THE ANSWER IS *GREEN!*

PROMOTING PHOTOSYNTHESIS EVERYWHERE THE ONLY VIABLE SOLUTION TO GLOBAL WARMING AND CLIMATE DISASTER

PREFACE

This paper does not represent original research. It is, instead, a ‘connecting of dots’ of basic science in an attempt to reveal truths that should be blindingly obvious but that are not generally recognized. It is also not presented as a scientific research paper, accessible only to a few, but as a general article with solid scientific underpinning, designed to be readable by any educated reader, in order to reach as many people as possible.

It is an attempt, grounded in that basic science, to make the case that a comprehensive strategy to increase photosynthetic activity is the only viable approach to drawing down excess carbon from the atmosphere in the limited time available to avert a global climatic disaster. It also presents the reasoning for doing so in every ecosystem where significant levels of photosynthetic activity occur, and lists the significant secondary benefits that can be expected from implementing those strategies. By no means is this paper intended to be a comprehensive blueprint; rather it aims to provide a badly needed ‘big picture’. It is an attempt to cut through the fog of misconceptions and the hopelessness that characterize our current understanding of global warming and our approaches to solving it.

ABSTRACT

The paper begins by briefly describing the danger of a global warming disaster on the scale of the Permian mass extinction (1). Next, it examines the misconception that fossil fuel use is the sole or even main cause of anthropogenic global warming (2). It proceeds to a review of basic soil and environmental science, and an examination of sources of Greenhouse Gas emissions, followed by a sampling of NGO and stakeholder-led efforts to restore Soil Organic Carbon (SOC), (3), in order to demonstrate the viability and effectiveness of the strategies outlined below (4). It concludes (5) by summarizing the main points, and by pointing out that the ongoing changes in average temperature and rainfall patterns caused by global warming mean that there is only a limited window of time to implement the photosynthetic CO^2 drawdown strategies that are our only hope of salvation from climate disaster on a Permian scale.

INTRODUCTION

Climate Change associated with Global Warming (GW) should be more properly described as climate disaster. The magnitude and scope of approaching disasters associated with rising temperatures are becoming steadily clearer and more terrifyingly existential.

Fossil fuel emissions are not the sole cause of GW, and possibly not even the main cause. Land and Ocean Mismanagement over the course of human history, and in particular over the previous two centuries (roughly, the industrial era), and especially in the last few decades, has greatly reduced total global photosynthetic activity AND, because of the resulting exponential increase in oxidation of organic matter, facilitated the release of enormous quantities of carbon stored in that organic matter to the atmosphere in the form of CO^2.[1] In addition, water vapor is a greenhouse gas and is the biggest overall contributor to GW, and desertification and degradation through loss of organic matter from agricultural lands, rangelands and forests have significantly reduced the water absorption and retention capacity of those lands. This may be a significant factor in the increasing build-up of water vapor in the atmosphere.

At present, the buildup of Greenhouse Gases (GHG) in the atmosphere is seen mainly as a fossil fuel emissions problem, with a mainly technological solution focused principally on those emissions reductions. Given the amount of anthropogenic carbon already in the atmosphere, and the feedback loops already being triggered (increased fires across the planet, melting of the permafrost, release of methane hydrates from the seabed, reduced reflection of sunlight associated with sea ice loss, etc.) reducing or even (improbably) eliminating that fossil fuel use will only result in wrecking our climate system at a slightly slower pace. Most discussion of potential drawdown of CO^2 already in the atmospheric is also technological in nature (CCS, or carbon capture and storage technology). But neither present nor foreseeable CCS technology can economically remove CO^2 and other GHG from the atmosphere, and in any case CCS technologies cannot possibly capture enough carbon in the needed time frame to avert disaster. And such strategies totally disregard the enormous benefits of restoring organic carbon to the world's soils and oceans. Thus, although fossil fuel emissions reductions and transition to renewable energy are essential in the long term, there is NO realistic fossil-fuel reduction strategy NOR technological solution to GW within the time frame remaining to avoid

[1]

climatic disaster.

One viable solution does exist, and it consists of systematically augmenting photosynthetic activity, through land and ocean management strategies that mimic natural processes, in every ecosystem where significant amounts of photosynthetic activity occur.[2] Photosynthesis is the driver of the carbon cycle, and converts carbon from the atmosphere to organic forms contained within the soils and the waters of the planet, in a form beneficial to life. Photosynthesis 'moves' carbon at a scale far outstripping, even now, any human activity, and it moves it in the desirable direction. Land, Urban and Ocean Management strategies to promote and increase photosynthetic activity, if implemented in a timely fashion, will not only drawdown sufficient carbon from the atmosphere in time to avert the worst of global climate disaster, but are extremely desirable management options simply for their side benefits alone. These include reversing desertification, increasing food production in both rural and urban areas and in the oceans as well, promoting biodiversity, increasing water retention and mitigating water shortages, revitalizing rural economies, reducing heat-island problems in cities and making them more livable, and in general restoring the natural beauty of the planet.

1) THE LOOMING CLIMATE DISASTERS

Prior to the 2015 United Nations Climate Change Conference (the Paris talks), the three living diplomats who had led previous U.N. climate change talks claimed there is little chance the next climate treaty, if it is ever approved, will prevent the world from overheating. "There is nothing that can be agreed in 2015 that would be consistent with the 2 degrees," said Yvo de Boer, who was executive secretary of the United Nations Framework Convention on Climate Change in 2009, when attempts to reach a deal at a summit in Copenhagen crumbled. "The only way that a 2015 agreement can achieve a 2-degree goal is to shut down the whole global economy."[3]

If there is one defining characteristic of our responses to the existential threat of runaway Global Warming, it is that we have consistently underestimated its speed and scale. The history of our assessments of the scope of climate change is basically a history of those assessments being continually revised upwards:

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- Late 2007: The Intergovernmental Panel on Climate Change (IPCC announces that the planet will see a one-degree Celsius temperature increase due to climate change by 2100.
- Late 2008: The Hadley Centre for Meteorological Research predicts a 2C increase by 2100.
- Mid-2009: The U.N. Environment Programme predicts a 3.5C increase by 2100. Such an increase would remove habitat for human beings on this planet, as nearly all the plankton in the oceans would be destroyed, and associated temperature swings would kill off many land plants. Humans have never lived on a planet at 3.5C above baseline.
- October 2009: The Hadley Centre for Meteorological Research releases an updated prediction, suggesting a 4C temperature increase by 2060.
- November 2009: The Global Carbon Project, which monitors the global carbon cycle, and the Copenhagen Diagnosis, a climate science report, predict 6C and 7C temperature increases, respectively, by 2100.
- December 2010: The U.N. Environment Programme predicts up to a 5C increase by 2050.
- 2012: The conservative International Energy Agency's World Energy Outlook report for that year states that we are on track to reach a 2C increase by 2017.
- * November 2013: The International Energy Agency predicts a 3.5C increase by 2035.[4]

A briefing provided to the failed U.N. Conference of the Parties in Copenhagen in 2009 provided this summary: "The long-term sea level that corresponds to current CO2 concentration is about 23 meters above today's levels, and the temperatures will be 6 degrees C or more higher. These estimates are based on real long-term climate records, not on models." On December 3rd, 2013, a study by 18 eminent scientists, including the former head of NASA's Goddard Institute for Space Studies, James Hansen, showed that the long-held, internationally agreed upon target to limit rises in global average temperatures to 2 degrees Celsius was in error and far above the 1C threshold that would need to be maintained in order to avoid the effects of catastrophic climate change. Given present trends, limiting rises to 2 C, let alone this newer perhaps more realistic limit of 1C, seems unlikely in the extreme. [5]

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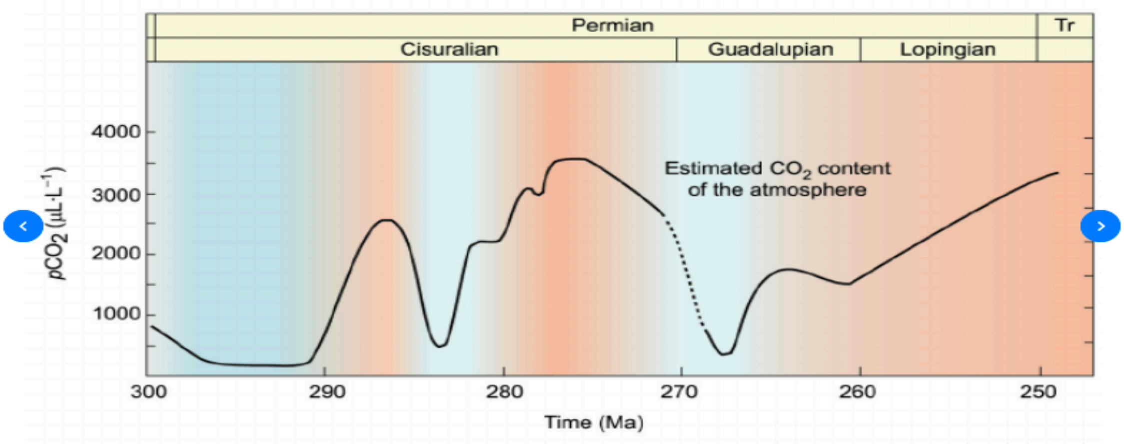
EXTINCTIONS

These disheartening facts can and do lead to serious pessimism. Are we doomed, and if so, what will the effects of this catastrophic climate change look like? The geologic record is very sobering: There have been five great extinction events in the half billion years of animal life on this planet. Although most people imagine that these events were all caused by asteroid strikes, most evidence indicates 4 out of the 5 extinction events were actually caused by enormous spikes in greenhouse gases that led to global warming events. The world is very aware of the danger of asteroid strikes; they are very dramatic indeed and the stuff of many a movie. But the geologic record suggests we should be far more concerned with global warming events.

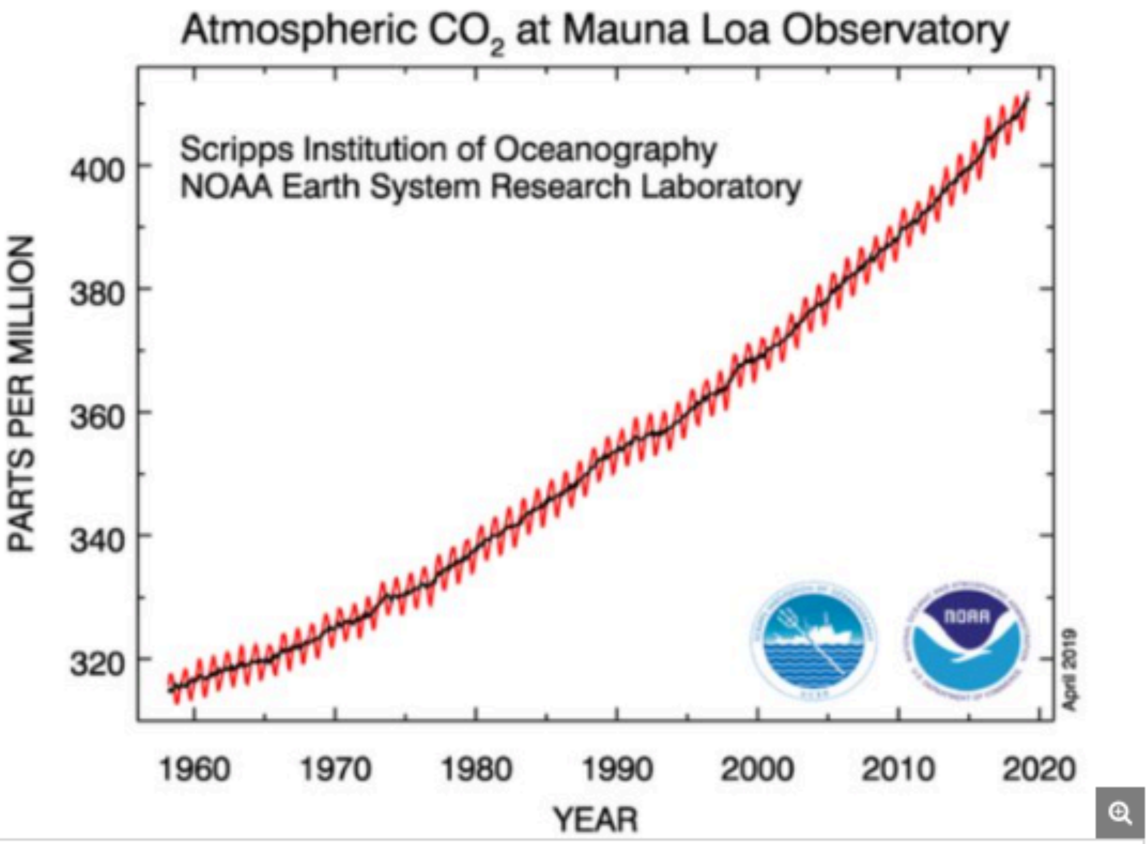
The greatest of them all, the End-Permian extinction, also known as the Permian-Triassic mass extinction event, is widely considered to have been the result of a catastrophic global warming event that played out over an estimated period of 80,000 years. It is thought that 96% of marine organisms went extinct, as did more that 70% of land vertebrates. It is also the largest, some say the only, mass extinction of insects and other terrestrial invertebrates in the fossil record. It is known colloquially as the Great Dying. Details are in some dispute, and there is a range of assessments as to the scope of the mass extinction and its timing, and of the mechanisms at work. But there is broad agreement that the proximate cause of the End-Permian extinction was a relatively rapid and very large surge in the greenhouse gases $CO^{2,}$ and methane, triggered most probably by the enormous volcanic events that produced the Siberian Traps. Not only would this vulcanism have injected massive quantities of CO^2 into the atmosphere, but would likely have set huge coal beds on fire, releasing yet more gigatons of carbon into the atmosphere. Recent research shows that approximately half of the area covered by the basalt flows of the eruptions was actually shallow seas that existed at the time. This influx of lava would have resulted in enormous releases of methane trapped in methane hydrates on the sea floors. This, in addition to all the CO already released to the atmosphere, resulted in a runaway greenhouse effect, with average temperature increases of at least 6C at the equator ranging up to 10C or more in arctic regions. The resulting ocean acidification, temperature induced oceanic hypoxia, violent climate disruptions such as fire, flood and storm events, etc. led to the Great Dying.



