Climate Geo-engineering with ‘Carbon Negative’ Bioenergy

Climate saviour or climate endgame?

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and

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Cooling the Planet with Biomass?

> *“Biochar can remove 6 billion tones of carbon*
> *from the atmosphere every year”*
> Tim Flannery

> *"If humanity wishes to preserve a planet similar to that on which civilization developed and to which life on Earth is adapted, CO_2 will need to be reduced from its current 385 ppm to at most 350 ppm. An initial 350 ppm CO_2 target may be achievable by phasing out coal use except where CO_2 is captured and adopting agricultural and forestry practices that sequester carbon. …Biochar, produced in pyrolysis of residues from crops, forestry, and animal wastes, can be used to restore soil fertility while storing carbon for centuries to millennia. More rapid drawdown could be provided by CO_2 capture at power plants fuelled by gas and biofuels."* James Hansen et al [1]
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> *"We have already taken more than half of the productive land to grow food for ourselves. How can we expect Gaia to manage the Earth if we try to take the rest of the land for fuel production?"* James Lovelock[2]

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[1] James Hansen et al, "Target Atmospheric CO_2 : Where Should Humanity Aim?", 2008, www.columbia.edu/~jeh1/2008/TargetCO2_20080407.pdf

[2] James Lovelock, The Revenge of Gaia, 2006

This report represents a critical analysis of proposals for 'carbon negative' bioenergy as a means of reducing atmospheric carbon dioxide concentrations and thus mitigating climate change. The report concludes with a discussion of adequate responses to the climate crisis in the context of the converging ecological and social crises we also face.

The proposals discussed are advocated by a number of scientists including James Hansen and campaigning groups including 350.org, Beyond Zero Carbon, and the authors of Climate Code Red.

The report represents the authors' response to those proposals. It is also intended to contribute to the wider debate about bioenergy, climate change mitigation, and the nature of the converging planetary crises.

We believe that there is an urgent need for a wider civil society debate about the concept of 'carbon negative' bioenergy. We hope that this report will help to initiate such a discussion. We would welcome critical comments, which you can send to almuthbernstinguk[at]yahoo.co.uk or dee.rughani[at]btinternet.com.

We would like to thank Dr Rachel Smolker for comments and contributions to the report.

CONTENTS

0.1 Executive Summary

The two bio-geoengineering proposals discussed in this paper are attempts to address probably the greatest threat humankind has ever faced – catastrophic climate change. We attempt to answer the question: Will such global bio-geoengineering 'solutions' help to stabilise climate or could they trigger wide-scale collapse of our life support systems?

The evidence presented in **Section 1** makes clear that The UN Framework Convention on Climate Change has failed in its intention. Atmospheric concentrations of greenhouse gases (GHGs) are already at dangerously high levels. James Hansen along with other prominent scientists, environmental campaign groups such as 350.org and Beyond Zero Carbon, as well as the authors of Climate Code Red rightly state that even *dramatic reductions in GHG emissions, on their own, are now unlikely to be enough to stabilise climate.* Current atmospheric concentrations of 385ppm CO2, according to Hansen, need to be reduced to 350ppm CO2 or below.

Section 2 considers the different proposals for achieving this. We look at the potential for rapidly reducing emissions of short-lived, high-impact greenhouse gases and warming aerosols. We then give an overview of the two broad groups of geoengineering proposals for cooling the planet: Making the planet more reflective, and removing CO2 from the atmosphere. This paper is focused primarily on one aspect of this second grouping; the large-scale use of biomass as a substitute for fossil fuels, whilst simultaneously drawing down atmospheric CO2 by sequestering some of the carbon in the biomass, either underground or as charcoal to be added to soil.

Sections 3 and 4 consider in detail the two major proposals promoted by James Hansen and others for achieving these outcomes. They are; *bioenergy with carbon capture and storage* (BECS), and *bioenergy with biochar,* which is charcoal produced as a by-product from certain types of bioenergy production. We argue that the development of both BECS and biochar fits very neatly into a wider industry and political strategy to build a wider 'bio-economy'. This would entail the progressive replacement of fossil fuels with industrial biomass under corporate control, linked to a highly centralised energy system and modes of production. From an industry point of view, biochar in particular offers an attractive opportunity to make large, centralised bio-refineries more profitable and, potentially, commercially viable. Both BECS and biochar should therefore be seen as part of a wider corporate strategy for a bio-economy, which is based on industrial monocultures. Corporate patenting (which is already), the scale of biomass use for this purpose suggested by James Hansen and others, and any future inclusion into carbon trading would effectively rule out any different mode of biochar production and energy production based on BECS.

We further consider the energy balances of both technologies which are relatively poor because with BECS as well as biochar, the amount of energy that can be gained from a set amount of biomass is significantly reduced, resulting in a greater land requirement than many other types of bioenergy. There are serious doubts about the commercial viability of large-scale carbon capture and storage, and about the safe long-term storage of carbon either with BECS and even more so with biochar. Biochar is also being promoted as a way of increasing soil fertility, however there are no conclusive studies to say whether it does anything other than raise short-term productivity immediately after charcoal is added, or whether and how successful ancient methods of using charcoal to make soil more fertile can be replicated.

Section 5 looks at the likely impacts of large-scale 'carbon negative' bioenergy on ecosystems, climate and people. James Hansen and several other proponents of the concept promote large-scale bioenergy production based on low-input, high-biodiversity cultivation methods and on the use of forestry and agricultural 'waste', although Hansen has recently indicated in the media that he may also be looking at tree plantations. We examine those ideas and conclude that the scale and speed of bioenergy expansion required for the purpose of trying to reduce atmospheric carbon dioxide levels is fundamentally incompatible with sustainable production. It will require policies that favour short-term high yields per hectare, which is incompatible with sustainability. We therefore conclude that any policies aimed at scaling up bionergy use, to the scale proposed by Hansen and others will result in a dramatic expansion of industrial monocultures, even if this is not the intention of those scientists. We note that the key study on which Hansen relies for his concept of 'low input, high biodiversity' bioenergy presumes a major intensification of high-input, low-biodiversity industrial agriculture in all other sectors.

We further show that large-scale bioenergy expansion by itself, regardless of the mode of production, can be expected to accelerate ecosystem and biodiversity destruction which in turn will accelerate climate change. It will further deplete freshwater and soil and will inevitably compete with food production and threaten the livelihoods of large numbers of people, primarily in the global South.

We show that the bioenergy figures used by Hansen and others rely on calculations by other scientists which suggest that at least 500 million hectares worldwide would have to be dedicated to bioenergy production. This represents 1.5 times the entire land mass of India. This vast area is 20 to 25 times the land area currently used for agrofuel production. Conversely studies show that there is no productive land which is not either natural habitat or already under cultivation. Misleading terms such as 'degraded' and 'marginal' lands are used to describe, for example, semi-arid and community lands slated for conversion to bioenergy.

We also argue that large-scale removal of so-called agricultural and forest residues will deplete soils, greatly speed up soil erosion and soil carbon emissions, as well as greatly reducing biodiversity.

We analyse the concept of 'carbon negativity' and show this to be a misleading term. Industrial agriculture and forestry are already one of the leading causes of climate change, as a result of large-scale ecosystem destruction, soil carbon losses, nitrous oxide emissions from fertliser use and high energy inputs. Large-scale bioenergy and industrial agriculture and forestry expansion go hand in hand. Calling them 'carbon neutral' or, potentially 'carbon negative' is misleading and unjustifiable.

Finally, we argue that indigenous peoples, small-scale farmers and other communities in the global South, including many who practice truly low-carbon and sustainable or almost sustainable living, are likely to pay the price for any large-scale bioenergy expansion, including in the false name of 'carbon negativity'. The number of people who will be displaced could be of a magnitude greater than those currently being displaced by agrofuels, given the scale of land-use change advocated by proponents of such policies.

Section 6 considers the bio-geoengineering proposals in context of the wider impact on our life support systems. We ask whether it is correct to speak about a 'climate crisis' or whether we should be even more concerned about a 'convergence of crises', which include not just climate change, but also species extinctions and ecosystem destruction, soil losses and freshwater depletion, as well as different forms of pollution. We argue that it is dangerously reductionist thinking to view those crises in isolation from each other. Not only does each of the crises threaten the very foundations of life on earth, but they interact and compound each other. This is illustrated with the example of the wide-scale collapse and extinction of amphibian populations which is currently occurring. Amphibians as a class have survived not just the extinction of the dinosaurs but the end Permian extinction, the worst ever mass extinction event, yet their complete extinction is now a distinct possibility. The cause of these losses include the converging impacts of agri-chemical pollution, loss of vegetation cover, ozone depletion, the introduction of invasive species as well as climate change. Reptiles and insect pollinator species (essential for crop production) are also collapsing. Biodiversity losses can trigger ecosystem degradation and eventual collapse. Throughout the planet's history, ecosystems have either maintained a stable climate or ensured that climate change did not run out of control. Their role cannot be measured in terms of carbon storage alone: Natural forests, for example, help to regulate the global carbon and nitrogen cycle, the freshwater cycle, cloud formation, thus increasing the planet's reflectivity. They can act as a 'heat pump' which regulates rainfall and storm tracks. Without biodiverse ecosystems, conditions amenable to life could not be contained and true runaway warming – a 'planet Venus scenario' would be a possibility.

Section 7 discusses adequate responses to the converging crises. We note that responses which address only one aspect of the crisis – for example fossil fuel burning – whilst ignoring or even aggravating others offer no realistic hope of avoiding runaway warming and a mass extinction event. Such reductionist approaches need to be replaced with a holistic discourse which deals with multiple risk factors interdependently. Such a discourse needs to start from the realisation that we are well beyond safe levels of greenhouse gas concentrations, ecosystem destruction and biodiversity losses. Our hope of survival depends on ending any further destruction and giving the biosphere the best possible chance of maintaining and, if possible, increasing its resilience through ecosystem restoration. Ending further destruction means ending ecosystem destruction, industrial agriculture, industrial forestry and mining, as well as abandoning destructive forms of energy production including fossil fuel burning, industrial bioenergy, and large-scale hydro-electric power. This will inevitably require not just a drastic 'power down' but rapid de-industrialisation. As we will show, there are no adequate responses to the current crises within the industrial paradigm. Food sovereignty and energy sovereignty will be essential principles in the context of de-industrialisation.

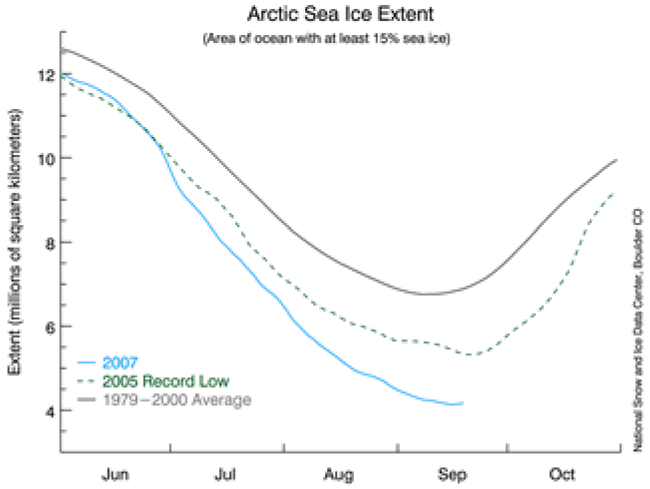
Alongside this we need to utilise and harness the ancient knowledge of those indigenous and forest peoples who have managed to live within ecological limits, often for millennia. Diversity of peoples has conferred a diversity of solutions which aren't even acknowledged by formal bodies like the IPCC as a transferable knowledge source. The quickest way to harness this knowledge is to reinstate land rights along with food sovereignty, particularly in the developing South. Alongside this, human society as a whole would need to dismantle the global free-market economy. *In short, the level of energy consumption, resource exploitation and inequality perpetrated by free-market economics, and by the industrial model are fast removing our very last chance of preventing complete collapse of our life-support systems.*

The prevailing debate about 'climate targets' and carbon accountancy is a distraction from the more important question of how societies can live without causing harm to the biosphere and without causing more global warming, whilst reversing some of the damage already done.

Chapter 1. Introduction: Abrupt climate change and the search for solutions

In 1992, governments worldwide agreed the UN Framework Convention on Climate Change, which obliges all states to work towards stabilising greenhouse gas concentrations "at a level that would prevent dangerous anthropogenic interference with the climate system", allowing ecosystems to adapt and protecting food production from climate change. It is increasingly clear that the Climate Convention and the Kyoto Protocol have failed: All the signs are that dangerous climate change is a reality now, not a threat for the distant future, and that current greenhouse gas levels in the atmosphere are anything but safe.

The dramatic loss of Arctic sea ice in 2007 and 2008 confirmed those fears:



National Snow and Ice Data Center, http://nsidc.org/news/press/2007_seaiceminimum/20070810_index.html

Just as the Intergovernmental Panel on Climate Change published its latest report[3] warning that Arctic summer sea ice could almost disappear in the second half of the century, satellite reports revealed a far more rapid meltdown: By September 2007, the sea ice extent had dropped to half the extent it had during the 1950s and 60s, 30 years ahead of what climate models had predicted. Since 2005, half of the thicker perennial sea ice cover has melted.[4] The 2008 summer melting season came close to, but did not reach the 2007 minimum sea ice extent, following a relatively cold Arctic winter and a cooler summer than the previous year. However, it is likely to have seen the lowest ever volume of sea ice, given the continued thinning of the ice that remains and August 2008 saw the fastest rate of Arctic sea ice melting ever recorded as well as the disintegration of Canadian ice shelves believed to have had survived since the last ice age.[5]

As the Arctic warms, methane hydrates released from melting permafrost and released from biomass decomposition in shallow waters is causing global methane levels to rise again.[6] This could well accelerate dramatically as the sea ice disappears: According to a new study by the National Centre for Atmospheric Research in the US, the rate of warming over northern Alaska, Canada and Russia could more than triple during periods of rapid sea ice loss.[7] Global methane levels have begun to rise again, having been stable for around eight years.[8]

Altogether, up to 400 or even 450 billion tonnes of methane or carbon dioxide could eventually be released from melting permafrost The thawing of the Arctic sea floor could release all or part of a further 540 billion tonnes of methane stored in submarine hydrates and far greater amounts are stored in deep marine clathrates (methane ice), stored in or close to the continental shelves across much of the world's oceans. Any major methane releases from the Arctic would threaten the future of all life.

Melting Siberian permafrost is releasing large amounts of greenhouse gases.
(Photo by Michael Succow, IMCG)

Not surprisingly, leading climate scientists, such as James Hansen, now warn that not only do we need to cut greenhouse gas emissions more dramatically than previously thought, but that our future also depends upon taking carbon dioxide out of the atmosphere. Without the removal of excess atmospheric CO_2 other climate tipping points will be crossed, the impacts of which will be catastrophic and irreversible. Catastrophic impacts could include sea level rises at the rate of one metre every twenty years, as happened at the end of the last ice age along with ecosystem breakdown and mass extinction of species, (see Section 5).

Some NGO climate campaigners are beginning to look seriously at those proposals – for example the report 'Climate Code Red', published by Friends of the Earth Australia,[9] calls for zero carbon emissions and a massive effort to take carbon dioxide out of the air. Just like James Hansen, the authors of 'Climate Code Red' regard bioenergy with carbon sequestration as essential for reducing carbon dioxide to safe levels. Other groups advocating these proposals are the Norwegian Bellona Foundation and the Australian NGO, Beyond Zero Carbon. 350.org, a new organisation founded in the US, with growing international support, promotes James Hansen's paper as the basis for climate action, without officially referring to the proposals for planetary engineering contained in the paper.

The US Administration has long been interested in exploring ways of countering global warming by dimming the planet or increasing the earth's albedo (reflectivity), in the hope that geo-engineering can allow 'business as usual' to continue. Calls by James Hansen and others for reducing atmospheric CO_2 levels are different: They support drastic measures to move away from fossil fuel burning, but also believe that equally drastic measures are required to sequester carbon in soils, forestry and underground. This, of course does not mean that the same proposals are not also promoted by those who see them as an alternative to reducing fossil fuel burning.

The case for 'drastic action', which goes beyond ending fossil fuel use, is strong since runaway global warming in the worst possible scenario threatens the survival of all life on earth. The Intergovernmental Panel on Climate Change (IPCC) predicts that the planet could this century warm by up to 6.3°C, even without taking account of major feedbacks, such as methane releases from melting permafrost and ocean clathrates. There is strong evidence that 6°C warming, almost certainly over a much longer time-scale, (probably triggered by carbon dioxide releases from super-volcanoes), caused the planet's biggest mass extinction event ever, 251 million years ago. At that time, 96% of marine species and 70% of terrestrial vertebrate species, as well as most insects became extinct. Large parts of the planet became lifeless and it took 30 million years for life to recover and for biodiversity reaching similar levels as before the extinction event.

The question is: Can the proposed actions for withdrawing carbon dioxide from the atmosphere prevent catastrophic climate change and a mass extinction event, or will they, instead, trigger an even faster and more severe ecological and climate collapse

For the purpose of this report, we will use the term 'catastrophic climate change' in the same way as the term 'dangerous climate change' is generally used by the UNFCCC and by climate scientists, though there is no universally accepted definition. The term is generally used in a very restrictive way, to describe climate change which triggers major and potentially rapid sea-level rises, which threatens global food security and which causes a mass extinction. It is also widely used to mean abrupt and self-reinforcing climate change, where feedback mechanisms ensure that the planet will continue to warm even in the absence of any further anthropogenic GHG emissions. We recognise that such a definition is very questionable, given that even today's level of climate change causes impacts which are not just dangerous but catastrophic for hundreds of millions of people.

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[3] IPCC Fourth Assessment Report, 2007, www.ipcc.ch/ipccreports/ar4-syr.htm

[4] http://www.reuters.com/article/environmentNews/idUST22148420080512

[5] www.sciencedaily.com/releases/2008/09/080922195943.htm

[6] www.spiegel.de/international/world/0,1518,547976,00.html and http://news.bbc.co.uk/1/hi/sci/tech/7364679.stm

[7] http://www.ucar.edu/news/releases/2008/permafrost.jsp

[8] www.spiegel.de/international/world/0,1518,547976,00.html and http://news.bbc.co.uk/1/hi/sci/tech/7364679.stm

[9] www.climatecodered.net/

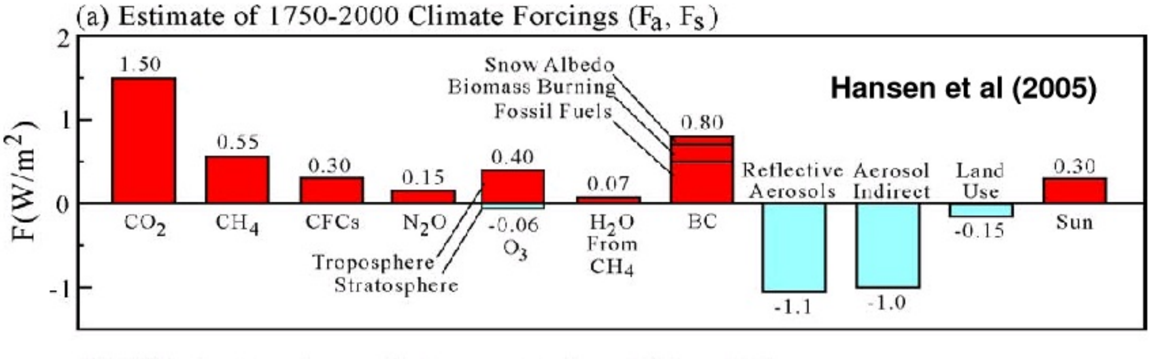
Chapter 2. Proposals for cooling the planet

2.1 Beyond safe levels: the climate science background

Today, the planet is absorbing considerably more heat from the sun than it is radiating back into space, resulting in the earth warming faster than ever before in recorded history. This energy imbalance is caused mainly by humans putting additional greenhouse gases into the atmosphere, mainly through fossil fuel burning, ecosystem destruction and intensive agriculture. Up to 25% of warming may be caused by black soot emissions from fossil fuel and biomass burning.[10] Carbon dioxide is responsible for about 40% of global warming, and the remaining 35% is due primarily to methane, tropospheric ozone (caused mainly by methane and NOx emissions), CFCs, nitrous oxide and other trace gases.

Right now, 55% of the global warming caused by humans is masked by other types of air pollution, sulphur aerosols, which are keeping the planet cooler than it would otherwise be. Those aerosols, the result of fossil fuel and biomass burning, persist in the atmosphere for no more than a couple of days. If air pollution were cleaned up, even if fossil fuel burning were completely halted, we would feel the full impact of warming.

Since there is a delay between increasing greenhouse gas emissions and planetary warming, at least half of the warming we have already caused, has yet to manifest itself.



www.realclimate.org/images/forcing_1750-2000-toppanel.jpg

The global warming (or radiative forcings) to which we are committed at current levels of greenhouse gases and aerosols is generally expressed in terms of CO_2 equivalents. Today, CO_2 concentrations are around 385 ppm. If we take all the greenhouse gases and the black soot which humans have added to the atmosphere into account and measure this in terms of CO_2 (known as the CO_2 equivalent or CO_2 e), we are actually at around 560 ppm Co2e. The impact of the difference between 385 and 560 ppm, however, is coincidentally almost exactly cancelled out by sulphur aerosols. This means that, in the absence of air pollution, we have nearly doubled CO_2 levels in the atmosphere from the pre-industrial levels of a little over 300ppm. We cannot be sure how much warming this will mean, but James Hansen believes that, in the long term, a doubling of CO_2 levels (or their equivalents) could mean 6^{o}C warming, even if we could stop all GHG emissions today. This is quite clearly not a safe level: It is the same level of warming believed to have caused the end-Permian extinction event.

At the same time, fast rising levels of carbon dioxide in the oceans are already causing dangerous levels of ocean acidification and threaten to trigger a mass extinction event regardless of global warming. Ocean acidification is endangering the survival of all shell-forming organisms, including many zooplankton species, sea shells, and corals, on which virtually all marine life depends. Marine life, including plankton, plays an essential role in regulating the planet's climate and biochemistry. The former chief scientist with the Australian Institute of Marine Science, Dr Veron, has warned that ocean acidification will cause mass extinctions once CO_2 levels go beyond a 'tipping point' and that those extinctions will become unstoppable.[11] A recent study suggests that even if carbon dioxide levels in the atmosphere could be stabilised at current levels, less than half of all coral reefs will remain in an environment with the chemical conditions to which they are adapted.[12] Clearly, there are no safe levels for any further fossil fuel burning or for other carbon dioxide emissions.

Proposals for reducing global warming fall into three categories:

- Reducing short-life greenhouse gases and black soot;
- Cooling the planet by making the earth more reflective;
- Taking CO2 out of the air.

This report focuses on the last of these categories, and in particular on the proposed use of bioenergy to reduce CO_2 levels. However, in this section we will also give a very brief overview of the other two concepts.

2.2 Reducing short-life greenhouse gases and black soot

Climate scientist David Archer has calculated from geological records of past global warming episodes that the mean atmospheric lifetime of carbon dioxide emitted today will be around for 30,000 years – an average derived from the fact that most carbon dioxide is currently dissolved in the ocean and taken up by the biosphere very quickly whilst some will remain in the atmosphere for over 100,000 years.[13] The amount of carbon dioxide absorbed by the ocean and the terrestrial carbon sink is currently declining, partly because climate change has led to the Southern oceans absorbing less CO_2, and we cannot rely on short-term carbon sequestration by oceans, terrestrial vegetation and soils to continue as the planet warms further.

Black soot, on the other hand, stays around for a few days at the most, methane for around 12 years. Hence, if anthropogenic emissions could be stopped, atmospheric concentrations would drop very quickly, provided that those reductions are not offset by methane released as a result of climate change feedbacks, such as melting permafrost. Tropospheric ozone, most of which is derived from methane, other hydrocarbons, carbon monoxide and oxides of nitrogen , should also reduce very quickly if the source emissions (fossil fuel and biomass burning and agricultural emissions) could be stopped because it only remains in the atmosphere for very short periods.

