Paper 2

The Virgin Earth Challenge

Regenerating the Earth's soil carbon sponge

Humanity's last chance to regenerate its soils so as to secure its safe climate and future

Draft Science Paper for the *Healthy Soils* Proposal to the Virgin Earth Challenge

A discussion paper analysing why and how we can regenerate the Earth's 'soil carbon sponge' as now our only practicable means to safely; cool climates, limit dangerous climate extremes and secure the water, food, energy and sustainable habitats critical for humanity's future

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Introduction - Responding to the Virgin Earth Challenge

In 2009 Sir Richard Branson announced the Virgin Earth Challenge (VEC) - a call for a solution to humanity's climate crisis. Specifically, to find sustainable and scalable ways to remove abnormal greenhouse gases from the atmosphere so as to help secure humanity's safe climate and future.

Despite five years and some 10,000 applications, of which 11 were shortlisted, the VEC panel of climate scientists and strategic leaders has not found an adequate global scale climate solution.

More recent evidence that we have locked in a mean temperature rise of 4-6^oC later this century under business as usual, dictates that we require a 'solution' urgently. This must address not just the greenhouse effect but also buffer and limit the collapse of bio-systems and communities from such climate extremes. The confirmation by the IPCC in 2013 (p469) that; 'The removal of human-emitted $C0_2$ from the atmosphere by natural processes will take a few hundred thousand years', reinforces the magnitude of our crisis and the need for its solution to consider fundamental change.

In view of the reality of our rapidly deteriorating climate the VEC has sought a further proposal that may provide more comprehensive, practical and commercially viable options for responding to our global climate imperative and its dangerous consequences to humanity under current practices.

The following, outlines the scientific case for how we can still meet this challenge safely and naturally via practical grass roots action by leading land managers to regenerate our soils and landscapes.

It proposes to restore the natural hydrological processes that we have impaired and govern 95% of the heat dynamics and climate of the blue planet so as to safely and naturally offset greenhouse effects and regenerate the resilience and productivity of bio-systems to restore our safe climate.

To do this it will **restore the Earth's 'soil carbon sponge'** to provide the water for these processes. To restore this sponge communities and farmers globally need to return the thousands of billions of tonnes of carbon that our land use has oxidized from our soils and bio-systems as its CO_2 symptom.

This paper, details how we can do this by bio-sequestering some 20 billion tonnes carbon annually (btC/a) from the atmosphere back into the Earth's soil carbon sponge. How this can draw down CO_2 levels over time and restore the hydrological processes needed to cool regions and the planet.

Extended locally and globally, it is now humanity's only means to secure its safe climate and future.

While ongoing effort and support is still needed to reduce our carbon emissions through re-design, demand reduction, energy efficiency, alternative lower emissions and renewable energy and pricing, such reduction strategies are no longer enough. We must also urgently safely cool climates and regenerate the resilience of our soils and landscapes that humanity depends on for its water, food, resource needs, social stability and safe future.

The following details the scientific basis for why and how we can achieve these outcomes. The scientific and economic substantiation of the processes and evidence for these strategies and their outcomes are outlined, in part, in the appendices to this paper and can be provided in greater detail as needed.

We welcome your consideration of and any questions on this paper and the Healthy Soils proposal.

1. Our climate challenge - The scientific reality as of 2015 and its consequences

Despite 50 years of scientific evidence and warnings, humanity is running out of time to respond to our serious abnormal climate changes and its consequences given the reality that:

1. Atmospheric CO_2 levels have been increasing abnormally for over 200 years a result of our ongoing extensive clearing and oxidation of carbon from our soils and landscapes and from our increased combustion of fossil fuels; largely over the past 70 years.
2. Associated changes have altered the Earth's natural heat dynamics, balance and climate, including the greenhouse effect. Some 3 watts per square meter or1% of the incident solar energy that enters the earth's troposphere is no longer being dissipated back out to space. This is resulting in the abnormal warming of the global climate.
3. Over 90% of this additional heat is currently being absorbed by the earth's oceans. The residual is warming the atmosphere; raising mean surface temperatures by 0.8°C to date. As evidenced by global 'dimming', a similar additional temperature rise may be being masked by the increased levels of human induced pollutant hazes that absorb this solar radiation.

These greenhouse and climate effects have been modeled and are discussed by the IPCC.

What are less well understood are additional abnormal changes to the heat dynamics of the planet. These have accelerated a range of positive feedback processes that are intensifying dangerous climate extremes. These feedbacks and extremes have altered hydrological and climate processes, resulting for example in the systemic aridification of regions such as south west Australia, the SW USA and the Mediterranean, well in advance of the abnormal CO_2 rise. These hydrological and climate extremes, now threaten the collapse of key bio-systems due to increased droughts and wildfires and with that the survival of agricultural regions and their communities.

While the Earth's vast oceans have absorbed much of our past CO_2 emissions and temperature rises and masked their climate effects, this buffering capacity will decline as the oceans warm and acidify. This will result in the release of some of the 38,000 btC the oceans hold as dissolved CO_2 into the air. Similar increased CO_2 emissions will occur from our soils, tundras and ocean hydrates as they warm. This has been projected to raise CO_2 levels to above 500 ppm by as early as 2030 even without further emissions from our fossil fuel use; further raising greenhouse effects and abnormal warming. While it is difficult to predict the speed and extent of such further CO_2 increases and their warming effects, they are now inescapable and risk inducing climate extremes that bio-systems can't survive.

Given that we are already experiencing dangerous climate changes and impacts with the current buffered mean temperature rise of 0.8°C, we must not assume that the already locked in temperature rise of 2°C is safe or can be sustained by humanity. We can be certain that most current bio-systems and their dependent communities cannot survive the projected mean temperature rise of 4-6°C nor the extremes it will induce by later this century under business as usual.

Effectively our past impacts and ocean lag effects, have locked in dangerous climate extremes and the collapse of bio-systems and much of humanity within decades under business as usual.

Humanity must find ways to avoid these dangerous climate consequences if it is to survive. It can still do this - but only if it takes responsibility and implements the available safe solutions, urgently.

2. Our response imperative if we are to take our last chance at address our climate crisis

Clearly we must find and implement safe effective solutions to our global climate crisis; urgently. While lag effects have and may delay some of our locked in climate impacts, business as usual with its 4-6°C warming later this century is not sustainable for most bio-systems and communities.

These ocean lags and buffers, also dictate that no level of future reduction in emissions from fossil fuels, by themselves, can now prevent these climate changes, their extremes or their impacts.

This is further reinforced by the 5th (2014) IPCC report (Part6) that confirms at high confidence that; 'The very long time required (hundreds of thousands of years) by (current natural) sinks to remove anthropogenic CO_2 makes climate change caused by elevated CO_2 irreversible on human time scales'.

Instead, we need to find more effective solutions to this reality, overcome our policy inertia and limit the adverse immediate extremes and impacts that risk our bio-systems and communities. Practical action is needed at grass root levels globally and urgently to:

1. **Buffer the impact** - from intensifying climate extremes, on key bio-systems and the economies and communities that depend on them for their wellbeing and survival.
2. **Safely naturally cool regional climates -** to offset the warming and limit extremes from these locked in human induced changes to the natural greenhouse effect and to our climate.
3. **Regenerate the resilience and health** - of natural and managed bio-systems globally so they can survive and supply essential water, food and material needs despite climate extremes.

Once we have secured these imperatives we can focus on progressively reversing the processes that have caused the dangerous and abnormal systemic climate changes.

Fortunately there are safe, natural options for doing each of these, provided we have enough time.

To do so we must however be prepared to adopt thinking beyond that which created our problem. We must be prepared to critically re-examine the proven science of what governs the Earth's heat dynamics, heat balance and its climate, how we have impaired this, and how we can restore these.

We must be prepared to think beyond the simplistic assumptions and models that have dominated our failed climate policy and constrained our options and effective action in preventing this crisis. We must avoid reacting to the obvious symptom of these changes the abnormal rise in CO_2 levels or assume that we can fix its assumed cause and our crisis by slowing or even reducing emissions.