Estimated atmospheric carbon dioxide levels during the Permian, shown as parts per million by volume (μ L · L − 1) and relative to pre-industrial levels (PIL: 280 μ L · L − 1), against a background of low (blue) and warm (red) global temperatures. Adapted from Montañez et al. [36] for the Cisuralian, and from Royer [41] for the later Permian. Note that there are considerable uncertainties in these estimates, which are based on modelling and proxy data, but they indicate a general warming, caused by increasing atmospheric CO 2 levels, throughout much of the Permian.

Graph from “The Siberian Traps and the End-Permian mass extinction: a critical review” by Andy Saunders and Marc Reichow

The point of this discussion is that, largely as a result of human activities, the world is presently in a situation analogous to the onset of the End-Permian extinction event. Extinction rates now are one to two hundred times the background extinction rate, equaling or exceeding the End-Permian event, and greenhouse gas concentrations are rising in fact far faster than they did then. The scope of that mass extinction could very easily be repeated and on a far more rapid time scale, in our own lifetimes even. This should terrify us into effective action to avoid the fate of Permian life.



A chart from the National Oceanic and Atmospheric Administration shows the drastic increase in atmospheric carbon dioxide measured in Hawaii over the course of the last several decades.

Credit: NOAA

We are already seeing fiercer storms, with more severe floods occurring more often, an increase in the frequency and intensity of fires, more droughts, melting glaciers in the arctic, Antarctic and montane regions of the world, sea level rise, the spread of infectious disease, rapidly increasing rates of extinction, and other symptoms and warnings of the impact of global warming. And the disasters are just beginning. Most of the statements in the following paragraphs are adapted from one of the most sobering books ever written, “The Uninhabitable Earth, Life after Warming” by David Wallace Wells, published in 2019. For incorrigible skeptics and climate denialists, extensive notes substantiate the statements made therein.

Wildfire

Wildfires are already reaching terrifying proportions, and as the temperature rises, they will become exponentially worse. Australia is suffering disastrous fires, as is California, now on a yearly basis. Unprecedentedly, there are wildfires in Greenland, and in Sweden north of the arctic circle. Smoke from Siberian wildfires reaches the continental USA. In 1997, it is estimated that just the peat fires of Indonesia released over 2 billion metric tons of carbon, over one-third of annual global emissions, and this episode was topped by the Indonesian fires of 2015. Over 35,000 fires have been recorded in Indonesia, and over 100,000 fires in the Amazon in 2019 and the carbon emissions from these fires are huge as well. Wildfires are not only becoming more destructive, they are a fearsome feedback loop, releasing ever-more carbon to the atmosphere, and fast-forwarding global warming. Which in turn creates more wildfires.

Above: The Washington Post/Getty Images – The Woolsey fire burns above Malibu
Below: Daily Mail, UK - Flames rage across woodland during deadly California wildfires

Floods

As the atmosphere warms, it can hold more moisture. Torrential rains, once in a hundred-year events, are now occurring several times a decade. Some, such as Hurricane Harvey, have been described as once in 500-year events. Inland flooding affected over 2 billion people and killed over 150,000 in the 20 years between 1995 and 2015, and the numbers can only rise along with the temperature. In July 2010, flooding on the Indus river in Pakistan affected one fifth of the country, and over 20 million people. Houston, Texas normally receives 1.264 mm of rain a year, but Hurricane Harvey, in 2017, dropped more than a year's worth of rain on the city in 48 hours, and about

125 trillion liters on the US as a whole. It was the wettest hurricane in US history, but this record is sure to be broken. New words are entering the Japanese vocabulary: it is now no longer torrential rain, but *guerilla* torrential rain. As I write this, Nagano and the Kanto region are recovering from the flooding of Hagibis, one of the largest typhoons ever to hit Japan, and one that hit just a month after another typhoon, Faxai, also made landfall in the same general area in Japan, causing over 70 billion yen in economic losses. The economic losses calculated so far for Hagibis, surely only a fraction of the final total, already exceed 100 billion yen. A March 21, 2018 article in The Guardian, citing a European science paper, stated that “Flooding and heavy rains rise 50% worldwide in a decade . . .” and that “Such extreme weather events are now happening four times more than in 1980”.

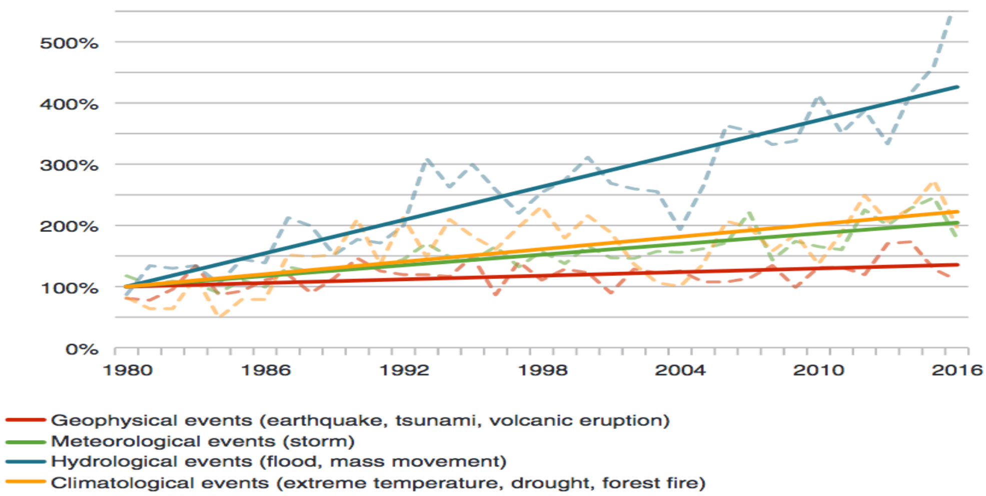


Figure 1. Trends in different types of natural catastrophy worldwide 1980–2016 (1980 levels set at 100%). M NatCatSERVICE.

Coastal flooding, due to sea level rise from the melting of the world’s ice, is already becoming noticeable, and due to get much worse. The West Antarctic Ice Sheet has more than doubled its rate of loss in the last five years, and has probably already passed a tipping point of collapse. In Greenland the situation is similar; the ice sheet is losing nearly a billion tons of ice daily. The last time the earth was four degrees warmer, there was no ice at the poles and the seas were about 80 meters higher, which, if repeated, would a catastrophic loss of habitable land beyond comprehension. Even if we are able to limit temperature rise to about 2C, the sea level will eventually rise by up to 2m. Vast amounts of land will be submerged regularly or completely by flooding: two thirds of Bangladesh, Miami Beach and much of south Florida, the Maldives, Venice, etc. etc. Every beach we have ever swum at will disappear, and the geologic processes to produce new sand will take many millennia. A majority of the world’s cities are on the coast, and will be directly affected, among them Jakarta, Shanghai, Mumbai, Tokyo, Hong Kong, London, New York and many more. According to the European Academies' Science Advisory Council, flooding has quadrupled since 1980 and is speeding up. The losses will be incalculable.

Drought

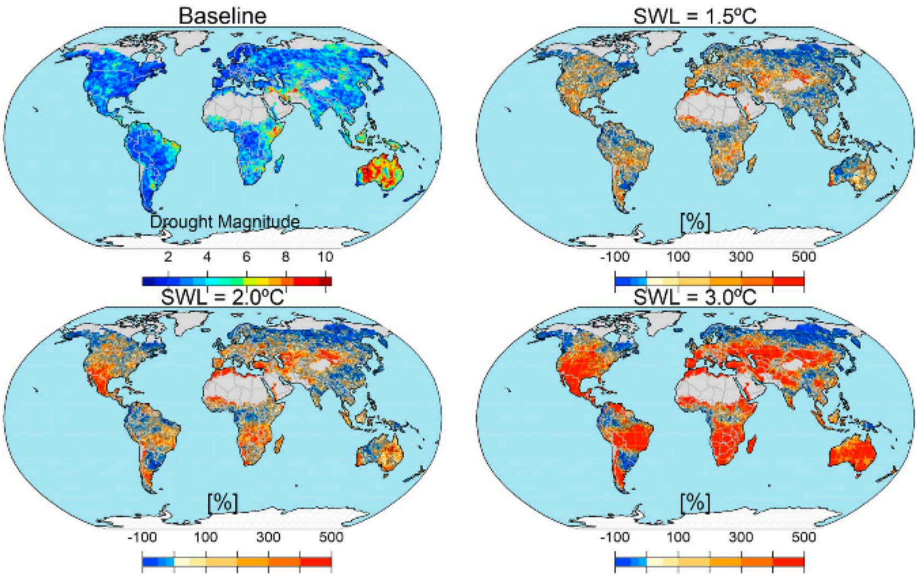


Figure 1. (top left) Drought magnitude and relative changes (%) in drought magnitude with respect to the baseline for the three specific warming levels (1.5, 2.0, and 3.0°C). Changes that are not statistically significant at the 10% level are shaded out in black. Territories excluded from the analysis are masked in grey.

From: Global Changes in Drought conditions Under Different Levels of Warming" by Gustavo Nauman, Lorenzo Alfieri et al. in Geophysical Research Letters, March 2018

Just as devastating will be cataclysmic droughts on much of the land that remains. Australia and the American West are already struggling with protracted drought, but it is due to get much worse. The more densely populated parts of Africa, Southern Europe, much of the Middle East and India, and large areas in South America and China are expected to be stricken with severe and prolonged drought. Food production will fall precipitously, and famine, and consequent war, will become widespread. Already the drought in Syria is regarded as a major cause of the disastrous war unfolding in that unhappy country, a war that already has spawned a flood of refugees. In a country with a pre-war population of about 22 million, half are now refugees. There are over 6 million internally displaced refugees and over 5 million who have crossed international borders into countries ill-equipped to assimilate or care for them. The number of refugees from the coming natural disasters, and the wars and famines they engender, will number in the hundreds of millions, overwhelming any capacity to care for them or resettle them. The ensuing humanitarian disasters will be horrific beyond any in human history.

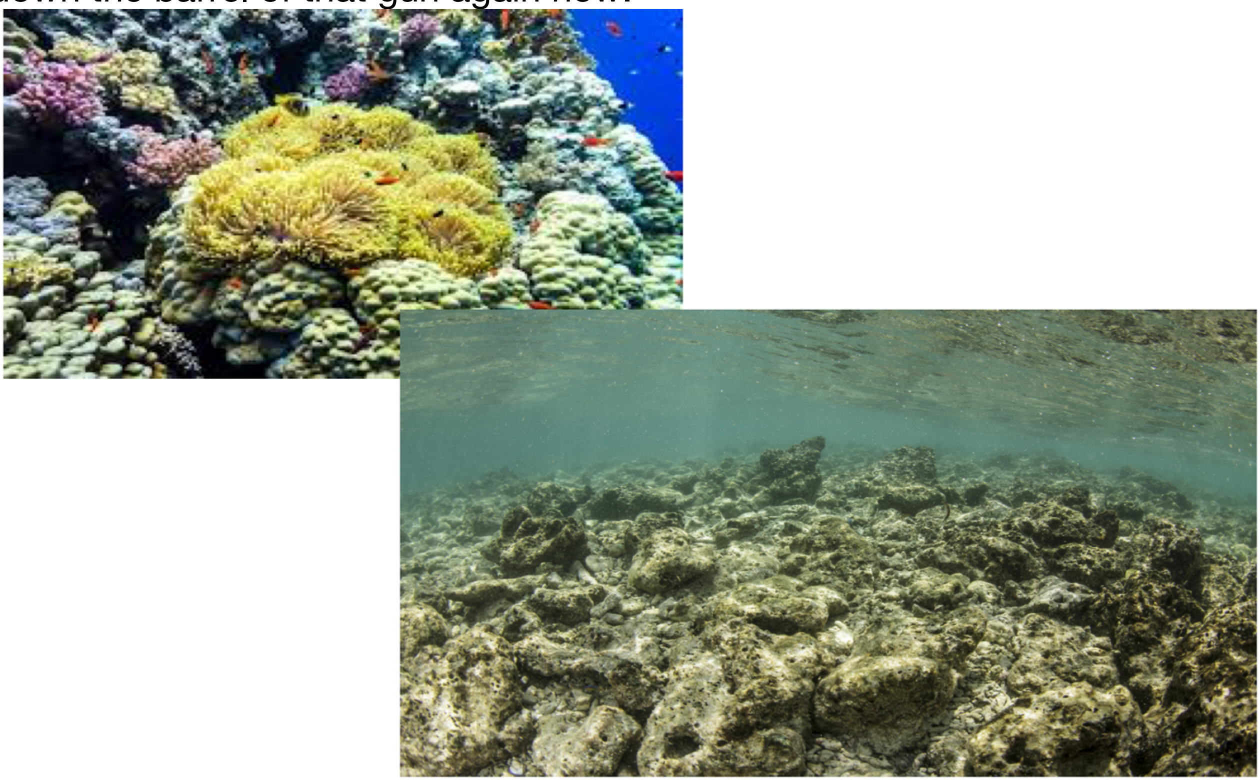
Ocean Death

The oceans, at roughly 70% of the earth's surface area, are the planet's predominant environment. The oceans feed us, providing nearly one fifth of all our animal protein. They maintain our seasons and our regional climates. Without the Gulf Stream, for example, London's climate would be like Iceland's and Europe would be a much colder place. The phytoplankton living in the oceans produces between 50 and 85% of atmospheric oxygen. And, through heat absorption on a massive scale, the oceans modulate the average temperature of the planet. The vastness of the oceans has made them seem impervious to any human effect, but that is not the reality. ALL of the above eco-system services of the oceans are endangered by climate change, as described in the following four paragraphs.