Cutting emissions of black soot, oxides of nitrogen and human-caused emissions of methane would bring down the total warming caused by humans, particularly if carbon dioxide (CO_2) and nitrous oxide (N_2O) emissions were dramatically cut at the same time. This would require a drastic emissions reduction programme rather than geo-engineering. Provided that methane emissions from the Arctic do not accelerate, such measures would slow down climate change and they are clearly a safe option, albeit one which would require major social, political and economic change. However, if one is looking for planetary cooling, sufficient to re-freeze the Arctic sea-ice, as the authors of Climate Code Red intend, those measures are unlikely to be sufficient.

2.3 Geo-engineering to make the planet more reflective

Permafrost forest, image57.webshots.com - Cutting down those boreal forests is one geo-engineering proposal for cooling the planet.

The earth's 'heat budget' depends not just on greenhouse gases but also on how reflective the planet is. Scientists are looking at various ways of increasing the earth's albedo (reflectivity), so as to offset the warming caused by additional greenhouse gases. Proposals include injecting sulphate particles into the stratosphere, spraying a thin mist of seawater onto clouds, putting solar shades into space, or even deliberately cutting down permafrost forests because of their lower albedo or reflectivity.[14] All of these proposals carry extremely high risks of causing major ecosystem destruction and changing the planet's climate and biochemistry in ways that are very difficult to predict and could have very severe adverse effects. A recent study, for example, has shown that injecting sulphate into the stratosphere could further destroy stratospheric ozone, on which life depends for protection from dangerous UV radiation.[15] For a detailed discussion of geo-engineering, see: "Gambling with Gaia, ETC Group, January 2007[16].

2.4 Taking carbon dioxide out of the air

Proposals for taking carbon dioxide out of the atmosphere include different attempts at making the biosphere more productive, as well as ideas for directly capturing carbon dioxide from the air. All of the proposals with the exception of direct air capture of carbon dioxide can be classed as 'bio-geoengineering

1) Ocean Fertilisation

Planktos ship getting ready to dump iron particles in the Pacific, http://i.treehugger.com

A number of companies have been attempting to fertilise the oceans by dumping large amounts of iron particles in the ocean in order to stimulate plankton blooms, in the hope that the plankton will sequester carbon dioxide and move it to the ocean bed, where it should theoretically remain. There is however no evidence that much of the carbon dioxide taken up by algae blooms actually makes it to the ocean floor- in natural algae blooms, only 5% of the dead algae sinks more than 300 metres deep.[17] Furthermore, there is evidence that, in most areas fertilising one part of the ocean with iron reduces ocean fertility elsewhere. Toxic algal blooms are a serious threat to marine biodiversity and raise concerns about the spread of hypoxic dead zones. There are also concerns that plankton blooms could increase methane or nitrous oxide emissions.

Another ocean fertilisation proposal involves dissolving lime in marine waters in the hope that this will allow more CO_2 to be absorbed from the atmosphere and also reduce ocean acidity, impacts which have not so far been proven. The impacts on marine life are untested and could be severe. In addition, large amounts of energy would be needed to obtain the lime from heating limestone.

The London Convention, which oversees dumping of wastes at sea, has endorsed a scientific statement of concern about ocean fertilisation and declared its intention to develop international regulations to oversee such schemes[18]. The Convention for Biological Diversity has agreed on a de-facto moratorium on all ocean fertilization activities, with a very limited exception for small scale scientific research, which cannot be used for selling carbon offsets or for other commercial activities. Nonetheless, further ocean fertilisation schemes are expected in the near future, including a large project sponsored by the governments of India and Germany which is to commence in 2009.

For further information about ocean fertilization, see the different publications by the ETC Group on this topic[19].

2) Ocean Mixing

James Lovelock and Chris Rapley, formerly director of the British Antarctic Survey, have suggested installing 10,000 to 100,000 pipes to bring cold water from the lower ocean layers to the surface in order to stimulate plankton blooms and hence increase CO_2 sequestration.[20] They suggest that further research and small-scale experiments are needed to test the feasibility of such a scheme. The impacts on marine life have not been explored and concerns have been raised that the technique could increase CO_2 emissions by bringing high-CO_2 deep ocean water to the surface where on warming, the water would discharge its excess CO2 to the atmosphere.[21]

3) Air capture of CO_2

Proposed 'synthetic trees' to capture carbon dioxide from the atmosphere
http://sign0ff.files.wordpress. com/2007/05/grt-prototype.gif

Direct air capture of CO_2 involves the use of alkali materials, such as sodium or potassium, which are called sorbents and which adsorb carbon dioxide to form a stable carbonate or bicarbonate. Klaus Lackner of the company Global Research Technologies (GRT) and researchers from Colombia University have created a workable prototype which when scaled up, they estimate, could sequester 90,000 tonnes CO_2 a year. The researchers suggest that "planting" 250,000 such synthetic trees would reabsorb the 22 billion tonnes of CO_2 produced annually.

Of all proposed technologies for sequestering atmospheric CO_2, air capture would have by far the least impact on ecosystems and biodiversity. Many problems remain however. The amount of energy needed to capture and store the CO_2 would be enormous. Large amounts of energy are required to construct the units, to move the air, manufacture the sorbents, produce the oxygen, fuel and other chemicals, to separate the CO_2 from the stable carbonate, to restore the sorbent for reuse, and to compress and transport the CO_2 to an underground repository. Howard Herzog of the Massachusetts Institute of Technology has warned that it could take more energy to capture the carbon dioxide from sorbents than would be saved from this process and that far more research was needed.[22] The problem of where and how to safely dispose of the carbon once it is captured also remains.

There are proposals for making air capture more energy efficient by using thermal systems which use heat that can be generated on site. However, very few research projects looking at air capture of CO_2 exist. Klaus Lackner and his colleagues hope to build one prototype which will capture one tonne of CO_2 per day and cost £100,000. They are still researching ways to dispose of the CO_2, including possibly connecting the scrubbers to greenhouses or using the CO_2 to grow algae for food, fuel or fertilisers. This, however, would not actually remove CO_2 from the carbon cycle at all.[23]

According to the IPCC's Assessment Report Four, "no experimental data on the complete process are yet available to demonstrate the concept [or air capture of CO_2], its energy use and engineering costs." [24]

James Hansen has stressed that no large-scale technologies for CO_2 air capture exist at present and decades of strong research and development support, with large-scale pilot projects would be required. Even then, the technology is likely to remain very expensive.

Given the high energy intensity, and the fact that 80% of global energy use comes from fossil fuels, there is a high risk that any major air capture scheme would maintain or even increase fossil fuel burning.

4) Carbon capture through 'carbon negative' bioenergy and tree plantations:

Carbon 'bio'-sequestration through forestry and agriculture has long been promoted as a climate change mitigation strategy. Ecosystem restoration, if done sensitively and in a socially just way, can clearly play a role in climate change mitigation and will be discussed in Section 7, however the carbon sequestration projects supported or proposed under the UN Framework Convention on Climate Change, are by and large not related to ecosystem restoration.

However, climate change mitigation strategies that involve forests must be understood in the context of the official UN definition of forests. The definition used by the UN Food and Agriculture Organisation (FAO) and by the Convention on Biological Diversity (CBD) includes most industrial monoculture tree plantations. The definition used under the Kyoto Protocols for the purpose of the Clean Development Mechanism (CDM) is even broader than that of the FAO and CBD, including any type of tree and shrub plantation of any height, even, potentially oil palm and jatropha monocultures.

Both 'reforestation' (meaning planting on previously forested land) and 'afforestation' (meaning planting on previously unforested land) are currently supported under the Kyoto Protocol as a means of further promoting monoculture expansion, even though monocultures are the main driver of deforestation, particularly in the tropics.

James Hansen's proposals for bioenergy and 'bio-sequestration' of carbon dioxide include:

- Ending 'net deforestation' by 2015. 'Net deforestation' is loosely defined within the massive efforts for 'reforestation' until at least 2030, sufficient to remove 1.6 billion tonnes of carbon from the air every year.
- Biochar (charcoal) from pyrolysis of biomass, which retains a portion of the carbon in the biomass and can, theoretically be useful in sequestering that carbon over a long time frame. The goal is to remove and sequester 160 million tonnes of carbon from the atmosphere every year through this method. It is suggested that this could be achieved through the use of biomass residues and the replacement of slash and burn with slash and char agriculture although, as we shall see below, the sustainability or indeed the feasibility of relying solely on those sources is highly questionable.
- Rapid expansion of liquid biofuels from a current 0.8 EJ worldwide, to 23 EJ by 2025, with biochar, a by-product of one type of second-generation biofuel production, being used on a large scale, particularly after 2025.
- Faster CO_2 reductions through burning biomass in power plants on a large scale and capture with sequestration of the carbon (Bioenergy with Carbon Capture and Storage or BECS).

[Note: Both bioenergy with carbon capture and storage, and biofuels with biochar are classed as 'carbon negative' bioenergy, based on a belief that the carbon sequestered through those technologies will be greater than the total greenhouse gas emissions linked to producing the bioenergy.]

Unfortunately, Hansen, like many other proponents of bio-geosequestration technologies, does not appear to clearly distinguish between forests and plantations or provide a clear definition of the terms 'net deforestation' and 'reforestation'.

In the context of the Kyoto Protocol's definition of forests, each of those four proposals either permits or directly encourages large-scale monoculture expansion and further destruction of natural ecosystems.

'Net deforestation' can, under the current definitions by UN agencies, be 'ended' by replacing natural biodiverse forests with industrial tree and even shrub monocultures. 'Reforestation', as we have seen is used as another term to cover the expansion of plantations. Growing large-amounts of biomass for charcoal, biofuels and bioenergy use with carbon capture and storage will require vast additional plantations, as we shall discuss in detail in Section 5. James Hansen has openly declared his support for large-scale tree monocultures in a media interview in which he advocated replacing coal with wood from tree plantations (presumably a substantial proportion rather than all) and sequestering the carbon dioxide. [25]

Although monocultures count as 'carbon sinks' under the Kyoto Protocol, in reality they speed up global warming, because they are not capable of driving key biospheric cycles, including the carbon, nitrogen and rainfall cycles upon which a stable climate depends. Instead, they further destroy the planet's ability to regulate climate. This is discussed more fully in the later sections. For a more detailed discussion of the impact of tree monocultures, see for example www.wrm.org.uy/plantations/carbon.html.

Plantations for 'carbon negative' bioenergy are so far only a proposal, however, the reality of bioenergy monocultures can be seen from the impacts of agrofuel plantations today. Those impacts have been discussed in detail elsewhere, for example in "The real cost of agrofuels" by the Global Forest Coalition and Global Justice Ecology Project [26].

This report will focus on bioenergy with carbon capture and storage, and biochar, i.e. the two main ideas linked to the concept of 'carbon negative' bioenergy. However, the wider issues around large-scale land-use change to allow for more intensive industrial agriculture and tree plantations apply to the debate about all types of large-scale bioenergy use for 'climate change mitigation' and to proposals for 'carbon sinks enhancement' through plantations established in the name of afforestation and reforestation. It is important to note that studies about presumed land availability for biomass, including for 'carbon negative' bioenergy draw heavily on older studies about the potential for sequestering carbon in tropical 'carbon sinks', including tree plantations. Those studies were the first to suggest that at least 500 million hectares of land, particularly in the tropics, are 'available' for climate change mitigation.[27]

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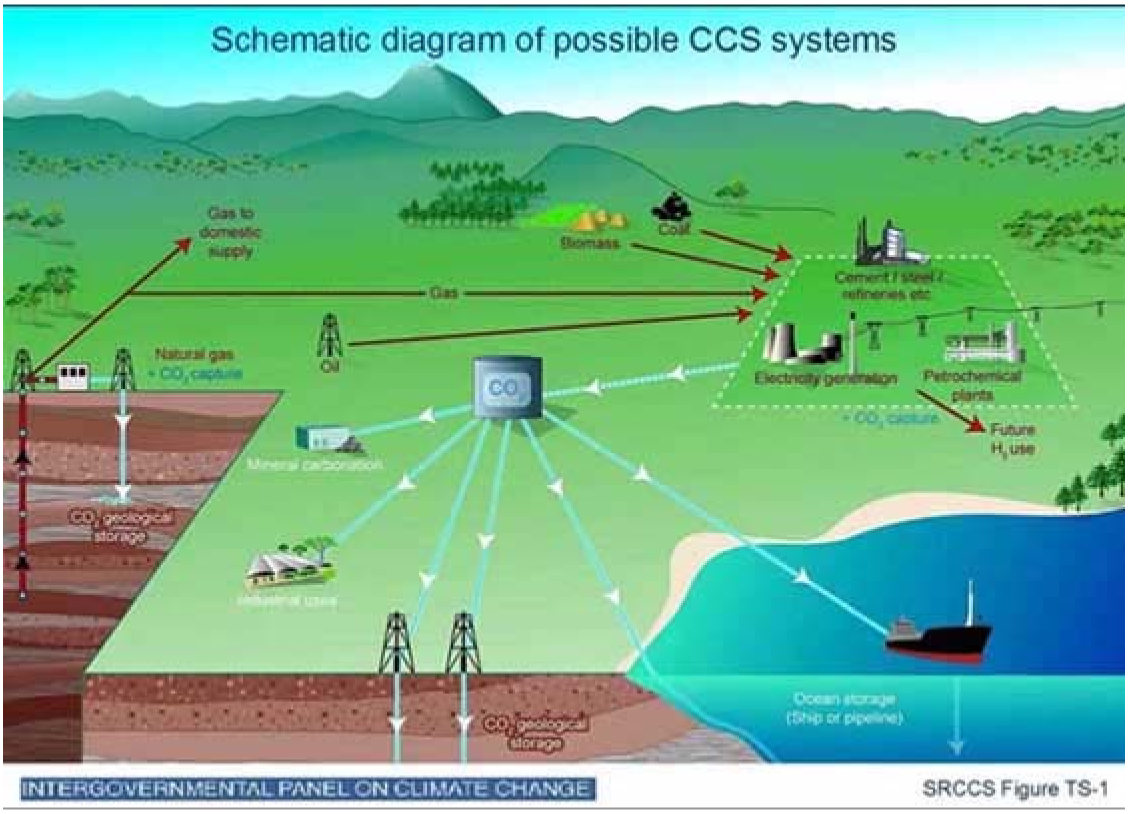
[25] "Phase out coal and burn trees instead, urges leading scientist", Geoffrey Lean, Independent, 14th September 2008, http://www.independent.co.uk/environment/climate-change/phase-out-coal-and-burn-trees-instead-urges-leading-scientist-929889.html

[26] http://www.globalforestcoalition.org/img/userpics/File/publications/Therealcostofagrofuels.pdf

[27] for example "Current Land Cover in the Tropics and Its Potential for Sequestering Carbon", Richard A Houghton et al, Global Biogeochemical Cycles, Vol 7, No. 2, 1993

Chapter 3. 'Carbon negative' bioenergy from vast monocultures?

> *"Humanity must urgently embark on a massive programme to power civilisation from wood to stave off catastrophic climate change, one of the world's top scientists has told The Independent on Sunday."*
>
> Geoffrey Lean quoting from James Hansen [28]



Peter Read and Jonathan Lermit were amongst the first to publicise the idea of achieving 'negative emissions' by combining bioenergy production with carbon capture and storage. They presented their proposal of a large-scale Bio-Energy with Carbon Storage (BECS) project as a response to accelerated climate change in February 2005 at the high profile 'Avoiding Dangerous Climate Change' conference in Exeter. At the time, they suggested it as a cheaper alternative to capping fossil fuel burning.[29] Since then, the idea has won widespread support in principle. It has been incorporated into the EU's 'Flagship Programme' for carbon capture and sequestration.[30] In the United States, three out of the four planned carbon capture and sequestration projects linked to synthetic fuel production involve co-firing of biomass.

The technology is exactly the same as carbon capture and storage from coal power stations or from coal gasification plants except that the carbon would be captured from installations which burn or gasify either solely biomass or, more likely, a combination of biomass and fossil fuels (usually coal). Once captured, the CO_2 must be stored. This means injecting it into depleted oil and gas fields, saline aquifers, coal seams, or into deep ocean waters. Some researchers are also looking at the possibility of 'mineralising' the CO_2 as stable carbonates and using this process to obtain valuable industrial products.

3.1 What CCS projects exist?

CCS is not a mature and tested technology. At present, no complete carbon capture and storage (CCS) system exists, although one small demonstration power plant with carbon storage in a depleted gas field opened in Germany in September 2008.

Commercial carbon sequestration has been undertaken by StatoilHydro since 1996, however the carbon dioxide has been removed during natural gas production as a 'waste product' rather than being captured during power generation. StatoilHydro currently operates three such projects, with CO_2 being injected into a deep sea saline aquifer and into underground formations below gas reservoirs. They are also planning new CCS projects involving carbon capture from a CHP plant at the Mongstad oil refinery in Norway. Furthermore, Statoil is researching the mineralization of carbon dioxide to obtain industrial products.

The largest research project into CCS is being undertaken at the Weyburn oil field in Saskatchewan, Canada. Carbon dioxide is purchased from the North Dakota Gasification Great Plains Synfuels Plant, which turns coal into synthetic natural gas and captures other gases, including CO_2 in the process. The carbon dioxide is pumped into oil wells providing pressure that increases the amount of oil that can be recovered (Enhanced Oil Recovery).

There are other relatively small research projects. In the US the Southeast Regional Carbon Sequestration Partnership which has a mandate to trial CO_2 storage in coal shafts which cannot be mined, whilst recovering coal-bed methane. Clearly this facilitates additional fossil fuel burning and thus new CO_2 emissions. Another is the carbon capture of CO_2 from smokestacks of a coal power station for conversion to baking soda at the Big Brown Steam Electric Station in Texas. In the US, four planned gasification plants would use CO_2 for Enhanced Oil Recovery which, as we shall see below, will increase overall CO_2 emissions. A 250 MW demonstration plant with carbon sequestration had been planned in Illinois under the US government's FutureGen project, however the government withdrew funding in early 2008. Barrack Obama has promised to set up private-public partnerships to build or equip five power plants with carbon capture and sequestration.

In Australia, there is a demonstration project capturing a very small proportion of CO_2 emitted by a power generation plant in the Latrobe Valley. Another demonstration project for capturing CO_2 from a power station and storing it in an old gas field has been approved in Western Victoria, but has not yet commenced.

Other research projects are planned in Japan, Canada and the EU. The EU has set up the European Technology Platform for Zero Emission Fossil Fuel Power Plants. Their plan for 10-12 demonstration plants across the EU by 2012 has been approved by the European Council. The ultimate aim is large-scale commercial availability of CCS, but not until 2020.

Overall, there is little evidence of any major plans for serious public or private sector investment beyond small technology development projects in CCS. Commercial carbon sequestration projects are so far linked to natural gas recovery, not to large-scale plans to sequester CO_2 from power stations.

3.2 Problems with commercial application

Enhanced oil recovery - www.co2capture.org.uk and www.trib.com

Serious technical and practical difficulties remain which explains why so far there have been few signs of industry or government commitments to large-scale adoption of CCS in the near future:

1) Scale of infrastructure investment needed:

According to Professor Vaclav Smil, energy expert at the University of Manitoba, capturing and sequestering 10% of the CO_2 emitted per year from all current coal-fire plants would require moving more liquefied CO_2 than the total annual flow of oil worldwide. Building the network of pipelines would require trillions of dollars of investment.[31]

2) Long time-scale before moving beyond R&D:

According to the IPCC's Assessment Report 4, there are still uncertainties relating to "proving the technologies, anticipating environmental impacts and how governments should incentivise uptake" and at the very best 60% of CO_2 emissions from power production and 40% from industry could be captured and sequestered by 2050 (IPCC Special Report, Carbon Dioxide Capture and Storage, 2005). A more optimistic forecast by the International Energy Authority, suggests that CCS could begin to be deployed from 2015 and to be scaled up between then and 2050. The EU aims for commercialisation by 2020.

3) Increased energy inputs:

CCS could capture 85-95% of CO_2 produced by power stations but would require on average more fuel to be burnt for the same energy output, such is the energy intensity of the carbon-capture process.

In spite of these obstacles, the coal industry has been promoting the idea of 'clean coal' with CCS, with a view to making further coal expansion politically acceptable. In the United States, CCS is especially promoted in the context of proposed coal-to-liquids gasification plants. This technology has been supported by the US Bush administration and by several US states and the U.S. Air Force. It has also been supported by Barack Obama, although he has stated that he would require such plants to result in 20% emission reductions which would require not only CCS but also substantial amounts of biomass co-firing, with the emissions linked to biomass production presumably to be ignored[32].

Without CCS, coal-to-liquid gasification results in transport fuel linked to almost twice as much CO_2 emissions as petrol. The promise of carbon capture and storage appears to be used by the industry to market their plans as 'environmentally friendly', thus gaining wider political support.[33] They neglect to say that, even with CCS, coal-to-liquids still results in carbon dioxide emissions at least as high, if not 8% higher than those from petrol.[34] Furthermore, CCS is not consistently included in industry plans for coal-to-liquid plants. For example, a US government report revealed in December 2007 that a leading CTL development in Gilberton, Pennsylvania was planned without any carbon capture. This appears symptomatic for the CCS debate; whilst widely promoted as 'clean coal' technology, major industry and government investment and implementation are lacking.

3.3 Environmental concerns about reliance on CCS for climate mitigation

A number of serious environmental concerns arise from CCS technologies. The long time-scale before CCS could become widely available on a large scale means that it will not help to stabilise greenhouse gas levels before much higher, and even more unsafe levels have been reached. The high profile given to CCS in the climate debate detracts from the urgent need for social and economic changes, in particular drastic demand reduction in the global North. The European Technology Platform for Zero Emission Fossil Fuel Power Plants (ZEP) summarises the 'CCS promise' thus: "With CCS, Europe can grow its economy, ensure a secure energy supply…and meet its CO_2 reduction targets" - an unsubstantiated, overly optimistic but widely promoted claim.

Because the energy input required per unit of energy obtained is higher when CCS is used, CCS will translate into more mining or in the case of biomass use, more land allocated for bioenergy production.

There are other serious concerns. Depending on the type of sequestration chosen, CCS will not necessarily reduce overall CO_2 emissions and may even increase them. The technology likely to be most attractive economically is Enhanced Oil Recovery (EOR), which the IPCC lists as one of the options. EOR involves injecting CO_2 into partially depleted oil wells in order to increase the amount of oil that can be extracted. A technology which directly results in greater fossil fuel burning and thus higher carbon dioxide emissions is thus being falsely promoted as 'clean energy', including by the IPCC.

Four of the current larger carbon sequestration projects involve EOR, as do the four proposed coal-to-liquids plants with CCS in the US. If the emissions from burning this additional oil are taken into account, which indeed they must be, the additional CO_2 emissions from burning more oil could outweigh CO_2 savings seven-to-fifteen-fold.[35]

Another technology which has been proposed is deep ocean "storage". This involves injecting the carbon dioxide into deep ocean water. It does not amount to permanent sequestration, but it would take hundreds of years before the deep waters, to which CO_2 has been added, would come to the ocean surface and for the carbon dioxide to enter the atmosphere. There have been proposals about increasing the time for which the CO_2 would remain in deep ocean waters, for example by trying to form solid CO_2 hydrates on the ocean floor. If CO_2 was injected into deep ocean waters, it would immediately increase the acidity levels of those waters. The IPCC[36] warns that this could have serious impacts on deep ocean ecosystems: "Adding CO_2 to the ocean or forming pools of liquid CO_2 on the ocean floor at industrial scales will alter the local chemical environment. Experiments have shown that sustained high concentrations of CO_2 would cause mortality of ocean organisms. CO_2 effects on marine organisms will have ecosystem consequences."