Even though Charles Keeling confirmed that CO_2 was rising abnormally; we must not assume that:

1. The abnormal rise in CO_2 over the past 200 years is due to our increased use of fossil fuel in the past 70 years; rather than a symptom from our oxidation of our soils and bio-systems over the 200 but also the preceding 10,000 years of agriculture and civilization.
2. This abnormal rise in CO_2 was the primary cause of the observed warming, via its undisputed minor contribution to the Earth's natural greenhouse effect, and that the CO_2 rise and its associated greenhouse effect can be controlled by reducing our fossil fuel emissions.
3. Other factors associated with extensive land degradation that had resulted in the abnormal CO_2 increase since 1750, well before the mass increase in fossil fuel use, may not be also contributing to the resultant increased greenhouse warming and climate extremes.
4. Key processes governing the Earth's heat dynamics and climate.

Even though Arrhenius, 100 years ago, calculated that doubling CO_2 could induce temperatures rises equivalent to those being projected, this does not confirm that the abnormal CO_2 rise over the past 60 years is the prime cause driving the real climatic changes observed over more than 100 years.

There are many variables and processes that govern our climate. We need to objectively analyze all of them if we are to understand the cause of our climate crisis and design effective responses to it. To do this we must go back to the science governing the Earth's heat dynamics and the reality that:

- For most of the past 4 billion years it has been water that has governed some 95% of the heat dynamics, balance and climate of the 'blue planet' via known hydrological processes.

- It is water that has, and still governs, most of the Earth's natural greenhouse effect. This has enabled the Earth to maintain a surface temperature some 33°C above what it would otherwise be; thereby enabling liquid water and life to be sustained over most of this time.

- While atmospheric CO_2 levels contribute to some 4% of this global heat balance through its minor greenhouse effect; it can not be assumed to be the key factor governing the Earth's relatively stable buffered climate over this 4 billion years.

Given that CO_2concentration may have varied from 950,000 to as low as 100 ppm over this period due to volcanism and bio-sequestration, it is difficult to see how its direct minor greenhouse effect is consistent with it being the key determinant of the Earth's stable elevated temperature. Similarly, it should thus not be assumed to be the key cause of our abnormal warming or its solution.

While we know a lot about our climate there is clearly much that we still need to learn. To do this we need open objective observations, analyses and debate of the evidence not just belief in our past assumptions and the models and projections that are based on these assumptions and lock them in.

Given these caveats we can however be confident that:

- Humanity has induced an abnormal rise in global CO_2 levels starting from about 1750.
- These levels have more recently been added to by our burning of more fossil fuels.
- There is clear evidence of abnormal increases in global warming over the 20th century.
- This warming may already be triggering climate feedbacks and extremes, some of which long pre-date the marked abnormal rise in CO_2 levels or fossil fuel use.
- We need to understand what has caused these changes and their effects so we can respond to them, and not just their symptoms, effectively and in time.
- We should not assume that these realities are causally related or the only factors involved.

Furthermore, given the many inconsistencies and the lack of a clear understanding, agreement or solution to our climate crisis to date, we need to be receptive to examining all feasible options.

The following analyses seek to do this by reviewing the evidence and our understanding of the Earth's wider carbon, hydrology and climate processes, how this may have caused our recent changes and to see if this wider understanding can provide us with viable response options, in time.

3. Understanding and restoring the global carbon balance - Can it secure our safe climate?

To date most of the public narrative and policy responses to climate change have been based on the simple assumption that there is a sequential causal linkage between: the abnormal recent rise in atmospheric CO_2 levels, our increased combustion of fossil fuels and their resultant emission of CO_2, the undisputed role of CO_2 as a minor contributing factor in the natural greenhouse effect and the observed abnormal warming and climate changes over many parts of the planet.

Based on these associations, most of the public and policy responses have assumed that we can simply reverse the abnormal CO_2 rise, and its associated dangerous climate extremes, by simply limiting our use of, and thus carbon emissions from, fossil fuels, by some token amount.

These assumptions have been reinforced over the past 30 years by a consistent simple scientific and then economic and policy narrative and models and projections that reinforce these assumptions. The fact that there are major inconsistencies in the evidence and that these assumptions have not led to an effective solution to our climate crisis, reinforces that the climate may be more complex. It follows that we may need to re-consider the evidence behind these assumptions

If we do reconsider the evidence, it is clear from Charles Keeling's evidence 50 years ago, that the abnormal rise in global CO_2 levels is driven not by our emissions from fossil fuels; but by our impairment of the capacity of our residual terrestrial bio-systems to sustain the balance between:

1. The over 110 billion tonnes of carbon that the Earth's bio-systems and we emit annually and
2. The ability of the Earth's residual bio-systems to now only bio-sequester some 100 btC/an.
3. As a result an additional 10 btC/an has stayed in the atmosphere progressively raising global CO_2 levels by some 2-3 ppm/an, as a key symptom of this emissions/draw down in-balance.

While some 8 btC/an of this 10 btC/an deficit currently comes from our fossil fuel use, the cause of the CO_2 increase is this overall in-balance in the Earth's carbon emissions and residual draw down capacity - due to our impacts on both, not simply our emissions primarily from our fossil fuel use.

While we may slow down the global increase in CO_2 levels if we reduce or stop the 8 btC/an we emit from our industry and fossil fuel use, this can only help reduce the expression of the CO_2 symptom, not address our need to draw down carbon or more importantly fix the in-balance we have caused.

To address the cause of the CO_2 increase we must re-balance the Earth's emissions and its capacity to draw down carbon. Similarly if we wish to return CO_2 to its former levels we need to draw down extra carbon annually, adequate to re-balance the current annual deficit of 10 btC/an plus an equivalent level of past deficits for an extended period; effectively to draw down some 20 btC/an.

The draw down of an additional 20 billion tonnes of carbon annually for extended periods requires us to increase the Earth's residual terrestrial carbon sequestration of 50-60 btC/an by some 40%. While challenging, it is doable given that the more extensive terrestrial bio-systems pre agriculture may have been bio-sequestering carbon at some 100 btC/an, twice its current residual level.

To draw down an additional 20 btC/an we need to understand and limit the factors that contribute to the oxidation of the 110 btC/an from current bio-systems as well as enhance the factors and processes that aid the residual and potentially expanded bio-systems to draw down more carbon.

While challenging we should be able to achieve this 20 btC/an additional draw down target if we:

1. Extend the area of active green vegetation globally including via the regeneration of the over 5 billion hectares (bha) of previously vegetated man made desert and wastelands.
2 Enhance the carbon fixation capacity of the Earth's residual 8 bha of forest and grassland by limiting fires and restoring the microbial bio-sequestration of plant matter into soil carbon.
3 Extend the retention of rainfalls in such 'in-soil reservoirs' and thereby the longevity of green growth of new and existing bio-systems and their ability to bio-sequester further soil carbon.
4 Limit the oxidation of biomass carbon back to CO_2 by limiting the extent and intensity of wildfires and the stubble, game and control fires that annually burn 2-3 bha.
5 Limit carbon emissions from our use of fossil fuels and industrial processes via a wide range of demand reduction, energy efficiency, alternative lower emissions and renewable energy and industrial ecology and re-design measures.

Natural bio-systems under ideal conditions can sustainably bio-sequester well-over 100 tC/ha/an. As early as 1871 Charles Darwin confirmed that earthworms may bio-sequester some 13 tC/ha/an. Leading regenerative farming systems can conservatively often bio-sequester up to 10 tC/ha/an.

By contrast industrial agricultural systems, due to their oxidative practices, often lose 5-10 tC/ha/an. Similarly bio-systems at risk of wildfires or regular burning often lose 5-30 tC/ha with each fire.

It follows that by limiting current oxidative farming practices and by adopting relevant regenerative practices relevant to each site, land managers globally should be able to limit the massive, often unaccounted for, loss of carbon from our soils and landscapes to help achieve the 20 btC/an target.

Currently some 400 mha of forests and 2 bha of grasslands are burnt annually in wildfires and via stubble and fuel reduction burns. These emit up to 30 of the 110 btC/an in current global emissions. Given that we can limit the area frequency and intensity of many of these fires safely and naturally by restoring ecological grazing to bio-digest these fuels into bio-fertilizer and soil carbon, this alone can contribute to achieving our 20 btC/an global emission reduction and carbon draw down target.

