperature increase. Thus, even Category I allows for the possibility of an increase of up to almost 4° C. Also, a footnote to Table SPM.6 makes the important qualification that these estimated temperature increases achieve an equilibrium level over a few centuries. Therefore, they cannot be assumed to be applicable over the next 50-100 years and indeed the footnote adds that "estimates for the evolution of temperature over the course of this century are not available…for the stabilization scenarios".

These are significant concessions in terms of the level of current scientific understanding of the critical link between particular stabilization targets and related likely temperature increase over the next 40 -50 years[18]. The correlation between a stabilization target of 450ppm and a limit in increase of global average temperatures of 2 – 2.4° C above pre-industrial levels is far from strong and there is an acknowledged possibility that, even within this target, temperature might increase by up to almost 4° C.

[17] Id., at 19.

[18] Note, however, the projections for temperature increase over the next century at Figure SPM.5, referred to above in fn.* and accompanying text, which are based on earlier scenarios developed in 2000 (and suggesting a best estimate range of 1.8 – 4.0° C increase).



IPCC, Summary for Policy Makers, 2007: **Figure SPM.11** CO_2 emissions and equilibrium temperature increases for a range of stabilisation levels

The other critical question in terms of targets and timetable is the level of reduction in emissions of GHG's required to achieve a desired stabilization target. The particular difficulty with the principal GHG, CO2, is that it has a relatively long life in the atmosphere, so that to the extent that emissions are not able to be sequestered naturally in oceans or forests, they will accumulate for many years.[19] It is this momentum from historic emissions of CO2 that renders the task of achieving a low stabilization target extremely difficult. It also explains why the longer the delay in reducing CO2 emissions, the greater the eventual challenge will be in terms of achieving a target such as 450ppm CO2-eq.

Table SPM.6 in the Summary for Policymakers provides a summary of the peaking years and changes in CO2 emissions required by 2050 (compared to 2000 emissions) for each of the six stabilization scenarios. For Scenario 1, it indicates that emissions of CO2 would need to peak by 2015 and to reduce by 50-80% by 2050.

[19] CO2 will reduce by about one-third after 10 years in the atmosphere, by two-thirds after 100 years and by four-fifths after 1000 years: Brook, B.W., *Climate Change and Population,* presentation at University of Adelaide, 8August 2008 (powerpoint presentation on file with author).

Table SPM.6. *Characteristics of post-TAR stabilisation scenarios and resulting long-term equilibrium global average temperature and the sea level rise component from thermal expansion only.[a] {Table 5.1}*

Category	CO_2 concentration at stabilisation (2005 = 379 ppm)[b]	CO_2-equivalent concentration at stabilisation including GHGs and aerosols (2005 = 375 ppm)[b,c]	Peaking year for CO_2 emissions[d,e]	Change in global CO_2 emissions in 2050 (percent of 2000 emissions)[d]	Global average temperature increase above pre-industrial at equilibrium, using 'best estimate' climate sensitivity[f,g]	Global average sea level rise above pre-industrial at equilibrium from thermal expansion only[f]	Number of assessed scenarios
	ppm	ppm	year	percent	°C	metres	
I	350 – 400	445 – 490	2000 – 2015	-85 to -50	2.0 – 2.4	0.4 – 1.4	6
II	400 – 440	490 – 535	2000 – 2020	-60 to -30	2.4 – 2.8	0.5 – 1.7	18
III	440 – 485	535 – 590	2010 – 2030	-30 to +5	2.8 – 3.2	0.6 – 1.9	21
IV	485 – 570	590 – 710	2020 – 2060	+10 to +60	3.2 – 4.0	0.6 – 2.4	118
V	570 – 660	710 – 855	2050 – 2080	+25 to +85	4.0 – 4.9	0.8 – 2.9	9
VI	660 – 790	855 – 1130	2060 – 2090	+90 to +140	4.9 – 6.1	1.0 – 3.7	5

To achieve this significant level of reductions, it will be necessary for developed countries (usually identified by reference to Annex 1 of the Kyoto Protocol) to reduce emissions even more substantially in order to accommodate unavoidable growth in emissions in the rest of the world. In the 2007 report of Working Group III, it is suggested that to achieve a stabilization target of 450ppm CO2-eq, reductions would be required from Annex 1 countries in the range of 25-40% by 2020 and 80-95% by 2050 (compared to 1990 values).[20] The WG III report also recognizes the need for mitigation efforts by many developing countries between now and 2020 if the lowest mitigation target of 450ppm is to be achieved:

> "Under most of the considered regime designs for low and medium stabilization levels, the emissions from developing countries need to deviate – as soon as possible – from what we believe today would be their baseline emissions, even if developed countries make substantial reductions. For the advanced developing countries, this occurs by 2020 (mostly Latin America, Middle East and East Asia)."[21]

These suggested levels of cuts in emissions for the Annex 1 countries under the 450ppm target are very substantial, even in the period between now and 2020, but the IPCC concludes that "all stabilization levels assessed can be achieved by deployment of a portfolio of technologies that are either currently available or expected to be commercialized in coming decades…"[22]. The Summary also suggests that "60-80% of the reductions would come from energy supply and use, and industrial processes, with

[20] IPCC, Working Group III Report, *Mitigation of Climate Change,* at 776 (Box 13.7), available at http://www.ipcc.ch/ipccreports/ar4-wg3.htm .