Deep-sea ecosystems have been shown to play an essential role in global biochemical cycles, including the nutrient cycle on which all marine life depends. They also help to regulate the global carbon cycle which, to a significant degree, depends on marine plankton. The consequences which destruction of such ecosystems through CO_2 injections would have on phytoplankton and thus on the global climate are unknown.

CCS using geological sequestration (not deep ocean storage) *without* EOR is the only technology that has the potential under the right circumstances reducing overall CO_2 emissions. However a question remains: How reliable is geological sequestration given that the earth's surface is in fact in continual flux and not just across geological timescales.

The possibility of sudden, catastrophic CO_2 releases which could cause mass fatalities in the vicinity of the CO_2 leak have been raised, however evidence provided by the IPCC suggests that this is not a realistic risk. However, slower or more limited CO_2 releases through fault leakage, caprock leakage and pipeline leakage are possible and, depending on the scale of the leakage, could render CCS less effective than hoped. Thirty million tonnes of CO_2 are already being transported every year in the US through pipelines. Occasional non-deadly sudden releases are likely, and a total of seven larger releases due to well failure have been reported.[37] The IPCC, however, suggests that, with geological sequestration, it is very likely that at least 99% of the CO_2 sequestered will be remain sequestered for 100 years and that this is likely to be the case for 1000 years. Their figures do not include possible leakage during CO_2 transport from the power plant to the sequestration site.

3.4 Bioenergy with CCS

Sugar cane production for ethanol; sugar cane is one of the highest yielding grasses for any type of bioenergy production.

Even if we had several decades to reduce emissions, which we do not, and even if CCS could play a significant role in reaching this goal, there would be serious questions over using it with bioenergy whilst at the same time continuing to burn fossil fuels without CCS. This would add more carbon which had been locked up in fossil fuels into the atmosphere. The current experience with agrofuel expansion shows how the myth of 'carbon neutrality' is being used by governments and industry to claim 'greenhouse gas reductions' under the Kyoto Protocol, even though the actual emissions from the production of some agrofuels have been shown to be orders of magnitude higher than those of the fossil fuels that are replaced. This is possible because under the Kyoto Protocol, the greenhouse gas emissions from growing agrofuel and other bioenergy feedstock are attributed to the forestry and agricultural sectors of the countries where they are grown and not to agrofuel or other bioenergy production. Europe, for example, can claim greenhouse gas savings from replacing some fossil fuels with, for example, palm oil, whereas the emissions linked to deforestation or peatland destruction, which may be hundreds or even thousands of times greater are attributed to the countries where the palm oil is produced. If bioenergy with CCS became available, then countries with commitments under the Kyoto Protocol or its successor could claim that they are switching to 'carbon neutral' energy and, if CCS was included into carbon trading, they could get additional 'carbon credits' for that. Discussions about future inclusion of CCS into carbon trading are still ongoing, but there is a high chance that this will be agreed and that bioenergy with CCS will be classed as 'carbon negative'. In this case it could attract greater credits than fossil fuels with CCS. Although land-use change and agricultural emissions as well as indirect impacts are supposed to be addressed under the Clean Development mechanism, current experience with carbon trading and afforestation and reforestation as well as biomass use shows that there are no effective mechanisms for achieving this. Bioenergy with CCS could thus, in future, generate high carbon savings on paper, whilst in reality greatly accelerating climate change through monoculture expansion. The climate impacts of large-scale industrial biomass will be discussed in more detail in Section 5.

The German Government's Advisory Council for Sustainable Development, WGBU, has spoken out against biomass with CCS for climate change mitigation because of the large amounts of additional biomass which would be required.[38] Adopting bioenergy with CCS as a climate mitigation strategy would require the conversion of hundreds of millions of hectares to bioenergy plantations, the details of which will be discussed fully below. The IPCC suggests that CHP and other power plants of less than 40 MWe are unlikely to be viable with CCS, so the scaling up of plantations would also be accompanied by large power stations. This model could also effectively preclude community ownership and direct community use of bioenergy, whilst vast acreage of community land is expropriated. Large power plants would also require connection to major infrastructure in order to dispose of the CO_2, which in turn would require high capital investment. Moreover, economics would favour power plants with surrounding plantations close to sites suitable for geological sequestration of CO_2, since both the transport of large volumes of biomass and the transport of CO_2 over long distances are expensive. Laurence Rademaker of Biopact has suggested that the most suitable areas from an economic point of view would include tropical countries with large offshore sequestration sites such as Gabon, Indonesia, Malaysia, Papua New Guinea, Ecuador, DR Congo, Nigeria and others.[39] Those countries are already being targeted for rapid agrofuel expansion resulting in accelerated deforestation as well as large-scale displacement and impoverishment of rural communities. A climate mitigation strategy which includes BECS could significantly aggravate this situation.

The IPCC has already endorsed bioenergy with carbon capture and storage as one technology for climate change mitigation and is likely to do so even more strongly in future, given strong endorsement by the two new working group co-chairs. One of them is Christopher Field, who described BECS as "one of the ways you could potentially think about actively decreasing the CO_2 concentration in the atmosphere".[40] Another is Ottmar Edenhofer, co-author of a recent publication which states: "Biomass and CCS on the one hand and energy efficiencies and other demand-side regulatory measures on the other hand, play a very important part in reaching this low stabilisation level [400ppm]." [41] The EU formally support the development of bioenergy with carbon capture and storage and Barack Obama's comments about future coal-to-liquids plants with 20% carbon reductions suggests that the new US administration may also support it.

3.5 Biomass and CCS: current investments

Currently there are no examples of BECS in operation. The agribusiness giant Archer Midland Daniels (ADM) has confirmed its plans to utilise CCS technologies at its corn ethanol plant in Decatur, Illinois but the refinery processing is fossil fuel driven. Corn ethanol already has a very poor, if not negative energy balance. Hence increasing the amount of energy needed for adding CCS by 10-40% makes no sense in terms of energy balance, economics or climate mitigation.

Most of the bioenergy with CCS projects put forward thus far involve gasification of fossil fuels with biomass to make synthetic fuels. Bioenergy will represent only a small part of those investments. An example of a company investing in synthetic fuel which is looking at co-firing with biomass is the US firm GreatPoint Energy. They state: "Biomass will be secured in select markets for scaled facilities designed to meet renewable energy mandates by using the syngas for power generation." The company's overall investment will greatly increase fossil fuel use, in particular oil, as well as oil production, since the storage of carbon dioxide facilitates Enhanced Oil Recovery and CO_2 can be sold to "coal bed methane producers for additional revenue and CO_2 tax credits".[42] And a Norwegian CCS project by Aker Kværner, SINTEF and NTNU will involve burning biomass to provide the energy for capturing the CO_2 from fossil fuel burning.

Probably the largest plans for bioenergy with CCS are forwarded by the US Air Force: Their official aim is to supply half of the Air Force's fuel requirement for the lower 48 US states from domestic synthetic sources, including fossil fuels and biomass, by 2016. The US Department of Defence insists that the overall CO_2 emissions must be no higher than those from burning kerosene. Given that synthetic fuel from coal results in 1.8 times as much CO_2 emissions as kerosene, even with CCS, and large amounts of biomass will have to be co-fired and all land use change emissions ignored even to meet this target. According to the US National Energy Technology Laboratory, meeting the requirement will require a land area of almost 5 million hectares for switchgrass and poplar plantations, or 3.18 million hectares for corn stover.[43] The technology development is still in the relatively early stages.

Clearly, none of those projects could claim to be 'carbon negative' overall, even if biomass was truly 'carbon neutral', which it is not.

3.6 Future investment?

As an investment strategy, BECS offers little attraction: CCS requires high levels of capital investment, considerably reduces energy yields, and puts companies at risk of liability in case of sudden catastrophic CO_2 releases from storage sites. The vague possibility of future carbon finance has generated little interest in this supposed 'climate mitigation' strategy. Even without CCS, bioenergy is likely to attract ever greater funding in the future anyway, including from carbon finance and from clean technology funds. The most likely use of BECS is as a means of making synthetic fuel production and in particular coal-to-liquids plants politically acceptable. As the current US Air Force plans show, this could well result in a very large biomass demand and thus land requirement.

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[28] Geoffrey Lean quoting from James Hansen, http://www.independent.co.uk/environment/climate-change/phase-out-coal-and-burn-trees-instead-urges-leading-scientist-929889.html

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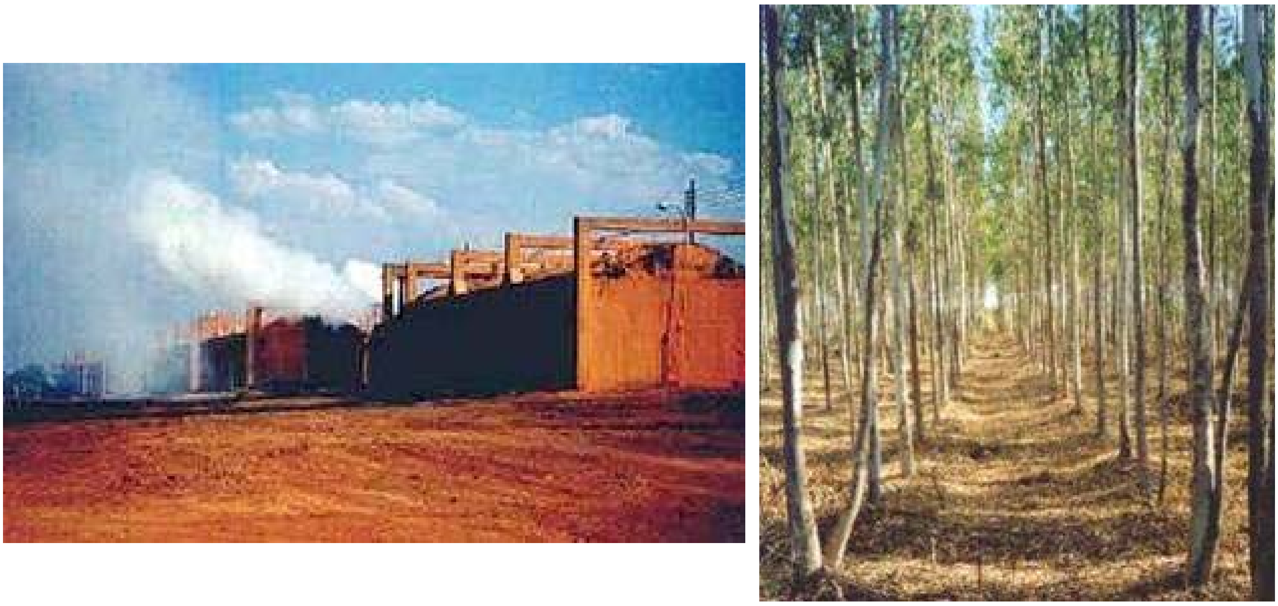
[42] www.greatpointenergy.com/faq.htm#Q4

[43] National Energy Technology Laboratory. Increasing Security and Reducing Carbon Emissions of the U.S. Transportation Sector: A Transformational Role for Coal with Biomass, www.netl.doe.gov/energy-analyses/pubs/NETL-AF%20CBTL%20Study%20Final%202007%20Aug%2024.pdf

Chapter 4. Biochar: cooling the planet with charcoal?

"They want to follow what the green revolution did for the developing world's plants with a black revolution for the world's soils", Emma Marris[44]

"By driving, you will be saving the planet. And the more you drive, the more you prevent catastrophic climate change." Biopact[45]



Plantar, Minas Gerais: Eucalyptus plantation and pig-iron production ovens, photos by World Rainforest Movement www.wrm.org.uy

The second type of 'carbon negative' bioenergy being promoted is biochar. Biochar is charcoal derived as a waste product from thermal conversion of biomass by a process known as pyrolysis (see box below). This process produces bio-oil, which can be used as fuel, although not a high-grade one, syngas, a mixture of hydrogen, carbon monoxide and other trace gases, which can also be used as a fuel source and as a precursor to making synthetic diesel char (another type of charcoal).

Proponents of biochar support pyrolysis methods which maximise the amount of char produced and its application to soils. This, they believe will sequester about 50% of the original carbon in the biomass permanently in soils whilst, at the same time, increasing agricultural productivity and also reduce nitrous oxide and methane emissions from agriculture. [46]

Biochar promises to do what BECS cannot offer: A presumed way of sequestering carbon from biomass burning whilst guaranteeing a new income source for bioenergy companies, replacing synthetic fertilisers and boosting agriculture. The potential for carbon finance may be the same as for BECS, however such funding is less likely to be a precondition of investment. Fertiliser prices are at record levels and expected to rise further, to a large extent due to agrofuel expansion. Selling biochar as a fertiliser is thus likely to be highly profitable. Many of the main proponents of BECS today advocate biochar either as a better alternative, or as a complementary strategy, including James Hansen, Peter Read, and Biopact, a lobby group for bioenergy apparently run by the biofuel consultancy company Equator Energy, which poses as a non-profit volunteer organisation. [47]

Second Generation Agrofuels and Co-products from Thermal Conversion of Biomass

Second-generation agrofuels are agrofuels made from solid biomass. There are two types of technologies for turning solid biomass into liquid fuel: Biochemical conversion (involving enzymes and microbes, almost certainly genetically engineered) which produces liquid agrofuel, and thermal conversion which amongst other products produces biological char of 'biochar'. The cheapest and most advanced technology is a type of thermal conversion called pyrolysis, in which solid biomass is exposed to high temperatures (ideally 350-450^{o}C) for a short period of time in the absence of oxygen. This yields syngas, bio-oil and the by-product 'biochar'. The bio-oil and syngas can be used as fuels for heat and power and bio-oil for 'bunker fuel'. Syngas and bio-oil could also provide feedstocks for future agrofuel refineries that produce synthetic biodiesel for cars and possibly airlines, through a process called Fischer-Tropsch gasification. Syngas can also be used as a precursor for diesel-char (see main text) which can be used as a solid fuel, for use in steel manufacturing, in purification and filtration, tyre manufacturing, ink-jet printer ink, or as a soil supplement. All second generation agrofuels are still at the research and development stage.

4.1 Terra preta: fertile soils created by small farmers

The rationale for biochar comes from the study of highly fertile soils found in Central Amazonia, called terra preta, which cover an area of more than 50,000 hectares. The soil is believed to have been created by farmers over a long period between 1000 BC (and possibly as early as 5000 BC) and 1500 AD. Instead of slash-and-burn agricultures, those farmers are thought to have practiced slash-and-char, burning a variety of biomass on low-intensity smouldering fires, covered, possibly with dirt and straw, to reduce oxygen. The remaining charcoal was mixed with unburnt biomass, human and animal excrements, fish and animal bones and ash and applied to the soil.

Whilst most of the surrounding soils in the Amazon are relatively low in carbon and nutrients and cannot be used for agriculture for more than three years without needing substantial amounts of fertilisers, terra preta, contains up to 70 times as much carbon as well as high levels of nutrients such as nitrogen, phosphorus, calcium and potassium. It also has a high capacity for retaining nutrients and moisture, and maintains higher pH values. Terra preta has remained fertile over thousands of years and is associated with high agricultural productivity. The long-term retention of nutrients and possibly carbon appears to be linked to increased microbial and fungal activity in terra preta.

The history of the terra preta soils is one of small farmers who, over thousands of years, sustained highly biodiverse farming systems which increased soil fertility, rather than depleting it, as modern industrial agriculture does. Given the catastrophic environmental impacts of modern intensive agriculture – species extinctions, nitrogen overloading, soil depletion, pollution, and high greenhouse gas emissions – learning from sustainable practices, such as those that led to terra preta, is vital.

However, without any deeper understanding of how terra preta formed, companies, scientists and lobby groups are today calling for large-scale carbon funding and public subsidies for a byproduct of bio-oil and syngas production. They claim that this will create fertile soils and reduce global CO_2 levels.

> *"The biochar sequestration technique is now confirmed to boost soil fertility while storing carbon long-term. No other renewable energy technology has both the advantages of being carbon-negative while at the same time being physically tradeable", Biopact,*[48]

Modern biochar, developed by companies such as Dynamotive, Eprida and BestEnergies, is an industrial product, with feedstock derived from monocultures. Lobby groups such as the International Biochar Initiative, promise that this modern biochar, mixed with soil, re-creates terra preta, not over a period of decades or centuries, but instantaneously. How credible is that?

4.2 Do the claims made for modern biochar add up?

> *"Bio-char sequestration could amount to 5.5–9.5 PgCyr*$^{-1}$ *if this demand for energy was met through pyrolysis, which would exceed current emissions from fossil fuels."* [49]

> *"No one is sure what types of biomass should be used as raw material or exactly what production methods work best, so calculating the costs is really an exercise in speculation.", John Kimble, former USDA soil scientist*

Even if modern biochar were identical to terra preta, that would not necessarily make it a credible tool for climate change mitigation. Many agrofuel feedstocks have been shown to have positive greenhouse gas balances in micro-studies looking only at a small plot and ignore the wider impacts of converting large areas of land to agrofuels. However, as two recent studies published in Science confirm,[50] direct and indirect emissions from land-use change greatly outweigh any greenhouse gas savings recorded in micro-studies.

This will be discussed further below, but indicates that even if small-scale pyrolysis with biochar projects could be shown to sequester carbon dioxide from the atmosphere, this does not mean that such carbon sequestration gains will be achieved from large scale industrial plantations linked to pyrolysis biochar.

In this section, we will look at whether the claims made for modern biochar can be substantiated at the field-level.

4.3 Will soil with modern biochar retain nutrients and carbon?

Before moving onto concerns of scale, we consider whether the aforementioned claims for modern biochar can be substantiated at a field-level.

Terra preta has retained carbon and nutrients for thousands of years, although nobody doubts that the black carbon will eventually be mineralised and will one day find its way back into the carbon cycle, i.e. the atmosphere, vegetation or oceans. The question however is whether modern biochar will sequester the carbon for similarly long periods and, if so, under what circumstances?

Johannes Lehmann, one of the leading scientists on biochar advised Biofuelwatch in March 2008:

> *"So far, there are no longer-term studies looking at the retention of carbon and nutrients from biochar in soil. One four year experiment was abandoned and another four-year old study is still ongoing, however neither of those has been published. There appears to be no other study older than about two years."*

A 2007 article by Johannes Lehmann[51] sums up the different issues which still need to be resolved before modern biochar can be said to improve long-term soil carbon storage and fertility:

1) We do not know what the half-life of biochar is, i.e. how long the carbon and nutrients will stay in the soil. The answer will depend on the type of biomass used, production conditions, soil properties and climate. Not all biochar will have the same properties.

2) Terra preta is highly fertile, not just because it is rich in nutrients, but because it provides the nutrients to plants in an easily accessible form. This property is called high cation retention and high cation exchange capacity. Terra preta has a high cation exchange capacity, but this is not the case for modern, newly produced biochar which has low cation retention and a low cation exchange capacity, at least initially. At temperatures between 30 and 70^{o}C, it takes several months for soil with fresh biochar to develop good cation retention. Those temperatures are, of course, higher than under natural conditions. Nobody knows under what circumstances and during which time-scales those processes can happen in the tropics, let alone in cooler climates.

3) Different feedstocks and production conditions affect how many phytotoxic and possibly carcinogenic materials are produced during pyrolysis. This means that a full environmental risk assessment is needed, which must examine possible public health impacts.

4) Nobody knows how to incorporate biochar into the soil in a way which prevents it from eroding and, in the worst case, aggravating soil depletion.

In the short term, adding char to soil clearly does improve plant growth and nutrient transfer, i.e. char acts as a fertiliser. However, as a 2003 study by Lehman et al shows[52] there are differences between the properties of terra preta compared to modern biochar: In terra preta, all nutrients showed a high uptake-to-leaching rate. In modern biochar, this was the case for most, but not for all nutrients. The study showed that additional fertilisers would be required to maintain high plant yields over several growing seasons on soil containing modern biochar, something not needed with terra preta. The authors concluded: "Long-term studies with charcoal applications are needed to evaluate their effects on sustained soil fertility and nutrient dynamics."

According to German soil scientist Bruno Glaser, field trials with modern biochar plus compost or chicken manure in Amazonia resulted in higher crop yields initially, but those yields declined after three or four harvests. Glaser suggests that "You would need 50 or 100 years to get a similar combination between the stable charcoal and the ingredients".[53] There are further hurdles faced by researchers before modern biochar can be said to help with climate change mitigation:

A recent comparative study of black carbon measurements in soil showed that a wide range of methods is being used to measure black carbon in soil and sediments, yielding very different results.[54]

No one method has been identified which would be applicable to all soil samples and scientific questions. This makes a comprehensive review of the science regarding biochar very difficult.

Various other recent 'findings' have been announced, based on press releases by scientists or on abstracts without full studies being publicly available and without clear information on methodology. For example, an abstract on "Soil Organic Matter Stabilization and Land-use Change in Tropical Ecosystems" by Joseph Kimetu et al claims that "we demonstrate that highly weathered tropical soils possess great potential for C increase", yet no information about the experimental set-up and methodology is given.[55] Researchers at NSW Department of Primary Industries have press-released findings that "reinforce[d] the potential of 'biochar' to revolutionise climate mitigation and adaptation", however no details are publicly available at present. [56]

Even if modern biochar was to bind black carbon in soil for long periods, those effects could be at least partially offset by increased loss of soil organic carbon in humus: Those were the findings of a 10-year long study published in May 2008: A Swedish team mixed charcoal with forest soil and left the soil in each of three different forest stands in boreal Sweden. Charcoal substantially increased soil bacteria and fungi which, in turn, decomposed the organic carbon already present in the soil and led to soil organic carbon losses through respiration or leaching. Much of that soil organic carbon was emitted as carbon dioxide and thus greatly reducing any 'climate benefits' from adding biochar to boreal soils. [57]

Finally, there are major gaps in the general scientific understanding of the role of soil organic carbon in the global carbon budget and thus in global warming. Some studies suggest that losses of soil organic carbon through soil erosion are a major source of CO_2 emissions.[58] Others suggest that soil erosion has a negligible impact on CO_2 emissions although it is a very serious concern for many other reasons.**[59]** In the absence of any knowledge about the impact of biochar additions on soil erosion rates, and without any firm understanding of what soil erosion means for climate change, any claims that biochar will help mitigate climate change are premature.

4.4 Other claims made for modern biochar

Various other claims have been made about modern biochar which have even less scientific backing than claims about long-term carbon storage and soil fertility.

A 2007 article in the Bio Science Magazine, for example, written by two members of Eprida, a bioenergy company involved in biochar development, claimed for example:

> *"Because charcoal increases soil retention of water and nitrogen, runoff is reduced and nitrogen is prevented from leaching into groundwater and surface water."* [60]

Others make observational claims that biochar reduces emissions of nitrous oxide and eliminates methane emissions from agriculture.

However, according to the 2007 article by J Lehmann, quoted above:

> *"No information exists at present whether this adsorption behaviour would translate into a significant reduction of non-point source pollution of ground and surface waters by fertilizers or other pollutants in agricultural watersheds…The environmental benefits of bio-char applications other than C [carbon] sequestration are still poorly quantified externalities."*

Even Lehmann's assertion about biochar sequestering carbon is highly optimistic given the large number of uncertainties he himself has revealed.

4.5 Conclusion

The farmers who, hundreds to thousands of years ago, created terra preta in Central Amazonia succeeded in creating highly fertile soil which retained carbon and nutrients over very long periods. The formation of terra preta may well have depended on a combination of soil type, choice and diversity of biomass, climate, and it may have taken many decades to establish. Modern biochar, made from the pyrolysis of monoculture feedstock or from a small range of forestry and agricultural residues, has not been shown to be comparable to terra preta. No conclusive evidence exists about its potential for long-term carbon storage or its long-term impact on soil fertility. Conversely the longest running study on biochar in Boreal forests indicates a significant risk of soil organic carbon loss as a result of charcoal additions.