While we have deemed such emissions from fires as 'natural' so we don't have to account for them, their greenhouse effects are real, as are the benefits from returning this carbon back into our soils.

By improving the health, water holding capacity, nutrient dynamics and productivity of soil through such carbon draw down and regenerative land management it is possible to further increase their capacity to draw down carbon and the resilience of their bio-systems to climate extremes.

Just as these processes drove pedogenesis to form the Earth's organic soils and extend natural productive terrestrial bio-systems across the land surface over the past 420 million years, we must and can now use these natural processes to regenerate our soils, landscape and our safe climate.

They are our only means to do this and by restoring the Earth's former soil carbon sponge, practically restore its terrestrial hydrology and safe climate.

4. However we have a fundamental problem

While these natural draw down processes can technically restore our former carbon balances and safe climate, we have left it decades too late to be able to prevent the intensification of dangerous climate extremes and the collapse of bio-systems by just reducing our industrial carbon emissions; or even by restoring the Earth's current carbon in-balance by drawing down our target of 20 btC/an.

This is because whatever carbon we draw down from the atmosphere will be partly re-equilibrated naturally by the release of some of the 38,000 btC dissolved in the earth's ocean buffers. As such it may take many centuries for the draw down of even 20 btC/an to return CO_2 to its former safe level, or reduce the CO_2 component of the natural greenhouse effect enough for it to stabilize the climate.

Effectively we have locked in a 4-6^oC global temperature rise and climate extremes under business as usual this century if we are limited to relying on just reducing our CO_2 emissions, or CO_2 levels. We have left it far too late to prevent these extremes by just re-balancing the carbon cycle.

Given that few of our current bio-systems and the communities and economies dependent on them will survive in a world with a 4-6^oC warming and the associated extremes, we must urgently find safe **options to also cool climates**. Only by cooling the climate can we now limit the induction and offset the dangerous climate feedbacks, extremes and impacts that are already accelerating.

Fortunately there are highly effective and safe natural cooling processes that we can use for this.

However they all depend on us restoring components of these natural hydrological processes and balance that govern 95% of the heat dynamics and cooling of the planet that we have impaired.

While science has long recognized their fundamental importance, our assumptions and models in understanding and responding to global warming have assumed that, because these hydrological processes are so dominant and powerful in regulating the Earth's heat dynamics and climate, that humans could not possibly have altered them. They were thus seen as a stable background factor.

They were also far too complex and variable in time and space to model accurately and include in the initial global warming models, scenarios and risk assessments that focused on the assumed causal association between the increase in CO_2, its greenhouse effects and global warming.

Humans have of course been grossly impacting the terrestrial hydrology of the planet for millennia through their drainage of wetlands, burning and clearing of forests, the disturbance, degradation and erosion of soils, fallowing and desertification of over a third of the land surface. Clear evidence confirms the dramatic effects this has and can have on local landscapes, hydrology and climates.

Given that collectively our hydrological impacts also influence the global climate it is essential that we consider these in understanding how they may have contributed to recent abnormal climate changes and how we may be able to reverse these changes by restoring key impaired processes.

Given that all the hydrological cooling and rainfall restoration options being examined simply seek to restore the natural hydrological dynamics and balances that existed previously in such bio-systems, and given that they are all self regulated via negative feedback processes, there is no risk of negative impacts. This contrasts with some unproven geo-engineering proposals that could result in serious hydrological and climate in-balances with major adverse ecological and social impacts.

5. Why we must and how we can naturally cool climates to limit dangerous climate extremes

Given that we have effectively locked in a 4-6^{o}C temperature rise under business as usual and given that ocean carbon buffers will offset much of the carbon we draw down, we have no option other than to safely cool regional and the global climate if we are to limit the dangerous climate extremes.

While past climate analyses, response strategies and public information have largely ignored such natural cooling processes and options, how we have impaired them and if we can manage or restore them; we need to foster this understanding and debate urgently. While there is always more to know, the science governing these natural hydrological cooling processes is well understood.

On average some 342 w/m2 of incident solar radiation (ISR) enters the Earth's troposphere. To sustain its stable climate it needs to re-radiate and dissipate this 342 w/m2 back out into space. Over the past centuries we have impaired these dissipation processes, altering the Earth's heat balance so that it now retains some 3 w/m2, or 1% of this ISR as additional heat in its atmosphere. It is this impairment that has caused the Earth's abnormal global warming over the past century.

To offset this warming and re-balance its heat dynamics we need to restore some 3 w/m2 of cooling. We can do this safely and practically by simply restoring the natural hydrological processes that we have impaired and which regulated the Earth's former cooling balances. These include processes to:

1. Limit the absorbance of ISR by limiting the water micro-droplets in the atmosphere.

2. Coalesce warming haze micro-droplets into cooling high albedo cloud covers.

3. Enhance the albedo, reflectance, insulation and thus cooling of soil surfaces.

4. Limit the re-radiation of heat from soils to help turn off the greenhouse effect.

5. Cool soil surfaces and landscapes via enhancing latent heat fluxes.

6. Naturally induce rain to remove warming hazes from the air and sustain bio-systems.

7. Re-open night time radiation windows to help cool regions and the planet.

A more detailed outline of the science underpinning the processes governing and effectiveness of each of these hydrological cooling options is provided at Appendix 1.

While their relative importance may vary in time and place, collectively they were responsible for continually dissipating 342 w/m2 back out to space to balance and sustain our stable safe climate. Locally they can provide over 200 w/m2 of surface cooling. Given that on average we need to cool the planet by some 3 w/m2 to restore its heat balance we can do this safely by minor adjustments to this natural balance through the regeneration of our soils, their hydrology and these processes. Specifically such adjustments can restore the re-radiation of infra red energy from the soil and the level and longevity of water vapor in the air, processes that we have altered and which dominate the enhanced greenhouse effect and can be reversed practically, safely and naturally via these means.

Given the critical role that these hydrological processes play in the Earth's heat dynamics and climate, and our need to urgently cool regional climates to offset pending extremes, we need to focus on how we can implement the strategies to restore such safe hydrological cooling effects.

6. Regenerating the Earth's soil carbon sponge - to provide the water to cool our climate

Given our clear need to urgently cool climates and to offset the impacts from dangerous climate extremes and given that this can only be done safely, as in nature, by restoring key hydrological processes and balances, priority must be given to how we can practically do this in time.

Specifically how to ensure that bio-systems have adequate water over time so they can restore and sustain the natural hydrological cooling effects and continue to draw down carbon to restore the Earth's soil carbon sponge and provide the water, food and habitats we all need for our safe future.

Fortunately nature provides us with an elegant, effective and practical solution for doing this.

As demonstrated by pedogenesis, the formation of soils and thus bio-systems over 420 million years, the only way we can secure adequate water for this cooling and to regenerate landscapes is to actively regenerate the Earth's former natural 'soil carbon sponges' and 'in-soil reservoirs' globally.

It was and is the formation of these soil carbon sponges and in-soil reservoirs that enabled terrestrial bio-systems to evolve and extend across the land and rapidly create our habitats and our climate.

As in nature, the formation of these soil carbon sponges is governed by how effectively carbon can be-sequestered from the air into our soils. This carbon bio-sequestration process in turn is governed by plants and soil microbes, particularly fungi, and how effectively they can:

1. Maximise the photosynthetic fixation of sunlight, CO_2 and water into plant matter.
2. Minimise the oxidation of that plant matter back to CO_2 particularly by fires.
3. Maximise the fungal polymerisation of this plant matter into stable soil carbon.

As such the soil carbon sponge is largely fixed solar energy that is stored in a stable carbon matrix. It is unique as the only process and product in the known universe that reverses the 2nd law of thermodynamics by capturing and then storing solar energy here on earth - instead of dissipating it.

The sponge is also fundamental to life as it enabled organic soils to form from mineral detritus and for them to retain the rainwater and sustain the microbial processes that make available nutrients and enable plants to grow and fix more carbon. Effectively the soil carbon sponge enabled plants and bio-systems to operate as a positive feedback process, progressively increasing the draw down of carbon to extend healthy terrestrial bio-systems over most of the land.