[21] Id., at 775.

[22] IPCC SMP 2007, at 20.

energy efficiency playing a key role in many scenarios"[23], but acknowledges that "non-CO2 and CO2 land-use and forestry mitigation options provides greater flexibility and cost-effectiveness".[24]

It is far from clear, however, that a stabilization target of 450ppm CO2-eq, and the associated targets for Annex 1 countries of up to 40 % reductions in CO2 emissions by 2020 and 80-90% by 2050, have sufficient support to be reflected in the proposed post-Kyoto agreement – especially since this stabilization target also requires significant reductions from baseline emissions by 2020 by many developing countries[25]. This may be a much too simplistic formula for the negotiators to consider, as is recognized in the excellent survey in Chapter 13 of the WG III Report (which canvasses the extensive range of options available to negotiators). On the other hand, given the range of possible temperature increase which may be possible under this scenario, and the IPCC view that an increase in excess of 2° C seems highly likely to result in significant impacts[26], it is understandable that any outcomes of the negotiations in Copenhagen in December 2009 will be measured against such standards.

(ii) **Recent reassessments of targets and timetables to avoid "dangerous climate change**

Since the release of the IPCC's Fourth Assessment Report, a new wave of scientific opinion has emerged which strongly suggests that the IPCC's lowest stabilization scenario (Category I), upon which the target of 450ppm CO2-eq is based, will not be capable of avoiding dangerous climate change. These most recent papers and reports highlight four aspects of the IPCC assessment that are considered open to question[27].

1. Acceleration of CO2 emissions

In a report published in September 2007, Canadell et al. reported that the growth in CO2 emissions, especially since 2000, has been much faster than anticipated by researchers and was 35% higher in 2006

[23] Ibid.

[24] Ibid.

[25] A very recent indication to this effect is the recommendation in a report submitted to the Australian government on 5th August 2008 by an independent expert, Professor Ross Garnaut, that it is unrealistic to press for an initial international stabilization target of less than 550ppm CO2-eq, given current levels of economic growth. The report also recommends that Australia should aim for an interim target of 10% reduction in CO2 emissions by 2020 and 80% by 2050 to meet its contribution to the 550ppm target; however, the 2020 taregt should be reduced to just 5% if major developing country emitters such as China do not undertake mitigation commitments as well; see Garnaut Climate Change Review, Targets and Trajectories, Supplementary Draft Report (Commonwealth of Australia, 2008), available at http://www.garnautreport.org.au/reports/Garnaut%20Review%20-%20Targets%20and%20trajectories%20-%20Supplementary%20Draft%20Report%20-%205%20Sept%202008.pdf

[26] Id., at 10 (Figure SPM.7: "*Examples of Impacts Associated with Global Average Temperature Change").*

[27] For an excellent summary, see The Climate Institute, *Evidence of Accelerated Climate Change,* report prepared by the Climate Adaptation Science and Policy Initiative, The University of Melbourne, November 2007; available at http://www.climateinstitute.org.au/images/stories/CI056_EACC_Report_v1.pdf

than in 1990[28]. During the period 1990-1999, the growth rate in CO2 emissions was 1.3%, but this rose to 3.3% in the period 200-2006[29], driven to a large extent by the rapid expansion in energy production and use in China and India. The International Energy Agency, in its World Energy Outlook 2007 report released in November 2007, notes that between 2005 and 2007, China's emissions have gone from 35% of USA emissions to overtake the USA as the world's largest emitter of CO2. It also notes that India will be the world's third largest emitter by 2015 under current trends[30].

According to one report, this recent high growth rate "exceeds that in the most fossil fuel intensive emissions scenarios used by the IPCC".[31] Thus, the possibility of driving GHG concentrations to levels that will result in 'dangerous climate change' may be higher than suggested by the IPCC and the capacity to achieve a peak in emissions by 2015, as called for in the Category 1 scenario, will be correspondingly less. The urgency of the need for mitigation strategies is clearly much greater in view of these trends.

2. Declining carbon sinks

Recent studies indicate that the capacity of both the oceans and terrestrial ecosystems to serve as 'sinks' for CO2 is decreasing, thereby contributing further to the acceleration in CO2 concentrations beyond the rate of emission increase[32]. It is argued that the IPCC has not taken this trend sufficiently into account in its predictions:

> "IPCC science expected this decrease but the observed changes are larger than estimated, suggesting that the carbon cycle is resulting in stronger and earlier warming than anticipated."[33]

Proposals to enhance ocean CO2 sequestration by iron fertilization have been found in a recent Canadian experiment to not be feasible[34] but other means of bio-sequestration not currently being employed may be able to assist in reversing this trend. These options will be discussed below.

3. Accelerated warming

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[28] Canadell, J. et a., "Contributions to Accelerating Atmospheric CO2 Growth from Economic Activity, Carbon Intensity, and Efficiency of Natural Sinks", *Proceedings of the National Academy of Sciences,* September 2007.