4.6 The Investment Rush Begins

> *"The case for substantial investment in R+D, as well as changing the regulatory incentives to sequester carbon, is overwhelming.", Carbon Commentary on biochar, November 2007* [61]

Scientists may be years away from finding out how to use charcoal to sequester carbon and nutrients long-term. This, however, is not slowing the enthusiasm of bioenergy companies, particularly those already investing in pyrolysis.

4.7 Industry-science links

Many of the science institutes working on biochar have close links with the industry:

Iowa State University, for example, has signed a £22.5 million research programme with Conoco Phillip, with support from the US Department of Energy, to develop pyrolysis technology, as well as cellulosic ethanol. The same university works closely with the US Department of Agriculture's National Soil Tilth Laboratory, with the company Heartland BioEnergy LLC, and with the Iowa Soybean Association.

Wollongbar Agricultural Institute in Australia is the New South Wales Department of Primary Industries' Centre of Excellence for the Environment, the main agricultural science centre within the NSW government. They are involved in joint research on biochar with BEST Energies Australia.

One of the carbon trading firms promoting biochar is Crucible Carbon, a collaboration between the Crucible Group Ltd and Pekabu investors. They work closely with scientists at Macquarie University in New South Wales and Deaking University in Victoria.

A significant number of scientists are on the Advisory Board and Steering Committee of the International Biochar Initiative, which promotes not just research into biochar but also deployment and commercialisation.[62]

4.8 Pyrolysis making second-generation agrofuels profitable

Investment in bioenergy and in particular in agrofuels for transport is fast increasing, however poor or negative energy balances and rising feedstock costs (the latter at least in part driven by the agrofuel industry itself) makes the industry highly dependent on public subsidies and incentives. According to researchers at UNICAMP, Brazil, "the future of biofuels is very likely to be linked to the ability of clustering biofuel production with other agro-industrial activities at an appropriate scale and mode of production to take advantage of the potential supply of valuable co products." [63]

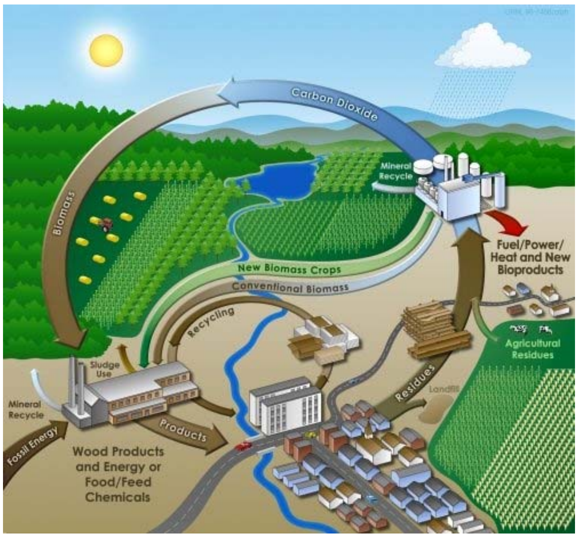
Growing concerns over rising food prices and rainforest destruction in particular are being countered with promises of 'second generation' agrofuels from non-food crops and agricultural and forest residues. The US government, the US Airforce and the European Union are amongst the supporters and funders of second generation research and development. There are two broad pathways to second generation, or solid biomass to liquid fuels (agrofuels): The first one, biochemical conversion involves the use of enzymes made from microbes or fungi to break down the plant cell walls so that the sugars in the plant can be turned into s. Cellulosic ethanol and biobutanol are the two main areas of research involving biochemical conversion. Those technologies currently yield considerably less net energy than the least efficient type of first generation biofuels, corn ethanol. Any future breakthrough in turning those fuels into a net energy source will heavily depend on genetic engineering.

The second pathway is thermal conversion, particularly Fischer-Tropsch gasification, which produces synthetic biodiesel. Significant R&D will be needed to make Fischer-Tropsch gasification commercially viable, however, there is evidence that energy efficiency from this process is just over 50%, considerably better than for cellulosic ethanol at present.[64] A first Fischer-Tropsch gasification plant relying solely on solid biomass has been opened by Choren in Germany. Choren are planning a much larger facility which will use one million tonnes of wood every year.

Another company investing in research and development of synthetic biodiesel is the Finish pulp and paper company UPM, which is developing a pilot plant near Chicago, together with two other firms.[65]

One of the barriers to making Fischer-Tropsch gasification cost-effective lies in having to ensure a large constant stream of biomass to a capital-intensive central plant. Transporting large amounts of wood and other biomass will reduce the overall efficiency of the process. One way of overcoming this problem is to have small, decentralised plants where wood and other biomass is 'pyrolised' to make syngas and bio-oil. Fischer-Tropsch gasification could use the bio-oil and syngas as a feedstock, rather than the much bulkier and less energy dense original feedstocks. Pyrolysis could thus make future synthetic biodiesel production far more efficient. In the meantime, pyrolysis plants can be used to produce fuel for heat and power or bunker fuel for shipping.

> *"By bringing the factory to the forest, instead of the forest to the factory, 'biomass-to-liquids' production becomes much more economical." , Biopact[66].*



http://www.repp.org/bioenergy/bioenergy-cycle-med2.jpg

One of the first companies to develop decentralised pyrolysis plants is the Canadian energy firm Dynamotive. They currently run a commercial bio-oil and biochar plant as well as two pilot plants and a research laboratory in Ontario. Dynamotive, also a minority stakeholder in a similar venture by Ecolution Biofuels Inc., is developing a plant in Taiwan, and planning six pyrolysis plants in northeastern Argentina which will produce bio-oil for export, rather than energy for domestic use, as well as a plant in Taiwan.

The US Department of Energy, in their new Multi-Year Biomass Program, describes pyrolysis as an important component of future integrated biorefineries, a concept which would integrate the companies currently involved with agrofuels more closely with the pulp and paper industry as well as the livestock industry Maximising the use of byproducts will be essential if biorefineries are to become profitable.

Finally, a different process, called 'fractination' is being developed by Biofine Renewables LLC, in cooperation with Embrapa (Brazilian Agricultural Research Corporation), the University of Sao Paulo and the University of Limerick. This has been reported to produce biochar as a by-product, amounting to 25-30% of the original biomass.[67] Fractination involves several processes to separate lignin, cellulose and hemicellulose and it yields a variety of products which can be used by the chemical industry as well as energy. The company has commissioned a first commercial plant in Italy. A similar technology is being developed by Scott Convertech in New Zealand. The by-product, called 'Cellulig' is understood to be similar to biochar and can also be used either as a soil additive or as an energy source.

4.9 Biochar: a byproduct in search of a market

> *"Char is a secondary product, but from that perspective, one is always looking to see what one can do with it. The activated carbon market is very big. But (agricultural uses) would be a potentially very big market.", Desmond Radlein, Dynamotive's chief scientist*[68]

At best, biochar accounts for 35% of the biomass in weight after pyrolysis, though it could contain up to 50% of the original carbon. Such high biochar yields are linked to a process called slow pyrolysis, where biomass is heated to 350-450 °C rather than higher temperatures. Slow pyrolysis is used by US companies Eprida and BEST Energies.

Many other companies, including Conoco Phillips, ADM, Dynamotive and Heartland BioEnergy, however, are investing in fast pyrolysis, which yields at most 20% char.

The profitable use of byproducts is vital for companies investing in this technology. Fertilisers are in ever greater demand and fertiliser prices were rising considerably in line with recent agrofuel expansion, up until the recent decline in oil and commodity prices linked to the global financial crisis. Already, companies like Eprida have patented biochar-based fertilisers as well as different pyrolysis processes, depriving communities of potential affordable access to both.

To quote the Best Energies website:

> *"We are well positioned to win the current land grab in next-generation fuels"*[69]

Biochar supporters claim that pyrolysis and char can provide poor rural communities with fuel and more fertile soils. The Biochar Fund, set up by Biopact, for example invests in trial biochar and pyrolysis projects in villages in Southern Cameroon and the Democratic Republic of Congo. They promise to help small farmers gain access to modern agricultural inputs and markets, to connect them to the carbon market, to help them use biochar and to acquire small pyrolysis plants. No information is provided about the financial risks and any liability in case the projects fail, nor about the financing of the pyrolysis plants and any possible future debt burden.

Other companies, meantime, are patenting pyrolysis and biochar processes. A 'terra preta' patent has been granted for the identification and isolation of micro organisms in that soil.[70] Different pyrolysis technologies, biochar-based fertilisers, types of bio-oil and biochar have already been patented. It is clear that companies, not communities will profit.

Much of the research into biochar is focused on potential carbon funding. Carbon trading almost exclusively benefits larger companies that can afford specialist consultants, not rural communities. A 2006 study looked at three biochar projects to establish the feasibility of carbon finance.[71] This study provides insight into the types of projects likely to benefit from any future carbon finance for biochar:

The first project involved pulp and paper companies that own an acacia plantation in Sumatra. The second project used wood residue from a eucalyptus pulp and paper monoculture in Australia, and in the third project heat from a waste incinerator was used for turning sawdust into biochar.

Plantation, and in particular pulp and paper companies, together with agribusiness firms are likely to benefit the most from the development of pyrolysis and biochar and from any future government support in the name of climate change mitigation.

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Chapter 5. Five Hundred Million Hectares of Plantations to Cool the Planet?

5.1 What BECS or biochar plantations would mean for people, climate and the environment

> *"A land use change programme and related capacity building, potentially on a very large scale, to be prepared for bad scientific news that may reveal the need for 'Manhattan project' style carbon management" Peter Read and Jonathan Lermit 72*

FSC-certified Eucalyptus pulp and paper plantation in Brazil, www.fsc-watch.org/archives/s. Hundreds of millions of hectares of similar plantations will be required for large-scale BECS or biochar programmes.

So far we have focused on the technological and economic hurdles and the scientific doubts regarding the application of BECS and biochar. However, it is possible that at least some of those hurdles could one day be overcome. For example a major global investment programme could be launched to make bioenergy plants with carbon capture and storage a reality and apparently safe ways of storing large amounts of CO_2 might be found. Research may eventually show that modern biochar can indeed help to retain carbon and soil nutrients over long periods, at least in some circumstances, although recreating terra preta may take decades and long-term trials are needed to draw any reliable conclusions. In the meantime even without considering the wider impacts discussed in this section, BECS and biochar represent a high-risk strategy.

Proposals for 'cooling the planet with biomass' rely on a major scaling up of global bioenergy production and use. They are thus closely linked to plans to replace a significant proportion of fossil fuel use with biomass. This section focuses on the impacts which such a large scale BECS or biochar programme would have on land use, climate, soil, water and peoples, assuming that a significant amount of carbon released during bioenergy production could indeed be safely sequestered.

We ask, 'Could large scale BECS or biochar in theory mitigate against global warming, or might they hasten catastrophic climate change and the mass extinction event they are intended to help avoid?'

5.2 Unprecedented Land-Use Change: How much land for energy production and carbon sequestration?

> *"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." Peter Read*[73]

The main proponents of BECS and biochar, including Johannes Lehmann make it clear that their vision of reducing atmospheric CO_2 levels involves at least 500 million hectares of dedicated bioenergy plantations. Peter Read and Jonathan Lermit in 2005, supported the 500 million hectare figure, however Read now speaks about one billion hectares of new tree plantations by 2035, as well as 750 million hectares of perennial grasses and 460 million hectares of sugar cane largely for bioenergy.

By comparison, the entire land mass of India is 329 million hectares.

The 500 million hectare proposal is in line with a large number of bioenergy feasibility studies which have informed policy making by governments and international organisations.

Johannes Lehmann, for example, speaks of the potential for 180-310 EJ of bioenergy by 2050, referring to a review of 17 studies by Berndes et al.[74] Berndes et al conclude that insufficient information exists to predict how much land can realistically be converted to bioenergy plantations, particularly if climate mitigation is the aim. They make it clear that even the more 'modest' predictions amongst the studies would require 500 million hectares of bioenergy plantations by 2050, which would mean converting an additional 10 million hectares to plantations every year, on top of the 4.5 million hectares being converted annually to plantations at present.

Peter Read and Jonathan Lermit suggest that 500 million hectares of bioenergy plantations used for bioenergy with carbon capture and storage could produce 250 EJ of energy every year by 2030 which, after conversion, could replace 115 EJ of crude oil, or 23% of current global energy consumption by humans.

Some researchers are even more optimistic about the future bioenergy potential: E. Smeets et al, for example, suggests that 'surplus agricultural land' could, by 2050 produce 215 - 1272 EJ of bioenergy, provided forests (but not necessarily other ecosystems, such as grasslands) were protected, and global agriculture was significantly intensified. This would require converting between 700 million and 3.5 billion hectares of land to bioenergy production. This, in turn, would rely on the intensification of agriculture in Africa, Latin America and Asia and in particular on the conversion of pasture to bioenergy plantations, with live-stock being confined to feedlots. Additionally, Smeets et al suggest that 76-96 EJ of bioenergy could be gained from agricultural and forestry residues, plus 74 EJ from 'surplus forest growth'.[75] This is based on an assumption that 729 million hectares of land could be converted to bioenergy without additional need for irrigation, and without all pasture-land being turned into bioenergy plantations.

However, some of the bioenergy forecasts regarded as more 'conservative' also involve very large-scale land-use change. For example, the OECD[76] consider that up to 440 million hectares could be used for bioenergy plantations, most of it in Africa and Latin America, and that bioenergy could, by 2050, yield around 245 EJ of energy a year. A recent 'pessimistic' study by Field et al suggests that the future additional bioenergy potential may be as low as 27 EJ per year, but nonetheless suggests that, on such a 'small scale' it can play a role in climate mitigation. 'Small scale' in this case means conversion of 386 million hectares of so-called 'abandoned cropland', significantly greater than the size of the Indian subcontinent. [77]

To put these forecasted bioenergy increases into perspective, consider the current contribution of biomass to energy, including all current agrofuels:

5.3 Current global bioenergy use

'Traditional biomass', mainly wood fuel [1]	About 30 EJ
Modern biomass for heat and power[1]	8.6 EJ
Energy from Agricultural and forestry residues[1]	6 EJ
Municipal solid waste (including plastics as well as biomass) [1]	1 EJ
Landfill gas [1]	0.2 EJ
Biofuels for transport[2]	0.8 EJ

[Sources: 1 IPCC Assessment Report 4 (see footnote [78]) 2: Biofuels for transport accounted for about 0.8 EJ in 2005 (see footnote [79])]

Humans currently use 500 EJ of energy globally, 86.5% of which comes from fossil fuels (US Department of Energy, 2006). According to the IPCC, bioenergy currently accounts for around 47 EJ, or 10% of global primary energy production.

It is important to note that all the figures quoted in this section are gross, not net energy figures. They merely reflect how much energy is held in the biomass, without subtracting the, in some cases greater amount of energy needed to grow the crops, i.e. to produce fertilisers and other agro-chemicals, to transport crops, to build and maintain biomass plants, etc. This means that they do not show how much energy is actually gained from the use of biomass. Net energy gains will be discussed below.

Terms relating to energy gained from biomass

Gross energy: This is the total energy contained in biomass, either before conversion (egg the total energy contained in a tonne of wood) or after conversion (egg the total energy contained in a litre of bio-oil).

Net energy: This is the total energy gained from biomass: It is gross energy, minus the energy which has gone into producing the feedstock, transporting and converting it.

Energy balance: The energy balance is the ratio between gross energy and net energy.

Energy density: Energy per volume of fuel.

John Mathews of Macquarie University states that biochar "would mesh with the shift worldwide towards a bioeconomy as successor to the fossil fuel economy that has created a planetary crisis in the form of global warming". [80]

In June 2007, the NGO Grain wrote about agrofuel expansion and plans "We are talking about expropriation on an unprecedented scale". [81] If 'biomass with carbon sequestration' (whether through biochar or CCS) was adopted as a climate mitigation strategy, then the current rate and the scale of conversion of community lands, ecosystems and food production to bioenergy plantations could be greatly increased in a major experiment at 'planetary engineering'. Under such a scenario, dramatic negative impacts on food production, societies, ecosystems and on the climate will be unavoidable.

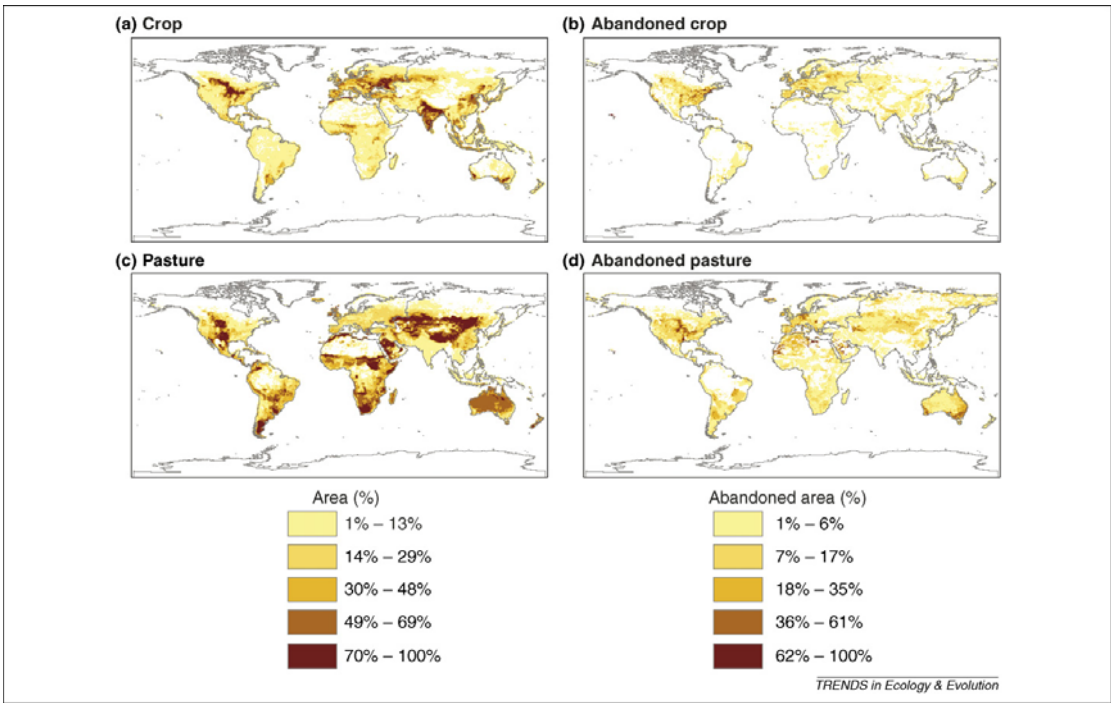
5.4 Dubious assumptions in bioenergy feasibility studies

Virtually all bioenergy feasibility studies are based on assumptions which appear unjustifiable and raise serious ethical concerns.

Smeets et al, for example clearly ignore both the impact of bioenergy production on biodiversity and the predicted impact of climate change on agricultural yields. Although they warn against deforestation for bioenergy, they do not preclude the destruction of other types of ecosystems. They also ignore the impacts of fresh water depletion and scarcity, soil degradation and pollution, describing them as 'too complex and time-consuming to take into account', and they ignore all previous studies which suggest that future food production might not rise in line with population growth. As we discuss below, climate change, freshwater depletion, soil depletion and erosion are already having a dramatic effect on agriculture, particularly in regions widely seen as having the greatest 'bioenergy potential', like sub-Saharan Africa. Such assumptions render the results – and thus the optimistic claims about 'bioenergy potential' highly questionable if not invalid.

Even the more 'pessimistic' studies, such as the 2008 study by Christopher Field et al are based on assumptions which are difficult to justify. Christopher Field assumes that apparently 'degraded' land or 'abandoned cropland' is suitable for growing sustainable and 'climate friendly' bioenergy crops, and he uses figures which suggest that 385-472 million hectares of abandoned cropland are globally available. Those assumptions are not based on social or environmental realities. The definition of 'abandoned cropland' includes land left fallow by communities and farmers, an essential practice for maintaining soil fertility. It is based on historical land use data since1700, even though it is impossible to verify those sources. All current pasture, grassland or scrubland believed to ever have been cultivated over the last three centuries is called 'abandoned cropland', even if it is pastureland which sustains the livelihoods of large numbers of people, or if it is a biodiverse ecosystem which may even store large amounts of carbon. Included in this definition would be all set-aside land in Europe and all of the US Cropland Reserve Programme. A recent study by Joseph Fargione et al[82] suggests that turning such land, once it has been set aside for 15 years over to corn ethanol production releases so much carbon dioxide that it would take 48 years of biofuel production to 'offset' those initial emissions. This figure does not take the full greenhouse gas emissions from agrofuel production, including nitrous oxide, into account. Nor do any of these studies look at the climate and wider environmental benefits of allowing natural vegetation to re-grow, rather than converting land to bioenergy plantations.

The same studies ignore not just the environmental but also the human realities: For the purpose of the studies, land is divided into areas used for food production, allegedly 'unproductive' cropland, and ecosystems. The livelihoods of pastoralists, small farmers not practicing intensive industrial agriculture and other communities, including indigenous peoples are either ignored or they are more explicitly to be sacrificed in the drive to 'optimise' agricultural productivity. Land ownership and rights are disregarded. A large proportion of the world's rural population has been virtually brushed out of existence in these bioenergy feasibility studies on which the proposals for BECS and biochar are based. Their displacement to make way for more intensive agriculture and plantations is thus a cornerstone of the proposals, not an unintended side-effect.



Assessment of land availability for bioenergy by Christopher Field et al

5.5 <u>How much bioenergy from how much land?</u>

> *"When humans are not a natural part of an ecosystem, large-scale biomass harvesting by the humans leads to an eventual breakdown of that ecosystem. Remedial actions (waste cleanup, erosion management, and applications of nutrients) are necessary to slow down – but never stop – the ecosystem deterioration All these actions require massive inputs of fossil energy and are unsustainable"* Tad Patzek, "Can we outlive our way of life?"

5.5.1 Energy and land use figures for first generation agrofuels

Whilst the scale of planned land conversion is clear, it is far less certain how much net energy can actually be obtained. For first-generation agrofuels, the example of Brazilian sugar ethanol gives us an idea about land-requirement for a set amount of energy gain. Brazil's tropical climate and intensive production lead to Brazilian ethanol having the highest per hectare yields of all types of ethanol worldwide.

Brazil currently produces 5019.2 million US gallons of sugar ethanol per year [83]which replaces 3312.62 million gallons of petrol. This amounts to gross energy of 0.4 EJ per year. According to the government, 3.6 million hectares of land in Brazil are used for growing sugar cane for ethanol. This means that, the highest-yielding type of monoculture for agrofuels in the tropics currently yields 0.11 EJ of gross energy per 1 million hectares. The net energy gain will, by definition be smaller. According to an optimistic 2005 assessment by Isaias de Carvalho Macedo[84], Brazilian sugar ethanol has an energy balance of 8.3. Based on this figure, the net energy gain from the most energy-efficient type of agrofuel production worldwide, 1 million hectares of land would yield 0.097 EJ of net energy. This example shows how large a land area is required for supplying a relatively small proportion of transport energy.

5.5.2 Energy and land use requirements for other types of bioenergy

The land requirement for bioenergy other than first generation agrofuels (i.e. biomass for power generation and other uses that do not entail refining into liquid fuel) will be different and in many cases the energy balances will be better than for any current ethanol or biodiesel. Nonetheless, of all commercially used energy sources, bioenergy provides by far the least energy per hectare of land. According to the OECD report on biofuels[85], photovoltaics yield 10 W/m^2. Bioenergy, on the other hand, has at best an energy yield of 1.2 W/m^2 - a figure only reached by biomass for heat and power from intensively managed tree plantations which, as we shall see below, are not sustainable. Furthermore, bioenergy also has a lower energy density (i.e. energy per unit) than fossil fuels.