As this is what we must now do urgently and massively, we need to also restore such soil sponges.

While it varies with soil types, structure and stage of pedogenesis, every extra gram of carbon that we can bio-sequester back into these stable soil carbon sponges can retain up to 8 grams of extra water in that soil - in turn enabling that soil to grow plants and fix yet more beneficial soil carbon.

These sponges are thus critical in capturing, retaining and sustaining the supply of water, not just to optimize carbon fixation, limit oxidation and enhance polymerization processes above but also:

1. Provide the essential water for the ongoing productive growth of our bio-systems.
2. Enable us to restore the natural hydrological cooling processes and climate balances.
3. Ensure humanity has secure access to adequate safe water and food for its future.

We need to, and can, urgently bio-convert sunlight, water and CO_2 into stable soil carbon sponges.

Instead, humanity has been oxidizing some 2 billion tonnes of carbon per annum from our soils for 10,000 years via our burning, forest clearing, soil cultivation, exposure, erosion and aridification. In so doing, we have created 5 billion hectares of man-made desert. We must reverse, not just slow this (ie, our creation of deserts).

To regenerate our soil carbon sponges we must massively draw down carbon from the air back into our soils. We can do this but must change our thinking about carbon 'pollution' and recognize that:

1. CO_2 is not a pollutant but the essential building block and resource for this regeneration.
2. The recent abnormal rise in CO_2 levels is a symptom of our degradation of our soils and landscape and impairment of the former bio-sequestration processes - not its cause.
3. We can only restore the natural carbon and hydrological cycles that we have impaired by urgently regenerating our soil sponges via practical commercial grass roots action.

Only by drawing down 20 btC/an back into soil carbon sponges can we restore the needed cooling.

7. How we can regenerate the Earth's soil carbon sponge and hydrological cooling

While the scale of regenerating the Earth's soil carbon sponge may seem daunting it need not be so. Just as the land consisted of lifeless bare rock 420 million years ago it was converted into soil and bio-diverse forests within 100 million years. These same processes can now restore our bio-systems.

Similarly, within thousands of years after the last ice age these same fungal plant symbioses fixed vast quantities of carbon to recreate new soils and bio-systems such as in the US Prairies, Kalimantan swamp forests and northern tundras. These now store up to 1000 tC/ha in their carbon sinks.

Some natural forest and grassland bio-systems still sustainably bio-sequester 100 tC/ha/an. Leading farmers worldwide are bio-sequestering up to 10 tC/ha/an. Even at a fraction of these rates, extended action by farmers can readily secure our carbon draw down, sponge and cooling targets.

Current industrial agricultural systems, in-the main, do not achieve this - often still losing up to 10tC/ha/an via their oxidative practices and soil erosion. That is why we need to change.

To achieve this confirmed practical land management changes need to be extended that:

1. Limit the incidence and impact of wildfires and stubble, hunting and control burning.

2. Increase carbon bio-sequestration by the ecological grazing of perennial pastures.

3. Extend the longevity of green growth within existing rangeland and forest bio-systems.

4. Naturally regenerate shelterwoods and hydrological buffers and cycles in rangelands.

5. Accelerate the bio-digestion of stubbles by herbivores and through composting.

6. Extend opportunistic pasture and cover cropping systems to extend grain production.

7. Use microbial symbionts to reduce the need for oxidative agricultural practices.

8. Foster the safe recycling of essential nutrients from wastes back onto farm soils.

9. Utilise biomass systems to produce renewable energy and carbon bio-fertilisers.

10. Regenerate shelterwood, food production and resilience in urban areas.

An analysis of these practical strategies and their potential to draw down carbon is at Appendix 2.

Collectively, adoption of these relevant practical strategies on available degraded land could avoid and bio-sequester well over the 20 btC/an needed to restore the Earth's soil carbon sponge. In doing so they could restore the natural hydrology, cooling and bio-productivity of regions and the planet.

The changes needed, however, have not and will not come from the status quo. Consequently we must find ways to catalyse the commercial extension of such practices, urgently.

8. The practical extension of grass roots action to regenerate our soil sponges and landscape

While the above confirms why we must, and how we can, draw down 20 btC/an so as to regenerate the Earth's soil carbon sponge, the issue is doing it urgently, practically via global grass roots action. As nature did repeatedly, following far greater geological and galactic shocks to the climate than our current impacts, we have the imperative and now the means to do it.

Natural bio-systems, via these processes, have regenerated prodigious soil carbon sponges, such as:

- The many meters deep tropical peat soils over as short as 6000 years since the last major sea level rise through the carbon draw down capacity of rainforests in Kalimantan.
- The deep prairie soil that often had over 15% organic matter in the US mid-west and in Ukraine on glacial till following the last ice age.
- The many meters deep peat soils that formed in situ above Bronze Age settlements in many moist cool locations such as western Ireland, England and parts of Scandinavia.
- The deep soft 'moulds' containing often over 20% organic matter that the early European explorers described over much of south east Australia, despite cool aboriginal burning.

Lead farmers are bio-sequestering up to 10 tC/ha/an and in doing so can reverse the oxidation often of over 5 tC/ha/an from the soils under conventional high input industrial agriculture. Forests and shelterwoods integrated into these regenerative farming systems can bio-sequester up to an extra 20 tC/ha/an while restoring water cycles critical to extend their green growth and carbon fixation. This evidence is providing farmers with the compelling case for adopting such regenerative practices.

What is needed is to extend the wider adoption of such leading regenerative practices urgently. Initiatives such as our Healthy Soils 'Regenerate Australia Vision' seek to do this at a national level by catalysing and helping local groups of farmers to plan, implement and extend such viable regeneration strategies. Similar global initiatives could target the regeneration of the many at risk landscapes and regions. Collectively they could form the basis of a global land and climate regeneration movement focused on rebuilding the Earth's soil carbon sponge so as to cool climates and secure our safe future.

However there are also formidable impediments. Much of the current industrial agriculture and food industry may resist facing these land degradation and climate realities and need for change. To help overcome these impediments and catalyse the commercial extension of such global change strategic support may be critical in key areas such as:

- Documenting the practical and commercial effectiveness and benefits from such changes.
- Communicating the potential from the adoption of such relevant regeneration strategies.
- Overcoming information lags and gaps in designing and actioning leading practices.
- Providing specialist training in relevant lead technologies and catalytic mentor skills.
- Coordinating and providing brand support for this global soil and land regeneration change.
- Creating innovative commercial supply chains and value capture options in support.
- Documenting the commercial returns and business case for such investments and change.
- Creating wider community awareness and demand for such food integrity and land values.
- Supporting school education initiatives that empower such local grass roots youth actions.
- Making the 'Regeneration of the Earth's soil carbon sponge' a global focus for climate action.

Conclusion

How the Virgin Earth Challenge can be a potent catalyst to extend such changes and our safe climate

While our Healthy Soils 'Regenerate Australia Vision' and grass roots farmer and regional activities confirm that we can rebuild our soil carbon sponges, rehydrate, cool and regenerate landscapes and revitalize regional communities; we are running out of time and must scale up action urgently.

To do so we need global leadership and action to reinforce our Vision, the potential, the imperative and the benefits from practically rebuilding the Earth's soil carbon sponge as now our only means to safely cool climates and secure our essential water and food needs and our safe future.

People of all ages, globally, intuitively know we come from and depend ultimately on our soils and that the sustained health and productivity of their soils is critical for their welfare and future.

As President Roosevelt advised – "A nation that destroys its soils destroys itself".

Given that we have seriously degraded the Earth's soil resources we must regenerate them urgently.

Fortunately we can do this naturally, safely and beneficially by regenerating their soil carbon levels.

By **restoring the Earth's soil carbon sponge** and, with that, their hydrology, cooling and productivity.

All that is missing are the global champions and catalyst to drive this message and these changes globally.

The Virgin Earth Challenge has raised these same issues and the imperative of a solution. The Virgin Earth Challenge, by championing the restoring of the Earth's soil carbon sponge, as now our only option to secure our safe climate, can provide this as '**Virgin Soils**'.