[29] Ibid.

[30] International Energy Agency, *World Energy Outlook 2007 – China and India Insights,* 2007, Executive Summary, at 50.

[31] The Climate Institute, op.cit fn *, at 3.

[32] Canadell, op.cit.; see also The Climate Institute, op.cit. at 7 (citing a recent study of the Southern Ocean); and Hengeveld, H. et al. (eds.), *Enhancement of Greenhouse Gas Sinks: A Canadian Science Assessment,* Canada, PERD POL 6.2.1 Final Report, 2008, at 60.

[33] The Climate Institute, op.cit, at 7.

[34] Hengeveld, op.cit., at 70.

Since the IPCC report in 2007, there has been a common assumption that a 450 ppm CO2-eq stabilisation target can restrict the amount of atmospheric warming since the industrial revolution to around 2° C. However, this assumption is not justified even by the IPCC report which, as noted previously, allows for the possibility of a rise of up to 4° C over this century. The evidence is growing that the 450 ppm target may result in substantially more than a 2° C increase in average global temperature.

According to the leading US climate change scientist, James Hansen, the Earth's climate system is about twice as sensitive to CO2 pollution as indicated in the IPCC's century-long projections[35]. He argues that current levels of GHG's are sufficient to trigger significant impacts:

> "No additional forcing is required to raise global temperature to at least the level of the Pliocene, 2-3 million years ago, a degree of warming that would surely yield 'dangerous' climate impacts."

This conclusion is based on the observation that a rise of 0.8° C has already occurred since 1860 and that another 1° C increase is inevitable, given current levels of CO2.[36] But a much sharper increase could result from "feed-back" events, including:

- release of methane from the thawing of the perma-frost regions;
- additional release of CO2 from drying and burning vegetation;
- release of stored CO2 from carbonates and frozen methane deposits in the deep ocean; and
- major albedo effects associated with melting ice sheets and reduced aerosol levels.

Any or all of these events could rapidly drive up GHG concentrations, producing a "tipping point" sufficient to cause catastrophic climate change. Hansen defines a "tipping point" as "the concept that climate can reach a point where, without additional forcing, rapid changes proceed practically out of our control"[37]. He concludes:

> ""…Earth's history shows that the positive feedbacks allow global warming to be relatively rapid, including sea level rise as fast as several meters per century [7]. Thus if humans push the climate system sufficiently far into disequilibrium, positive climate feedbacks may set in motion dramatic climate change and climate impacts that cannot be controlled."

4. Ice-melt and associated sea-level rise

The most dramatic indication that climate change is progressing at a much faster rate than any of the IPCC's 2007 predictions arises from observations of melting sea ice in the Arctic ocean, land-based ice

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[35] Hansen et al., "Target Atmospheric CO2: Where Should Humanity Aim?" revised version 18 June 2008, available at http://arxiv.org/abs/0804.1126 at 11; see also Hansen et al., "Climate Change and Trace Gases", *Philosophical Transactions of the Royal Society* 365 (2007).

[36] Id., at 6; see also,Glickson, A.Y., "Milestones in the Evolution of the Atmosphere with Reference to Climate Change", 55 *Australian Journal of Earth Sciences 125, at 137*(2008).

[37] Hansen 2008, op.cit., at 11.

melt in Greenland and collapsing ice shelves in West Antarctica[38]. Hansen is particularly critical of the IPCC's projections in relation to sea-level rise:

> "Our concern that BAU (business as usual) GHG scenarios would cause large sea-level rise this century differs from estimates of IPCC, which foresees little or no contribution to twenty-first century sea-level rise from Greenland and Antarctica. However, the IPCC analyses and projections do not well account for the nonlinear physics of wet ice sheet disintegration, ice streams and eroding ice shelves, nor are they consistent with the palaeoclimate evidence we have presented for the absence of discernible lag between ice-sheet forcing and sea-level rise."[39]

Hansen's recent research departs from the use of climate models to predict future climate trends and instead utilizes evidence from the Earth's history, based on the study of cores taken from the bottom of the ocean, to measure CO2 levels millions of years ago. These indicate that the world began to glaciate at the start of the ice age, around 35 million years ago, when the concentration of CO2 was about 450ppm. Hansen believes de-glaciation is already commencing and argues that it is possible that substantial increases in sea-level could follow in as little as a few decades, rather than the centuries contemplated by the IPCC:

> "Sea level changes of several meters per century occur in the paleoclimate record, in response to forcings slower and weaker than the present human-made forcing. It seems likely that large ice sheet response will occur within centuries, if human-made forcings continue to increase. Once ice sheet disintegration is underway, decadal changes of sea level may be substantial."[40]

In a paper just published in *Science,* Pfeffer et al have presented the first assessment of how changes to the ice sheer may affect sea level rise, concluding that a rise of between 80 cms and 2 metres could occur "under physically possible glaciological conditions".[41]

The overall effect of these various recent scientific observations is to cast some serious doubt on the accuracy of the IPCC projections, including its most stringent scenario for the stabilization of GHG concentrations. With CO2 concentrations already at 384ppm, and being driven upwards at an accelerating rate, the strategy of limiting warming to just 2° C by stabilizing concentrations at about 450ppm CO2-eq is now highly questionable. Hansen notes that the forcing effect of other GHG gases than CO2 is currently being off-set to a large extent by the cooling effect of high albedo aerosols. He argues that even if these aerosols are eliminated in the future through enhanced pollution controls, their loss could be counteracted by significant reductions in another GHG, black soot, through the same

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[38] For a summary of recent studies of ice melt in Greenland and West Antarctica, see Russell, j., op.cit., fn *., at 2.