The highest bio-energy gains per hectare of land can be obtained using biomass in decentralised, combined heat and power (CHP) plants. According to the European Commission's Joint Research Council, 1MJ of biomass-derived energy replaces 0.95 MJ of fossil fuel-derived energy if used for heat and power, but only 0.35-0.45 MJ of crude oil-derived energy if used as a transport fuel, since the process of converting any type of biomass to liquid transport fuels requires substantial amounts of energy [86]

Within the heat and power sector, two thirds of the primary energy is lost as heat in non-CHP power stations, whilst CHP can achieve high average conversion rates of about 80% for small decentralised plants close to the point of use. Conversion rates can even be as high as 90% .[87] CHP used in large centralised power plants are considerably less efficient, with according to the IPCC, 40-50% conversion rates.

5.5.3 Energy efficiency and 'carbon negative' bioenergy

The most efficient bioenergy use – CHP in a decentralised energy system - could not easily be combined with biochar production or with CCS. Neither pyrolysis systems which produce biochar, nor the use of bioenergy with CCS are suited to decentralised combined heat and power: According to the IPCC[88], CCS is unlikely to be economic if used for smaller CHP plants of less than 40 MW. Furthermore, with CCS, as we have seen in Section 2, energy losses from having to rely on a less efficient centralised power system will be compounded by the energy investment required for capturing and storing CO_2.

Pyrolysis yields fuels which could potentially be used in small CHP plants, but it is an energy-intensive process in itself and, in terms of energy efficiency, it makes no sense to convert biomass before burning it for heat and power. Furthermore, biochar production requires incomplete burning of biomass, resulting in less biomass being available for energy. The more biochar is produced, the less biomass is available for energy. Some of this 'energy loss' could potentially be compensated if the biochar replaced synthetic fertiliser use, which is highly energy intensive. As we have seen in Section 4, research into the suitability of biochar as a fertiliser is still ongoing and additional fertiliser supplements may well be required to supply certain nutrients.

This means that, bioenergy with CCS as well as pyrolysis with biochar production ensure that only a fraction of the original biomass is turned into usable energy. This figure is even lower if biochar production is combined with the production of synthetic biodiesel through Fischer-Tropsch gasification, another energy intensive conversion process. Each energy loss described translates into a reduced amount of fossil fuels being replaced by a set amount of biomass.

5.5.4 Further energy losses for using 'carbon negative' bioenergy for agrofuels:

As we have seen above, converting biomass to liquid transport fuels, instead of using it for heat and power, inevitably leads to further energy being lost during that conversion process. This is relevant for both types of 'carbon negative' bioenergy, i.e. for bioenergy with CCS and for biochar, since both are being promoted partly in the context of liquid biofuel production:

Although carbon capture from ethanol or biodiesel burning is not possible, the IPCC has suggested that ethanol and biodiesel refineries are particularly suitable for CCS. At present, fossil fuels provide most of the energy for biofuel production, except in Brazil, however the new US administration's commitment to a low-carbon vehicle standard would favour biomass use in refineries and, in future, biomass use with CCS.

Pyrolysis and biochar development, as we have seen in Section 4, is very closely linked to research into synthetic biodiesel, a type of second-generation agrofuel which at present, has far lower net energy gains than the 'first generation' agrofuels now on the market, because of the high energy requirements for converting solid biomass into liquids. Not only is energy needed for the pyrolysis process, to convert biomass into syngas and bio-oil, but more energy is required to convert those into biodiesel through Fischer-Tropsch gasification. We have been unable to find any peer-reviewed study which looks at the energy balances of pyrolysis with biochar production, with or without subsequent Fischer-Tropsch gasification.

5.5.5 Net energy gains from biomass

Net energy gains from biomass are the subject of scientific controversy. Even studies which look at the same feedstock and conversion technology reach very different results. Researchers take different energy inputs into account and particularly in the case of ethanol and biodiesel, make different assumptions about the use and value of by-products. Evaluating these studies is beyond the scope of this report. What is clear, however, is that it takes considerably more energy, to produce one Joule of 'modern bioenergy' than it takes to get a Joule from conventional fossil fuels. And this has consequences which are rarely considered.

What do low net energy gains mean for our society? The example of sugar cane ethanol.

Net energy gains from oil were originally 1:100, i.e. for one unit of energy invested, 100 units of energy were returned. However, the most accessible oil reserves have been depleted and net energy gains from oil have fallen to 1:20. This means that five times as much energy has to be invested today than a century ago in order to gain one unit of energy from oil.[89] If Macedo's very optimistic figure of 1: 8.3 net energy gain from sugar ethanol is accurate, then that means that substituting ethanol for fossil fuels would, in the most optimistic case, more than double the initial energy investment for keeping the same number of cars on the road, raising overall energy consumption by over 10%. The figures would be considerably worse for many other types of ethanol, such as corn ethanol. Most climate mitigation scenarios are based on energy efficiency gains coupled with a switch to renewable energy. If, however, we switch to energy sources which provide relatively little net energy, then considerable energy efficiency savings would be needed, not to cut energy use, but to simply keep it at present levels. As we have seen above, sequestering the carbon dioxide from bioenergy, either through CCS or biochar, will reduce what in many cases are already low (and in some cases possibly non-existent) net energy gains from biomass. This runs counter to any attempts to reduce overall energy use.

The important question here is how much of the global energy demand – even a very much reduced overall energy demand - could be met with bioenergy which is combined with CCS or with biochar production. This is of overriding importance because, as we have seen in Sections 1 and 3, there is no safe level of further fossil fuel burning and we would need to look at the complete and almost immediate phasing out of fossil fuels and other types of energy production which contribute to global warming, i.e. the vast majority of current energy production. All types of bioenergy require more land per unit of energy than wind or solar power. Below we will discuss why sustainable uses of biomass will require far larger areas of land than destructive ones. Bioenergy use is thus severely restricted by land availability. The use of 'carbon negative' bioenergy for 'climate change mitigation' advocated by James Hansen and others would require very major infrastructure investments. Further, the energy required for CCS or pyrolysis with biochar production would lead to much greater reductions in bioenergy yield than would have been possible without such carbon capture measures. This situation would be aggravated, if 'carbon negative' bioenergy production was linked to agrofuel production. This runs counter to the overriding aim of replacing as much fossil fuel as possible within the shortest timeframe possible.

5.6 <u>The reality of 'high per hectare yields'</u>

If governments were to adopted so-called 'carbon negative' bioenergy as a climate change mitigation strategy (relying on the misleading concept of biomass itself being 'carbon neutral') and did so on a large-scale, what type of biomass production can we expect to see? And what will be the likely impacts on ecosystems, biodiversity, climate, people, soil and water of a project on this scale?

In order to achieve the very high biomass figures upon which proponents of 'cooling the planet with biomass' rely, maximising per hectare yields will be of the essence. As we have seen above, even with very optimistic assumptions, some plans to 'draw down atmospheric CO_2' rely on 500 million of hectares of biomass plantations. The less biomass harvested from the land (i.e. lower yields), the more land will be needed overall to reach those goals. Clearly, the amount of land available for bioenergy is limited. It is limited by the needs of ecosystems and other species and by human needs including for food and water. Even in purely monetary terms, if all other concerns the needs of planet and of humans are disregarded, land availability is still a limiting factor because the new demand for bioenergy pushes up land prices.

Tree plantations – photos courtesy of World Rainforest Movement, www.wrm.org.uy
(Photo of a clearcut from Swaziland, 2006, Report by Wally Menne and Ricardo Carrere)

If a 'climate change mitigation' strategy was adopted which included so-called 'carbon-negative bioenergy, then it would necessitate government policies similar to those used to create today's fast-growing artificial market in agrofuels, i.e. targets, subsidies and land allocations. Because of the very large amounts of biomass required, targets would have to be set very high. This would inevitably result in a 'competitive advantage' to the highest yielding, fastest growing trees and crops. These are inevitably found on lands with fertile soils, sufficient reliable rainfall or irrigation and a warm climate. In Brazil, for example, tree plantations have a cycle of just 5-7 years, compared to 25-35 years in temperate zones.[90] According to the paper and pulp industry, per hectare yields of wood from plantations in Brazil are ten times higher than in Sweden. It is thus not surprising that European paper and pulp firms are increasingly investing in plantations in the global South. Jonathan Lermit and Peter Read's proposal requires establishment of an additional 10 million hectares of tree plantations every single year until 2050, and the majority of those would almost certainly be in the global South.

All large-scale bioenergy plans involve the cultivation of large-scale grass monocultures as well as tree plantations. As described for tree plantations, the per hectare yield for grasses in the humid tropics is considerably higher than for temperate zones. Sugar cane can yield up to 25 tonnes (oven dry tonnes, or odt) per hectare per year, whereas one of the highest yielding grass crop used for bioenergy in temperate zones, *Miscanthus*, yields 10-18 oven dried tonnes (odt) per hectare.[91] As discussed above, in terms of energy-balances, sugar cane is the 'best-performing' of all ethanol feedstocks, and any large-scale bioenergy programme, not just for ethanol, is likely to heavily rely on it. However, sugar cane monocultures have a severe impact on soil and water, on rural communities and workers, on biodiversity and on climate. The impacts in Brazil, the world's leading producer of sugar ethanol, are summed up by Mateus Trevisan of the Movement of Landless Labourers (MST) "…large monoculture plantations, concentration of land/property, means of production and wealth; intensive mechanization and low rates of employment creation; intensive use of oil derivatives like fertilizers; increasing use of agrotoxics, especially in the cultivation of GM crops."[92]

Example 1: Bioenergy yields from natural forests vs. plantations

Natural forests hold considerably more biomass and carbon, and thus energy, per hectare than any tree plantation. According to "Alternatives to Slash and Burn", primary forest in the tropics holds around 300 tonnes of carbon per hectare. Secondary logged forest (i.e. natural forest regrowth after logging) holds 100-200 tonnes, but monoculture tree plantations hold only 11-61 tonnes per hectare. [93]

According to a CEEWeb report by Ivan Gyulai, sustainable extensive (rather than intensive) harvesting of wood from semi-natural forests provides net energy at a rate up to fifty times greater than the energy input. [94] Forest communities have been able to meet most of their energy needs for thousands of years whilst protecting biodiversity and forests. Industrial exploitation of forests and industrial tree plantations, on the other hand, rely on high fossil fuel inputs and are unsustainable in terms of their impacts on biodiversity, communities, fresh water and soil. Tree plantations not only hold far less biomass per hectare than forests but they also require high energy inputs for soil preparation, mechanical and chemical weed control, deep tillage, ploughing, row cultivation and fertilisation. Net energy gains are thus significantly reduced. Agro-chemicals pollute soil and water, groundwater depletion is common on tree plantations, soil fertility and the soil itself becomes depleted, whist biodiversity is lost.

Maintaining forests in semi-natural condition, without soil and water depletion, pollution and biodiversity destruction requires severely limiting the annual removal of wood. According to CEEWeb, in Europe a maximum of 15-20 GJ/ha of bioenergy can be taken from a semi-natural forest every year without destroying it but an intensively managed tree plantation, where virtually all biomass is harvested yields 200-350 GJ/ha. Monoculture tree plantations thus offer high yields of bioenergy and thus high short-term profits but at the expense of perpetuating fossil fuel use (including for agro-chemicals), depleting soil, water and decimating biodiversity. The often disastrous impacts on communities, workers and ecology are discussed below.

Regarding water; 1,500 - 3,000 litres of water are required to produce one kilogram of sugar, and up to 3,500 litres for each litre of sugar cane ethanol. Any bioenergy strategy which increases the demand for sugar cane will push up global sugar prices and thus make sugar cane expansion attractive even if irrigation is required and even if, in the long term, this results in depleted rivers and groundwater. Sugar cane is also linked to water pollution caused by run-off of agro-chemicals and by waste-water discharge from sugar cane mills (although the latter can technically be avoided with sufficient investment). The problems of water depletion are exacerbated by climate change rainfall patterns become less reliable, making irrigation ever more essential, particularly for water-demanding crops. Crops that require little water on the other hand, tend to produce lower yields or less bioenergy per hectare.

Most bioenergy feasibility studies suggest that much of the 'available land' is in the global south, however bioenergy expansion is forecast in most parts of the world, and particularly also in the Commonwealth of Independent States (former Soviet Republics), the Baltic States, New Zealand, Australia and North America (Quickscan Report, 2004). Fast growing perennial grasses are commonly advocated for bioenergy in temperate regions, along with fast-growing poplar, pine, along with genetically engineered trees such as cold-tolerant GE eucalyptus. GE trees threaten particularly serious ecological impacts, which are discussed in detail at www.globaljusticeecology.org/stopgetrees_about.php .

Just as monoculture tree plantations hold only a fraction of the carbon contained in natural forests, perennial grass monocultures also hold just a fraction of the carbon held in biodiverse natural grasslands. They, too, contribute to decimation of

Example 2: Perennial grasses for bioenergy

James Hansen's biomass proposals rely heavily on a study by David Tilman et al[95]. The authors compared biomass productivity in different plots grown with monocultures or with mixes of 2, 4, 8 or 16 grass species. The average productivity of the most biodiverse grass mixture outperformed that of the best monoculture by 40%. Compared to average monoculture, the average productivity of 16-species plots produced 170% more biomass. The study took place on relatively infertile soil, over a ten-year period. Carbon sequestration in roots and soil increased in line with biodiversity, whilst the need for agro-chemical inputs decreased to very low levels. Although the biomass was burnt rather than harvested once a year, the authors maintain that impacts of an annual harvest would have been very similar to those of an annual burn.

Other studies support the findings that high biodiversity goes along with high productivity and low inputs: An EU-funded study, for example ("Plant Diversity and Productivity Experiments in European Grasslands" by A. Hector et al., Science Vol. 286 Issue 5442, 1123-1127, 5th November 1999) shows that biodiversity is the key to reducing the need for synthetic fertilisers and pesticides and to increasing biomass yields. In the long term, biodiverse grass mixtures are not just far more sustainable but also have a far better energy balance than monocultures of for example, switchgrass or miscanthus.

Tilman uses his results as the basis for his proposed global 'carbon negative' bioenergy programme. This is problematic.

The study fails to highlight the fact that such a strategy depends on farmers and bioenergy companies foregoing higher short-term biomass yields in order to maintain higher long-term yields and long-term sustainable cultivation. However, as we have seen, government and market incentives to significantly expand biomass production will almost certainly favour maximising short-term yield. According to a study by the German NGO Naturschutzbund[96], biogas production has led to farmers cutting the grass four times, rather than once a year and before the reproductive cycle is completed. This maximises short-term yields, but decimates biodiversity. Furthermore, the use of biogas by-products as fertiliser, while it makes more frequent harvests possible, at the expense of biodiversity and future biomass yields. This suggests that the use of bioenergy by-products as fertiliser – which could include biochar in future – can have unintended negative consequences.

Moreover, the study looks at combining a specific ecosystem restoration project with harvesting of biomass. Ecosystem restoration, by definition is specific to different biomes, soils and local climate conditions. Experiences with native prairie grasses in the US cannot automatically be transferred to other countries, soil types and biomes.

The most important concern however is that Tilman assumes that 500 million hectares of 'marginal' land are available for 'carbon negative' bioenergy. Whilst he proposes high-biodiversity, low input agriculture for bioenergy, he has made it clear elsewhere[97] that this will require 'freeing' large areas of agricultural land through further intensification of food production, which means greater fertiliser and pesticide use on those lands. Even if micro-lifecycle assessments were to show that the bioenergy produced in this way was 'climate friendly', it will have resulted in a massive increase in GHG emissions associated with agricultural intensification elsewhere, as well as the displacement of communities and agriculture into natural ecosystems. Both factors would significantly accelerate climate change. Finally there are serious questions over the term 'marginal lands'. The term is frequently used to describe pasture land used on a seasonal basis, biodiverse forest, scrubland or savannah habitat used for gathering, or land periodically left fallow to allow soils to regenerate. The conversion of natural or semi-natural habitat or sustainable traditional farming methods into polyculture grasslands for bioenergy could also result in considerable initial carbon emissions.

biodiversity, and depletion of groundwater and soils. Furthermore the loss of natural ecosystems (both of forest and grassland) contributes to destabilisation of the biospheric cycles - in particular the carbon, nitrogen and water cycles.

Whilst the quest for high bioenergy yields is intrinsic to any proposal for using biomass for 'planetary engineering', short-term yield gains will almost certainly favour intensive production methods. Long-term sustainability, on the other hand depends on maintaining ecosystem productivity and functioning, and thus on not removing excessive amounts of biomass and not harvesting grasses or trees too frequently.

Healthy ecosystems are highly productive in terms of the amount of biomass they hold and in their ability to regulate climate systems, the water cycle and maintain healthy soils which serve as the basis for life on earth. However, they do not produce unlimited amounts of 'excess energy' which can be removed without destroying the ecosystem. Maximising energy yields from biomass and maintaining sustainability are two mutually exclusive aims. This will be discussed in more detail below.

Truly sustainable bioenergy production would be based on protecting or increasing local biodiversity, rather than maximising yields. It almost certainly would not yield tens and less so hundreds of extra exajoules of energy, or the vast amounts of biochar or sequestered carbon envisaged by 'carbon negative' bioenergy proponents. As Dr Ivan Gyulay says:

> *"If we want to avoid the deterioration of environmental conditions, it will inevitably conflict with high productivity, the main goal of using these plantations for energy purposes"*[98].

5.7 Can high energy yields from biomass be sustained in the longer term?

> *"From agricultural lands, the United States can produce nearly 1 billion dry tons of biomass annually and still continue to meet food, feed, and export demands. This projection includes 428 million dry tons of annual crop residues." USDA and US Department of Energy Report, Perlack, 2005* [99]

> *"We stand, in most places on earth, only six inches from desolation, for that is the thickness of the topsoil layer upon which the entire life of the planet depends" R Sampson* [100]

Maximising short-term bioenergy yields, as shown above, involves agro-chemical pollution, encourages soil and water depletion, and destroys biodiversity. Critics, such as Dr Ivan Gyulay and Tad Patzek have pointed out that nearly all studies of energy balances ignore the 'virtual energy cost' of what would be required to restore soil and water. In reality, no amount of energy input can remedy soil depletion and erosion, or freshwater depletion and pollution.

Soil protection, on the other hand requires limiting the removal of biomass from land, not removing soil cover, not destroying soil microbe communities through intensive farming methods and the application of agro-chemicals. Instead, biodiverse small-scale low-mechanised farming methods such as intercropping and permaculture, which include fallow periods would be required.

5.7.1 The problem with soil

(Severe soil erosion, Iowa, http://science.nationalgeographic.com and dead fish in the growing 'Dead Zone' in the Gulf of Mexico, caused by run-off of nitrate fertilisers, http://earthfirst.com)

Intensive agricultural methods needed to maximise short-term biomass yields, are fundamentally incompatible with protecting soil and freshwater. Since the 1940s, industrial agriculture has relied upon fossil-fuel derived synthetic fertilisers for replacing soil nutrients, with fertiliser use currently increasing rapidly in the global South. Synthetic fertilisers, however, only replace some of the key nutrients, primarily nitrogen, phosphorous and potassium. Meanwhile there are significant declines of essential trace elements. Applying nutrients through synthetic fertilisers is inefficient: considerably more nitrogen and other chemicals have to be applied than can be taken up by plants, and this nitrogen loading has serious consequences for the global nitrogen cycle, for global warming and for terrestrial, marine and freshwater biodiversity. Since synthetic fertilisers made from natural gas were developed in the 1940s, the global supply of nitrogen available to plants worldwide has doubled.

According to a comprehensive review of threats to global biodiversity[101], nitrogen deposition, most of it from fertiliser use, is the third greatest threat to biodiversity after land use change and climate change. Eutrophication (nutrient enrichment) of freshwater and anoxic 'dead zones' in oceans, many of them caused by fertiliser and chemical runoff and leaching from agricultural fields are amongst the main threats to fishstocks and other marine and freshwater life. Furthermore, excess nitrate fertilisers are metabolised by soil microbes into nitrous oxide, a greenhouse gas nearly 300 times as powerful as CO_2. According to the Stern Review, global agricultural greenhouse gas emissions increased by 10% in the 1990s and are likely to increase by a further 30% by 2020, mainly as a result of fertiliser use, particularly in the tropics. In Asia, nitrous oxide emissions have increased 250% in recent years.

Growing inputs of synthetic fertilisers, however, cannot prevent soil erosion and depletion, nor can they restore fertility in the absence of other measures. In short they are not a substitute for good soil stewardship. Currently 5-10 million additional hectares of land become severely degraded every year[102]. Even before the current bioenergy boom, soils in the US, for example, were eroding twenty times faster than they were being replaced[103]. In response to this crisis, the US government introduced the Conservation Reserve Programme in 1985, paying farmers to set aside land for conservation and to allow soils to recover. This relatively successful programme is currently under challenge due to lobbying, including by the ethanol industry and high commodity prices, pushed up in large measure by agrofuels.

Remoσσval of forest residue, Germany: Peter Wohlleben

Earth compaction with implications for new growth, Germany. Peter Wohlleben

The impact of intensive 'high productivity' bioenergy production is likely to be even more severe than that of intensive monoculture cropping for food and animal feed, because short-term yields are increased by removing all or most of the agricultural residue for energy. The use of so called agricultural 'waste' for bioenergy is supported by most bioenergy feasibility studies. Johannes Lehmann, for example, suggests that 160 million tonnes of carbon could be sequestered as biochar every year from forest and mill residues, field crop residue and urban waste. Already, growing amounts of agricultural and forest residue are being removed for bioenergy, providing fuel for power generation and ethanol refineries.

There is evidence that the removal of corn stover from fields can increase the rate of soil erosion up to a hundredfold[104]. In São Paulo state, the centre of Brazil's sugar ethanol industry, an estimated 31 tonnes of soil are lost every year from each hectare[105]. The removal of bagasse for bioenergy, as well as the still prevalent burning of cane residue in the fields, further harms soil microbes.

In a natural ecosystem, all plant residues will be recycled by soil microbes and will replenish soil nutrients. Removal of crop residues, strips the soil of nutrients, carbon and water. According to Hungarian scientist Marta Birka, this new practice exacerbated the 2007 drought in her country, as farmers were selling crop residues for bioenergy, leaving soils unprotected from the sun and from evaporation.[106] At a time when droughts and heatwaves are already becoming more severe and frequent, stripping fields of all biomass in the name of climate change mitigation is clearly dangerous and misguided.

"Forest residues" for bioenergy?

The use of so-called 'forest residues' is being increasingly promoted for bioenergy production, and it is also being promoted as a future feedstock for biochar production, including by many of the members of the International Biochar Initiative.

It has been known for some time that the use of such 'residues', including dead wood, results in lower carbon storage as well as serious biodiversity losses. In natural forests, deadwood accounts for around 40% of all biomass, yet in managed forests in Germany, for example, it accounts for just 5%, with ever larger amounts being removed for bioenergy. As a result, managed forests in Germany store only 0.7 – 3.5 tonnes of carbon per hectare, whereas natural forests in the same location, where deadwood is not removed, store 6.3 – 11.5 tonnes of carbon. In Germany, 1,500 species of fungi and 1,350 species of beetle along with many other species of insect, lichens, birds and mammals depend on sufficient amounts of deadwood being left in forests.[107] More intensive forest management for bioenergy is highly likely to accelerate biodiversity losses, including the loss of species which play an essential role in the recycling of nutrients and pollination and thus the future survival of ecosystems upon which we depend. Furthermore, industrial 'forest residue' removal for bioenergy has been shown to permanently damage forest soil and to diminish or destroy the possibility of forest regeneration[108].Heavy machinery is used to remove roots, branches, leaves and other biomass after clear-cutting. This results in severe soil compaction as well as the removal of nutrients in the biomass which would otherwise have been returned to the soil. Soil depletion, groundwater reduction and susceptibility to drought, flooding and thus soil erosion (as soil is washed away after heavy rainfall) follow. This results in soil which will not be able to support either natural forests or high biomass yields in future.