Fish populations are already migrating hundreds of kilometers north and south from the equator, fleeing warmer waters. During the end-Permian great extinction, cold-water species, the most significant as food sources, suffered most because they ran out of colder water to flee to. Counter-intuitively, it was the species of tropical seas, in our time deemed less commercially and nutritionally valuable, that had cooler waters to flee to and had some chance of survival. The ongoing acidification of oceanic water due to increased carbon dioxide absorption (think soda water) also means shell-forming species are at serious risk. Already oyster farmers in the Pacific Northwest are having trouble propagating oysters, and populations of the region's famous clams are declining as well. Ocean acidification will devastate mollusks, probably arthropods too, and zooplankton in general. Larval stages of all marine species are at serious risk. What does all this bode for the world's supply of seafood?

The world's system of ocean currents is also vulnerable to a warming world. As the Gulf Stream's flow approaches Iceland, its water become cooler and, through evaporation, saltier and thus denser. Huge quantities of this colder, denser, and thus heavier water plunge more than 4 kilometers to the depths of the North Atlantic. This phenomenon, named the Atlantic Meridional Overturning Circulation (AMOC), has been called the driver or conveyer belt for the whole world's system of ocean currents, which is a major factor creating and stabilizing our present world climate system. The danger is that that water reaching the North Atlantic is getting warmer, and, with a steadily increasing influx of fresh meltwater from Greenland's glaciers, less salty and thus less dense. Already there are signs that the AMOC is slowing down. There have been sudden releases of unimaginably huge quantities of meltwater in the world's past, on the order of hundreds of cubic kilometers, and there is a clear danger of such a glacial lake outburst emanating from Greenland. This could actually stop the AMOC altogether. This would likely cause massive climate changes: ice-age conditions in Northern Europe; El Niño events in the Pacific dwarfing any we have experienced so far, leading to both droughts and catastrophic floods; and anoxic oceans. We have no way to predict the global climate consequences of such an event, except to say two things: One, the consequences will be enormous, and, two, we will be much happier and safer if we never have to find out.

The atmospheric increase in CO^2 would have been much larger if the world's oceans had not been steadily absorbing a large portion of anthropogenic emissions. This has slowed the onset of global warming, but it also means that the oceans are growing more acidic. Past a certain threshold, the consequences for coral reefs, for shell-building animals and for the oceans' plankton will be disastrous. This will affect not only our food supply and the rate of coastal erosion through loss of coral reef defenses, but even the oxygen content of our atmosphere. A combination of ocean acidification and anoxic/hypoxic ocean conditions are thought to be the main cause of the huge marine extinctions of the end-Permian. And we're looking down the barrel of that gun again now.



Both: Shutterstock.com

It is claimed by some that increases in ocean floor geothermal activity are the proximate cause of observed ocean warming. But the direct correlation of that ocean warming with the increase in atmospheric carbon due to fossil fuel burning and to destructive land-management practices makes that claim improbable in the extreme. It is far more likely, by orders of magnitude, that ocean warming is due to global warming caused by the massive transfer of carbon-containing greenhouse gases to the atmosphere as a result of human activities. This ocean warming means the oceans' ability to modulate climate fluctuations is decreasing. It also means that marine organisms will require more oxygen as a result of living in warmer water. This will occur just as anoxic and hypoxic conditions induced by Global Warming are on the increase. A recent study from Stanford University has proposed that such a collision between decreasing oxygen levels and rising oxygen demand was one of the major causes of the marine extinctions of the End-Permian.

Air Pollution

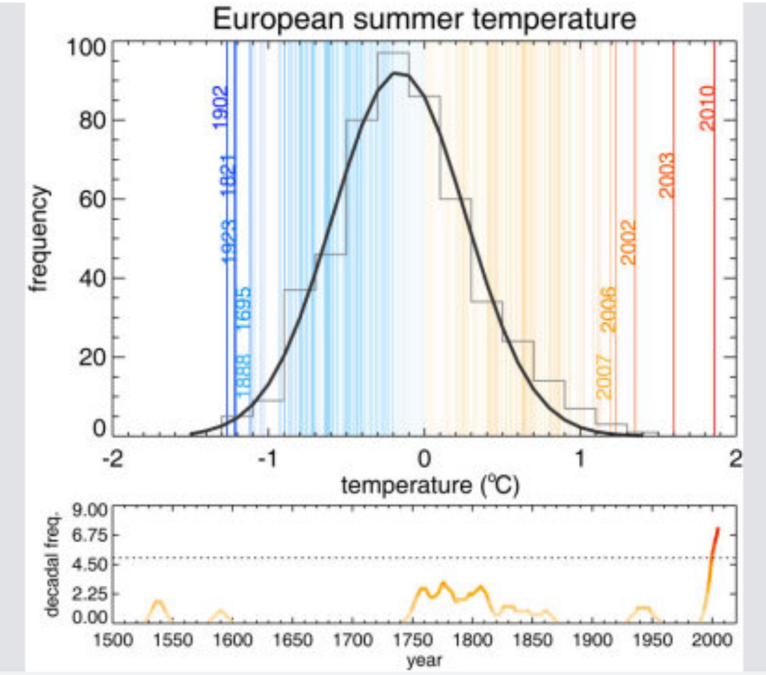
As if this weren't enough disasters, we are facing increasingly horrendous air pollution as Global Warming advances, from the dust storms of the droughts to the smoke of the wildfires. The Air Quality Index categorizes risk on a scale that tracks a range of pollutants. Warnings are first triggered by readings of 51-100. At 201-300 the warnings include a "significant increase in respiratory effects in the general population". The high end is in the 301-500 range, where the warnings are "serious aggravation of heart or lung disease and premature mortality in persons with cardiopulmonary disease and the elderly", adding to that the recommendation that "Everyone should avoid all outdoor exertion". In 2013, Beijing doubled the high end of the scale, reaching a peak Air Quality Index of 993, as did New Delhi with 999 in 2017. Also, in 2017, due to the California wildfires, the index around San Francisco soared past 400 and almost hit 500 in Napa Country. In 2018 smoke from wildfires made it unsafe for anyone around Seattle to breathe outside. One study found that "exposure to smoke from the Indonesian wildfires of late 1997 led to more that 15,600 child, infant, and fetal deaths . . ." These record-breaking fires were topped in 2015, when 2.5m hectares burned, leading to a US$16 billion loss, substantially larger than the economic losses inflicted by the 2004 Tsunami even. 2019 is on track to match or even top 2015, with over 35,000 fires and air pollution levels classified as "hazardous".

Air pollution is already a killer of millions yearly; one in six deaths worldwide is attributable to it. It also results in a whole range of health damages in those that don't die: cognitive declines, impacted cognitive development in children, asthma, all kinds of cancers, strokes, heart disease, and more. Recent research has also linked air pollution to declines in memory and attention span, and increases in autism spectrum disorders. These and related air pollution problems will only worsen as Global Warming advances.

Plagues

The world will also see the resurgence of plagues and epidemics comparable even to the Black Death of the Middle Ages, or the epidemics that devasted the Aztec and Inca Empires, diseases introduced unwittingly by the conquistadors (who had immunity to them) and that proved to be by far their most effective weapon in the subjugation of the New World. These plagues will come from two directions in all likelihood: First, and of more immediate concern, as the world warms, the range of disease-carrying insects, in particular mosquitos but also ticks and others, will spread north. We will see ancient scourges such as malaria, yellow fever and dengue, and newer diseases such as Zika, in areas where they have been previously unheard of, such as New York and Berlin. Two, and far more unexpectedly, known and unknown pathogens will possibly be released from melting ice at the poles. This ice contains known and deadly pathogens such as the Spanish Flu, bubonic plague, smallpox and anthrax, which could easily prove viable once again when re-exposed to sunlight, air and potential victims. Already, one outbreak of anthrax has resulted from a reindeer carcass exposed by melting ice. But more ancient ice is melting as well, and probably contains microorganisms dating back to a time well before humans even existed on the planet. Should any of these prove both viable and pathogenic, no person and no animal on the planet can possibly have any immunity to it. In effect, we could be sandwiched between expanding sources of epidemic disease from both the tropics and the arctic and antarctic. The interconnected nature of our globalized world means that any outbreak of disease can very conceivably spread around the world in mere days.

Heat Death

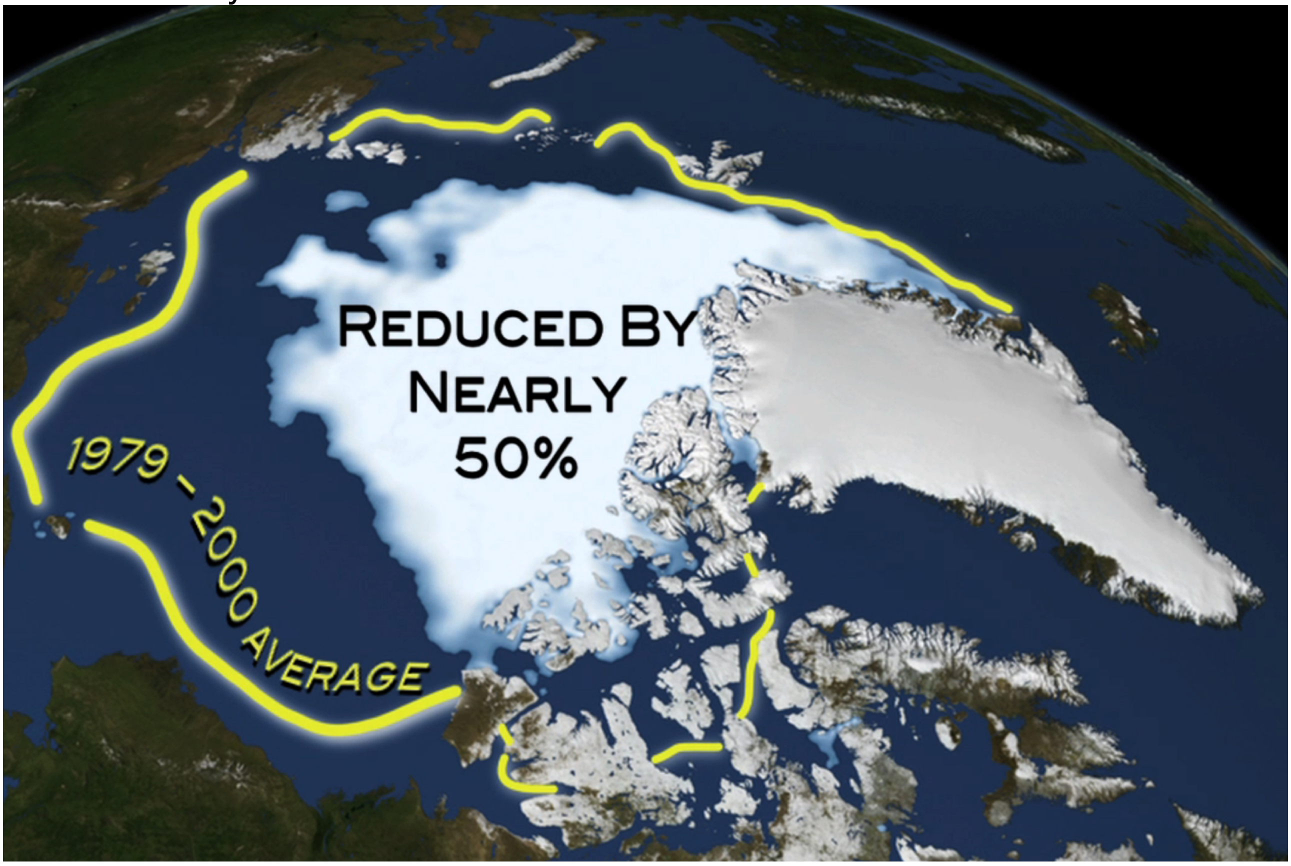


The 2010 heatwave (see at the right side of this picture) shattered all the records in terms of the deviation from the average temperatures.

The IPCC has established a median prediction of 4C in average global temperature rise by 2100, should we continue down the present emissions path. At that point, whole equatorial sections of the globe will become literally unlivable. Cities in India and the Middle East would be so hot that stepping outside in summer could be fatal. Even at 2C warming, similar scenarios will occur with frequency. The crucial factor is something called “wet-bulb temperature”. This is a measurement of the combination of humidity and temperature, taken by wrapping a thermometer bulb in wet gauze and swinging it in a circle through the air. Basically, it indicates the potential for evaporative cooling. Humans sweat, and dogs and birds pant, to take advantage of evaporative cooling. But this becomes impossible when the wet-bulb temperature reaches 35C. At that point, evaporating sweat will not remove any heat energy and thus will not cool the skin, and humans begin dying just from the heat in a matter of hours, even in the shade. Currently, most regions reach a wet-bulb maximum of 26 or 27C, which leaves us a margin of 8C or so. Hotter air can hold more humidity. A combination of extreme humidity and high heat is frighteningly conceivable. Already, in the Persian Gulf, wet-bulb temperatures of almost 32C have been recorded. And even before we reach such disastrous levels, work will become difficult or impossible, and many will die in the coming heat waves. The European heat wave of 2003 killed over 35,000, and in 2010, 55,000 died in Russia. Clearly, heat alone can be disastrous beyond any conception we have today.

Feedback Loops

A warmer atmosphere holds more water vapor, and since water vapor is a greenhouse gas, this will lead to yet more warming. The warming of the arctic means more ice melts, which means the surface of the ocean is darker and reflects less heat back into space (a reduced albedo effect), and thus the arctic warms yet more.



Ocean Today: Arctic Sea Ice Sets Record Low – January 28, 2017

Higher temperatures lead to more wildfires, which leads to fewer trees and less plant cover, and that leads to less carbon absorption and storage through photosynthesis, which leads to higher carbon levels in the atmosphere and thus leading to yet higher temperatures. Even without wildfire and drought, higher temperatures have a negative effect on plant growth, resulting in what is called "forest dieback" of vast areas of tropical and temperate forest, with resulting reduced carbon absorption, and thus more in the atmosphere, etc. etc. Droughts lead to famines lead to wars lead to floods of refugees, as we are seeing in Syria and also in Central America. Climate disasters can overwhelm our response capabilities even when striking singly, as seen in the aftermath of Hurricane Maria in Puerto Rico. Now the likelihood is emerging that several climate related catastrophes could strike simultaneously, or in close succession, and then again within a year or two. Just this year, Japan saw two typhoons within a month of each other strike Tokyo and nearby areas, with record-breaking floods, and initial estimates of damage exceeding 100 billion yen. In California, disastrous fires led to disastrous mud flows within months, when freakish monsoon-like rains followed the drought. The resulting lush growth then dried out in the following dry year, leaving huge stores of fuel that led to new major wildfires.