[39] Hansen 2007, op.cit., at 21.

[40] Hansen 2008, op cit., at 6.

[41] Pfeffer et al., "Knematic Constraints on Glacier Contributions to 21st Century Sea-Level Rise", *Science, 5* September 2008, Vol 321, pp. 1340-1343.

controls[42]. He therefore concludes that an initial stabilization target should be focused on CO2 levels[43], and set at 350 ppm, but "to be reassessed as effects on ice sheet mass balance are observed"[44].

A 350 ppm target for CO2 concentrations is well beyond the contemplation of the negotiators of the post-Kyoto agreement. Both the European Union and, most recently, the Garnaut Inquiry in Australia, have recommended a target of 550ppm CO2-eq, which would allow for some further increase in CO2 concentrations above current levels. The Hansen target, on the other hand, requires radical mitigation strategies, including the phase-out of coal by 2030 (which could reduce CO2 concentrations to 400ppm), and accompanying bio-sequestration of CO2 (through improved forestry and agricultural practices) in order to reduce concentrations by a further 50ppm or more (see figure below)[45].

The idea of a 350 ppm target for CO2 concentrations is gathering support in the non-government sector[46]. The British commentator, George Monbiot, who has written about climate change for over 20 years[47], has endorsed the target and suggested "we are talking at a minimum of a 100% cut [in Co2 emissions], and it looks like it might have to go to 110% or 115%."[48] This extends the mitigation strategy from a "zero carbon" to a "negative carbon" scenario, something that must boggle the minds of those charged with negotiating a post-Kyoto agreement.

[42] Id., at 12.

[43] However, strategies directed to non-CO2 GHG's, in particular methane and nitrous oxide, will also "buy time" with respect to the necessary reduction of CO2 emissions and consequent concentrations: see Hansen, J and Sato, M., "Greenhouse Growth Rates", available at www.pnas.org/cgi/doi/10.1073/pnas.0406982101 .

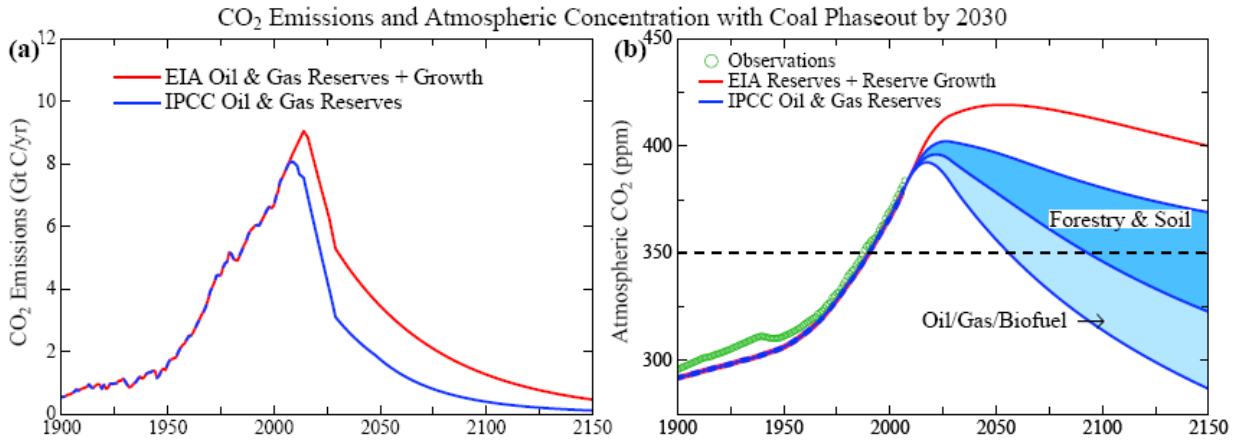
[44] Hansen 2008, op. cit., at 13.

[45] Hansen 2008, at 14

[46] See for example, the campaign launched in June 2008 to call on international leaders to adopt a 350ppm level for CO2: www.350.org .

[47] See, e.g., Monbiot, G., *Heat: How to Stop the Planet Burning,* Penguin Books, London, 2006.

[48] Monbiot, G., speech at the Camp for Climate Change, London, 18 August 2007, available at http://www.indymedia.org.uk/en/2007/08/378866.html .



Hansen, 2008: Fig. (6). (a) Fossil fuel CO2 emissions with coal phase-out by 2030 **(b)** Resulting atmospheric CO2 based on use of a dynamic-sink pulse response function representation of the Bern carbon cycle model.