Biochar proponents claim that the use of charcoal as a fertiliser will improve soil health and fertility. As discussed above, there is no evidence so far that modern biochar does in fact improve longer-term soil fertility. However, even if it did work, proposals for using biochar for 'climate change mitigation' involve a major and rapid scaling up of global biomass production based on intensive agriculture, grass and tree plantations, as well as on the excessive removal of biomass from agricultural fields and forests, on a worldwide scale. Under these conditions it is very doubtful that any properties which biochar might have as a fertiliser would outweigh the damage caused by the greatly increased human pressures on land and soil. Soil dynamics and the impacts of human interventions are still poorly understood. According to soil scientist Daniel Richter "properties and processes in the soil are more dynamic and susceptible to change than we previously thought. Only recently are we documenting how [many aspects of soil chemistry and composition] are all highly responsive to human activities."[109] There is no reason to think that soils used for high-yielding biomass plantations will remain as healthy as soils remaining within natural ecosystems, or within biodiverse, integrated small-scale farming systems, just because charcoal is added.

5.7.2 Running out of water

Nobody has yet assessed the impacts which large-scale 'carbon negative' bioenergy programmes would have in terms of freshwater demand. One recent study estimates that implementing current national biofuel targets would require 180 km^3 of extra irrigation worldwide, which would put significant extra strain on water reserves in some countries, such as India and China[110]. However the scale of biomass removal envisioned by James Hansen, Peter Read or Johannes Lehmann, are an order of magnitude greater than current national biofuel policies. Water requirements would thus be proportionately greater. Moreover, most studies, including those by the International Water Management Institute, look solely at irrigation for crops, rather than for tree plantations. Wood would be amongst the main feedstocks for either pyrolysis with biochar, or for bioenergy with carbon capture and storage. The highest-yielding, fastest growing trees, particularly eucalyptus, have large water requirements, characteristically leading to the depletion of groundwater and soil moisture. According to an Australian study, fixing one kg of carbon in eucalyptus requires 421 litres of water. [111]

Professor John Anthony Allan, winner of the 2008 Stockholm Water Prize, called the effect of the growing use of biofuels "too frightening to even begin to realize." [112]Yet fixing billions of tonnes of carbon in trees will require many trillions of litres of water, eclipsing the demands of today's biofuel industry. There is, so far, no discussion as to where this additional water could come from.

5.8 Speeding up the carbon cycle?

The scale of land use change, or planetary engineering, which James Hansen and others envision, is put into stark perspective when compared to the total amount of energy currently produced by the biosphere. Currently, the terrestrial biosphere absorbs a net 300 million to 1.5 billion tonnes of carbon per year.[113] This constitutes the total net energy produced by plants and soils. In healthy, undisturbed ecosystems in a stable climate, virtually no net energy would be produced. Instead, all energy and carbon would be recycled. However due to higher atmospheric concentrations of CO_2, plants and soils are currently taking up more carbon than they return to the atmosphere ('CO_2 fertilisation'), even taking account of losses due to deforestation and fires etc. This represents one of the very few existing negative climate feedbacks, temporarily compensating for higher CO_2 emissions.

Scaling up bioenergy production means continually removing large amounts of energy/carbon and nutrients which would otherwise be recycled. The same is true for all forms of intensive agriculture and industrial tree plantations, resulting in a dramatic loss of soil and soil nutrients, mitigated, at present, primarily through energy-intensive fossil-fuel inputs.

James Hansen[114] suggests that 'forest and soil sequestration', primarily reforestation, afforestation and biochar, can sequester 106.5 billion tonnes of carbon in 50 years, which is 2.13 billion tonnes per year. Additionally, he expects bioenergy with carbon capture and storage to sequester carbon even faster. This would represent an attempt at major planetary engineering with a view to increasing the entire biosphere's productivity more than twofold. Hansen's proposal essentially suggests that humans can and should speed up the terrestrial carbon cycle by at least 240% and possibly far more. It is of great concern that by ignoring the macro-impacts, the risks of triggering ecological collapse and thus removing all future possibility of stabilising climate are also ignored. Additionally, even if it was possible to speed up the terrestrial carbon cycle, in the first couple of decades the emissions from biomass loss would far outweigh the gains from new biomass. This is a serious problem when one considers that key tipping points associated with radiative forcing will be crossed within two decades, making large-scale bioenergy a significant contributor to runaway warming.

Helmut Haberl of Klagenfurt University and others have tried to estimate the total amount of energy produced by the biosphere which humans already use, looking at the relationship between human pressures on the biosphere on the one hand and biodiversity losses on the other hand.[115] They estimate that humans currently use

23.8% of the total net productivity of the terrestrial biosphere. They warn: "Land use transforms earth's terrestrial surface, resulting in changes in biogeochemical cycles and in the ability of ecosystems to deliver services critical to human well being. The results suggest that large-scale schemes to substitute biomass for fossil fuels should be viewed cautiously because massive additional pressures on ecosystems might result from increased biomass harvest."

5.9 Cooling or heating the planet: the likely climate impacts of large-scale biomass

In order for bioenergy to qualify as 'carbon negative', the following conditions would need to be met:

- The carbon that was sequestered and stored would have to remain stable: The stability of carbon, particularly carbon contained in biochar cannot currently be guaranteed.
- The amount of carbon sequestered would need to exceed the carbon released during the entire production process. The emissions associated with land-use change and soil organic carbon losses are vast, virtually unquantifiable and routinely omitted.

However, even if those conditions were met, this does not mean that 'carbon negative' bioenergy would actually be 'climate friendly' or 'climate neutral'. For that to be the case, at least two further criteria would have to be fulfilled:

- There must be no adverse impacts on the climate-stabilising role of ecosystems: As we shall discuss later, climate change cannot be reduced to greenhouse gas emissions alone. Ecosystems play a vital role in regulating the climate, not just because they regulate the carbon cycle and the nitrogen cycle. They also help to regulate the Earth's reflectivity, through cloud formation, with natural forests acting as a 'heat pump' which regulates rainfall and storm tracks, essential for ensuring predictable rainfall and climate stability. The climate impact of replacing ecosystems with plantations cannot be reduced to greenhouse gas calculations – ecosystem collapse could trigger a number of positive feedbacks causing climate stability to unravel much more rapidly and unpredictably.
- There must be no significant emissions of other GHGs, including nitrous oxide (N_2O):

N_2O, the third most important greenhouse gas, is nearly 300 times as powerful a greenhouse gas as CO_2. Up to 81% of global N_2O emissions come from agricultural soils, caused by the use of nitrate fertilisers and also by legume monocultures (including soya). N_2O emissions are now increasing fastest in the tropics, where, according to the IPCC, applying the same amount of fertiliser to one hectare of land as in temperate zones results in 10-100 times the amount of N_2O emissions.[116] Given that a large proportion of the plantations for biochar and BECS would be in the tropics, greater use of synthetic fertilisers would mean very significant increases in global N_2O emissions. Those emissions will remain in the atmosphere for an average of 114 years. Rapidly increasing concentrations of one of the most powerful, long-life greenhouse gases in the name of 'climate change mitigation', when we are already above 'safe' levels is a highly dangerous and nonsensical 'strategy'. If the decision was made to avoid N_2O emissions from bioenergy production, that would rule out using nitrate fertilisers (synthetic and organic) as well as legume monocultures. It would require non-industrial, sustainable farming and forestry methods which, as we have seen above, would not be compatible with the aim of rapidly scaling up overall bioenergy production and attempting to maxmise short-term yields.

Even when we look solely at carbon emissions from bioenergy production, the figures give no grounds for optimism about what a massive scaling up of biomass production will mean for the climate. Current agrofuel production is greatly accelerating climate change. As we discussed in the context of biochar, once direct and indirect land use change are considered, all current agrofuels result in a 'carbon debt' which will take decades or even centuries to repay. As productivity declines due to soil and water degradation it is highly unlikely that the debt will ever be repaid. Even the most pessimistic estimates, including by J. Fargione et al. and by T. Searchinger et al., take a very conservative view of land-use change emissions: They show that agrofuels cause land-use change both directly by destroying ecosystems for plantations, but also indirectly if agricultural land is converted to fuel crops and food production itself is displaced into natural ecosystems. However, those studies confine the carbon emissions caused by land-use change to the carbon emitted from destroying natural vegetation and soil carbon losses for each hectare converted. In reality it is not possible to calculate the effects of expanding the agricultural frontier in this way. Agricultural, and bioenergy expansion, proceeds hand-in-hand with major infrastructure developments such as roads, pipelines etc which open up the last large connected ecosystems to further exploitation and resource extraction. This is happening at an alarming rate in the tropics and sub-tropics. In Brazil, for example, the government's Plan for Accelerated Growth strongly supports and relies on major agrofuel expansion. It includes major infrastructure investments in the Amazon basin, which are likely to open up large areas of forest to logging as well as different agricultural and mining activities. The full indirect climate impacts of agrofuel expansion, because they contribute to these infrastructure developments, are thus impossible to measure and almost certainly well exceed the calculations of even the most pessimistic studies.

James Hansen proposes that large-scale bioenergy expansion should be combined with an end to 'net deforestation'. This is a very questionable term which permits old growth deforestation in one area to be 'offset' by planting in another, with massive ecosystem and biodiversity destruction and carbon sink losses masked in the process. It appears that Hansen uses the Food and Agriculture Organisation's definition of forests, which includes monoculture tree plantations. Only total protection of the world's natural forests (and therefore protection from being converted to plantations), would be a credible climate change mitigation strategy. Hansen understandably stresses that "the nature of a biofuel approach must be carefully designed". There is a consensus amongst most scientists who support large-scale bioenergy expansion, with or without CCS, that deforestation and the destruction of carbon-rich ecosystems for bioenergy must be avoided. However, there is no evidence that such protection is feasible: any large-scale bioenergy programme will greatly increase the price of land and agricultural / forest commodities. This will inevitably lead to an expansion of the agricultural frontier i.e. direct or indirect ecosystem destruction.

According to the World Rainforest Movement[117] , there were 100 million hectares of industrial tree plantations by 1998 and they have replaced many real forests as well as other biodiverse ecosystems. There are no reasons to expect that much faster expansion of tree and other plantations advocated for 'cooling the planet' would not follow the same model, hence destroying much of what remains of the world's primary forests and other intact ecosystems.

Quite apart from the questions around the assumption that large areas of 'wasteland' and unused 'marginal land' suitable for bioenergy expansion actually exist, there are no credible proposals as to how even the most vulnerable rainforests can be protected from further monoculture expansion. The only long-term experiment in (voluntary) certification of an international commodity market is the Forestry Stewardship Council (FSC). After 15 years, there is no evidence that the FSC has had any success whatever in countering deforestation: The International Tropical Timber Association reported in 2006 that less than 5% of tropical forest was 'sustainably managed'. This even though they generously included the Malaysian timber industry in this definition, in spite of the fact that the rate of deforestation in that country increased by 85% between 2000 and 2005. Moreover, the FSC is still unable to guarantee that the wood it certifies has been produced in accordance with its own FSC principles and criteria (which in any case are so lacking that industrial monocultures of non-native species are granted certification as 'sustainably grown').

Western Shores, South Africa, FSC plantation following fire outbreak; Wally Menne

The proposals by James Hansen and David Tilman for 'carbon negative' bioenergy are based on three assumptions regarding land use:

1) At least 500 million hectares of land can be converted to bioenergy production without any loss of ecosystems and without an impacting on food production.
2) Governments can ensure the full protection of ecosystems, including forests.
3) It can be ensured that farmers and bioenergy companies will forego high short-term yields in favour of sustainable high yields in the long term.

In reality, however, there are no large areas of 'spare land'. Virtually all usable land is either under natural vegetation, or in use for food production and/or relied upon by people for their livelihoods. This will be discussed further below.

The other two assumptions run counter to economic, social and political realities: A climate change mitigation strategy would almost certainly rely on government measures similar to those which are currently being used to promote agrofuel expansion: Targets and mandates, subsidies and tax incentives. Can one expect governments worldwide to implement such policies whilst at the same time ensuring that companies and farmers consistently forego short-term high yields and profits and produce bioenergy only through biodiverse, extensive farming and without the use of agro-chemicals? This would require a degree of government intervention, control and regulation which would be virtually unprecedented, certainly in recent decades.

The current industry interest and investment in biochar does not reflect interest in low-input high-biodiversity bioenergy. Rather it is based on the very different model of 'integrated biorefineries' based on large-scale scale industrial agriculture and industrial forestry. Furthermore, as we have seen, and as David Tilman has admitted, making large areas of land 'available' for such bioenergy will require large-scale intensification of other forms of agriculture which will result in a very significant increase emissions of nitrous oxide and probably of carbon dioxide from soil organic carbon losses.

5.10 Plantations versus people: who will pay the price for biochar and BECS?

(Eviction of Paraguayan communities for soya plantations, photo www.lasojamata.org)

A major expansion of bioenergy for BECS and biochar will put unprecedented additional pressures on the world's freshwater resources, soils and indeed on the entire biosphere. As we shall see below, those pressures could accelerate and deepen not just the collapse of the different climate-related systems, but also of other essential earth systems on which all life depends.

In the short-term, however, the communities who would be affected most severely are those living on the millions hectares of land earmarked for bioenergy expansion. Given that there is no 'spare' uninhabited but fertile land and that all of the natural ecosystems which are likely to be converted as a result of bioenergy expansion are home to and sustain the livelihoods of large numbers of people, we can expect very large numbers of people to be affected.

Many proposals stress that communities should participate in and benefit from bioenergy development, including for biochar or BECS. We have, however, found no proposal linked to 'carbon-negative' bioenergy that suggests that communities will be consulted as to whether they wish their land to be used in that way or informs them about the consequences for their lives and livelihoods. All of the bioenergy feasibility studies we have found completely ignore social realities and land rights.

Current agrofuel production, which so far covers less than 25 million hectares of land, is already leading to large-scale displacement of communities, including often violent evictions. For example in Brazil, according to the Movimiento Sim Terra (MST), the expansion of monocultures, particularly for sugar cane, soya and eucalypt (all of which are in part for agroenergy), has led to the expulsion of small farmers. Since 1960, 60% of the rural population has migrated to the cities in part because of land appropriation. In 2006 land conflicts in Brazil involved 10 million people across 25 million hectares.[118]

Turning 500 million hectares of land into biomass plantations for 'climate mitigation' is likely to exponentially worsen the already disastrous impact of plantations on indigenous peoples as well as other forest communities. Jobs 'created' by plantations tend to displace the livelihoods of far greater numbers of people, and working conditions are commonly poor and dangerous. An article by Red de Acción por los Derechos Ambientales (RADA) describes the conditions on tree plantations in Chile:

> *"The loss of access to natural resources affected by tree plantations, such as water -which is becoming increasingly scarce around the plantations- is causing the migration of peasants and poor Mapuche people to the cities. The new arrivals normally end up in urban poverty belts and require assistance form the different social welfare services."*

Workers are paid according to volume of timber cut, not the hours worked. Accidents are frequent and men work away from their families for twelve days at a time and are then given three days of rest. There are no regular health checks and workers receive insufficient information about the risks from pesticides, herbicides and fungicides to which they are exposed. [119]

Contact with plantations recently sprayed with pesticides, herbicides and fungicides, among others, and the companies' scant concern over regular health checks does not enable the workers to receive due information on the risks to which they are exposed.

In 2007, the UN Permanent Forum on Indigenous Issues published a working paper on the impact commercial tree plantations and monocultures on indigenous peoples. They summarise the social and environmental impacts of commercial plantations, as well as industrial logging, on indigenous peoples:

> *"…denial of rights to lands, territories and resources, land alienation, forced evictions, the prevention of access and rights which have lead to a decline in the population of indigenous peoples, especially in isolated and remote territories' and the destruction of resource management systems. There has also been habitat loss that has lead to destruction of livelihoods, cultures and loss of traditional forest-related knowledge. There has been an increase in social conflicts between indigenous peoples and the state and private corporations… There has been food insecurity, severe health problems, including increasing malnutrition and increased mortality. There has been a breakdown of traditional social structures, introduction of new inequalities, undermining customary laws, social support networks and systems of land management."* [120]

The Indonesian pulp and paper companies PT Perhutani, PT Musi Hatan Persada and PT Tenjung Enim Lestari, who have been involved in research on biochar, with a particular emphasis on the potential for carbon credits for biochar production, are all implicated in serious human rights violations.121

State-owned PT Perhutani has for many years been the focus of criticism over land conflicts, violent confrontations and corruption, as well as for failing to curtail illegal logging and for destroying large areas of rainforest.[122] According to a local NGO, 31 local people have been killed and 69 injured through beatings or shootings by forest guards employed by PT Perhutani since 1998, including three villagers shot dead and one injured in April and May 2008. Those responsible for the killings were subsequently offered promotion for "having fulfilled their duties to protect the forest". [123] PT MHP's and PT TEL's pulp mill plantations in Southern Sumatra were set up against strong national and international protests. Both companies evicted several thousands of people with little or no compensation, and without even complying with national legislation on land rights. The plantations were established at the expense of large areas of rainforest, small farmers' land, local rubber plantations and villages. [124]

Acacia plantations in Indonesia (Trivani Noor of Cappa)

Companies such as these will be amongst the first to benefit from biochar. Their record so far makes it clear that local communities will be paying the price of further plantation expansion for 'climate mitigation' through more land-grabs, evictions, more hunger and malnutrition, land conflicts and more human rights abuses.

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Chapter 6. BECS, Biochar and the converging ecological and social crises

The concept of using large-scale biomass with carbon sequestration, as well as a vast expansion of 'carbon sink plantations' for climate mitigation relies on a reductionist understanding of the current planetary crisis and as such is fundamentally flawed.

Greenhouse gas concentrations in the atmosphere, which are being rapidly increased primarily by fossil fuel burning but also by ecosystem destruction and agro-chemical use, are seen as susceptible to human influence – not just through reducing or stopping emissions (which of course is essential to survival) - but by manipulating the biosphere. The aim is to force an already dangerously degraded biosphere to do what nature has never been able to do; to sequester and retain billions of tonnes of atmospheric carbon, not over thousands of years but within decades. Despite the overwhelming evidence that industrial agriculture and industrial forestry are rapidly depleting the biosphere, soil and freshwater worldwide at an ever faster rate, it is proposed that both these can be expanded further and that this will somehow make the biosphere considerably more productive than it has ever been before.

Those who advocate such proposals appear to view climate change, and specifically, dangerously high atmospheric concentrations of CO_2 not only as the single greatest threat which we are facing, but as a crisis which can be seen in isolation from the much wider accelerating destruction of the biosphere and of all the earth's life support systems. They disregard the fact that ecosystems have, throughout the planet's history maintained the conditions under which life can exist. This includes regulating the carbon and nitrogen cycles, rainfall, storm patterns and to a considerable extent cloud formation, as well as maintaining healthy soils, regulating the freshwater cycle, and providing habitats for all species. What they ignore is the fact that biodiverse ecosystems maintain the conditions, including a climate, which is amenable to life on earth. Reductionist thinking however diminishes ecosystems to the concept of 'biomass' or 'carbon sinks', seen primarily for their capacity to convert atmospheric carbon into a stable form for storage whilst, ideally, at the same time delivering usable 'products'. This simplistic view of climate mitigation (carbon sequestration accounting) pays scant recognition of the vital role played by species diversity in driving the biochemical processes involved in maintaining ecosystems and thus the conditions for life.

Biodiversity is thus seen primarily as a future victim of climate change, not as a natural 'buffer' against catastrophic climate change. In reality, biodiversity is the immediate victim of a combination of direct habitat and ecosystem destruction caused largely by industrial agriculture and industrial forestry, nitrogen overloading and other forms of chemical pollution, freshwater depletion, the introduction of invasive alien species, and increasingly climate change. Without healthy ecosystems we cannot sustain agriculture and human survival.

6.1 Ecosystems Regulate the Climate

Ecosystems, including healthy soil, hold considerably more carbon than the atmosphere at present. When they are destroyed, not only is the carbon that was stored in the ecosystem released, but also the capacity for future sequestration is lost.

However, this is only one of many ways in which ecosystems regulate the climate. Tropical forests for example play a crucial role in maintaining concentrations of the free radical, hydroxyl (OH^-) [125] Hydroxyl plays a particularly crucial role in stabilising the earth's temperature by breaking down methane as well as various pollutants such as sulphur dioxide. Methane is 25 times more powerful as a GHG than CO_2 when averaged over the IPCC assessment period of 100 years. However methane in fact takes just 12 years to break down making its potency compared to CO_2 skewed downwards. Reduce the IPCC assessment period to 20 years (a more relevant period in relation to climate tipping points) and methane becomes 72 times more powerful than CO_2 as a GHG. Hydroxyl thus represents an even more important negative climate feedback than the IPCC data at first sight suggests. If global hydroxyl concentrations were to suddenly decline, for example because of large-scale tropical deforestation or ecosystem collapse, the additional global warming resulting from the accumulation of methane could be catastrophic. In fact, some scientists are concerned that the recent increase in atmospheric methane levels follows a pattern which suggests that it may be partly caused by declining hydroxyl levels[126].

Ecosystems, and in particular large contiguous old growth forests, play a crucial role in regulating the rainfall cycle over large areas. The Amazon forest, for example, has been shown to recycle up to 80% of its rainfall through evapo-transpiration, around 6 tera tonnes ($6x10^{12}$) of water vapour a year. This recycling of the original rains takes place up to six times from East to West as storm clouds are drawn by a gradient of convection from the Atlantic seaboard, across 4000 Km to the Andes before being carried north across the equator via the Hadley Cell. It is widely accepted that this massive evapo-transpiration engine depends entirely upon a large enough area of contiguous forest: break the forest canopy with extensive agricultural plantations and the recycling of rains could break down, threatening the whole forest. Daniel Nepstad, senior scientist at the Woods Hole Research Center, has warned:

> *"The nightmare scenario is one where we have a 2005-like [drought] year that extended for a couple years, coupled with a high deforestation where we get huge areas of burning, which would produce smoke that would further reduce rainfall, worsening the cycle…While some climate modellers point to the end of the century for such a scenario, our own field evidence coupled with aggregated modelling suggests there could be such a dieback within two decades." 127*

Evapo-transpiration: Forests play a key role in regulating rainfall systems and storm-tracks; jrscience.wcp.muohio.edu

About half of the rainfall received by the Amazon forest is exported to an area that extends from Argentina to the US Midwest. New research suggests that the Amazon forest also plays a major role in the energy transport, and therefore rainfall and storm tracks, across a large part of the planet. Science writer Peter Bunyard, reporting on studies by Pedro Silva Dias and Roni Avissar, states:

> *"Teleconnection is the name given for such transfers of energy by means of rainfall to the United States, to South Africa and towards Europe from Amazonia and it comprises relatively slow-moving moist masses of air that, like a slowly moving train, push their way northwards and southwards out of the Basin, carrying their precious cargo of water in the form of water vapour. In effect, we are talking of water that is absolutely essential for the growth and survival of crops fundamental to the needs of the United States, to Argentina, the Northeast of Brazil and even South Africa."*

Furthermore, the Amazon rainforest, has been shown to produce small organic particles – isoprenes and terpenes - which play an important role in cloud formation and in increasing the Earth's albedo, i.e. reflectivity.[128] Other tropical forests, and indeed other ecosystems, including marine plankton, play a similar role. Old growth boreal forests have recently been shown to also release terpenes.[129]

Ecosystems other than tropical forests also play a crucial role in regulating rainfall and temperatures. According to a study by University of Queensland scientists, the destruction of native vegetation has played a major role in recent droughts. They suggest that the 2002-03 drought was 2-3°C hotter because of vegetation clearing and that the same is likely to be true for other droughts.[130] And on a regional level, land-conversion to cropland, particularly using 'C3 crops' such as soybean (which now covers millions of hectares of agricultural land worldwide), has been shown to result in significant regional warming and drying, for example in Mato Grosso, Brazil.[131]

6.2 No Stable Climate Without Biodiversity

The survival of species and ecosystems is therefore entirely interdependent. As species are lost, ecosystems become less resilient and more vulnerable to collapse. According to the 2005 Millennium Ecosystem Assessment [132]:

> *"There is established but incomplete evidence that changes being made in ecosystems are increasing the likelihood of nonlinear changes in ecosystems (including accelerating, abrupt, and potentially irreversible changes)… The increased likelihood of these nonlinear changes stems from the loss of biodiversity and growing pressures from multiple direct drivers of ecosystem change. The loss of species and genetic diversity decreases the resilience of ecosystems, which is the level of disturbance that an ecosystem can undergo without crossing a threshold to a different structure or functioning".*

This 'different structure or functioning' as becomes clear from reading the Millennium Ecosystem Assessment, essentially means ecosystem collapse.