Just as Virgin Galactic extends our vision of a high technology future, we need a vision and practical vehicle for a healthy planet and people that is ‘grounded’ on ‘Virgin Soils’, based on regenerating the Earth’s soil carbon sponge; and the ecological and climatic benefits it brings.

Beyond visions, we must also urgently take responsibility for our impacts and their consequences.

After 50 years of debate and delay, the regeneration of the earth’s soil carbon sponge may be our last chance and practical grass roots means to do this and secure humanity’s safe climate and future. While there are impediments to fostering such change globally, it is now our only viable safe option.

Whatever happens we can be certain that nature, as it has done many times previously, will again use these very same processes to regenerate soil carbon levels, its hydrology, healthy bio-systems, and the cooling needed to restore the Earth’s heat balance and safe stable climate.

The only question is will we take responsibility for this and use these same safe processes to secure our safe climate and future, in time, or let nature do it for us, after most of humanity has gone?

Appendix 1

Key hydrological processes to naturally cool regions and the planet to offset climate extremes

For 4 billion years the Earth has maintained a stable elevated global temperatures some 33°C above that expected by physics. It has buffered and maintained this despite extreme impacts from galactic, volcanic and marked changes to our atmosphere and the sun's ever intensifying 'solar constant'.

This elevated temperature and buffering has enabled the Earth to sustain its liquid oceans and life. Both these effects are due to the unique high capacity of water to absorb and transfer heat and the role of the vast quantities of water, in the oceans, atmosphere and on land, in governing 95% of the Earth's natural heat dynamics, balance and the global climate.

Indeed, because water was known to be such a dominant driver of the Earth's climate that it was assumed that humans could not possibly have altered its dynamics and thus alter the global climate. As a result, our assumptions and models about the cause of human induced climate change largely excluded these hydrological dynamics as a possible causal factor. These hydrological processes are also highly variable in time and space and thus difficult to model and explain simply to the public.

Given the clear abnormal rise in CO_2 levels and the fact that it is a greenhouse gas, it has been widely assumed and promoted that this is the dominant and primary factor causing the abnormal recent warming and more recently, climate change and its increasing dangerous extremes.

However, even with these assumptions, the rise in CO_2 and its greenhouse effect, by itself, could only account for a very modest global temperature increase, well below observed levels. To account for the much higher observed temperature rise, greenhouse models need to include a 'force multiplier'. This has been done by assuming that the water vapor greenhouse effect, which is often four times larger relative to the CO_2 greenhouse effect, is a secondary positive feedback induced by the minor direct warming from the CO_2 greenhouse effect. This has been rationalised on the assumption that the amount of water vapor that can be held in the air is governed only by the temperature, which in turn is assumed to be governed by the CO_2 concentration and its greenhouse effect.

This conflicts with reality, in that the amount of water held in the air, either as vapor or haze micro-droplets, is not governed just by the air temperature or the CO_2 level but by the balance between:

1. Aerosol micro-nuclei that enable the water in the air to form persistent hazes, and:
2. Much larger hygroscopic precipitation nuclei that can coalesce millions of haze micro-droplets into cloud droplets and then raindrops that remove this water from the atmosphere.

Contrary to these assumptions and models, water is not removed from the air as the temperature declines but simply condenses to form haze and fog micro-droplets. These remain in the air at levels of up to 50,000 ppm till either re-evaporated to water vapor or precipitated by precipitation nuclei. Instead of being a convenient secondary positive feedback to enable CO_2 greenhouse models to account for the observed temperature reality, the vast but variable quantities of water in the air are governed largely by a balance of two opposing biological nucleation processes that have their own profound climate effects, largely independent of the CO_2 concentration or its greenhouse effect.

We need to understand these hydrological processes: how they influence regional and the global climate, how have we influenced them and if we can influence them to possibly cool our climate.

Given that we have impaired the escape of some 3 watts per square meter or some 1% of the incident solar radiation back out to space to induce our abnormal global warming: can we, by restoring these natural hydrological dynamics, generate a safe global cooling of some 3 w/m2 to restore our safe climate? If so, how can we do this practically, at global scales and in time?

In fact, we may be able to do this practically and safely if we restore the natural processes to:

1. Limit the absorbance of incident solar radiation (ISR) by limiting water micro-droplets in the air

Each day on average, some 342 watts per square meter of ISR enters the Earth's troposphere. This ISR can be partially absorbed by liquid water micro-droplets in the air. This warms the atmosphere and the climate. We can limit this warming by limiting the concentrations and retention of these water micro-droplets in the air. Vast quantities of water vapor are evaporated and transpired daily into the air. How much of this water is retained in the air and for how long depends largely on the numbers of aerosol micro-nuclei in that air. Where micro-nuclei are abundant they form humid hazes of liquid water micro-droplets that are highly effective at absorbing ISR to warm the air. Because of their small size and electrostatic charges, these haze micro-droplets often stay suspended for extended periods forming humid hazes that warm the air and impair the formation of rain.

The types and level of these micro-nuclei can have a profound effect on our climate and rainfall. The production of such aerosols, specifically di-methyl sulphide from marine algae from some 3.5 billion years ago, is still critical in maintaining the Earth's humid atmosphere, its absorption of ISR, much of the dominant water vapor greenhouse effect and thereby the Earth's elevated basal temperature.

Humans have recently massively increased the addition micro-nuclei to the air. This includes adding some 3-5 bt/an of fine clay dust aerosols as a result of our land management and desertification as well as many billions of tonnes of particulate carbon from our burning of over 2 bha/an of land and fossil fuels. Further aerosol micro-nuclei are also released as pollutants from many industries.

These additional micro-nuclei have resulted in extensive persistent brown pollutant hazes that alter the Earth's climate, and increased the absorption of ISR and the global 'dimming' over large regions. This has systemically warmed the atmosphere and reduced rainfalls by up to 30% over large regions. Their acid rain also acidifies and degrades bio-systems and their capacity to bio-sequester carbon. While not due to the CO_2 greenhouse effect, they are a major causal factor in our climate crisis.

As we are responsible for increasing these haze effects we must take responsibility to correct them. We can do this simply and safely by limiting our emissions of haze micro-nuclei: for example, by re-vegetating bare soils and deserts to limit dust emissions and filtering fuel and pollution particulates.

We can also enhance and speed up the removal of the warming and aridifying humid hazes from the air by restoring a second group of nuclei that naturally coalesce and then precipitate these hazes. These natural precipitation nuclei include: ice crystals, some salts and particular microbial cells that are highly effective at hygroscopically coalescing millions of haze micro-droplets into raindrops heavy enough to fall from the air under gravity. While the ice crystals are dominant at high latitudes and altitudes and the salt nuclei are dominant over the oceans, the microbial nuclei are critical over many land areas.

2. Coalesce the warming haze micro-droplets into cooling high albedo cloud covers

As these hygroscopic precipitation nuclei coalesce haze micro-droplets into ever larger drops, they naturally form denser clouds with higher albedo that can reflect more of the ISR back out to space. Such clouds naturally covered some 50% of the planet and reflected 36% the ISR back out to space. Recent data indicates that their extent, duration, reflectivity and thus cooling effects are declining.

Humans have greatly impeded the effectiveness of these precipitation nuclei in removing the hazes. Our clearing and warming of over 50% of the land surface has greatly increased the re-radiation of heat into the atmosphere and impeded the formation and effectiveness of the ice nuclei. By clearing 75% of the Earth's primary forests we may have also impaired the natural formation of the microbial precipitation nuclei that induce dense clouds and rainfalls in many warmer inland, forested regions. As a result we may have fewer, less dense clouds that reflect less ISR to space and lower rainfalls.

We urgently need to restore these natural hydrological cooling processes in and by our atmosphere, particularly the role that the microbial precipitation nuclei played in such safe cloud cooling. While we know a great deal from our scientific and field studies there is always more to know about how we can do this practically. Better understanding these processes should now be a critical priority.

3. Enhance the albedo, reflectance and insulation and thus the cooling of soil surfaces

Just as dense high albedo clouds can reflect up to 80% of their ISR back out to space, the reflectivity of the land surface also governs how much ISR is either reflected into the air or absorbed by the soil. Dense light colored perennial ground covers such as snow and ice can reflect up to 90% of the ISR while dense white grasses may reflect up to 30% back to the sky. By contrast, exposed dark soil surfaces may reflect less than 10%, absorbing 90% of the ISR to raise the temperature of that soil. Above 30°C this can impair the microbial health, the cycling of litter and bio-productivity of that soil.