The message behind the calls for a 350ppm target is brutally simple but highly unpalatable for policy-makers: it is necessary for all nations to shift to a low[49], or possibly zero[50] carbon economy within the next 20-30 years, and in addition to find the means to 'soak up' additional CO2 from the atmosphere in natural sinks, if dangerous climate change is to be avoided. The de-carbonization of national economies will require radical innovations with respect to energy systems, focused initially on energy efficiency and ultimately on alternative, renewable sources[51]. But it is the potential for bio-sequestration to also contribute to the attainment of the 350ppm target that is of particular interest in this paper. Given that there is evidence of a declining capacity of natural sinks to absorb CO2, as noted above, how can bio-sequestration possibly contribute to a reduction of CO2 concentrations in the order of 50ppm in the future? The final section of this paper will address this question.

Part Two: Strategies to Address Climate Change – the Critical Role of Bio-Sequestration

(i) Linking targets to the global carbon cycle

[49] For an excellent analysis of policy options for a "low carbon economy", see Epstein, P.R. et al., *Healthy Solutions for the Low Carbon Economy – Guidelines for Investors, Insurers and Policy Makers,* The Centre for Health and the Global Environment, Harvard Medical School, July 2008, available at http://chge.med.harvard.edu/programs/ccf/healthysolutions.html

[50] See, for example, Makhijani, A., *Carbon-Free and Nuclear-Free,* Institute for Energy and Environmental Research, 2007, available at http://www.ieer.org/ .

[51] The option of nuclear power is susceptible to serious risks in terms of nuclear proliferation, terrorism, serious accidents and management of wastes (see Mahkijani, op.cit., at 11); it is also questionable whether the additional energy capacity can be developed within a necessary time scale. Any benefits derived will also be offset initially by the substantial GHG emissions involved in construction of nuclear facilities.

To examine the potential role of bio-sequestration as a mitigation strategy, it is necessary to first understand the global carbon cycle. Indeed, this understanding is critical to the calculation of appropriate targets for the reduction of greenhouse gas emissions, since it is necessary to take into account the amount of CO2 that is likely to be sequestered naturally in undertaking this exercise.

A recent Canadian government publication that summarizes 25 years of research on the carbon cycle provides an excellent overview of the sources and sinks of GHG's[52]. The introductory chapter indicates that whilst global, anthropogenic emissions of CO2 have averaged 8.6 gigatons (Gt C) per year from 2000-2005 (and, as noted before, have increased by 3% per annum during this period), the net addition to the atmosphere is approximately 3.4 -4.4 Gt C per annum after allowing for natural sinks.[53] The oceans comprise the largest reservoir of CO2 and have provided a net annual sink since 1990 of about 2.2 Gt C. However, as noted before, there are serious concerns about the reducing capacity of the oceans to serve as a carbon sink which suggest that it is not safe to assume this level of uptake will continue in the future. Terrestrial ecosystems have provided an additional net annual sink of 2-3 Gt C (though this reduces to 1Gt C/year if emissions from forestry and other land use change are taken into account)[54]. These elements of the carbon cycle are clearly described in Figure 1.1 within the report:

[52] Canada, *Enhancement of Greenhouse Gas Sinks: A Canadian Science Assessment*, PERD POL 6.2.1 Final Report, Minister of Public Works and Government Services, Canada, 2008. This report is also available electronically at http://www.msc.ec.gc.ca/education/scienceofclimatechange/understanding/EGGS/EGGS_e.pdf (hereinafter cited as "Canada, 2008").

[53] Hengeveld, H., "An Overview of the Background Science and Goals of Canadian Research Activities Relevant to Enhancement of Greenhouse Sinks in Canada", in Canada 2008, op. cit., at 4 – 5.

[54] Ibid.