A large variety of studies illustrate the crucial role which biodiversity plays in allowing ecosystems to survive and thus to regulate climate, rainfall, soil metabolism, in other words, to keep the planet habitable. In line with the warnings from the Millennium Ecosystem Assessment, a large number of studies which look at marine as well as terrestrial ecosystems show that when species are lost, the decline in ecosystems can be severe and in many cases abrupt and irreversible.

- A study in Patagonia showed that species diversity correlates with carbon sequestration: The more species of grasses and shrubs which populate an ecosystem, the more carbon is sequestered. This is due to the fact that different plants vary in their root depth, in the form of nitrogen they use and in the timing of photosynthesis, so they can fill different ecological niches. [133]

- A study of deep-sea ecosystems shows that biodiversity losses can lead to an exponential decline in the ability of ecosystems to function which is of serious concern since, as the authors stress "deep sea plays a key role in ecological and biogeochemical processes at a global scale [and]… are essential for the sustainable functioning of our biosphere and for human wellbeing."
- A recent review of the literature on drivers of biodiversity extinction[134] illustrates how ecosystems can unravel when species loss triggers 'chains of extinction', with 'amplifying feedbacks' that can become impossible to stop. Examples include:
- In Australia, localised extinctions of dingoes have led to an increase in cats, foxes and rabbits which have caused large numbers of marsupial extinctions.
- Overhunting of mammals in tropical forests has led to the local extinction of dung beetles. Dung beetles are essential for seed dispersal and probably for the control of parasites spreading to vertebrates. They also a role in nutrient recycling. Their disappearance, together with the loss of birds and mammals has stopped many trees from reproducing.
- Overhunting of primates, who play an important role in seed dispersal, has been linked to the loss of species diversity in trees.
- A study of different extinction scenarios in a rainforest in Panama [135] concluded that selective logging of tree species with high wood density can reduce carbon storage by up to 70% but also warned that the impact of biodiversity losses on the ecosystem cannot be measured just in terms of carbon storage:

  > *"Human domination of terrestrial and aquatic landscapes has made us increasingly dependent on a reduced number of species to provide critical ecosystem services. Given uncertainty in both the nature of extinction and the variety of ecosystem services required for human well-being, we may best be able to meet these demands by maximising the pool of species on which we depend."*

- One study in the Brazilian Pantanal found that pacu fish play a vital role in the dispersal of seeds, including those of palms. Overfishing of pacu is thus a major threat to the forest.[136]

These studies clearly show that losing any species can put the entire ecosystem at risk, and that species diversity must be a central feature of any approach to mitigating climate change. The destruction of biodiversity and ecosystems go hand-in-hand with climate collapse, as is illustrated by analysis of the current mass extinction already underway.

6.3 Vanishing Frogs: Lessons From an Unfolding Mass Extinction

Dead yellow-legged frogs in Sierra Nevada, California, killed by chytridiomycosis, a fungal disease responsible for amphibian deaths in large parts of the world. *Photo by Vance Vredenburg, www.sciencedaily.com/releases/2008/08/080812135654.htm*

Amphibians are amongst the most successful and adaptive classes of animals on earth. They have been around for around 350 million years and have survived at least three mass extinctions, including the End Permian Extinction, which wiped out around 70% of all species on land and is believed to have been the most catastrophic of all previous extinctions. Relatives of modern frogs evolved 190 million years ago and survived the mass extinction event that killed the dinosaurs.

Yet amphibians are now declining, and extinctions are occurring across the world, much faster than amongst birds and mammals. The very survival of amphibians as a class is uncertain. As David Wake, co-author of a recent paper in PNAS warns: "There's no question that we are in a mass extinction spasm right now. Amphibians…made it through when the dinosaurs didn't. The fact that they're cutting out now should be a lesson for us". [137]

According to the Global Amphibian Assessment, over 160 species have already become extinct in recent years and decades, and a further 32% of all amphibian species are threatened with extinction. The true figure could be even higher because for 22.5% of amphibian species there is not enough information to assess their extinction risk, but many of them may be threatened, too. Habitat destruction and fragmentation are widely seen as the cause of most amphibian declines worldwide, but not the only one: Frogs, toads, salamanders and caecilians are dying in great numbers even in well protected rainforests and wetlands, far from sources of pollution. There have been many reports of seemingly healthy populations suddenly dying out. Field biologist Martha Crump described seeing golden toads in the Montverde cloud forest in Costa Rica in 1987: "There must have been a hundred male golden toads. They were this brilliant golden orange, just sitting there like little statues." She saw around 1500 of them during that breeding season. The following year, only ten were found and none of them bred. In 1989, the last single golden toad ever was spotted and the species has been declared extinct. Twenty out of fifty species found in the same area disappeared at the same time. A fungal disease called chytridiomycosis is widely believed to have been the immediate cause of extinction, although it had not been identified at the time and so cannot be validated. Biologist David Wake describes the fungus which causes chytridiomycosis as "the most devastating wildlife disease ever recorded". [138]. It may have been implicated in the first ever reported 'mysterious' mass deaths of amphibians – that of boreal toads in the Colorado Rocky Mountains in the 1970s.[139]

According to the conservation alliance Amphibian Ark:

> *"Where Bd [the fungus that causes chytridiomycosis] thrives, generally moist cool habitats, 50% of amphibian species and 80% of individuals can be expected to disappear within 1 year.*[140]

Many scientists believe that the fungus can only kill such large numbers of frogs because they are already vulnerable to disease. Climate change, pollution, particularly from agro-chemicals and increased UV-B radiation due to ozone depletion have been implicated as the underlying causes of the deaths. Others believe that mass deaths, at least in lower Central America and in the Andes, could be explained solely in terms of a newly introduced disease spreading in a wave-like pattern, typical for epidemics, without any other factors playing a role.[141] There is indeed strong evidence that chytridiomycosis was spread from Africa through international trade in frogs and toads [142] – but there is equally strong evidence that the spread of the pathogen was facilitated by the vulnerable state of amphibian populations.

The idea that amphibian populations are more vulnerable is supported by their susceptibility to other pathogens such as Ranaviruses or trematode parasites. A global mass extinction event amongst one of the earth's oldest and most adaptable classes of animals clearly suggests that something very fundamental is going wrong and chytridiomycosis is only one of the factors. In 2007, a study by Steven Whitfield et al143 revealed 75% declines of reptile and amphibian populations in a lowland rainforest. Chytrid fungus was not found in the area, nor does it affect reptilians, and the forest had not been diminished by logging or deforestation. Pesticides, which elsewhere have been shown to drift over large areas, were ruled out as a cause of the declines because populations of the same species increased in nearby abandoned cocoa groves, though soil and water were not actually tested for pesticides. The authors concluded that climate change was the most likely cause of the declines: More dry days and higher temperatures had reduced the amount of leaf-litter in the rainforest on which many reptiles and amphibians depend. Clearly, climate change is a major threat to amphibians, in large part because they depend on ample and clean freshwater for breeding. The 20 species which disappeared from Monteverde forest, for example, did so after the driest year on record in Costa Rica, during which breeding pools had dried up too quickly for tadpoles to develop. Yellowstone National park too is experiencing massive amphibian losses; John Varley former chief scientist for Yellowstone, commenting on a recent study said "Everybody can identify with the loss of glaciers, but in Yellowstone the decrease in lakes and ponds and wetlands has been astounding… some wetlands that were considered permanent ponds are no longer there". http://www.sciencedaily.com/releases/2008/10/081028184830.htm Global warming has been shown to cause more dry days during the dry season and also to alter cloud cover in a way which could also favour chytrid fungus.144 Droughts and heatwaves will undoubtedly decimate remaining amphibian populations in many parts of the world. For example Mediterranean countries are rich in amphibian species and climate change is projected to result in increasing desertification.

Agrichemical pollution and ozone depletion have also been shown to decimate amphibian populations on a scale that puts their global survival at risk. Introduced invasive species and other forms of pollution further exacerbate the losses. The evidence linking agrichemicals to amphibian deaths is solid and widely accepted. A large number of pesticides and herbicides have been shown to kill amphibians even in low concentrations, lower than those found over ever larger parts of the planet. Chemicals that have been implicated include organophosphates such as chlorpyrifos, malathion and diaznion, endosulfan, carbamates, paraquat, atrazine and a surfactant used with glyphosate. Even where pesticide exposures are not directly lethal, they sometimes cause lethal malformations and interfere with reproduction and behaviour in agricultural areas: These chemicals are difficult to contain and are easily blown over large areas, for example from the San Joaquin Valley to the top of the Sierra Nevada mountains and to Yosemite National park in California.145 While most of the discussion of amphibian extinctions in the Monteverde forest has focussed on possible interactions between climate change and chytridiomycosis, nobody appears to have studied the possible impacts of pesticides which could have been transported into the forests by wind, given that many including some that have been banned in Europe and North America and known to kill amphibians, are used in the vicinity. Fertilisers, which pollute freshwater over large areas are also known to kill amphibians. For example, a study in Oregon found that levels of nitrite in water permitted as 'safe' for fish killed all five species that had been studied.146

Ozone depletion has substantially increased UV-B radiation. UV-B radiation has been shown to harm amphibians, causing cancers promoting reproductive defects and inhibiting immune system functioning, killing tadpoles, affecting their growth and development, and causing adult amphibians to go blind.[147]

A very recent report by Peter Hudson, co-author an independent research study, confirms "We are facing a cataclysmic global decline in amphibians caused primarily by the effect of a fungus that was historically not important, but the emergence of which might be associated with climate change, along with the use of herbicides and pesticides," Hudson explained. "The bottom line is that there doesn't seem to be one single explanation for the massive amphibian declines. It could be a mix of other factors." [Peter Hudson et al. Penn State University www.sciencedaily.com/releases/2008/11/081112113708.htm]

6.4 Biodiversity in Meltdown: the Lessons for Climate Change Mitigation

As extinction waves are spreading rapidly across the world's amphibian populations, it seems clear that the causes are multiple and include habitat destruction, agrichemical use, climate change, ozone depletion, and the trade and movement of animals across continents. Even without climate change impacts, the remaining factors leave little room for optimism about the future of amphibian and other biodiversity. As a recent paper on the drivers of global extinction states: "Conservation actions which only tackle individual threats risk becoming half-measures which end in failure, due to uncontrolled cascading effects." [148]

Amphibian extinctions, while they have been particularly well studied are by no means unique: Global reptile populations are far less well monitored yet there is evidence that they may be at an even greater risk of global extinction, for many of the same reasons. As ecologist Whitt Gibbons warns: "The disappearance of reptiles from the natural world is genuine and should be a matter of concern. Current evidence suggests that these declines constitute a worldwide crisis". [149]

Pollinator declines are widely acknowledged and pose a major threat to ecosystems and to human survival. About one third of all plants, including two-thirds of the most important food crops depend on pollination. The recent collapse of large numbers of European and North American honey-bee colonies has been given particular attention, though other pollinators are also in less well studied decline. The key to pollination and thus to the survival of both natural ecosystems and agriculture is species diversity.[150] This diversity is disappearing fast: A 2006 study found that bee species in the Dutch countryside have declined by 67% since 1980 and those in the British countryside by 52%. Wildflower species have declined simultaneously. [151] Epidemics of new diseases, climate change, agrichemical use, alien invasive species and the destruction of ecosystems and agricultural biodiversity are all believed to be contributing to the pollinator extinction crisis – a scenario very similar to that of amphibian extinctions.

Such massive biodiversity losses are reducing the capacity of ecosystems to regulate the climate, water cycles, soil fertility, and other systems essential for life. Most climate change mitigation policies recognise that unmitigated climate change will wipe out biodiversity but they fail to recognise the core implication: that there can be no stable climate and no capacity for resilient ecosystems and therefore resilient agriculture in the face of climate change without biodiversity.

The authors of a recent study on climate change and species extinctions, Rik Leemans and Bas Eickhout show: "Even small magnitudes of climate change will impact species, ecosystems and landscapes considerably. With the already ongoing high rate of climate change (i.e. larger then 0.2°C per decade), a decline in biodiversity and many ecosystem services will accelerate soon." [152] This is particularly concerning because the Earth's landmass will almost certainly continue to warm at a much faster rate than 0.2°C per decade quoted in the study. In the last decade (1998-2007), compared to the previous decade (1988-1997) for example, global surface land temperatures rose by more than 0.4°C. There is also evidence that only half of all ecosystems and only 36% of forests will adapt to global warming of just 0.1°C per decade over a century. Faster warming will trigger far more widespread ecosystem collapse. Only 30% of ecosystems and 17% of forests are expected to adapt to warming of 0.3°C per decade over a century, according to Leemans and Eickhout. Clearly, most ecosystems and thus most species will not be able to adapt to ongoing warming at the present rate. Hence, any presumption that we can avoid abrupt and self-reinforcing climate change impacts by only gradually reducing emissions in the future is false, especially given the time-delay between changes in greenhouse gas concentrations and global temperatures. This means we are already locked into very significant warming.

In the light of what we know about the current vulnerability of the earth's life support systems, and the knowledge that climate change will make these systems more fragile, the notion that we can make the biosphere more productive over a period of decades and in the process draw down atmospheric CO_2 appears not simply dubious but extremely dangerous.

Some climate models predict that global warming of 3-4°C will warm and dry the Amazon basin to such an extent that large-scale forest die-back will be triggered. This level of warming could be reached by mid-century. Yet there are already signs that the rainfall cycle over the Amazon basin is at or close to the point of breakdown. A process of savannisation has already been observed in parts of the eastern Amazon. Each of the last four dry seasons has been exceptionally dry over large parts of the forest and different adjacent areas. Those impacts are difficult to explain other than in terms of regional rainfall changes linked to deforestation and selective logging. Even without a die-back scenario, the Amazon forest is being destroyed at an accelerating rate: In the 12 months up to August 2008, the deforestation rate in the Brazilian Amazon rose by 64% compared to the previous year according to Brazilian government figures. During August 2008, deforestation was at least 228% greater than during the same month the previous year. Large-scale infrastructure plans, linked to the escalating global demand for agricultural commodities, including for agrofuels and wood, will further accelerate the destruction. Given that up to one third of all terrestrial species are thought to live in the Amazon basin, mass extinctions are highly likely well before climate change alone would threaten the survival of the forests.

Elsewhere in the tropics and subtropics, monoculture expansion, industrial logging and other forms of industrial exploitation are also destroying ecosystems far in advance of serious climate change impacts. Brazil's Cerrado, the world's most biodiverse savannah, for example, is being destroyed twice as fast as the Amazon forest, largely for monoculture plantations of sugar cane, soya and eucalyptus.[153]

Other tropical biomes are similarly affected. In South-east Asia, one study predicts that habitat loss, largely through deforestation alone will cause the extinction of 79% of all vertebrate species, most of them (over 4000) being endemic to the region. [154] Malaysia and Western Indonesia are home to at least 15,000 endemic plants and over 200 threatened endemic mammals, birds and amphibians. Yet the United Nations Environment Programme expects that the habitat of most of those species, 98% of the lowland forests of Sumatra and Borneo (the two islands studied by UNEP) will have been destroyed, largely due to oil palm plantation expansion and illegal logging, with similar rates of destruction and likely species losses in other parts of the region, including in West Papua and Papua New Guinea. At the same time deforestation the oxidation and burning of peat stores beneath much of this forest will continue in parallel and add massively to warming.

Meantime, most extinction scenario studies focus on the impact of agricultural expansion rather than agricultural intensification. Yet, as we have seen, agrichemicals play a major role in current extinctions, including of amphibians and pollinators. The loss of biodiversity in soils – soil microbes, worms, insects – through industrial agriculture has barely been studied in its own right but is linked to the greatly increasing soil erosion and humus depletion rates.

As we have seen in the discussion about amphibian extinctions, the most devastating impact on biodiversity comes not solely from climate change or habitat destruction or pollution but from multiple destructive impacts happening simultaneously – i.e. from the converging crises. As biologist David Wake has said about frog declines: They "have really been hit by a one-two-punch, although it's more like a one-two-three-four punch". The same is true for other species and for ecosystems. And the 'punches' described by David Wake do not necessarily just add up – they can also reinforce each other and thus lead to even more catastrophic extinctions. This has been shown in a recent study of rotifer zooplankton in a controlled environment. Over-exploitation, habitat fragmentation and warming each led to population losses which could eventually lead to extinction. However, if the three impacts were combined then the rate of population losses were over 50 times faster.[155]

Amphibian declines demonstrate why we cannot strive to protect biodiversity solely by protecting some areas, whilst maintaining or even increasing pressures on adjacent lands. Impacts from industrial agriculture, such as pesticide use for example have been shown to extend over such large areas that the concept of maintaining separate protected areas as 'biodiversity havens' lack plausibility.

In summary; implementing misguided climate change mitigation strategies which are based on or coupled to industrial agriculture and forestry are thus likely to accelerate the ecological and climate systems breakdown already well underway and risk triggering abrupt, unpredictable and irreversible collapse.

6.5 Agro-biodiversity, cultural biodiversity and climate change

We have shown in Section 5 why "climate change mitigation" strategies which depend on industrial monocultures, including those which involve industrial bioenergy production, will inevitably lead to the displacement of very large numbers of people and to the loss of food sovereignty and livelihoods.

Small farmers, indigenous peoples, other forest and rural communities already suffer the greatest impacts of climate change and, increasingly, the negative impacts of so-called 'climate change mitigation' strategies, such as agrofuels, large hydro power and carbon trading schemes. As we have seen, pressures on communities particularly on the global South (but also indigenous peoples and other communities in many countries of the North) could increase many-fold if so-called 'carbon negative' bioenergy was adopted by governments as another tool for 'climate change mitigation'.

This is more than a humanitarian disaster. Not only are the livelihood of communities destroyed but also their culture and their knowledge and experience of living in harmony with nature, of biodiverse sustainable farming, and of living without reliance on fossil fuels. This means that the very knowledge and community technologies most needed to try and prevent climate and ecological collapse are being destroyed.

The concept of biochar as a global soil conservation strategy disregards the many locally adapted sustainable farming and soil conservation methods which communities have developed over long periods. This approach to soil conservation mirrors the 'Green Revolution' approach to agriculture, where 'experts' promoted one set of 'solutions' to farmers, as 'superior' to traditional farming practices. Diversity and adaptation to local climate, soil and culture continue to be dismissed in favour of allegedly 'science-based' large-scale solutions, no matter how tenuous the scientific basis actually is.

The legacy of the Green Revolution includes not just the environmental destruction linked to industrial agriculture described above and the displacement of tens of millions of people, but also the loss of a much of the world's crop varieties, developed by farmers over thousands of years. According to a report by the Forum for Food Sovereignty, "More than 90% of crop varieties have been lost from farmers' fields in the past century and livestock breeds are disappearing at the rate of 5% per year".[156] As we have seen, policies based on maximising short-term bioenergy yields will favour industrial monocultures and thus further erode crop varieties, whilst the shift from pastoralism to industrial livestock feedlots will accelerate and further reduce varieties of livestock breeds. Agro-biodiversity, however, will be increasingly essential if humans are to adapt to and survive the degree of climate change to which we are already committed. The continued loss of this diversity will further undermine food sovereignty and food security and threaten the survival of ever larger numbers of people.

A 'biochar revolution' would inevitably be led by those companies who hold the patents and have access to funding, and would accelerate the industrialisation of global agriculture and forestry. Successful soil conservation strategies such as inter-cropping, permaculture, composting, the retention of crop residues, fallow periods are likely to be sacrificed for a 'one size fits all solution'. Fallow periods, essential for protecting soil in many non-industrial farming systems already lead to land being classed as 'abandoned' or 'degraded' and thus earmarked for conversion to plantations – a trend likely to accelerate with further bioenergy expansion.

As we have shown above, there can be no stable climate without biodiversity. The survival of biodiversity, however, depends directly on cultural diversity, as Jelson Oliveira of the Pastoral Land Commission in Brazil discusses[157] :

"Genetic diversity is very closely tied to the ethnic diversity of our peoples; it is not by coincidence that countries such as Brazil, that possess the greatest diversity in plant life, also have the largest number of ethnic groups...The more pluri-ethnic a people are, the greater are their chances to live together in a sustainable manner with natural resources, because their tastes and imagery contribute to saving seeds, plants, and animals."

Chapter 7. Towards an adequate response to the converging crises

The current debate about climate change is dominated by responses which reflect dangerously reductionist thinking. Climate tends to be viewed in isolation from the rest of nature. The debate on climate change is reduced to a debate about numbers and about numerical 'targets'. 'Emission reduction scenarios' are being discussed in a 'pseudo-scientific' debate, which fails to take account of macro-interrelationships. This is heightened by our lack of knowledge of how earth systems will respond to even the current atmospheric and ecosystem changes, let alone those caused by geo-engineering interventions. This discourse reflects a widespread inability to think holistically, to see patterns and interconnectivity within the natural world. A reductionist discourse and understanding of the wider planetary crisis results in reductionist 'solutions' which exacerbate the very crisis they are meant to address.

Virtually all of the 'solutions' which are being forwarded in the mainstream debate involve merely *reducing* fossil fuel burning and/or the *rate* at which we destroy the biosphere, or moving to a 'fossil fuel free' *growth* economy. Some rely on patently dysfunctional market mechanisms, such as trading in 'ecosystem services'[158], or carbon trading. The fact that carbon trading has been a monumental failure, and in many cases resulted in a net increase in emissions appears not to dent the enthusiasm of those who promote it.

Other proposed 'solutions' include planetary geo-engineering, which generally involve sacrificing biodiversity and further disrupting poorly understood earth systems. These include changing the composition of the atmosphere, cloud cover or manipulating the biosphere in the hope that we can lower the planet's temperature. Such interventions, as we have seen, are dangerous and unproven. By threatening biodiversity and ecosystems – a primary, negative climate feedback – we increase the risk of not only triggering runaway warming but also destroying the planet's ability to recover from a mass extinction event. Such a runaway scenario could be described as 'beyond catastrophe'; without the powerful negative feedback provided by ecosystems (a situation which planet earth has never previously faced), oceans would warm releasing dissolved CO2 and eventually the ocean water itself would begin to vaporise. Water vapour, a powerful GHG represents a potent positive feedback which would raise temperatures inexorably. Because of the inhospitable nature of such a hot planet, and atmospheric similarities with Venus, this situation has been termed a 'Planet Venus' scenario and would result in a permanent end to life on earth[159].

At this late stage, where the signs of earth systems failure are evident all around us, we need as a primary response to search for ways of living which cause no further harm to the planet. Alongside this we need to find ways of allowing ecosystems to heal and to increase in resilience.

The following three most urgent questions are central…and hardly ever raised in the mainstream climate discourse:

- How can humans actually live without further accelerating climate and ecological collapse?
- Insofar as is possible how can we undo some of the damage which humans have caused to give life on earth the greatest chance of survival?
- How can we bring about the necessary social and economic changes to make such a transition possible?

And underpinning all these questions; how can our understanding of earth systems inform both our thinking and responses?