The mother of all feedback loops would be the release of vast stores of organic carbon built up over millions of years in the soils of the Arctic, an estimated 1,400 to 1850 peta-grams worth (one peta-gram is 1 billion metric tons or one gigaton). Most of this carbon is held in top soils than can easily thaw within 10 feet of the surface. For comparison, an estimated 350 peta-grams of carbon have been emitted by all fossil-fuel burning and other human activities since 1850. According to research scientist Charles Miller of NASA's Jet Propulsion Laboratory, and the principal investigator of the Carbon in Arctic Reservoirs Vulnerability Experiment (CARVE),[6] "Permafrost soils are warming even faster than Arctic air temperatures, as much as 1.5 to 2.5C in just the past 30 years . . .". As the permafrost melts, it will release these organic carbon deposits into the atmosphere as carbon dioxide and/or methane. The drier the arctic conditions created by Climate Change, the more will be released as carbon dioxide, the wetter, the more as methane. This has enormous implications for Global Warming, because methane is a much more powerful greenhouse gas than carbon dioxide. Over a hundred-year span it is 22 times more powerful, but up to 105 times more powerful over a 20-year span. If wetter warming prevails, most of this stored organic carbon will be released as methane, and the impact would be cataclysmical. Methane is also stored in the form of methane hydrates, a kind of methane sherbet, on the ocean floor mainly in the arctic, in staggering amounts: between 1,000 and 10,000 gigatons.

A study published in Nature in July 2013[7] suggested a 50-gigaton "burp" of methane from thawing Arctic permafrost beneath the East Siberian Sea is possible at any time, with a greenhouse gas impact equivalent of at least 1,000 gigatons of carbon dioxide over a twenty-year span. Active and growing methane vents up to 150 kilometers wide have been discovered in the arctic. One scientist described the ocean as looking like a vast pool of seltzer water. Between the summers of 2010 and 2011, scientists discovered methane vents that grew from only 30 centimeters across to more than a kilometer wide, a totally non-linear exponential 3,333% increase. It is in fact methane release events like this that were the final blow leading to the End-Permian extinctions described earlier in this article. The potential for a global climate disaster on a scale that would lead to the extinction of humanity along with most other life on earth is far more real and far nearer that just about anyone realizes. This would be the final massive nail in our collective coffin, a planetary holocaust and final solution on a scale to match the previous 5 great extinctions. Given the exponentially increasing speed with which we are approaching it, a few centuries versus the 80,000 years of the End-Permian, we could possibly be triggering the greatest, most all-encompassing extinction of all, within

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decades even. The time frame for effective counter-measures is shrinking rapidly. We must identify the mitigation strategies that can work and we must act now.

2) SOURCES OF GREENHOUSE GAS EMISSIONS

As I write this in late 2019, the 2020 U.S. presidential campaign is already heating up, with various Democrats vying to be the Democratic Party contender for president in the general election. One of them is Bernie Sanders, a progressive populist with a generally intelligent platform of ideas, with a main focus on the staggering income disparity that has accumulated over recent years. But he also has proposals for dealing with Global Warming and they are among the most progressive of such proposals. He advocates spending more than any other candidate (a total of US$16.3 trillion) and all of it would come from the Federal government. He claims that most of that money will be recouped in short order, and that the long-term economic and social benefits will far outstrip the outlays now. His claims are believable, and it is a remarkable proposal in many ways. It would go a very long ways towards reducing our fossil fuel emissions and their related pollution, and by extension towards rectifying the skewed and highly destructive foreign policies and the extraordinary military expenditures of the United States, both aimed at securing a stable fossil fuel energy supply. So far, so wonderful! What is discouragingly apparent is that his plan, the most progressive one out there at the moment, deems the build-up of Greenhouse Gases in the atmosphere to be almost exclusively the result of fossil fuel burning. And thus, the answer to also be almost exclusively based on reducing and eventually eliminating that reliance on fossil fuel.

Bernie Sanders is not alone. A cursory review of writings about Global Warming and proposals for solutions is overwhelmingly focused on fossil fuel emissions. Not surprisingly, the general public, if it is concerned at all about approaching doom, also thinks that any and all efforts to find a solution must obviously and necessarily focus on reducing and eliminating fossil fuel use. **Unfortunately, that is not true.** It is undeniable that fossil fuel emissions are a very large part of the problem, and the goals of activists fighting to reduce and eliminate them are worthy goals indeed, with many subsidiary benefits as well. But what is **not** generally realized is that fossil fuels are only part of the problem. They are, by far, **not** the only source of Greenhouse Gases, and may not even be the main one. Destructive land management policies over the ages, and particularly since the industrial revolution, have led to loss of organic carbon from the world's soils and oceans, and that carbon went somewhere. It went into the atmosphere, resulting in carbon dioxide emissions on a scale that easily rivals fossil fuels. Tragically, this is not generally recognized. As a result, also unrecognized is the reality that solution(s) to Global Warming **must** include fundamental revisions of land and ocean management practices, in grazing and crop agriculture, in forestry, in urban development, and even in wildlife management in the oceans. **In fact, it is these solutions ONLY that can be implemented quickly enough to begin drawing down carbon dioxide at the scale needed to reverse the Global Warming trend.** This will be discussed in detail in 3) below.

To recap, at present, the buildup of Greenhouse Gases (GHG) in the atmosphere is seen mainly as a fossil fuel emissions problem, with a mainly technological solution focused principally on those emissions reductions. Given the amount of anthropogenic carbon already in the atmosphere, and the feedback loops already being triggered (increased wildfires across the planet, melting of the permafrost, release of methane hydrates from the seabed, reduced reflection of sunlight associated with sea ice loss, etc.) reducing or even (improbably) eliminating that fossil fuel use will only result in wrecking our climate system at a slightly slower pace. There is already enough carbon in the atmosphere to take us to an extra 2C warming and beyond. As discussed above, that level of warming alone will bring disasters on a scale beyond any humanity has endured so far. And that level of warming seriously risks triggering the methane release feedback loops that would mean game over for most life on the planet. It is too late to solve the problem just by reducing and gradually eliminating fossil fuel use. We need to also actively start **drawing down** the carbon in the atmosphere. The question is, how to do it!

Most discussion of potential drawdown of CO_2 already in the atmospheric is also technological in nature (CCS, or carbon capture and storage technology) and a lot of it looks pretty expensive. But let's be honest! This won't save us. Neither present nor foreseeable CCS technology can economically remove CO_2 and other GHG from the atmosphere, and in any case CCS technologies cannot possibly be deployed at the scale needed to capture enough carbon in the needed time frame to avert disaster, even in the unlikely event that more efficient and economical CCS technologies are unexpectedly developed in the future. They can't be built fast enough. Thus, although fossil fuel emissions reductions and transition to renewable energy are essential in the long term, there is NO realistic fossil-fuel reduction strategy NOR technological CCS solution to Global Warming within the time frame remaining to avoid climatic disaster.

Does this mean we are literally doomed to soon follow the dinosaurs, and the other 99% of species that have ever lived but that are now extinct? Only if we remain locked in our self-centered technological-fundamentalist way of thinking. This is almost a religion, a way of thinking that says we can do it all by ourselves, and that technological answers are the only ones out there, and that they can and will save us. Because we are that smart. This is the thinking that, among other things, has held for over fifty years that we can solve the problem of high-level radioactive waste from nuclear power. That solution still remains fifty years in the future, which does not inspire much faith in the power of modern technology to solve the exponentially building problem of Global Warming. We need to free ourselves from our insane self-centered over-confidence, and look beyond modern human technology, with its limited history of centuries. We need to look at “natural technology”, which has been evolving now for several billion years. There is where we will find a solution, and it involves working with other life on the planet. And that other life is green in color.

3) NON-FOSSIL-FUEL GREENHOUSE GAS EMISSIONS

An interesting article appeared in the New York Times on October 25th, 2019. Entitled “climate Change will cost even more than we think”, the main thrust of the piece was that economists are badly underestimating the costs of climate change, something the authors described as "as bad or worse than" the underestimation of the effects and speed of climate change itself by scientists. They went on to analyze why this was so, and as I read their conclusions, I realized that very similar mechanisms are behind the underestimations of both scientists and economists. Let’s look at the economics first.

In the first place, economic estimates of risk are typically grounded in experience, something statisticians term “stationarity”. But when conditions change so much, as they indisputably are with climate change across the board, that past experience is no longer a reliable guide, then stationarity no longer applies and estimates become more and more uncertain. Alas, economists have by and large been approaching climate damages as temporary perturbations “from the norm” instead of unprecedented, long-term, and just beginning to worsen. They are taking little account of the fundamental destruction we are facing, simply because it is so outside the realm of human experience. A second problem leading to those dangerous underestimations stems from a failure to include some risks in the calculations because those risks can’t be properly quantified (or so it is assumed). The economists do not want to be accused of “making things up” and so they just leave those risks or factors out. Just because something is not easily or perfectly quantifiable does not mean it is not real and significant. The underestimations of economic damage stemming from both these factors are doing great damage. Government policy and the concerns of the public, which can have a large influence on that government policy, are both largely grounded on the economic assessments of loss, and these are now turning out to be far from reliable. Most people have a much harder time grappling with scientific explanations than with economic figures, so basically, they go with those. The alarming reality is thus hidden from view, and we are making irreversibly disastrous mistakes.

Scientists may to some degree also be misled by stationarity, though by and large nowhere near as badly as economists seem to have been. Scientists are, however, missing key elements of the massive shift of carbon to the atmosphere, failing to recognize the scale of transfer of carbon, in the form of beneficial organic compounds in the soils and oceans of the planet, to carbon, in the form of harmful greenhouse gases, in the atmosphere. And they are going astray not only because of their preconceptions and single-minded focus on fossil fuel emissions, but also because the losses of soil organic carbon and organic carbon from the oceans are so varied and hard to quantify. To repeat from the above paragraph, they do not want to be accused of "making things up” and so they just leave that all out. And by badly skewing the results, that is a recipe for disaster. We not only fail to understand a large part of the cause of Global Warming, but more importantly we cannot therefore come up with effective solutions and mitigation strategies. Understanding where a major portion of anthropogenic carbon in the atmosphere originated points the way to effective solutions. And although curtailing fossil fuel consumption is needed, the most effective immediate solutions instead involve regenerative agriculture and ocean management practices.

Dr. Rattan Lal and worldwide losses of Soil Organic Carbon

One of the most prominent scientists to have made the connection between the loss of soil organic carbon and the surge in greenhouse gases, and to have seriously attempted to quantify it, is Dr. Rattan Lal, Distinguished University Professor of Soil Science and the director of the Carbon Management and Sequestration Center at Ohio State University. Dr. Lal is a member of the IPCC panel awarded the Nobel Peace Prize in 2007, and the recipient of many other awards including the 2019 Japan Prize. He has spent his career studying Soil Organic Carbon (SOC) depletion, and established a methodology for establishing baselines to estimate that SOC loss. He does this by comparing degraded soils with undisturbed forest soils nearby. His research has demonstrated that agricultural soils worldwide have lost significant amounts of SOC, in the ranges of 50 to 80%. According to Dr. Lal, the world's soils are like a bank account, and carbon is the currency. And we are currently near bankruptcy. His key insight is that re-sequestering SOC can both restore degraded soils and, crucially, mitigate Global Warming. It is laid out comprehensively in a paper published in 2010.[8]

In that paper, the increase in atmospheric concentration of CO^2 from 280 ppm in 1750 to 367 ppm in 1999 (it is well over 410 ppm now in 2019) is attributed to emissions from fossil fuel combustion estimated at 270 + 30 Pg C, and land use change at 136 + 55 Pg C. Basically, Dr. Lal has declared that the land use change that he has been able to quantify accounts for about 1/3 of the increase in atmospheric CO^2. He estimated the global potential of SOC sequestration and restoration of degraded and desertified soils at 0.6 to 1.2 Pg C/y with a cumulative sink capacity of up to 60 Pg C. He stated that the SOC sequestration is a cost-effective strategy for mitigating climate change during the first several decades of the 21st century. He has estimated that the potential of C sequestration in the terrestrial biosphere is estimated to be equivalent to a drawdown of 55 ppm of atmospheric CO2 over a century. This could get us back down under 400 ppm and is very encouraging, but not really good enough to save us now that we are approaching the end of the second decade of the 21st century and have done far from enough to shift to a non-fossil fuel energy economy. I personally think that Dr. Lal, as a good scientist, is erring on the side of caution, both in his assessments of emissions from land mismanagement, and of the potential of photosynthetic sequestration of carbon to drawdown sufficient atmospheric carbon to begin reversing climate change, when applied to not just to agriculture, but to every ecosystem on the earth's surface with significant photosynthetic activity. Arizona was largely grassland about a century ago, and so was much of Australia. Both are now generally far more barren. But there is no untouched adjacent forest land to establish a SOC baseline, and so these lands are left out of the equations. So is the phytoplankton loss from the oceans. An article published on July 29, 2010 in Scientific American is entitled: "Phytoplankton Population drops 40 percent Since 1950" with, the author states, "implications for the marine food web and the world's carbon cycle". Those implications haven't been considered in the estimates of soil carbon loss, because they are in the ocean. But they certainly represent a major amount of carbon shifted from organic form in the surface of the planet to the atmosphere, and an amount directly related to photosynthetic activity. A rough and ready guess would basically double Dr. Lal's estimates of no-fossil fuel organic carbon lost to the atmosphere. This would mean that these losses (call them emissions) are least as large as those from fossil fuel, where the data is far more reliable. And this definitely points out the low-

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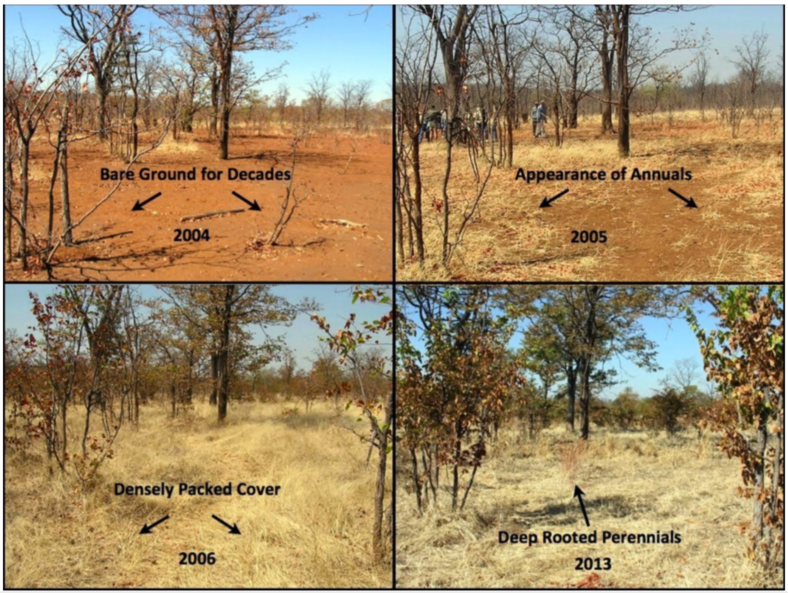
hanging fruit when it comes to strategies to drawdown carbon. The exact amount doesn't matter anymore. I also think humanity has run out of time to painstakingly verify these kinds of conclusions experimentally before taking decisive action.