Humans have greatly altered the Earth's surface cover via 10,000 years of burning, deforestation, soil cultivation, overgrazing, soil erosion and now aridification with climate changes. Fewer than half of the Earth's primary soil covers survive. We have created over 5 bha of man made desert, most of which is generating dust aerosols, hazes and absorbing ISR to warm our atmosphere and soils.

We need to restore the perennial ground covers and shelterwoods that naturally provided the albedo reflectance and limited this soil heating, erosion and degradation. Potentially this may give up to 50 w/m2 of surface cooling in some areas to help secure our bio-systems and safe climate.

4. Limit the re-radiation of heat from soils to help 'turn off' the greenhouse effect

The ISR that is not reflected but reaches and is absorbed by the soil surface will inevitably warm it. This heat is inevitably re-radiated back into the air, not as short wave ISR but as long wave infra red heat in line with the physics of black body radiators. This dictates that the amount of heat re-radiated is governed by its temperature, specifically by the 4^{th} power of its temperature. It follows that a black body or soil of higher temperature will re-radiate vastly more infra-red energy relative to a cooler black body. This is fundamental in understanding the natural and human induced greenhouse effect that is governed by, and limited to:

1. How much heat is being re-radiated as infra-red energy, and then:
2. How much of this is being absorbed by certain greenhouse gases, particularly by water vapor and CO_2 in the atmosphere.

To date our climate change policies and media have limited themselves by mainly focusing on one of these greenhouse gases, CO_2, whose concentration has risen from some 300 to 400 ppm this century despite it contributing some 20% to the greenhouse gas effect. In doing so, we have largely ignored the separate independent role of water vapor that may exist at up to 50,000 ppm and governs from 60-80% of the greenhouse gas effect.

Far more fundamentally, we have totally ignored the factors that determine how much infra red heat is being re-radiated from different sites, even though it is this that determines the size of, and drives, the greenhouse effect - far more so than the recent abnormal rise in $C0_2$ concentrations.

Effectively we can 'turn down the heat' to control the size of the greenhouse effect through our management of our soils and thus their re-radiation of the heat driving the greenhouse effect.

By limiting the absorbance of ISR by soils, we can greatly reduce soil temperatures and thus the infra red heat re-radiated from the earth that drives and governs the size of greenhouse effect.

We can do this simply by maximizing surface albedo and the reflectance of ISR back out to space. Land management practices that protect and cool soils greatly reduce this re-radiation of heat. Vastly more heat is re-radiated from exposed soil surfaces that may reach a temperature of up to 60°C, compared with nearby moist soils protected by groundcovers that may remain below 20°C.

Rather than failing in the now impossible task of reducing CO_2 levels in time, we can readily limit the greenhouse effect by turning down the re-radiated heat via soil protection and cooling practices.

As it is these natural soil and hydrological processes that have largely balanced the hydrological and greenhouse warming as well as hydrological cooling of the planet for 4 billion years, it may be wise that we restore them urgently, as now our only option to secure our safe climate.

5. Cool soil surfaces and landscapes via enhancing latent heat fluxes

In addition to protecting soil surfaces to enhance their albedo, limit their absorption of ISR, limit the re-radiation of heat and thus the greenhouse effect: we can also limit the heating of soil surfaces by keeping them moist so they can evaporate and/or transpire more water to cool those surfaces.

For water to evaporate or transpire it has to be turned into water vapor. This requires lots of heat. This heat has to be absorbed from the surface thereby cooling them. The heat in turn is transferred as latent heat back up into the air and rises with the water vapor into the upper atmosphere.

Over 24% of the ISR received by the Earth is naturally transferred from the surface back into the atmosphere via these latent heat fluxes in the evaporated and transpired water. The Earth's latent heat fluxes cool surfaces by some 80 w/m2. Locally these latent heat fluxes can be even greater, for example, cooling moist forested habitats by up to 15°C relative to adjacent cleared areas.

By clearing over 75% of the Earth's primary forest and degrading much of its soils and landscape, we have profoundly impaired these latent heat fluxes and thus local and global cooling. Conversely, by regenerating soils, shelterwoods and landscapes, we can significantly restore these cooling hydrological dynamics and start to reinstate the resilience of key bio-systems.

However, these cooling latent heat fluxes need water and cannot occur if soils do not have water.

Thus the extent, effectiveness and longevity of these cooling latent heat fluxes depends totally on the water status of our soils and the capacity of their 'in-soil reservoirs' to hold and make available water for such transpiration fluxes. These 'in-soil reservoirs' have been degraded via our land management so that they cannot hold and sustain water supplies to plants over time, no matter how prolific the periodic rainfall. We must restore these 'in soil reservoirs'.

6. The natural induction of rain to remove water from the air and sustain latent heat fluxes

These cooling latent heat fluxes need adequate soil water that can be evaporated and transpired. This water naturally has to come from rain or sub-soils supplied by rain. Hence to cool the climate and sustain the bio-systems that naturally do this, we need water, we need rain.

Just as importantly and as outlined in part 1 above, we also need to reduce the persistent humid hazes that are warming and aridifying regions. Hence we need not just rain but to transform these aridifying negative haze effects into positive cooling cloud albedos and rain.

We can do both simply and naturally by restoring the natural hydrological processes that do this.

Most importantly, we also need to restore the speed of this hydrological cycle so as to minimise the duration of adverse haze warming effects, enhance latent heat fluxes and the cooling of surfaces so as to limit the re-radiation the heat from soils driving the greenhouse effect. This is significant as our potential to cool regions may be governed less by the quantity of water in that cycle and more by the efficiency with which even limited quantities of water are cycled to cool and sustain bio-systems.

If we do restore the speed of this hydrological cycle, we may be able to cool and re-green even regions receiving even limited quantities of rain by restoring the speed and efficiency of these hydrological processes and cycles.

To do this we need to understand the balance between two natural water nucleation processes that govern much of the Earth's hydrological cycle and heat balance. These are:

- The formation of humid haze micro-droplets that are nucleated naturally by organic volatiles, such as di methyl sulphide dust and more recently by particulate pollutant aerosols; and
- The formation of larger cloud droplets via the action of a distinct second group of hygroscopic precipitation nuclei in coalescing millions of haze micro-droplets into dense high albedo clouds and then remove and recycle them from the air as raindrops.

It is the balance between these two opposing nucleation processes and their respective hydrological warming and cooling effects that appears to have been the basis of the homeostasis that has governed the Earth's heat dynamics and climate for most of the past 4 billion years.

While more sophisticated, the balance of their effect is not unlike models of 'white and black daisies'.

We have grossly disrupted this natural balance by:

1. Vastly increasing the production of additional haze micro-nuclei that reinforce the warming of the air and aridification of the land surface.
2. Reducing the production of the hygroscopic precipitation nuclei critical in transforming these hazes into dense cooling clouds and rain to cool the land surface.
3. Impairing the capacity of the Earth's residual terrestrial bio-systems to regulate these processes and thus the Earth's climatic homeostasis as they did naturally.

Significantly these processes are all governed by microbes via their formation of specific aerosols and the hygroscopic bio-chemicals able to act as nuclei to coalesce the haze micro-droplets.

While we know a great deal about their formation, bio-chemistry and ecology, there is more to know. Given that we need to urgently remove the humid warming hazes, protect and cool soil surfaces and restore cooling latent heat fluxes across extensive landscapes and given the key role that these natural precipitation nuclei play in this, enhancing our understanding of these processes is critical. How do we manage different bio-systems to optimally restore them and with that our safe climate?

7. Re-open night-time radiation windows to cool regions and the planet

By restoring the natural ecological production of these precipitation nuclei it should be possible to restore the former regular late afternoon rainfalls that characterized many regions and removed the warming humid hazes micro-droplets from the atmosphere. This rain can restore and sustain, not only the latent heat fluxes that cool soils and landscapes but also 're-open' radiation windows that allows infra red heat from the surface to be re-radiated back out to space without being absorbed by the water vapor molecules that had been removed by the rain.