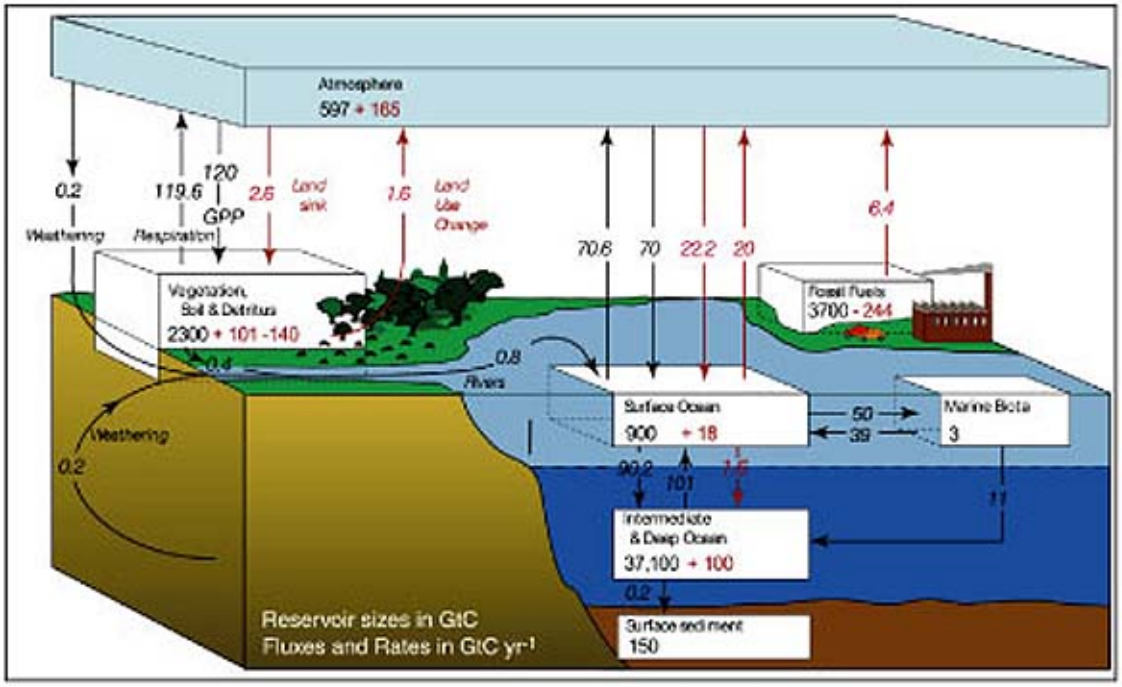


Figure 1.1: The global carbon cycle for the 1990s, showing the main annual fluxes in Gt C yr^{-1}: pre-industrial 'natural' fluxes in black and 'anthropogenic' fluxes in red.

Source: Canada, Enhancement of Greenhouse Sinks: A Canadian Science Assessment, 2008 [55].

These figures assist in understanding the basis of the emissions reduction targets currently under consideration by negotiators of the post-Kyoto agreement. If global emissions of CO2 can be reduced by half from their current level of 8.6 Gt C per annum (which would mean a reduction of about 80-90% in developed countries to allow for necessary growth in emissions in developing countries), this should

[55] Id., at 2. It is important also to understand that there are substantial variations from year to year in the natural uptake of CO2. The Canadian report notes that: "The amount of excess carbon removed will vary considerably from one year to the next, so that some years experience less than 20% removal while others experience more than 70% removal. That is because the processes for removal are sensitive to changes and variations in global climate" (ibid).

achieve a situation where emissions no longer exceed the rate of natural uptake[56]. This will result in a peaking of the atmospheric concentration of CO2 somewhere above the current level of 385 ppm, the exact point depending on when and to what extent the current trend of an increase in CO2 emissions is reversed[57]. It is this broad strategy that underpins the IPCC's most rigorous scenario for achieving stabilization of GHG's at a level that will have a strong chance of limiting global warming to 2° C.

However, if the most recent scientific advice is heeded that CO2 concentrations should be reduced eventually to 300-350 ppm in order to avoid the risk of dangerous climate change, it will be necessary to:

(1) reduce global emissions even further, for example by 75-80% to around 2 Gt. C per annum (which could mean having to achieve virtually zero energy-related emissions in developed countries by as soon as 2030, as proposed recently by Al Gore[58]); and

(2) to adopt strategies for increasing the removal (sequestration) of CO2 from the atmosphere.

Both of these approaches clearly are essential, whichever stabilization target is adopted. Furthermore, to the extent that the enhancement of natural sinks is used merely to "offset" ongoing emissions from anthropogenic sources, this will limit the rate of the reduction of global emissions and hence will impede the efforts to achieve the relevant stabilization target. In this sense, whilst off-sets under the Clean Development Mechanism (CDM) may have short-term benefits by assisting a transition to low or non-carbon technologies, they will not contribute to the achievement of a long-term stabilization goal for CO2.

(ii) Options for the sequestration of CO2

1. Carbon Capture and Storage

Considerable effort is being devoted presently to researching the feasibility of carbon capture and storage ("CCS") technologies as a means of achieving the long-term sequestration of CO2 underground or in the deep ocean environment. Attention is also being directed to the legal measures required to facilitate the use of this sequestration method. However, even if such schemes prove to be technically feasible, they have a limited capacity in terms of the volume of CO2 that it is possible to remove by such

[56] For a strategy based on this approach see the report prepared for the Union of Concerned Scientists (USA): Luers, A. et al, *How to Avoid Dangerous Climate Change: A Target for US Emissions Reductions* (2007), available at www.ucsusa.org/global_warming/science/emissinstargets. html .

[57] See, for example, Meinhausen, M. et al., "Multi-Gas Emissions Pathways to Meet Climate Targets", *Climatic Change* (2005), proposing that CO2 emissions should peak at 8 Gt C/ year, then decline to 3 Gt C/year by 2050 and 1 Gt C/year by 2100 for a peak of 470 ppm CO2-eq, declining to below 400ppm CO2-eq eventually.

[58] Gore, A., "A Generational Challenge to Repower America", speech delivered in Washington D.C., July 17 2008, available (with comment) at http://dotearth.blogs.nytimes.com/2008/07/17/the-annotated-gore-climate-speech/

means, and it is necessary therefore to also consider means for the enhancement of natural sinks. If effective ways can be found to increase the natural uptake of CO2 from the current levels, these could provide a significant supporting strategy alongside those aimed at reducing the rates of CO2 emissions.