Allan Savory, Reversing Global Warming through
Holistic management of the World's Grasslands

An extraordinary figure making precisely this claim (of the potential of photosynthetic sequestration of carbon to drawdown sufficient atmospheric carbon to begin reversing climate change) **in regard to grasslands,** is the ecologist Allan Savory. Based on his long experience in wildlife management in Zimbabwe, he developed a systems-thinking approach to rangeland management that mimics the movement of large herds of wild herbivores as they avoid predators and search out new pasture. He called it "Holistic management", and the results have been astonishing everywhere they have been applied, basically on every continent. His thinking is laid out most accessibly in his 2013 TED Talk, "How to green the desert and reverse climate change". In it, and in his writings, he makes the claim that applying holistic management techniques to less than half of the world's grasslands can quadruple livestock production, reverse desertification and, most importantly, sequester enough carbon to reverse Global Warming, and within the needed time frame of a decade or so. It is an extraordinary claim, and has been subjected to criticism, but his pilot projects in various countries have produced undeniable and amazing results. Others have replicated his rapid soil-formation success as well, using his holistic range management techniques combined with innovative crop farming approaches. Crucially, Savory has developed a system of rangeland agronomy that is radically different from the more conventional agricultural practices that even enlightened scientists such as Dr. Lal base their calculations and assumptions on. Thousands of cattle ranchers worldwide are empirically applying his methods, and making profits while simultaneously rebuilding soils and restoring their land at eye-popping speeds. Included in this section are several images showing the results of Holistic Management practice:

Images Republished Courtesy of the Savory Institute

Photo of Exact Location - Zimbabwe After 2 Growing Seasons
Left: Late 2006 - Low numbers of mismanaged livestock
Right: Early 2009 - Properly managed using Holistic Management
(400% increase in livestock numbers)



Images Republished Courtesy of the Savory Institute

Photo of Stream in Wyoming, USA - Taken on Same Day
Left: Upstream Land - Properly managed using Holistic Management
(150% increase in livestock numbers)
Right: Downstream Land - Managed conventionally

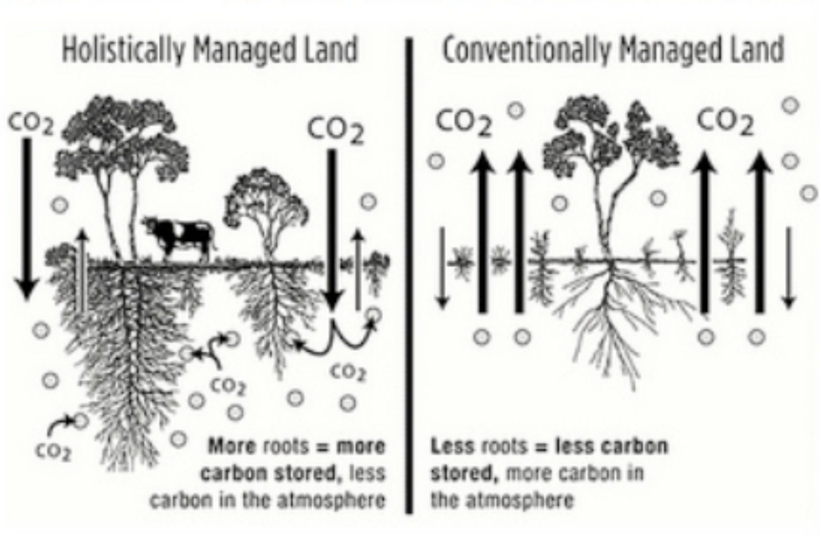


Image republished Courtesy of the Savory Institute

Basically, Allan Savory's method boils down to "more roots, more carbon in the soil and less in the atmosphere". Why is this the case? A simplistic and alas almost universal conception of plants growing in soil has it that a plant's roots take up water and dissolved minerals from an inert mass of soil, and combine that through photosynthesis to create the complex sugars that serve as nutrients needed for plant growth. The plant's energy becomes food for other living things, both directly and indirectly. In time, the plant dies, biodegrades and returns to the soil as organic matter. The plant's relationship with the soil is basically conceived as a chemical reaction initiated by only one biological player, the plant. The plant is seen as an organism that *only takes* from the soil. The soil's health is assessed by its 'nutrient status'. It is this mechanistic and mistaken assumption about what are in fact **living** soils that underlies the use of chemical fertilizers as the go-to means of restoring the nutrients in the depleted soil and improving production. This high school science version turns out to be simplistic in the extreme, and agricultural practices based on it very destructive of humus (soil organic carbon) over time. In reality, plants, working in concert with the soil microbiome, create soil organic carbon and enhance the nutrient content of soils. And they do it far faster and on a larger scale than is generally recognized. The plant's relationship with the living soil is a two-way street.

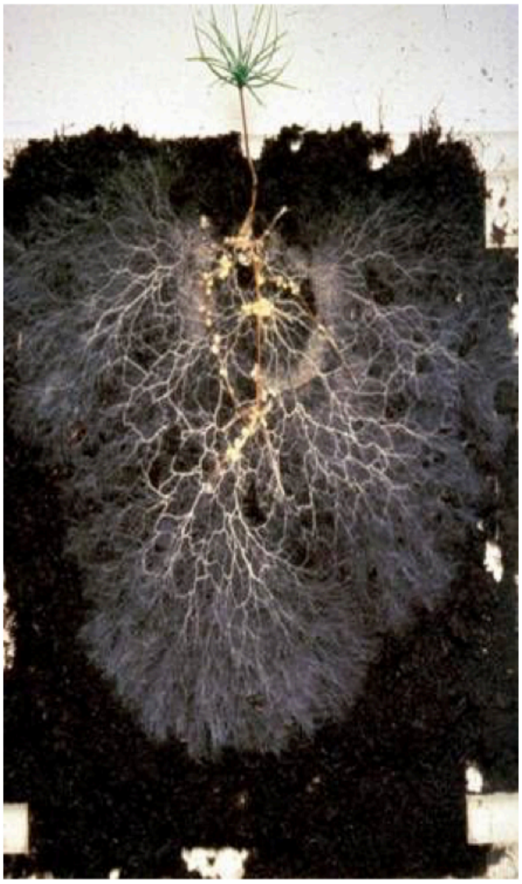
Dr. Christine Jones and Nature's sophisticated Version of Carbon Trading

Dr. Christine Jones, a noted Australian soils ecologist has, more than anyone, elucidated the crucial relationships between plants and the soil microbiome. Early on in her career she realized that plant-soil dynamics provided desperately needed answers to the dangerous build-up of greenhouse gases in the atmosphere, and also to the challenges of feeding the world's population. She coined the term 'carbon pump' to describe the process by which most flowering plants pump up to 40% of their nutrient production down to their roots to feed the mycorrhizae, which, working with soil microbes, in turn dissolve and transport soil nutrients back to the plant. She called this interaction "the liquid carbon pathway". Dr. Jones has worked tirelessly to spread this understanding, and many ranchers and farmers are profiting as a result, and simultaneously, as in the case with Allan Savory's methods, restoring soil fertility and water retention at amazing speed.

A closer look is needed to understand this far more complex reality of the plant's relationship with the soil. First off, healthy soil is not inert but teeming with life. There are hundreds of millions or even billions of microbes in a **single gram** of healthy soil: bacteria, fungi, algae, protozoa and viruses. There is also a wide variety of nematodes, earthworms and insects in the soil. All of them have a role to fulfill in the vibrant community that is that healthy soil. Perhaps among the most crucial of those roles is that played by mycorrhizal fungi or mycorrhizae, the fulcrum of the liquid carbon pathway. Over 80% of flowering plants have a symbiotic relationship with mycorrhizae (the name means root fungus). Far from simply absorbing nutrients and water, the plant's roots actually feed the mycorrhizal fungi attached to their roots by sending down complex sugars created through photosynthesis. A plant will send up to 40% of the nutrients it creates back down into the soil. This fact is key to understanding the role of plants as "carbon pumps" building humus (soil organic carbon) from the bottom up.

The mycorrhizae, recipients of and utterly dependent on this influx of complex sugars (the 'liquid carbon'), use some for their own growth and some to nourish microorganisms in the soil around them. These in turn break down minerals in the soil and send them back through the mycorrhizae to the plant. The process is still far from fully understood, but it is essential to healthy plant growth. In effect, there is a subterranean 'carbon trading' scheme so complex and interconnected that it makes Wall Street's derivatives trading look like child's play. And the mycorrhizal fungi are the stockbrokers that put the trades together. The end result is the sequestration of large amounts of carbon deep in the soil in organic form. The process rapidly builds humus, in other words; nutrient-rich, water-retentive healthy organic-carbon-rich soil.

It is worth looking at this in a little more detail, much of which is only just recently being revealed. The mycorrhizae grow long filaments called hyphae out into the soil in prodigious quantities; the filaments in one teaspoonful of soil could cover about a kilometer. These filaments substantially extend the 'reach' of the plant by proxy, and are coated with a sticky secretion called glomalin, only discovered in 1996[9]. Glomalin has been called 'soil's superglue" and it is significant for a couple of reasons. First, glomalin is mainly organic carbon and keeps that carbon deep in the soil for decades, representing over 30 % of the carbon in soils. And it binds soil particles together to create aggregates, clumps with spaces between and within them, that enable greater air penetration and significantly higher water absorption, reversing the problems of soil compaction associated with conventional plowing. This is also crucial and I will touch on it again later. Here is an image of a plant's root system with its associated network of mycorrhizal hyphae. This is the carbon pump view of a plant!



mycorrhizal fungus

アーバスキュラー菌根菌

Source: Faslanyc - Complications with Complexity – November 7, 2010

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To summarize, I quote from “Cows Save the Planet” by Judith D. Schwartz: To understand the liquid carbon pathway, key to reversing Global Warming, reversing desertification and improving the quantity and quality of food production, “we need to revise our conceptualization of a plant. Rather than a mostly green thing … that [just] pulls water and nutrients from the soil, Dr. Jones would have us think of a two-way pump. The upward flow is water, minerals, and other substances the plant needs; the downward flow is soluble carbon (dissolved organic carbon) that seeps into and out through the plant’s roots so as to feed other organisms in the soil. This downward carbon flow stimulates the production of humus, the organic component of soil that is a repository for carbon as well as the basis for fertility. The more carbon in the soil . . . the more humus.”

We have long thought that humus was solely created through the process of decay of plant matter. Dr. Jones is saying, and has demonstrated, that **living plants** also create humus, the crucial component for soil fertility and water retention, and, for the purposes of this discussion, carbon sequestration on a scale to actually drawdown the excess carbon in the atmosphere and begin the process of reversing disastrous Global Warming. Again, Dr. Jones, quoted from “Cows Save the Planet’: "Under appropriate conditions, 30 to 40 percent of carbon fixed in green leaves can be transferred to soil and rapidly humified, resulting in rates of soil carbon sequestration in the order of five to twenty tons of CO_2 per hectare per year . . . “. This all depends on the mycorrhizal affiliations that benefit the plant by both providing nutrients, creating humus, and building a loamy soft soil structure that enhances water retention.

Unfortunately, these appropriate conditions do not include the application of chemical fertilizers. Apparently, the easily available nitrogen and/or phosphate in chemical fertilizers signal the plant to reduce the dissolved organic carbon that it pumps to the symbiotic mycorrhizal fungi, essentially starving them. It seems probable that mycorrhizal fungi are also directly inhibited by chemical fertilizers, and by herbicides, pesticides, and, being fungi, without question severely impacted by fungicides. Thus, synthetic combinations of Agri-chemicals are very destructive to mycorrhizal health. The biological processes that build soil carbon and humus get destroyed by chemical additives. So-called ‘fallow’ land, land left bare after plowing, is as destructive. Basically, the mycorrhizal fungi are left to starve to death, as there are no plants pumping down the liquid carbon compounds on which they depend exclusively to survive. Combine that with the steady oxidation of organic matter that occurs when the sun shines on bare earth for extended periods of time, and one can see why this exceedingly common agricultural practice is like leaving a large engine idling for months at a time, pumping out

CO_2 all along. Leaving fields stripped of plant cover for extended periods of time is among the last things we need to do in a Global Warming world!

A note needs to be inserted here regarding water vapor. It is a greenhouse gas, like carbon dioxide, representing around 80 percent of total greenhouse gas mass in the atmosphere and 90 percent of greenhouse gas volume. Water vapor and clouds account for 66 to 85 percent of the greenhouse effect, compared to a range of 9 to 26 percent for CO2. Desertification and general loss of SOC means the absorptive capacity of soils is degraded across wide areas of land. It seems quite possible that reversing that desertification and restoring SOC will, besides significantly increasing carbon sequestration, also reduce the amount of water vapor in the atmosphere to a certain degree, and in this way also contribute to reducing the greenhouse effect. So, this can be another benefit of rebuilding healthy living soils.