Significantly over half of the observed recent abnormal greenhouse warming is associated with an increase in night-time and winter minimum temperatures rather than increases in maximum day-time temperatures. This suggests that heat that could formerly re-radiate back out to space is now being trapped by an increase in greenhouse gases in the atmosphere that exists during the day but can be removed by afternoon rainfalls. Given that CO_2 molecules remain in the air and don't vary diurnally, the fact that the observed temperature rise is largely due to an increased night time minimum temperatures indicates that much of this warming has been caused by a greenhouse gas that had previously been reduced at night and allowed the escape of heat through these radiation windows, but which now remain in the air preventing such night time cooling effects. As only water vapor is able to fluctuate so rapidly each day, this reinforces that it must be the key gas contributing to this radiation window effect and thus a dominant element in our abnormal greenhouse warming.

Re-opening these night-time radiation 'windows' can potentially cool climates by some 40 w/m2.

Collectively, each of these seven elements drive the hydrology and heat dynamics of the blue planet, and determine what happens to over 300w/m2 of the 342 w/m2 incident solar radiation entering the troposphere and the 339 w/m2 that is currently dissipated from the troposphere. They also interact and can be transformed naturally from cooling latent heat fluxes into warming hazes and then cooling clouds.

As our imperative is to cool the surface and troposphere by some additional 3 w/m2 or less than 1% of the ISR, it is clear that restoring a combination of these natural hydrological processes and dynamics can readily and safely do this. Just as different processes dominate in different regions and bio-systems in de-stabilising these natural hydrological and heat dynamics, so too may the restoration of different processes be required and optimally re-stabilise regional climates.

However, to do any of this we must restore the capacity of bio-systems to access the water needed to sustain these processes. To do that, we must restore regional rainfalls where these have declined. This may require restoration of the microbial processes that governed the production of the haze and precipitation nuclei and which regulated the former rainfalls, heat balances and these climates.

In addition to sustaining or enhancing rainfalls we also need to ensure that the needed water is available over time to sustain these hydrological cooling processes. We can only do this if we also regenerate the Earth's soil carbon sponge. To do this we must urgently restore the bio-systems that can bio-sequester carbon from the air back into the soil carbon sinks to sustain this water supply.

While the imperative for doing this is clear, how can we catalyse the needed practical action in time?

Appendix 2

Practical strategies to regenerate the Earth's soil carbon sponge and its hydrological cooling

Given that we need to draw down some 20 btC/an back into our soils to restore the Earth's soil carbon sponge, its hydrology and critical cooling effects, how can we practically do this? What options do we have, how effective is each, what are their specific needs, risks and outcomes?

Certainly natural bio-systems annually draw down some 100 btC at rates of up to 100 tC/ha/an. While less than nature, lead farming can help in sustainably bio-sequestering up to 10 tC/ha/an.

Thus nature, science and the field evidence all indicate we can bio-sequester the 20 bTC/an if we:

1. Limit the incidence and impact of wildfires and stubble, hunting and control burning

Currently some 350-450 million hectares of vegetation is burnt annually by wildfires worldwide. Over an additional 2 billion ha of land is burnt annually by hunting, fuel reduction and stubble burns. These fires emit from 10-100 tC/ha and from 5-20 tC/ha respectively as CO_2 and carbon particulates. Their emissions may collectively exceed those from all of humanity's industrial emissions.

While we have not accounted for these emissions in our statistics as they are deemed to be 'natural', they contribute equally to our emissions from fossil fuel use in driving abnormal climate changes.

More seriously, in many arid 'brittle' regions, the number and intensity of such fires are increasing. This risks negating efforts to reduce industrial emissions. It also risks the collapse of many bio-systems and their dependent communities as soils and their hydrological capacity degrade. Indeed such fires and their aridification and degradation impacts may now represent humanity's greatest existential risk from the locked-in climate changes, if these are not offset and addressed.

Given that we must limit such fires and their emissions, we can do this simply by 'eating their fuel'. By restoring the natural grazing ecologies that enabled herbivores to bio-convert fire fuels and risks into bio-fertilisers and soil carbon, as they have done naturally since their evolution. In turn these herbivore impacts can aid the regeneration, hydrology and the productivity of these pastures.

Such grazing and fire control ecologies were dominant in many bio-systems prior to human impact. Due to less intense fires these soils often had higher soil carbon and water levels and sustained more bio-diverse green growth for longer. While difficult to estimate, such strategies to limit fire impacts may enable us to achieve up to half of our global carbon draw down target of 20 btC/an.

2. Increase carbon bio-sequestration by the extension and planned grazing of perennial pastures

In addition to limiting the emission of carbon by fires, these ecological grazing systems may be able to sustainably stimulate the bio-sequestration of up to 10 tC/ha/an across these rangelands. This additional soil carbon comes from the extensive root systems, root exudates and fungal symbionts that can bio-convert up to 70% of the sugars produced by these perennial pastures into stable humus and glomalin within every grazing cycle.

Extended over just half of the Earth's remaining 6 bha of rangelands, even at rates of 5 tC/ha/an this could theoretically bio-sequester a further 15 btC/an.

3. Extending the longevity of green growth within existing rangeland and forest bio-systems

In order to maximise yields per unit area and time, much of our science has focused on cultivars and inputs that enable plants to grow bigger, faster. Natural systems by contrast, often reinforce strategies that enable plants to grow for longer given the ecological imperative of survival. As in nature we can also extend the longevity of green growth within existing rangelands by restoring the carbon content, structure and thus water holding capacity of our soils and landscapes.

For example Australia has 770 mha of land of which 95% is vegetated. Some 70% of this vegetation on average may be dormant and brown at any one time due to the lack of available soil water. By contrast regenerated bio-systems with higher soil carbon levels, structures and water holding capacities may remain green and productive for over 70% of the time. This can represent an increase in the bio-productivity and carbon draw down potential in Australia, of over 100%.

Australia's current bio-systems have a net primary productivity of some 2.3bt/an, based on the 30% of time they are green and able to grow. By extending this longevity of green growth to 70% of the time, we could possibly double Australia's carbon draw down potential. This would have major hydrological and bio-diversity benefits.

Extended globally, such strategies could also raise the carbon draw down capacity of rangelands. More importantly, this may provide options for re-vegetating some of the 5 billion ha of man made desert that still receive adequate rainfalls but whose soil structures are so degraded that very little of this rain can infiltrate and be retained to enable plants to re-establish and survive.

4. Naturally regenerate shelterwoods to enhance the hydrology and buffers in rangelands

Scattered trees often naturally colonize rangelands regenerated under ecological grazing to form extensive open grassy shelterwoods. These trees may buffer winds, reduce evaporation, harvest dew, provide habitat and shelter for diverse plants and animals, transfer essential nutrients from sub-soils to the surface and extend pasture productivities, greatly benefiting these bio-systems.

The shelterwood canopy and roots can also serve as a major additional carbon bio-sequestration source and sink, often sequestering from 5-20 TC/ha/an in addition to that of the grass understorey. The shelterwoods may also be a source of valuable additional products and income to enhance the viability of communities and help provide the regeneration investments required. These may include products such as timber, oils, honey, resins edible high protein seeds and bio-diesel fuels.

The natural regeneration of such shelterwoods across even half of the Earth's 6 bha of residual rangelands could significantly aid their productivity and resilience in the face of the pending climate extremes, provide valuable habitat, food and fuel and bio-sequester up to an additional 30 btC/an. Most importantly, their regeneration is critical in restoring the integrity of these brittle bio-systems, their hydrological dynamics, regional cooling effects, rainfalls and limiting wider desertification.

5. Accelerate the bio-digestion and bio-degradation of stubbles by herbivores and composting

Globally each year, farmers grow crops on some 1.5 bha of land and produce some 3 bt of stubble. While some is used for animal feed, increasingly under industrial monocultures most of this is burnt or left to decompose on the soil surface; both of which convert the 1-2 btC it contains into CO_2.