2. REDD and re-afforestation schemes

Deforestation currently accounts for 17-20% of global emissions of CO2. Indonesia is the now the world's third largest emitter of CO2, primarily due to the substantial logging of its forests, much of which has occurred illegally. The concept of "reducing emissions from deforestation and forest degradation", or REDD, has been given particular prominence in terms of the post-Kyoto framework for emissions reductions, following the Bali Conference in December 2007[59]. Whilst primarily intended as a strategy to reduce the rate of future emissions of CO2, recent scientific studies have suggested that the rate of uptake of CO2 in mature trees is far greater than previously thought, thus underlining the importance of this strategy in terms of maintain the current levels of uptake of CO2 through bio-sequestration.

Such schemes will not, of course, "enhance" the capacity of natural sinks, whereas re-afforestation can do so and has therefore been recognized as an appropriate mechanism for the development of carbon credits under the Clean Development Mechanism (whereas REDD has not, though for reasons related more so to accounting and reliability). Like CCS, there is a limit to the capacity of re-afforestation to provide for enhanced CO2 uptake, particularly given that mush deforested land has been converted to agricultural use[60].

There may, however, be other means of enhancing the capacity of the natural sinks provided by both the oceans and soils, in each instance borrowing from the REDD concept as applied to forests. It is these possibilities that will be addressed in the following section of this paper.

3. Enhancement of ocean sinks

It has been noted already that some proposals have been advanced for enhancing the uptake of CO2 in the oceans by artificial means such as iron fertilization, but have been found not to be practical[61]. Instead, recent scientific studies suggest that seagrass meadows may serve a significant function as carbon sinks. Given the substantial destruction of seagrass colonies in many parts of the world in recent decades, largely due to land-based pollution runoff, an effort to "re-afforest" these coliies and to protect those that remain could be a significant parallel strategy to those contemplated fro terrestrial forest systems.

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[59] See Fry, I., "Reducing Emissions from Deforestation and forest Degredation:Opportunities and Pitfalls in Developing a New Legal regime" (2008) 17(2) RECEIL 166.

[60] Though, often for the purpose of oil palm production, in countries such as Indonesia, and in conditions where the long-term viability of this land-use is unlikely.

[61] Canada 2008, op.cit fn*, at 69 - 70

A recent study undertaken for the South Australian Environment Protection Authority noted that over 25,000 hectares of seagrass meadows have been subject to catastrophic loss in the southern Australian coastal environment[62]. The dominant species of seagrass in this region (Presidiona Australis, which is similar to the Presidiona Oceanica species found in the Mediterranean region) has a large proportion of its biomass (up to 70%) stored below ground, most of which is likely to be lost when the above ground plant material is destroyed. The report suggests that stable bio-sequestration for decades to centuries could be achieved if environmental conditions can be maintained and seagrass plants continue to live above the stored carbon. Based on recent studies by Mateo et al (2006)[63], the report concludes that "seagrasses appear to be one of the most productive plant types with capacity to sequester carbon on the planet".

This is a most interesting perspective. Whilst considerable attention is now being focused by climate change negotiators on the role of terrestrial forests in contributing to climate mitigation strategies, the potential contribution of marine forests in the form of seagrass meadows does not seem to have yet been recognized. The protection of existing colonies from further destruction and the regeneration of lost colonies through appropriate marine protection and conservation strategies could provide an important additional mitigation approach, though of course it will involve the same issues with respect to measurement of carbon uptake and long-term storage as apply in relation to forests.

4. Enhancing the role of soils as carbon sinks

It is estimated that at the beginning of the industrial revolution, terrestrial ecosystems stored some 2300 Gt C, with 80 % contained in soils and surface litter, the rest being in above ground vegetation[64]. In Canada, the conversion of natural ecosystems to croplands has caused the loss of 15-30% of the carbon originally present in the surface soil layer, mostly in the first two decades of cultivation. However, it is thought that "soil carbon is reaching a new equilibrium, largely due to smaller amounts of land being converted to cropland, decreases in summerfallow, increases in no-till farming and increased fertilizer use"[65]. Of course, the situation is substantially different in other parts of the world where conversion to cropland, for example for the production of biofuels, is proceeding at a rapid pace.

[62] Balance Carbon, "Australian Seagrass Meadows as Potential Carbon Sinks: Focus on Gulf St. Vincent, South Australia", report prepared for the Environment Protection Authority, South Australia, December 2007 (on file with the author).

[63] Mateo, M.A. et al, "Carbon Flux in Seagrass Systems", in Larkum, A.W., et al, *Seagrasses: Biology, Ecology and Conservation,* Springer, The Netherlands, 2006.

[64] By contrast, some 39,000 Gt C are stored in the intermediate and deep oceans, including sediments on the ocean floor; the surface waters (or upper 100 metres) store an additional 900 Gt C: see Hengeveld, op.cit fn*, at 2.

[65] Id., at 8.

Scientists are exploring innovative ways of enhancing the uptake of CO2 in soils. For example, an Australian team has suggested that by selecting particular strains of crops such as wheat and sorghum, CO2 can be locked up in "plantstones", otherwise referred to as phytoliths, which form around a plant's cells as they take up minerals from the soil. These microscopic balls of silica are virtually indestructible so that after the plant dies, they remain behind in the soil where they can sequester CO2 for thousands of years[66]. Thus, as the report notes, it might be possible for famers to earn income from carbon credits by changing to crops that store the most CO2 – provided, once more, that reliable methods of measuring the increased carbon uptake can be developed.