One problem standing in the way of a more general acceptance of these truths about topsoil regeneration and SOC restoration is that, with very few exceptions, government and industry funded research is conducted on conventionally managed agricultural land. As seen above, between the applications of agri-chemicals and the practice of tilling soil and leaving it bare, the mycorrhizal pathway of carbon sequestration and fertility building gets decimated. Results of such research are inevitably skewed, inevitably showing that continued use of agricultural chemicals is what works best. The other problem is that no one believes soil can be built that fast. The conventional and unfortunately unquestioned wisdom is that it takes centuries. But it can be rebuilt very quickly, and there are numerous pioneer projects around the world demonstrating this. Constraints of time and space do not allow me to list more than a few, but they can be found easily on the internet. One example is Winona farm near Gulgong in New South Wales, run by a visionary farmer named Colin Seis. His farm is Australia’s exhibit A for the method known as pasture cropping, an ideal approach for rapidly building soil. Basically, instead of tilling the soil bare, a cereal crop is sown into a plant cover of native grass pasture, with only a very narrow band tilled for seeding the crop. This is as opposed to Broadacre farming, which removes existing ground cover completely, so that crops are sown on cleared fields. This damages soil structure, interrupts mycorrhizal and microbial associations, and releases stored carbon. In contrast, pasture cropping leaves all these positive qualities intact. At maturity, the tufts of grain are seen emerging, not from brown earth, but from green pasture. After two years Seis saw positive differences emerging: better drought resistance, greater biodiversity, and, crucial for our discussion, higher soil carbon levels. In ten years, a 200% increase in topsoil was achieved.

Basically, Seis and his collaborator, Daryll Cluff, used **biomimicry** to recreate the original and fertile community of native grasslands in which annual and perennial plants coexist, each benefitting the other. This is striking and tremendously instructive. Allan Savory has had the same success restoring rangeland and building topsoil by also using biomimicry of the wild grasslands and continually moving herds of herbivores. We humans have been at this for 10,000 years at most; Mother Nature has refined her methods for billions of years. A little humility and respect, please! Our technological fundamentalist hubris, secretly abetted by profit-blinded agrichemical corporations, will kill us otherwise!

Discussions of Global Warming are heavy with references to carbon dioxide, but, sadly, mentions of soil are almost non-existent. But the science is basic and should be obvious. As we have seen, topsoils are the carbon sink with the greatest potential, through photosynthesis, to <u>rapidly</u> sequester atmospheric carbon at sufficient speed and in sufficient quantity to begin to reverse and eventually eliminate Global Warming. Tragically, each year some seventy-five billion tons of soil are lost, enough to cover an area larger than Australia. According to Cornell soil scientist David Pimentel, 90% of our cropland is losing soil to wind and water erosion thirteen times faster than new soil is being formed. Dr. Jones says that "Every ton of carbon lost from soil adds 3.67 tons of carbon dioxide to the atmosphere." Multiply that by 75 billion tons of lost soil! "Conversely, every one ton increase in soil organic carbon is 3.67 tons of carbon dioxide sequestered from the atmosphere". Drawdown, plain and simple.

Although the conventional wisdom is that it takes centuries to build topsoil, examples abound where farmers and ranchers, using biomimicry and an understanding of the liquid carbon pathway and the crucial function of mycorrhizal fungi, have built topsoil, and thus sequestered carbon, with astonishing speed. Seis and Cluff, above, are just one example. Another is rancher Gene Goven in North Dakota, who started with hardpan and built six inches of topsoil (15 + cm) in one season! Then there is Allan Yeomans: Using the Keyline plow system (strikingly similar to pasture cropping described above) his father and he developed, and combining it with planned high-density grazing (holistic management, basically) Allan Yeomans reported producing 4 inches of humus-rich soil in three years, starting with bare sandy ground. Farmer and activist Abe Collins combined use of the Keyline plow with Holistic Planned Grazing in northern Vermont and says that in one year they went from eight inches of topsoil on top of gray clay to sixteen inches of topsoil. Unfortunately, all this anecdotal evidence is not easily accepted in the academic community and in government agencies, in part because of intellectual inertia and in part because the vested interests of agrichemicals rightly see this enlightened approach as an existential threat to their business. In response, an organization called the Soil Carbon Challenge has been formed, to assemble 'hard data' to back up the anecdotal evidence. And none too soon. The world needs to move quickly on these insights! The existential threat to the agrichemical business is a threat to their profit margins. The existential threat of Global Warming is a threat to life on earth, humans very definitely included.

4) THE PHOTOSYNTHETIC SOLUTION TO GLOBAL WARMING

Globally, photosynthesis moves about 9 times more carbon molecules than all human activity, including the burning of fossil fuels.[10] And it moves them in the right direction: out of the atmosphere and, converted into organic carbon, into the soils and oceans of the planet, where it can remain sequestered for varying lengths of time, some of them aeons. This fact alone should make it obvious that our first choice, when attempting to begin the process of drawing down excess carbon from the atmosphere, should be the maximizing of photosynthetic activity in every ecosystem on earth where it occurs. Based on the above statistic, increasing photosynthetic production on the planet by roughly 10% should be enough to reverse global warming. When we begin to consider these strategies for the various ecosystems, it also becomes quickly apparent that the side benefits alone of maximizing photosynthetic activity in these ecosystems is a more than sufficient reason to begin implementing them as soon as possible, regardless of their contribution to reversing Global Warming.

Standing in the way of salvation are arrayed intellectual inertia (a reluctance to change), entrenched commercial interests and power structures, and the reactionary suspicion of ignorance when confronted with knowledge. Strategies will be needed to cope with all of these. Demonstrating immediate economic benefits (soil reliance to flooding, elimination of costly fertilizers and the labor needed to apply them, increased livestock and crop production, the higher prices commanded by organically produced food, etc.) can be more convincing for many than long-term climate benefits. It is not, however, the intent of this discussion, to consider these strategies other than to point out that they will be needed.

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Implementing this photosynthetic solution to Global Warming will require fundamental changes to management strategies in the following land categories and in the ocean as well:

a) Grasslands and Drylands

Grasslands, perhaps better described as Drylands, comprise over 40% of the world's land area. They also include 44% of land under cultivation. But each year over 12 million hectares of productive land are turning into desert.[11] In ten years, that would represent a South Africa's worth of land lost to desertification. Desertification was described by Judith D. Schwartz in 'Cows Save the Planet' as "land that becomes dirt with life neither on nor within it". In fact, as discussed previously and also following, the crucial point is the lack of life not so much on as within the soils of deserts. By this I mean soil microbial life essential to the bio-sequestration of carbon because of its symbiotic relationship with most plants. At present over 1.5 billion people depend on drylands worldwide, and this ongoing staggering loss is a recipe for a snowballing humanitarian disaster on an unprecedented scale. It is important to understand that desertification in our time is generally not due to natural causes, but the result of an anthropogenic process: land mismanagement practices over time that disrupt the drylands ecosystem life cycles of both plants and animals adapted to those drylands. Examples include over-cultivation (too much plowing), poor livestock management resulting in over-grazing (not moving livestock regularly enough), deforestation, poor irrigation practice and more. Land degradation does not only happen in drylands, but they are the least resilient to disruption, the closest to the tipping point into desert.

To briefly outline the anthropogenic spiral into desertification of drylands, (paraphrased from 'Cows save the Planet'), mismanagement as listed above leads to degraded soils that lose some of their original plant cover. These soils consequently lose some more of their capacity to store organic carbon, and thus lose even more of their plant cover. The barer the ground, the more it absorbs heat, both directly from the sun, and by loss of the 'air conditioning' effect of evapotranspiration cooling provided by that plant cover. Loss over a small area increases heat absorption that affects the microclimate; over most of Australia, North Africa, the North American West, etc., it affects the planetary climate. More heat, more water loss, and thus the soils become even less livable for the soil microorganisms that provide

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plants with nutrients in exchange for the organic carbon the plants pump down to feed them. The plant cover loss is continuously exacerbated as a result. The range of plants that can survive these conditions becomes increasingly limited, and this leads inevitably to biodiversity loss, including the insects and birds that pollinate flowers and that spread seeds, leading to yet more plant cover loss. The sparser the vegetation, the less protection from winds or episodic heavy rains. This leads to yet more erosion, and even further loss of plant cover. All through this process, the remaining organic carbon in the soils, increasingly exposed to the heat of the sun, continues oxidizing, and emitting carbon dioxide to the atmosphere and worsening further the greenhouse effect behind Global Warming. It is a vicious downward spiral, increasingly self-sustaining the more land mismanagement continues.

As described in the preceding paragraph, the three ongoing evils of desertification, biodiversity loss, and climate change are so intertwined that they are just different aspects of the same macro-problem. Life's biological cycles have been greatly disrupted, and no solution to Global Warming is possible without remedial action to those disruptions. Alas, not only does the world remain largely fixated on Fossil Fuels as the problem, but also fails to recognize as aspects of Global Warming the fundamental interconnectedness of desertification and biodiversity loss, and the social disruptions of famine and war they result in. As a tragic result, because causes are not completely understood, effective solutions cannot be formulated. Desertification is indisputably a major cause of global warming, but this is not generally understood. Even less appreciated is the potential of Grasslands restoration to reverse Global Warming in the short time frame remaining for effective action.

The man who, more than any other, has elucidated the process of desertification, and, crucially, developed the new management strategies to reverse it, is the wildlife ecologist Allan Savory, described earlier in this discussion. He is one of the three pivotal figures underlining the photosynthetic solution to Climate Change. Savory is a polarizing figure. His improbable sounding claims are expressed in plain language rather than heavily annotated, dense and exceedingly cautious academic prose. These claims, that holistic management can reverse Global Warming while simultaneously reversing desertification AND increasing livestock production by up to 400%, fly in the face of many entrenched preconceptions about both proper agricultural practice and the causes of desertification, and furthermore, seriously threaten the business models of agri-chemical corporations. Predictably, Savory's claims provoke many footnote-loaded articles challenging his conclusions and claiming to prove him wrong. By and large, though, those who disparage him have little or nothing in the way of practical experience and/or success to show in the struggle against desertification or climate change in general. Savory, however, does. He honed impressive tracking and observation skills, and also his capacity for strategy thinking, during his youth as a wildlife manager and a tracking combat unit commander. He has spent a lifetime applying his unique skill set of proficiency in the wild, scientific rigor, and strategic military thinking, to the long-term observation of desertification, has searched almost obsessively for writings that explain it, and has devoted his life and financial resources to experimental approaches to reverse that desertification and restore the lands and way of life he loves. The results are astonishing and inspiring, and give hope at a time when it is in very short supply. Today more than ten thousand land managers are implementing Savory's Holistic Planned Grazing on more that 16 million hectares of drylands, and this land is being reborn in the eye-popping space of mere years, all while consistently out-producing neighboring lands.

Recognition is slowly coming for Savory, as it has for revolutionary thinkers throughout history. However, even back in 2003, he was awarded Australia's Banksia International Award "for the person or organization doing the most for the environment on a global scale". In 2010 his Zimbabwe nonprofit, Africa Centre for Holistic Management (ACHM) not only won the Buckminster Fuller Challenge Prize, awarded to a project with "significant potential to solve humanity's most pressing problems", but also received a $4.8 million grant from the United States Agency for International Development (USAID) to expand its work in Africa. He is among the finalists for the $25 million prize offered by entrepreneur Richard Branson for the most effective technology to drawdown excess carbon dioxide in the atmosphere. Joel Salatin, famous farmer/author and proponent of grass-fed beef, has said that Allan Savory will go down in history as the greatest ecologist who ever lived. Savory's claims may sound improbable to people locked in outdated preconceptions and limited understanding of the plant/soil microbiome symbiosis, but his results, in Africa, America, Australia and elsewhere, are nothing short of astonishing, and may in fact offer humanity its best hope for overcoming the existential climate crisis looming ever closer.

Savory's seminal understanding is twofold. First, that land can be classified on what he calls a "brittleness" scale. Basically, the drier, the more "brittle" or prone to desertification. Land that alternates between dry and wet seasons is also brittle despite heavy rainfall during the wet season, because the soil dries out during the dry season. The drier the soil, the greater the reduction in soil microbial activity, which, because of its symbiotic relationship with plants, is crucial for healthy plant cover and resulting bio-sequestration of carbon. Tree cover requires a minimum of 600 mm of annual rainfall and land with less than that or with extended annual dry seasons becomes either savannah or pure grassland. These grasslands, by definition, lie on the brittle end of the scale. Savory's second crucial insight, and as important, is the realization that grasslands, herbivores and pack predators evolved in concert, and their natural interactions are crucial for the health of those grasslands. It is these interactions that take the place of reduced soil microbe activity in drier times and thus keep grasslands flourishing. Pack predators keep the herds of herbivores constantly moving and also drive them to bunch up in defensive groupings. By virtue of being in constant motion, the herbivores do not overgraze any one spot, and their urine and dung is dispersed widely. And especially when bunching up in defensive postures (when they also tend to urinate and defecate in preparation for flight) and when stampeding, they trample the ground sufficiently to basically cultivate it, and drive in both seeds and their own manure, and further, pockmark the ground with their hooves, driving in seeds and creating depressions that aid water retention and absorption. But they don't remain in any one place long enough to trample the soil so much that it would become compacted. A grass plant, annual or perennial, that has been grazed back only somewhat, as the result of herbivores moving on under predator pressure, will not die but will prune back its own now excessive roots, in this manner also adding organic matter to the soil. Fertilized and cultivated by the moving herds, it grows back stronger than before. A corollary understanding, helpful in understanding the function of the herbivores' manure, is that the microbial decay function, impaired in the dry season, is compensated for by the digestion in the ruminant herbivores' guts. Lands in wetter climates benefit by being allowed to remain fallow. But the brittle drier lands actually degrade as fast without herbivores, as with herbivores in an unnatural pattern of constrained movement. The only drylands that flourish are those with natural movements of wild herbivores, or those where livestock is moved to mimic those natural movements. Land managers and bureaucrats whose understanding of livestock agriculture has been based on strategies developed in wetter lands fail to grasp this. It has become clear that the damage occurs at both ends: either too few or no herbivores on the one hand, or herbivores that do not move or are not moved around enough on the other. Imitate natural patterns that evolved over untold millennia, and the grasslands flourish (yet again a demonstration of the enduring value of biomimicry!).