In this final section, we will consider the first two of these crucial questions from a systemic viewpoint. Addressing the third question goes well beyond the scope of this report.

7.1 Sustainable energy?

80.5% of global energy consumption comes from fossil fuels. Much of the remainder (including industrial biomass and large-scale hydro power) is linked to ecosystem destruction and high greenhouse gas emissions, whilst 6.2% come from nuclear power, which is associated with destructive industrial mining and poses a serious threat to biodiversity. Ending fossil fuel burning as well as ecosystem destruction will thus require that we almost immediately dismantle most of our existing energy infrastructure and production.

Massive investment in renewable energy is widely promoted as being the key to addressing climate change. Yet much of the discourse about renewable energy reflects the reductionist thinking described above:

'Renewable energy' is used as a catch-all term which includes a wide range of energy sources, some of them highly environmentally destructive and/or linked to greater greenhouse gas emission than fossil fuels. Policies are being implemented to promote any type of non-fossil fuel/non-nuclear energy as 'renewable', in the name of 'climate change mitigation'. Even where a definition of 'sustainable renewable energy' is used, there tends to be little debate about the scale at which it could be 'sustainable'.

Amongst the most destructive types of energy which are promoted as 'renewable energy' forms are large hydro dams which can result in three and a half times more greenhouse gas emissions than gaining an equivalent amount of energy from burning oil[160], and the burning of logged ancient rainforests from Tasmania as 'renewable energy' in Japan[161].

In Germany, where legislation provides strong support for renewable energy, as much energy is sourced from burning palm oil as from solar power. Peat expert Professor Florian Siegert states

> *"We were able to prove that the making of these plantations and the burning of the rain forests and peat areas emits many thousands of times as much CO_2 as we then are able to prevent by using palm oil. And that is a disastrous balance for the climate."* [162]

Although palm oil burning accounts for only a small percentage of total non-fossil fuel and non-nuclear energy produced in Germany, the damage it causes is of such magnitude that it more than outweighs all the benefits from the country's sustainable renewables such as wind and solar power.

Replacement of fossil fuels by itself clearly cannot mitigate climate change unless fossil fuels are replaced with energy sources which protect ecosystems and species, soil, water and air. A new definition of "sustainable renewable energy" will thus be essential and must underlie all policies to phase out fossil fuel burning and nuclear power.

Such a definition would have to rule out any use of industrial agriculture and tree monocultures for energy in order to prevent further stress on biodiversity, ecosystems, soil, freshwater and climate from this source.

A definition of sustainable renewable energy would also *rule out* certain other forms and applications of so-called renewable energy, including all large hydro-dams.

Other forms of renewable energy, such as *solar, wind or wave power, offer significant potential for sustainable energy but their impact will depend on how they are developed, on what scale and for whose benefit.*

Any type of large-scale renewable energy project has the potential to pose a threat to biodiversity, ecosystems and climate, as well as to communities, depending on the particular circumstances. Large-scale wind farms, for example, are being built at the expense of biodiverse peatlands in Galicia in Spain, with carbon dioxide emissions from peat degradation potentially outweighing any climate 'benefits' from using less fossil fuel. In Maharashtra in India, forests which were home to a rich variety of wildlife have been cut down and villagers displaced in order to establish wind farms.[163]

It is impossible to imagine that today's consumption of fossil fuels and the use of other destructive forms of energy could be rapidly replaced with sustainable renewable energy, given the speed at which fossil fuel burning and ecosystem destruction need to be ended if we are to prevent ecosystem collapse or crossing further climate tipping points, and given that the scale of 'renewable energy' required to replace fossil fuels would almost certainly automatically render it unsustainable and destructive.

One of the most ambitious proposals for phasing out fossil fuel and nuclear energy is the 'Zero Carbon Britain' report [164] which suggests that the UK (and thus other countries) could meet its energy needs from renewable energy within twenty years, provided that overall energy use was reduced by half. Whilst this report contains many positive ideas about phasing out fossil fuel use, there are also some serious problems with relying on its findings.

As we have seen, even a power down over twenty years, however ambitious, may not be fast enough given that we are already beyond safe levels of greenhouse gas concentrations in the atmosphere, although there are no reasons why the time-frame should not be reduced. But more importantly, the report advocates a high reliance on large-scale industrial biomass, with 4 million hectares of biomass plantations, including willow and miscanthus monocultures, whilst at the same time advocating a shift to non-fossil fuel organic agriculture. The report states: "Although organic bio-energy production is a novel idea, there is no reason why it should not work, since the energy crops act as 'break crops' to maintain the health of soils in an organic rotation". The problem, however, is that the authors assume that the high monoculture per hectare yields achieved with high agrichemical inputs can be maintained without them. High-yield monocultures, which, as we have seen, are inherently unsustainable, depend on high energy and agro-chemical inputs. Without such inputs soils would be depleted much faster and yields would fall.

The assumptions made by the authors of 'Zero Carbon Britain' contradict the results of a study by the Elm Farm Research Centre which suggests that a UK-wide transition to completely organic farming would reduce cereal, oilseed rape and sugar beet yields fall by 30-60%. They are also contrary to predictions by the Soil Association that suggest such a transition would reduce yields by 30% - findings which cannot be extrapolated to other biomes and climate zones[165]. Such yield reductions would by themselves, be incompatible with food self-sufficiency in the UK. Indeed, a transition to mixed, biodiverse organic farming is essential for maintaining the long-term fertility of our soil and thus for making longer-term food self-sufficiency possible. However, yield reductions would indeed be incompatible food self-sufficiency if large areas of farmland were diverted to bioenergy production.

Nor do the authors appear to have considered the seriousness of the current biodiversity crisis. Furthermore, no account has been taken of farmland losses due to the now unavoidable warming and associated freshwater constraints. The report therefore does not represent evidence that even 50% energy reductions in a high-energy society, together with massive investment in sustainable renewable energy over twenty years will be sufficient to end fossil fuel burning as well as ecosystem and biodiversity destruction. Even deeper cuts in energy use and more significant economic and social change will be required.

Any reduction in energy use can be expected to end economic growth, since there is overwhelming evidence that economic growth is directly linked to growth in energy use. Studies by Robert Ayres and by Reiner Kummel show that growth in energy efficiency, labour and capital are important factors in economic growth, and that the biggest factor by far is ongoing growth in energy use.[166] Growth in GDP and growth in energy use have been consistently coupled. There are no reasons to believe that increased energy efficiency could break this link. Energy efficiency has been increasing not at the same rate as economic growth, but it has nonetheless consistently accompanied it. Efficiency rates have been improving at a rate of around 1% a year since the 19th century, whilst fossil fuel burning has increased dramatically. On the whole, greater energy efficiency is correlated with greater overall energy use, as discussed by George Monbiot in his 2006 book 'Heat – How we can stop the planet burning'. For example, central heating has greatly improved energy efficiency but it has led to more people heating more rooms to a higher temperature. There are no indications that, in future, policies aimed at improving energy efficiency will by themselves curb overall energy use.

Given the coupling between completely unsustainable growth in energy use and economic growth and the limitations of relying on energy efficiency, it seems clear that economic growth is incompatible with our survival. *Drastic reductions in global energy and resource use are needed and this will demand major social and economic change and a reversal of the current high-energy industrial growth model.*

7.2 Energy and climate justice

Fast growing and excessive energy use has been coupled with a highly unequal distribution of energy use, with around 2 billion people having little or no access to energy other than biomass, which is often burnt in stoves within dwellings, endangering health and lives. Many people are also forced to rely on unsustainable biomass burning with additional impacts on environment and climate. Communities in some parts of the world have found ways of sustainably using biomass and integrating this low-level use into biodiverse food-production in order to meet their own energy needs. Local community knowledge of truly low-carbon living without harming biodiversity and ecosystems will be essential for our survival, but biomass use in this context is invariably small-scale.

Meeting the basic human need for energy (in both North and South) whilst drastically curbing overall energy use is clearly essential if we want to have any hope of stopping fossil fuel burning as well as ecosystem destruction. However, relying on high energy prices as a means of curbing energy growth will result in ever more extreme fuel poverty amongst poorer people. This has already been happening since 2005 due to high oil and gas prices. The results are deepening poverty as well as a rush to burn more biomass. In the US, high fuel prices are leading to a major increase in wood burning, both in domestic households and at a far greater scale by energy companies, at a time when the US consumption of wood, particularly for paper, is already highly unsustainable and reliant on imports, on industrial tree plantations and on the destruction and degradation of US natural forests. In Lebanon, logging for fuel wood is reported to have risen sharply in line with fuel price rises as people see no other option for keeping their homes warm during cold winters. [167] Clearly, simply trying to substitute current energy and infrastructure with new forms of energy will do nothing to address the underlying resource exploitation, overconsumption and inequality.

Many civil society organisations, particularly in the global South, advocate *energy sovereignty* as an alternative to the highly unequal distribution of energy use as well as to climate change. Friends of the Earth International defines energy sovereignty as

> *"the right for all peoples to have access to sufficient energy within ecological limits from appropriate sustainable sources for a dignified life. Energy sovereignty is the right of peoples to decide over their sustainable consumption patterns that will lead them towards sustainable societies".* [168]

This definition is particularly helpful because all experiences of sustainable, low energy and low carbon living are specific to people's local environment, ecosystems, soil, climate and to their culture since, as we have seen in Section 6, cultural diversity is linked to maintaining biodiversity. Plans for large-scale bioenergy in the South, to meet primarily the needs of the North, sit in diametric opposition to this. They leave us with the tragic irony that those most at risk from the impacts of climate change are already losing their livelihoods and natural environments as a result of false energy and climate change 'solutions'.

As we have discussed, ecological limits are becoming ever tighter as a result of climate change, ecosystem destruction and biodiversity collapse. The fundamental question is whether living within such limits is compatible not just with economic growth (which it clearly is not) but also within any industrial society. Historically and at present, all sustainable, low-carbon and low-energy societies have been non-industrial societies or communities, although, on the other hand, it must be stressed that not all non-industrial societies have lived in sustainable ways.

It is difficult to see how any social change that does not include *rapid de-industrialisation* could allow for the rapid phasing out of destructive practices including fossil fuel burning, industrial agriculture, mining, over-abstraction of water. We are too close to global ecological collapse to suggest that any further industrial exploitation of resources and of the biosphere could possibly be considered 'safe'.

7.3 Ecosystem protection and demand reduction

It is not just the global demand for energy that is highly unsustainable and destructive of ecosystems, but also many other forms of resource use, including the global use of wood products, agricultural products and in particular meat and dairy, as well as mining. Just as with energy, consumption levels are growing fast and are also highly unequally distributed. Paper and pulp production, for example, has increased six-fold since the 1960s, resulting in large-scale deforestation and vast areas of destructive tree plantations, whilst 10% of the world's population consumes over 50% of the world's paper. Unsustainable levels of meat and dairy consumption are likewise concentrated amongst a global elite whilst per capita food consumption in large parts of the South is declining.[169] *Overconsumption, resource exploitation and inequality go hand in hand and must be addressed simultaneously* in any adequate response to the converging crises. It is difficult to see how this can happen fast enough without rapid de-industrialisation.

7.4 Agriculture and food sovereignty

As Via Campesina state:

> *"Industrialized countries and the industrialization of agriculture are the biggest sources of global warming gases, but it is farmers and rural communities - and especially small farmers and rural communities in*

> *developing countries - that are among the first to suffer from climate change... Moreover, plants, animal species and marine life are threatened or disappearing at an unprecedented pace due to the combined effects of warming and industrial exploitation. Life at large is endangered by the decreasing availability of fresh water resources."*[170]

Historically and today, sustainable agriculture has been represented by *small-scale biodiverse peasant agriculture* with low-energy and high labour inputs, adapted to local circumstances. Via Campesina and many other organisations have developed the concept of *food sovereignty* based on sustainable peasant farming, which they define as: "the right of peoples to healthy and culturally-appropriate food produced through ecologically sound and sustainable methods, and their right to define their own food and agriculture systems."

This will require not simply different farming methods but major social and economic changes, including land-reform, allowing for land currently used for monocultures, much of it in the South for export to the North to be used to food production instead, the dismantling of agribusiness, and an end of overconsumption of energy, wood and agricultural products by a global elite, which requires large areas of land to be used for plantations and not for food.

7.5 Increasing Resilience: alternatives to Geoengineering

So far we have discussed the need for rapid demand reductions, de-industrialisation, food sovereignty and energy sovereignty based on truly sustainable renewable energy. However, as we have seen, current levels of greenhouse concentrations in the atmosphere and the level of ecosystem destruction and degradation which humans have already caused are anything but safe and carry a high risk of a mass extinction which, in the worst case, could end in the loss of all life. Yet, as discussed above, geo-engineering carries a high risk of speeding up rather than preventing ecological collapse and thus climate collapse. What then are the hopes for preventing the worst possible outcome and allowing conditions for life to persist?

We have warned of the dangers of trying to speed up the carbon cycle, through large bioenergy plantations and/or through trying to impose global industrial models for soil conservation. This, however, does not mean that that soil cannot be regenerated and that a lot of the soil carbon losses caused by industrial and over-intensive farming cannot be reversed.

7.6 Reversing climate damage from industrial agriculture and soil depletion:

Small farmers, indigenous peoples and other rural communities have developed many different strategies for soil conservation and for improving soil fertility which could well help to reduce carbon dioxide in the atmosphere to some extent if locally adapted sustainable farming methods were to replace industrial monocultures. For example in the Deccan Plateau in India, farmers, have long grown a great variety of crops through rain-fed agriculture in a semi-arid climate, relying largely on women's knowledge of different soil types and crop varieties. Government policies however have promoted irrigated intensive rice production in other parts of the region and the distribution of cheap excess rice, which has caused water-logging and salination on irrigated lands and desertification as dry-land agriculture was increasingly abandoned. There are encouraging examples of farmers being able to revert back to traditional farming methods and reversing the process of desertification as a result. [171]

The US campaign group Food First describes soil and water conservation strategies as well as community-led reforestation in Tlaxcala, Mexico: "In the 1970s, the hillsides around Vicente Guerrero looked like a moonscape because they were so badly eroded. Chemical inputs had wasted the soil." Intercropping, hedgerows, reforestation and careful soil management based on local knowledge has returned soil fertility (and presumably soil carbon linked to humus content) and allows for highly diverse agricultural production for the benefit of farming communities today, whilst native vegetation and biodiversity have recovered at the same time. [172]

These examples are not climate change mitigation strategies which can be quantified in terms of 'greenhouse gas reduction' or 'carbon sequestration' targets, or which can be standardised as global 'solutions'. They are adapted to specific local conditions and cultures and led by communities, yet they clearly increase the resilience of ecosystems. High biodiversity, healthy soils and their ability to regulate local climate and contribute to the global climate, including by sequestering carbon are important indicators. Poignantly they strengthen the resilience of communities to climate change at the same time.

7.7 <u>Resilient Ecosystems for Stabilising the Climate</u>

Throughout the planet's history, ecosystems have played a vital role in stabilising the climate and the planet's life support systems even at times of severe climate change. This is no guarantee that they will be able to stabilise the climate in future, given that the rate of warming may be unprecedented in the planet's history and given the damage from ecosystem destruction, pollution and species losses at present. However, it is clear that ecosystem resilience will be key to the survival of all life. The most recent severe warming episode took place 55 million years ago (though far more slowly than the present). The precise events that led to the high levels of warming and subsequently to climate stabilisation at higher temperature levels are not known. The release of methane from clathrate stores (see Section 1) and/or widespread peat and coal-seam fires have been proposed as potential causes. Long-term chemical processes including rock weathering can explain the eventual cooling of the planet, but not the fact that climate change did not turn into runaway global warming. Nobody knows how the climate stabilised itself without the warming spiralling out of control, but there are good reasons to think that ecosystems, and in particular the spread of fern swamps into the Arctic provided an important 'negative feedback'.

Deciphering the soil and fossil data associated with this extinction event, it is known that large forest cover across the northern hemisphere survived and that species migrated polewards and ultimately vast fern swamps colonised the Arctic.

Geological evidence suggests that floating Azolla fern swamps drew down very large amounts of carbon dioxide 5-6 million years after the extreme warming event, possibly triggering large-scale global cooling. [173]

However, it is very possible that, during the global warming episode, fern swamps, as well as forests and other ecosystems sequestered enough carbon dioxide to prevent even more intense, and possibly runaway warming.

Similarly the repeated oscillation between glacial and interglacial periods spanning at least the last 1.8 million years may well have depended on key ecosystems – including South East Asia's tropical peat forests – to draw down the excess atmospheric CO_2 and prevent a runaway warming scenario. At the end of the last ice age for example, following the onset of warming, climate stabilized with just 90 ppm more atmospheric CO_2. *Evidence suggests that SE Asia's peat forests may have functioned like a 'thermostat', sequestering the excess carbon in the form of peat, thus contributing to climate stabilisation*.[174] Ironically these are the very peatlands which are currently being rapidly destroyed for oil palm and acacia plantations, removing one of the planet's key negative climate feedbacks.

Ecosystem protection combined with widespread restoration thus offers our best hope for climate stabilisation in the absence of further fossil fuel burning. Both protection and restoration depend on addressing the root causes of destruction, including overconsumption and inequitable resource transfer from South to North. There is very clear evidence that *legally establishing the territorial and customary rights of indigenous peoples and other forest communities is a critical ingredient in protecting forests.* Estebancio Castro Diaz writes in a Global Forest Coalition discussion paper:

> *"Most of these rainforests are the traditional land and territories of Indigenous Peoples, which they either reside in or have previously used or occupied. Indigenous Peoples have nurtured and maintained their lands and territories which has in turn protected large areas in which these resources are located."* [175]

Detailed discussions about effective policies for ending deforestation can be found elsewhere and would go beyond the scope of this report. [176]Similar principles apply to the protection of other ecosystems such as grasslands and wetlands.

There are a large number of successful or promising examples of ecosystem restoration, including true reforestation with diverse native species and forest regrowth, peatland and wetland restoration, or grassland restoration.

7.8 Examples of ecosystem restoration

1) Peatland restoration - Scotland

In Scotland, the RSPB is involved is purchasing conifer monocultures planted on peat bogs. The tree plantations are being cut down and drainage channels blocked to prevent further peat oxidation, thereby locking up the remaining carbon. In time, the return of native and often endangered birds, insects and plants leads to the re-establishment of the peatland ecosystem potentially with a renewed capacity to sequester carbon. There is enormous potential for similar peatland restoration in the UK and across the globe – essential if carbon dioxide emissions are to be stopped.

Peatland restoσration, RSPB

2) Removal of River Dams

According to a report by the International Rivers Network and Friends of the Earth Japan [177], 60% of the world's rivers have been fragmented by dams and diversions and one per cent of the world's land surface has been submerged by dams. "Cumulatively the world's large dams have replumbed rivers in a massive experiment that has left the planet's freshwaters in far worse shape than any other major ecosystem type, including tropical rainforests." [178] Dams and diversions are the main cause in the extinction or threatened extinction of one third of freshwater fish species, as well as driving shellfish, amphibians, plants and birds towards extinction. Dams accelerate global warming due to methane emitted from flooded vegetation and the displacement of up to 80 million people worldwide. However, the true climate impact is far greater than that from methane emissions alone: Rivers play a major role in the global carbon cycle, moving carbon which has been taken up by forests and other ecosystems to the ocean, where some of it is sequestered long-term. They also carry nutrients which fertilise plankton in the oceans which in turn absorb large quantities of CO_2 [179].

Experience with dam removal, mostly in North America, shows that dam removal is a highly effective form of ecosystem restoration. So far, around 500 out of at least 17,500 dams in the US have been removed. For example, the Sandy River in Oregon was dammed for nearly a century until the removal of the Marmot Dam in 2007. According to media reports; "Some predicted the river would need two to five years to carry off half the sediment pile. It did it in months. Federally protected Coho salmon were swimming upriver to spawn the day after the dam crumbled".[180] In Alabama, the Cahaba River, one of the North America's most biodiverse rivers, had been dammed by a coal company in 1960, leading to the loss of almost all mussels and snails upstream of the dam and blocking migratory fish. Original species have significantly recovered since the dam was removed in 2004 [181].

3) Community forestry – Gambia

Community management and control of forests has been shown to be the key factor in forest protection and restoration. There have been positive reports about the Gambian government's Community Forestry policy which seeks to encourage and assist rural communities in the control and sustainable management of forests. Bee-keeping has helped to raise rural income and to prevent forest fires, since farmers are given a stake in protecting forests. [182] 70% of Gambia's forests were destroyed and 78% of the remaining forest is severely degraded, yet since the new policy was introduced there have been reports of natural tropical forest beginning to expand again. [183] There are a large number of examples of successful community forest management and restoration. [184]

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Glossary of technical terms

Adsorption
Adsorption happens when a gas or liquid forms a film of molecules on the surface of a solid or a liquid.

Cation exchange capacity
The cation exchange capacity is the capacity of soil to allow exchange positively charged ions between soil and plant. This means that soil with a high cation exchange capacity can best make nutrients accessible to plants. It is used as a measure of fertility, nutrient retention capacity, and the capacity go protect groundwater from cation contamination.

Carbon Sequestration
Retention of carbon in ways which prevent or significantly delay its emission into the atmosphere as CO_2. Usually this takes the form of biomass, soil carbon or ocean storage, or using CCS technology stored underground in depleted oil and gas reservoirs, coal seams or saline aquifers.

Carbon Capture and Storage, or CCS
Capture of CO_2 emitted from large point sources, compression, transportation and injection into underground geological formations for long-term storage.

EJ
One exajoule or etajoule is 1018Joules.

Fischer-Tropsch gasification:
This is one of the 'second generation' or 'biomass to liquids' technologies being developed. It involves two different technologies: Gasification involves heating the biomass at high temperatures with a controlled amount of oxygen. This results in a mixture called synthetic gas or syngas. This syngas is then purified and, in a Fischer-Tropsch plant, carbon monoxide and hydrogen are combined in a catalytic reaction and turned into different liquid hydrocarbons.

Net Biome Production (NBP):
The net production of organic matter in a biome, which takes account of fire, forest clearance, erosion and harvests. NBP is the total carbon accumulated by the biosphere.

Net Primary Production (NPP):
The increase in plant biomass, or carbon in biomass, calculated over a set area. It is calculated as the total carbon taken up by the biosphere through photosynthesis, minus the carbon lost through autotrophic respiration, i.e. respiration by plants, including algae.

Pyrolysis:
Thermal degradation of waste without oxygen, to produce char, bio-oil and syngas. Biomass, ground into fine particles, is exposed to temperatures of 350 to 500 degrees C for short periods.

With fast pyrolysis, biomass is exposed to temperatures of 450-500 degrees C for 0.5-2 seconds.

With slow pyrolysis, biomass is heated more slowly to 350-450 degrees C. Slow pyrolysis yields more char and syngas and less bio-oil than fast pyrolysis.

Radiative forcings:
Radiative forcing is the difference between incoming solar energy and the energy radiated out into space by the planet. At present, the Earth is experiencing strongly positive radiative forcings, largely because of an increase in greenhouse gases and, to

a smaller extent, black soot and ozone. This means that the planet is absorbing more energy than it radiates back and is warming as a result. This situation is often referred to as 'radiative imbalance', implying that some degree of further warming is unavoidable.

Sorbents
Sorbents are materials which adsorb liquid or gases. Adsorption is a process in which gas or liquids accumulate on the surface of a solid or a liquid, forming a film of molecules or atoms. Sponges, for example, adsorb many times their own weight in water.

Syngas
Syngas is a gas mixture containing carbon monoxide, hydrogen and other trace gases. It is generated by gasifying fossil fuels or biomass. Gasification means breaking down hydrocarbons at high temperatures, by carefully controlling the amount of oxygen. Syngas from biomass is used as a fuel, for hydrogen production, or as a precursor to synthetic diesel.