A more radical and potentially far-reaching option that has been proposed recently is to turn biomass into "bio-char" and thereby store very large amounts of carbon in soils for centuries or even thousands of years. A short paper released by the Institute for Governance and Sustainable Development (IGSD) in March 2008 provides a concise summary of the recent scientific literature concerning bio-char[67]. It notes that soils enriched with bio-char contain substantially more carbon (150gC/kg) than their surrounding soils (20-30gC/kg) and on average are more than twice as deep, thus enhancing further their carbon storage capacity. It also notes suggestions that up to 9.5 Gt C per annum could be stored by 2100 using bio-char sequestration schemes, in combination with bio-fuel programs[68] . This exceeds the current total emissions of CO2 annually[69].

There is an ancient Amazonian technique for the production of this fine-grained residue that involves covering biomass with soil and letting it smolder, but a modern chemical process known as pyrolosis can enable biomass to be converted to bio-char whilst at the same time yielding a liquid or gas bio-fuel. This process is energy positive, producing more energy than is invested. The IGSD suggests that bio-char schemes "have the potential to be implemented quickly and at scale in developing countries"[70]. Simply by converting from "slash and burn" methods to "slash and char" could reduce emissions from land-use change by 12% per annum. Other benefits include reduced emissions of methane and nitrous oxides from soils, restoration of degraded soils and increased crop yields[71].

There may be serious questions to be resolved once more with respect to how to measure accurately the uptake of CO2 though this soil sequestration technique, and also as to how to source the substantial

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[66] Nowak, R., "…while others lock carbon away for years", *New Scientist,* 5 January 2008, at 9 (reporting research by Leigh Sullivan and Jeff Parr, Southern Cross University, New South Wales, Australia).

[67] Institute for Governance & Sustainable Development, "Significant Climate Mitigation from Bio-Char", 17 March 2008, available at http://www.igsd.org/docs/Biochar%20Note%2010July08.pdf .

[68] Ibid.

[69] Ibid.

[70] Ibid.

[71] Ibid

volumes of biomass required for producing bio-char on a major scale. Nevertheless, the potential to achieve a significant enhancement of soil sinks appears to exist and it would seem appropriate for further research and policy appraisal of this option to be pursued. Whilst governments and industry are prepared to invest very substantial sums in "clean coal" via CCS, this means of increasing the bio-sequestration of CO2 does not appear to have the same level of interest or support.

Conclusions

The development of new approaches to the mitigation of climate change in order to avoid dangerous consequences requires a strong linkage between science and policy. The stabilization of CO2 and other GHG's at concentrations in the atmosphere that are likely to limit warming sufficiently for this purpose may well require far greater reductions in emissions from current levels than was envisaged by the IPCC in the most rigorous scenario presented in its 2007 Fourth Assessment Report in 2007. Very recent scientific reports suggest that a stabilization target of 350 ppm CO2 may be required to avoid potentially disastrous feed-back loops that could, for example, trigger significant warming and related sea-level rise over the course of this current century. The challenge for the negotiators of a post-Kyoto agreement in this respect is to deal with potential risks that may be of a low likelihood but which could have catastrophic consequences – a task that is not readily accommodated by the complex and convoluted climate change international negotiation process.

Given that a target of 350ppm is below the current concentration of atmospheric CO2 and that the momentum associated with the longevity of CO2 in the atmosphere means that concentrations must inevitably continue to rise for some time yet, a goal of achieving near-zero fossil fuel emissions of CO2 over the next 20 – 40 years in developed countries, coupled with strategies to achieve reductions from current levels in countries such as China, India, Brazil and Indonesia, and to limit the growth of emissions in other developing countries , would be required to meet this target. In addition to a focus on the reduction of fossil fuel emissions, it would be necessary simultaneously to find new means of extracting the accumulated concentrations of CO2 from the atmosphere. Whilst "engineered" approaches such as carbon capture and artificial stimulation of the ocean sink are being widely canvassed, the potential for enhancement of natural sinks at present is recognized primarily in the context of forests. There may be considerable potential for much greater gains in the natural uptake of CO2 by the oceans through the replenishment of seagrass colonies that have been severely depleted in coastal environments over recent decades. There appears also to be potential for a very substantial increase in the sequestration of CO2 in soils through the production of bio-char and its application to agricultural soils in particular. Additional reductions in emissions could also be achieved where liquid or gas by-products of the pyrolosis process are captured for use as bio-fuels.

Whilst the Clean Development Mechanism under the Kyoto Protocol allows for the uptake and retention of CO2 by forest ecosystems, there is a need for the post-Kyoto scheme that it is hoped will be developed by the end of 2009 to recognize and allow for other sinks such as marine seagrass "forests" and soils. A greater focus on both the scientific and policy dimensions of these options, rather than

“engineering” solutions such as carbon capture and control, is needed if the aim of avoiding dangerous climate change is to be achieved.