Savory's contention is that this process can happen quite quickly, as both annual and perennial grasses grow far more quickly than trees, and that therefore grasslands hold the greatest potential to sequester carbon and reverse Global Warming. Over 40% of the world's land surface consists of these brittle drylands, and according to his calculations based on his pilot projects, if this process were to be implemented over approximately half that area, it would sequester enough carbon in just a few years to basically return atmospheric carbon dioxide to pre-industrial levels. And it would reverse desertification and significantly increase food production at the same time. pilot projects around the world have shown it is possible. Foremost among them is Savory's own 2600-hectare Dimbangombe Ranch in Zimbabwe, but also include places such as the Winona Ranch in Australia, Gene Coven's ranch in North Dakota and many other places. They all easily out-produce, in both quantity and quality, neighboring lands that are conventionally managed, show far greater water absorption capacity (a sign of carbon-rich well-aerated soils), and have far greater biodiversity. This should be all the proof we need, easily trumping any number of footnote-rich refutations of Savory's claims, that have no real-time projects demonstrating their validity. Grasslands restoration, using the biomimicry of Holistic Grazing, has the potential to be the greatest game changer in reversing desertification and Global Warming.

b) Agricultural Lands (Crop Lands)

The world's total land area is approximately 13.4 billion hectares, of which roughly 11%, or 1.5 billion hectares, is cultivated or under permanent crops. This cropland is covered by only a very thin layer of topsoil (usually between 12 and 25 cm at best), and this thin layer is literally all that stands between humanity and starvation. But the world is losing about 1% of its topsoil every year to erosion, mostly cause by agriculture. The USA is losing soil at a rate 10 times faster than the soil replenishment rate, and China and India 30 to 40 times faster.[12] One can imagine that the situation is as dire in Europe, Africa, Latin America, the Middle East and Australia; everywhere, basically. The world has lost between 50 to 80% of its Soil Organic Carbon (SOC) over the last century or so.[13] The relationship between SOC loss and soil loss through erosion is not often considered, but it is very real. Obviously the SOC in the topsoil washed away is mostly lost, but what isn't so obvious is that the loss of SOC through various kinds of land mismanagement is one of the main causes of that erosion in the first place!

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Even less taken into account is where all that carbon went; in fact, it went directly to the atmosphere, oxidized into carbon dioxide as a result of bad agricultural practices. This sounds like something out of a less enlightened past, but it can easily be seen in the countryside now, anytime, anywhere on earth. I can look out of my window as I write this, and see plowed fields lying bare under the sun. In many cases, agricultural land is left bare for half the year or more, and often during the hottest and/or driest times of the year. We are so accustomed to seeing soils left like this that we don't even question it. But the organic matter in that soil (the SOC), unshielded from the direct sun by plant cover and bereft of the cooling effect of evapotranspiration that plant cover also provided, is steadily oxidizing out of the soil. In effect, plowed land left bare is like leaving an engine idling for months on end, pumping carbon into the atmosphere. Few people would approve of that, but nobody thinks anything is wrong with leaving soil bare for extended periods of time.

Soil temperature is critical.[14] At around 20C, 100% of moisture is used for growth, but at only 37C, 85% is lost to evaporation and transpiration and only 15% remains to support plant growth. Anyone who has walked barefoot in summer knows how hot bare ground can get (think beach sand), far hotter than the air's ambient temperature. At 45C (not unusual in summer) some soil bacteria start dying. For comparison, rooftops, which can serve as a proxy for bare ground, can easily get much hotter than this even as far north as say Chicago, reaching temperatures well over 60C. At 54C, 100% of moisture is lost through evaporation and transpiration. And at 60C, soil bacteria die. Of course, the hotter and drier the soil gets, the more SOC (think humus here) oxidizes out as carbon dioxide. Hello Global Warming.

What prevents soil from heating up and drying out? Quite simply, plant cover first and foremost, but also plant residue cover, like straw or dry leaves. Plants shade the soil, and the cooling effect of evapotranspiration is far more significant than most people realize. Vegetated land is generally cooler than ambient air, but bare earth can exceed ambient air temperatures by up to an astonishing 50C (see the discussion and illustration on green roofs in the subsequent section on urban areas).

None of this is difficult to understand, and yet nowhere is it taken into account. Current agricultural practices are highly destructive. This should be obvious, and it has become obvious to a few enlightened and motivated individuals, now engaged in finding better ways. In a rapidly warming world, where hunger is also a growing problem, we can no longer afford these antiquated and highly destructive agricultural practices.

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In the section devoted to Dr. Christine Jones, we already looked at how SOC is formed, and briefly considered why its loss is so connected to erosion and loss of productivity. But a quick review is useful here. Living soil is not just a matrix to hold the plant in place, from which the plant takes water and nutrients in a one-way interaction. Living soil is an amazing **symbiotic net**, mindboggling in its complexity and biodiversity. It is estimated that over 95% of life forms exist within the soils of the planet. To understand this symbiotic net, one needs to start with the cornerstone symbiotic relationship between about 80% of flowering plants and mycorrhizal bacteria. The mycorrhizal bacteria act like the stockbrokers of the soil carbon economy. Plants pump down to the mycorrhizae up to 40% of their nutrient production (a huge proportion!) in the form of simple sugars. Dr. Christine Jones has called this ‘liquid carbon’ and described plants as ‘carbon pumps’. Both these formulations are extremely useful to help us change our understanding of plants and the soil, and their lynchpin function in a healthy carbon cycle. The mycorrhizae in turn use some of these simple sugars for their own growth and sustenance. Part of that involves growing a profusion of long thin tendrils called hyphae whose combined length can be astonishing. An essential feature of the hyphae is that they are coated with a sticky secretion called glomalin (only discovered in the late 90’s). Glomalin in its own right serves to create crumbly soil with a cake-like texture; its stickiness clumps mineral soil particles into ‘aggregates’. These aggregates create spaces in what would otherwise become highly compact non-absorbent soil, and enable air and water to percolate down into the resulting rich crumbly soil. The higher the amount of SOC in the soil, the greater its water retention capability, and glomalin-created aggregates are the reason why. But the glomalin-coated hyphae actually evolved to serve another function: one, the nourishment of a host of soil bacteria and other microorganisms, the third major component of the symbiotic net, and two, the collection and transport of the mineral nutrients that these microorganisms provide back to the mycorrhizae and on to the plant. The mycorrhizae pass on a good share of the carbon they receive from the plant to these microorganism symbionts. These then labor to dissolve minerals out of the non-organic components of soil: iron, magnesium, zinc, copper, phosphates, etc. These mineral nutrients are relayed through the hyphae, nourishing all living things along the way, back up to the plant, which cannot survive without them.

This, in a handful of words, is the soil symbiotic net. It is the definition of healthy soil, so crucial to the plant cover that provides our food, much of our oxygen, cooling, and - for the purposes of this discussion – an indispensable sequestering function in a healthy global carbon cycle.

To say this is not generally understood is a massive understatement. Modern industrial agriculture is, along with the mega-corporations that parasitize it and us, built on the simplistic conception that soil is just a matrix to root a plant in, not a living meta-organism. The plant/soil relationship is seen as a one-way transaction. Plants simply take nutrients from the soil (which exist there through some miraculous reason no one bothers to understand) and, giving nothing in return except some eventual dead plant matter, eventually deplete it. This necessitates 'inputs', in the form of chemical fertilizers, to remediate that loss. To be fair to modern industrial agriculture, these misconceptions predate it, and have been a part of destructive agricultural practice, such as broad-ground plowing (which removes plant cover completely) and slash-and-burn agriculture, for a very long time. What changed was the industrial-scale efficiency, enabled by the power of fossil fuels and the Haber-Bosch process to fix nitrogen from the air in the form of ammonia. Both are recent developments, made within the previous two centuries. Fossil fuels make possible ever-larger farm machinery, and the Haber-Bosch process removes the biologically available nitrogen limitation to growth by pulling more out of the air, creating chemical fertilizers. Armed with these two capabilities, we have run amok. And we have been hypnotized by our short-term successes, such as the so-called 'Green Revolution'. To chemical fertilizers we have added pesticides, fungicides and herbicides, and now we are genetically modifying plants so that they, and only they, can withstand massive applications of herbicides like glyphosate (Monsanto's Roundup) and 2,4-D. These two are now being applied in a combination called Enlist Duo, because weeds are rapidly evolving a resistance to glyphosate alone. With this modern armamentarium we can 'feed the World', as its proponents never tire of proclaiming. Paradoxically, these industrial agricultural practices do in fact turn the plant/soil into a one-way interaction, with plants simply taking nutrients from the soil and depleting it, mainly because the soil symbiotic net has been decimated. Chemical inputs are then required. Experiments on land degraded like this become a self-fulfilling prophecy. It appears to be the only thing that works, because everything that is done destroys the soil microbiome that would provide the true remedial action. Unfortunately, this soil is more dead dirt than soil, poor in nutrients, low in resistance to drought and flooding, and a proximate cause of Global Warming because of its wholesale loss of SOC. Not the answer we really want.

How sustainable is this modern fossil-fuel and chemical dependent agriculture? That is beyond the scope of this discussion, but common sense would indicate we should be very worried. More importantly, for our discussion, what happens to SOC and to the soil symbiotic net that creates it and dissolves essential nutrients out of the mineral portion of the soil? The short answer is that, in various ways, modern industrial agriculture destroys this soil symbiotic net. First, plowing: it strips the land of plant cover and also brings up more underground SOC to expose to the oxidizing heat of the sun. Loss of SOC means the soil compacts more, leading to reduced water absorption and more runoff. Soil compaction is exacerbated by heavier and heavier farm machinery, used to plow yet deeper into the soil to counter the increasing compaction of the soil. This brings up yet more SOC to be oxidized away. We have already discussed the destruction of soil microbiota when soil is left bare as a result. It is a vicious cycle, almost designed to take out the SOC. And that is without even considering the impacts of the chemical inputs that are also a large feature of industrial agriculture. In the first place, the application of chemical fertilizer tricks plants into deciding they no longer need to send down so much liquid carbon. They can still grow, but they do develop a lack of many essential nutrients. Chemical fertilizers cannot possibly provide the range of dissolved mineral nutrients the soil symbiotic net provides. More worrying is that the soil symbiotic net gets starved as a result of chemical fertilizer application and begins to die back, beginning with the mycorrhizae. When that happens, we are losing the engine of natural soil fertility along with the crucial carbon bio-sequestration function of healthy soil.

Herbicides require several paragraphs of their own. Both Glyphosate and 2,4-D have been implicated in non-Hodgkin's lymphoma (a blood cancer) and sarcoma (a soft tissue cancer). 2,4-D was a component in the infamous Agent Orange defoliant used during the Vietnam War, and linked to birth defects and other health disorders in the Vietnamese population and in returning American veterans alike. Simplistic short-term exposure studies have claimed that these herbicides are harmless to mammalian cells. But no studies exist that examine their impact on our crucial gut microbiome, which current research is finding to be more and more important to our health. And no studies really exist to examine the impact of these pesticides on the soil symbiotic net. A worrisome parallel exists here: in both cases a healthy flourishing microbiome is essential to systemic health, ours and that of the soil that gives us life. A large portion of that microbiome is fungi and bacteria. What impact do herbicides and fungicides have on them? In all probability, the effects are devastating. By definition, it is what these agrochemicals were designed to do. But scientific investigation in this area tends to be suddenly de-funded, and the credibility of any studies that do make it out is aggressively attacked. The researchers conducting them find themselves suddenly unemployed. All sucked into the black hole of protecting colossal corporate profits.

Glyphosate use has increased over 600 times in recent decades. Autism rates have risen during the same period from about 1 in 1000 to a staggering 1 in 30, a 3000% increase, and that's just the cases that are diagnosed. We have seen huge increases in the incidence of gastro-intestinal disorders such as Crohn's disease and irritable bowel syndrome as well. No mechanism has yet been identified to explain this anomalous and tragic increase. But one perhaps exists if we consider the enteric nervous system, our so-called second brain. The network lining our intestines contains over 500 million brain neurons, and is responsible for the secretion of over 50% the dopamine and 80% of the serotonin our body requires. It does not take a large jump of the imagination to imagines that shifts in the balance of our gut microbiome could lead to chronic inflammation of the bowel and adversely impact the function of these neurons. A lack of dopamine is implicated in Parkinson's Disease, and serotonin and dopamine deficiencies could well be the root cause of autism spectrum disorders. Could chronic herbicide exposure be the proximate cause of the bewildering and overwhelming increase in autism related disorders and the epidemic of bowel disease? Glyphosate has been detected in many of the foods we all eat, and in our bodies as well. And, to return to our discussion, what is the impact on the analogous soil microbiome, so crucial to a healthy carbon cycle? It can't be good. Almost as a side note, a final insult, is the fact that glyphosate chelates mineral nutrients and probably greatly reduces their bioavailability. In this way also glyphosate impacts plant growth and reduces the nutrient content of our foods.

To sum it all up, it seems almost certain that the impacts of chemical fertilizers and of pesticides, herbicides and fungicides are devastating to the soil symbiotic net. This correspondingly diminishes the carbon sequestration capability of healthy soil and leads to its degradation. When this already vulnerable soil is plowed, breaking up the soil structure and exposing more SOC to the sun, and when this soil is left bare for extended periods, often during the hottest times of the year, carbon pours out of the soil and into the atmosphere.

But soils can, when managed appropriately, rebound in amazingly short periods of time. Dinbangombe in Zimbabwe, Winona Ranch in Australia, Gene Goven's flourishing ranch in North Dakota, the Quivira Coalition in New Mexico, and indeed the more than ten thousand land managers implementing Allan Savory's Holistic Grazing on more than 16 million hectares world-wide are all testament to this. Allan Yeomans, combining use of the minimally-disruptive Keyline plow his father invented with planned high-density grazing, has reported producing over 10 cm of humus rich topsoil in three years, starting with bare sandy ground. Daryll Cluff and Colin Seis in Australia developed a system they called “pasture cropping”, which involves minimal plowing and seeding grain crops directly into a pasture cover of native grass perennials. This mimics the original biological community of native grassland, a mix of annuals and perennials that benefit each other. Within years, drought resistance improved, biodiversity increased, and over ten years, the depth of topsoil more than quadrupled, going from around 10 cm to an astonishing 45 cm, and their degraded land fully remediated. A routine internet search for ‘topsoil formation’ will yield the conventional understanding that it takes centuries. These magnificent pioneers are showing it can take mere years, decades at most.