Historically, such stubble had been bio-converted by herbivores into dung and soil carbon, both of which enhanced the subsequent hydrology, productivity and health of these grasslands. Restoring such systems could potentially avoid 1-2 btC/an in emissions by bio-sequestering them as well as enhance the carbon draw down capacity of such grasslands by up to some 10% each year.

Where such bio-digestion and sequestration is not feasible, options exist to use these stubbles in a wide range of: building products, paper manufacture, chemical feed-stocks and as mulches rather than oxidizing them back to CO_2. They can also be used to grown valuable fungi for human food.

6. Explore opportunistic pasture and cover cropping to extend the potential of grain production

Our industrial cropping systems currently result in significant carbon emissions both from:

- The vast quantities of subsidized oil based inputs used to grow our food; the calorific content of which may be 10 times that of the food produced; and
- The oxidative effects of the extensive cultivation, fertilizers and bio-cides used to grow these crops that often result in soil carbon losses of 5-10tC/ha/an.

We don't fully account for these emissions. They also contribute to our soil and climate degradation.

Both the demand for such highly subsidized carbon inputs and the carbon losses from cropped soil can be reduced significantly by the wider adoption of new pasture cropping or cover cropping practices. By these practices, short lived annual grain crops are sown into the root zone of perennial pastures whose normal competitive exclusion of such annuals, has been temporarily suppressed by grazing impacts.

By exploiting these short term niches created in the root ecology of the perennial pastures, pasture cropping can secure often comparable grain yields to conventional crops without most of the high carbon and nutrient inputs, losses and soil degradation under current oxidative cropping strategies.

Extended globally, where appropriate, such innovative practices may avoid emissions of 7 btC/an.

In addition, by stimulating the periodic microbial polymerization of the perennial root biomass into soil humus and then encouraging root regrowth, such pasture cropping practices have been shown to stimulate the bio-sequestration of up to 10tC/ha/an, even in former degraded soils. Adopted over half of our current global cropping area this could bio-sequester up to a further additional 7btC/an.

Most importantly, from a food security perspective, it should enable us to opportunistically crop far larger areas when soil water and growth conditions are suitable: to help feed humanity as our oil based inputs and their soil degradation consequences, make our current extractive cropping systems untenable.

7. Harness microbial symbionts to reduce the need for oxidative agricultural inputs and practices

Our current industrial agriculture uses and is now totally depends upon the high inputs of fertilisers. The production, transport and application of this fertiliser use large quantities of fossil fuels and produces large quantities of carbon emissions. For example, we now add 150% of additional nitrogen fertiliser to our cropping soils, over and above that supplied naturally from soils.

Every molecule of excess fertiliser nitrogen added to our soils may oxidize up to 30 molecules of soil carbon to CO_2. This has led to the serious degradation in the carbon content and structure of most cropping soils globally over the past 50 years and made their productivity dependent on ever more fertilizer inputs. Whereas pasture soils in Australia 200 years ago often had over 8% soil carbon, after 20-30 years of cropping, most now contain less than 1% carbon. Similar declines have occurred globally.

By contrast, natural bio-systems such as rainforests with very high productivities achieve these levels, not by fertiliser additions, but by how efficiently often limited quantities of nutrients are made available and cycled in soils to sustain their highly productive plant growth and carbon bio-sequestration. Microbial symbionts, particularly mycorrhizal fungi, are critical in the solubilisation, access, uptake and cycling of essential mineral nutrients in soils to sustain productive resilient bio-systems. Symbiotic algae and bacteria are critical in fixing nitrogen from the air and in making it available in the optimal forms and concentrations to sustain plant growth: but do not oxidize and degrade soils.

While sometimes slower growing, plants growing with the aid of such symbionts have comparable yields but far higher nutritional integrity, food and health values. They were also far more resilient and grew for longer, despite stress - than equivalent agricultural plants dependent on fertiliser inputs.

These symbionts were critical in the ability of plants to colonise and form highly productive resilient bio-systems over most of Australia, despite its dry climate and leached soils. As our ability to sustain our high fertiliser inputs and industrial agriculture falters, and given the degradation of soils globally, we need to use similar strategies to restore nutritional integrity and the productivity of our soils.

Extracting humic and fulvic products from vast reserves of lignitic brown coal is now a tried-and-tested and cost-effective input for significant improvement in soil physical chemical and biological properties. Initiated from research of Monash University Centre for Green Chemistry, the use of humic and fulvic products, complemented with specific microbial innoculum and applied with reduced applications of conventional fertilisers, have established a trend of increasing the percentage content of soil organic carbon (SOC) by 0.15% per annum, and reversing a century long decline in SOC. Farmers adopting this fertiliser approach are also achieving improved gross margin profit per hectare.

8. Safely recycle essential nutrients from wastes to aid the productivity of bio-systems

Annually, each consumer in markets like Australia produces 1-2 tonnes of waste, 60% of which is organic matter. This waste is often sent to landfills or incinerated where it emits CO_2, methane, toxic volatile organic compounds and carbon particulates. By safely composting such wastes into stable soil humus we can reduce such emissions and use them to grow more food in and for urban areas. Given that 50% of humanity already lives in urban areas we must extend such waste composting capabilities and outcomes globally and urgently. This could potentially avoid 2 btC/an being emitted.

The urban wastes and effluents also contain valuable nutrients that have been extracted from soils. We must return these nutrient back to our soils to sustain their productivity and our food supplies. Highly effective local harvesting options exist to recover these nutrients from wastes and effluents. We need to extend their adoption to limit emissions and the fertilisers that will not be needed due to the recovered composts and bio-nutrients. This can reduce the emissions from their production. The improved productivity and carbon draw down by bio-systems using these recovered nutrients can further offset the emissions and ecological impacts from, our current oxidative farming systems.

9. Utilise biomass systems to produce renewable energy and carbon bio-fertilisers

Vast quantities of waste biomass are produced continually from our residual 3.5 bha of forests, 8 bha of rangelands and shelterwoods, agricultural stubble and industrial wastes. Most of this is burnt or bio-degraded by fungi and termites into CO_2 - to generate much of the 'natural' terrestrial emissions. While most of it is too dispersed to be harvested economically, large volumes can be to limit fires and aid the growth of bio-systems.

Where it is economical to harvest such biomass, it can now be converted through leading anaerobic pyrolysis processes into volatiles to produce fuel or electricity, as well as quantities of activated carbon or bio-char. Rather than oxidising the biomass to heat and CO_2, this enables biomass to be converted into valuable products, with much lower emissions, in smaller autonomous facilities.

Depending on its purity, the activated carbon produced by pyrolysis may be valuable as a chemical feedstock, filter medium or soil amendment. The activated carbon may be an ideal medium to filter waste nutrients from air or effluents to form bio-fertilisers to recycle nutrients back onto farm soils.

Such bio-fertilisers can significantly aid the regeneration of degraded soils and landscapes, limit the need for chemical fertilizers with high emissions and impacts, aid the productivity and carbon draw down capacity of our bio-systems and help to regenerate the Earth's soil carbon sponge.

10. Catalyse the regeneration of urban shelterwoods, food production and resilience

While urban areas occupy limited land relative to rural bio-systems, they support people and voters whose awareness and values have profound effects on rural policies and public initiatives globally. To help them become informed and actively engaged in regenerating the Earth's soil carbon sponge, we can and must help them get involved in experiencing the benefits from restoring soils and their safe climate.

The regeneration of urban shelterwoods can help in this and make profound changes to cool urban habitats and reinforce their resilience to climate extremes. The composting of waste organic matter and its use in urban food production can similarly enhance the food security and health of urban communities, as well as empower them as active grass roots drivers of their own safe future.

The regeneration of the Earth's soil carbon sponge and bio-systems will require the active support of billions of people that are informed, committed and empowered to take local regenerative action. To help catalyse this support and action, demonstrations of the potential, practical feasibility and benefit from such community driven urban shelterwood and garden projects may be of major value.

While not exhaustive, the above ten practical strategies and actions outline how we can readily and safely achieve our 20 btC/an draw down target so as to regenerate the Earth's soil carbon sponge and through that the hydrology, climatic cooling, health and productivity of our landscapes.

While different strategies will be more relevant in different situations they need to be seen and used as tools to address our integrated challenge and task to cool and restore our safe climate and future.