The side benefits alone make these changes in cropland management worthwhile: increased topsoil formation, greater water absorption and consequent drought and flood resistance, increased biodiversity, reduced expenses for chemical agricultural ‘inputs’ and for the equipment and fuel costs of conventional mechanical plowing, greater nutrient content in foods, increased livestock and crop productivity, and less labor required. Oh, and let us not forget joy! A walk over these lands, such as on Gene Goven’s ranch in North Dakota, is a walk through living flourishing land. It makes you feel alive and give you hope and joy, with butterflies and birdsong everywhere. Contrast that with the dry, sterile, inert and spiritually deadening masses of dirt symptomatic of industrial farming. These are just the side benefits. Given the existential Climate Crisis we are confronting, these seemingly revolutionary but actually biomimicking agricultural practices can and will be part of our salvation. The reason they will help save us, here as in all other land categories where photosynthesis occurs, is that the photosynthetic solution to Global Warming is the only one that can be scaled fast enough and economically enough to draw down and re-sequester enough of the atmospheric carbon causing Global Warming in the time frame we have left.

c) Forests

Forests comprised 30.5% of the land area of the planet in 2015, according to the most recent Food and Agriculture Organization (FAO) data. This is down from 31.6% in 1990, and represents a 3% drop. The real figures are likely worse. Deforestation has been a feature of human life for thousands of years. The *kosa* or yellowish aeolian dust that cloaks Japan in an ochre haze in the early spring originates mainly in the Loess Plateau in China. It probably began to blow away when forests there were cut down during the Bronze Age for charcoal fuel to smelt that metal. In North America, about half the forests in the eastern part of the continent were cut down between the 1600s and the late 1800s. Deforestation is ongoing: The Union of Concerned Scientists estimates that an area the size of Switzerland (38,300 km^2) is lost to desertification each year. Other estimates are greater: A 2017 report by scientists at the University of Maryland showed that the tropics lost about 158,000 km^2 of forest in that year. This is about the size of Bangladesh. Most current deforestation is, in fact occurring in the tropics. What are we losing when we lose the forests? What is this loss doing to Global Warming, and how can forests contribute to the drawdown of atmospheric carbon needed to reverse it? In other words, what ecosystem services provided by forests are being destroyed, and how can forest management practices restore them? Answers are needed.

Forests are a harbor of biodiversity, home to 80% of terrestrial biodiversity (This figure does not include the biodiversity of subterranean life forms, which comprise up to 95% of total planetary biodiversity). Forests also provide many resources: timber, food, medicine and fuel. More recently, they have come to be seen as a major source of carbon sequestration, a bulwark against Global Warming. They are obviously a carbon sink; enormous amounts of carbon are locked up in trees. But there is considerable controversy over the role of forests in mitigating Global Warming. Forests at high latitudes have a much lower albedo effect than open snow-covered ground and ice, for instance. The darker land surface of coniferous forests reflects far less light, and thus heat, back out into space. Additionally, a Yale study by atmospheric scientist Nadine Unger found that forests emit volatile organic compounds, such as isoprene, that contribute to Global Warming. Another study, by Ecologist Sunitha Pangala, found that trees in the Amazon emit methane, a powerful GHG. She reported that trees account for around half of the Amazon’s total methane emissions. This is a staggering amount. So, there appear to be uncertainties over the over-all effectiveness of forests to mitigate Global Warming.

However, all these discussions are like the fable of the blind men and the elephant. Everyone is looking at a different part, and forms a different picture of what the animal looks like. All are right in a very limited way, but no one sees the elephant. To really understand the ecosystem services that forests provide, a focus on the overall picture is needed, not an obsession with one aspect. Forests are all different: boreal vs. tropical, deciduous vs. coniferous, rainforest vs. dryland forest, etc. In terms of their mitigating effect on Global Warming, they do, however, share several things in common. One, their wood does lock up carbon over biologic time. Two, through what is called the ‘biotic pump’ of evapotranspiration, they are a crucial component in the world’s large water cycle, operating often at continental scales. Three, through their part in the soil symbiotic net, they pump carbon exudates (the ‘liquid carbon’ described by Dr. Christine Jones) deep into the soil. The first of these three is obvious and well-known. The second, the ‘biotic pump’ which sends moisture far inland, is only now becoming apparent, thanks to the efforts of Russian physicists Anastassia Makarieva and Victor Gorshkov. The third one, carbon sequestration as a result of the symbiotic relationship of living trees and the subterranean microbiome, is almost universally ignored.

Since carbon sequestration in wood, etc. is well understood, let's consider the Biotic Pump first. According to a 2018 FAO report, three quarters of the Earth's freshwater comes from forested watersheds. Over half the world population relies on those forested watersheds for drinking water, and for water used in agriculture and industry. It is obvious that forests play a crucial role in the large water cycle. It is probable that without them, most rain would simply fall near the coasts of the oceans, from which the water vapor originates. Forests act like conveyer belts, moving rain in cycles inland. Makarieva and Gorshkov are perhaps the first to identify and truly comprehend the scale of this effect. As they describe it, the high rate of evapotranspiration in forests enriches the water vapor in the atmosphere above them. This moist air ascends and cools, causing the water vapor to condense. This produces a partial vacuum as the water vapor condenses out of the air, which creates a pressure gradient. This is the crucial point. That pressure gradient results in more moist air being sucked in from the ocean, creating an air flow. It is estimated that in the Amazon, water falls on rain forest, is evapotranspirated back to the atmosphere, and falls again, moving farther inland each time. The cycle repeats at least seven times before the moisture-laden air comes up against the eastern flanks of the Andes. There, it is forced very high into the atmosphere, and the resulting heavy condensation produces some of the highest amounts of rainfall on the planet. This is the 'conveyer belt' of water, the biotic pump function of forests. When large areas of forest are cleared or burnt off, the biotic pump and thus the ocean-to-land winds weaken. The rain-making process stalls. Unprecedented drought in Russia in recent years is, according to Makarieva and Gorshkov, linked to accelerated deforestation in western Russia. In 2019, there have been more that 80,000 fires in the Amazon, due in large part to the reactionary benighted policies of president Jair Bolsonaro. Experts have estimated that if over 20% of that rain forest is lost, the whole area will inevitably transition to savanna, and the rain forest will largely disappear. What the experts are talking about is the loss of the Amazonian biotic pump that provides the 'rain' in rainforests.

Earlier in this paper, we have seen how crucial moisture is to the soil microbiome. First, it ensures a healthy plant cover, which both protects the soil from heat, and pumps down huge amounts of organic carbon to feed the microorganisms below. Second, as the soil dries, microbial function declines. Too dry and too hot, and microbial life dies. Perhaps the main contention of this paper is that the soil symbiotic net, the symbiotic relationship among plants, mycorrhizae and soil microbes, is the most significant biological mechanism for the biosequestration of carbon in the soils of the planet. And that managing for photosynthesis by using it is only viable strategy we have at present to draw down sufficient atmospheric carbon to avert the worst consequences of global warming. We need to urgently fast forward this biosequestration process, and anything that damages it must be avoided at all costs. On this point alone, healthy forests are a crucial component in the fight against global warming. Their carbon storage is partly understood, but their lynchpin macro-role in the large water cycle needs to be more clearly comprehended, and forest management policy adapted accordingly.

The third commonality that all forests share is their contribution to what Dr. Christine Jones has called ‘the liquid carbon pathway’. To repeat the point, this is the symbiotic relationship between plants and the soil microbiome that results in plants pumping vast quantities of organic carbon deep into the soil. This fundamental function is almost universally ignored, for forests as well as for grasslands and crop plants. Calculations on the Global Warming Mitigation potential of forests must take into account this large-scale biosequestration of carbon. At present, universally, they do not, and appropriate forest management policy cannot be established or implemented as a result.

All forests provide this ecosystem carbon sequestration function, but not all in equal amounts. Conifers tend to have wide-spreading shallow root systems. In contrast, the root system of a deciduous tree can be large and deep enough to basically be an underground mirror image of the tree above. If we imagine the extent to which the hyphae of mycorrhizae multiply that, we get a more accurate picture of the scale of a deciduous tree’s carbon pump. Empirically, we can assume with confidence that a deciduous forest will pump more organic carbon into the ground to nourish its symbionts, and pump that carbon considerably deeper. The deeper the organic carbon, the more secure its biosequestration, and the resulting topsoil will be thicker, richer, and retain more water. In other regards as well, deciduous forests may tend to perform better at mitigation. They lose their leaves in winter, and thus reduce the albedo cooling effect of snow less than coniferous forests would. The fallen leaves form a thick cushy carpet on the forest floor, decaying into rich topsoil at rates far higher than coniferous forests do. The leaves of coniferous trees fall less often and less regularly, and have a high resin content which retards decay. No farmer gathers pine needles for their fields, but deciduous leaves are prized for compost. A healthy deciduous forest can easily form a centimeter of topsoil a year, but in a coniferous forest, that might take a century. Deciduous forests are higher in biodiversity, and their soils have significantly higher water retention performance as well. Unfortunately, in Japan and elsewhere, forest management policy is mainly focused on monoculture coniferous tree farming, with consequent loss of biodiversity, and of carbon storage and water retention capabilities.

Tropical forests also store vast amounts of carbon, an estimated 250 billion tons, according to the World Wildlife Fund. Due to rapid bacterial decay, nutrient cycling is fast in tropical forests, and the red clay jungle soils generally tend to be shallow and poor. The carbon, therefore, is sequestered in the trees and other plants more than in the soil microbiome. Aboriginal dwellers of the Amazon understood this empirically. They are known to have enriched their forest soils by adding biochar, often in large quantities. Even now, deposits of this *terra preta* or black soil can be found throughout the Amazon, and are evidence of human habitation and land cultivation on a scale previously unimagined. It can be said that the rapid and lush growth of tropical rainforests makes up for the low level of carbon sequestration in most jungle soils, but that the rapid decay when those trees die means the carbon is not sequestered that long. However, one exception to this general rule is the tropical peatlands. These are tropical forests where organic matter is protected from rapid oxidation by permanent submersion in swamp-like conditions. These peatlands only cover about 0.25% of the world's land area, but are estimated to contain between 50 and 70 billion tons of carbon (about 3% of global SOC). They are vulnerable to deforestation. When the forest cover is cleared, the peat dries out and oxidizes rapidly. It even burns, and the air quality in many parts of Indonesia in recent years is often very bad as a result of the burning peat. Obviously, all that sequestered carbon goes to the atmosphere. If most of the peatland organic carbon were to oxidize, that would result in a 50 gigaton jump in carbon emissions. For comparison, global anthropogenic carbon emissions were a bit under 10 gigatons in 2014.

To summarize, deciduous forests sequester more carbon through the soil symbiotic net than either tropical or boreal evergreen forests. Deciduous forest soils are richer and hold more carbon. But all forests provide Global Warming Mitigation inputs. All biosequester carbon in their trees. And perhaps most importantly, through their biotic pump function, all forests are crucial links in the world's large water cycle. A stable moisture cycling system is as important to halting and reversing Global Warming as carbon biosequestration itself, for the later cannot take place without adequate moisture. Global forest management strategies must take this into account. That should include halting deforestation and maximizing species diversity in any and all reforestation projects.

The Miyawaki Method can serve as a role model. Akira Miyawaki, a Blue Planet Award-wining botanist, has developed a method of reforestation or afforestation that is a soil, air, water, and climate remediating process. He developed his method through the study of sacred Shinto shrine forests. These fragments of forest all over Japan are time capsules of Japan's original indigenous forest. Miyawaki realized that they were naturally layered in four main categories: main tree species, sub-species, shrubs, and ground-covering herbs. His approach is modelled on that, and consists of taking between 50 and 100 local plant species from the above four categories and planting them as seedlings in a random mix mimicking natural distribution. They are planted very densely, 20 to 30 times denser than commercial tree plantings. As a result of the stiff competition, they tend to grow very rapidly, about 10 times faster. The site is watered, weeded, and monitored for two to three years until it is stabilized, and then left to flourish on its own without further interference. Miyawaki has planted over 40 million trees in this way, in 15 different countries, including Japan. But that figure doesn't begin to tell the whole story. He has restored forest ecosystems, complete with plant and animal biodiversity, and with renewed carbon biosequestration capabilities as well.

A recognition of the role forests play in the global climate, of the unique characteristics of the various types of forests, of the value of biodiversity, and of the power of the natural world to regenerate itself quickly under the right conditions, all are needed to formulate the kinds of forest management and restoration strategies that can succeed. Akira Miyawaki's afforestation efforts are one shining example. When these are implemented on a large scale, forests can play an indispensable role in the photosynthetic solution to Climate Change.

d) Urban Areas

Estimates of total global urban land area vary rather widely, ranging from .2% up to 3%. Compared to the areas occupied by forests, grasslands and croplands, it may not seem like much. But urban areas have an outsized impact because of all the resources needed and all the waste generated by the huge numbers of people who live in them. The scale of carbon emissions from urban areas makes them prime targets for every possible mitigation strategy. According to a September 18, 2012 article in Scientific American, more than half of the world's expected nine billion people will live in giant urban expanses by 2030. Some estimates say up to 80% of the world's population will be urban dwellers by that year. Cities will spill over into the surrounding countryside, occupying an estimated additional 1.2 million km^2 by 2030, roughly tripling in size to over 1.6 million km^2. I remember the Kathmandu valley in Nepal in 1988 with large expanses of countryside surrounding the city. When I went back in 2018 and viewed the valley from the hill of the famous Swayambhunath temple, the valley was a sea of buildings in every direction. As I moved through that urban sprawl, very little of it was beautiful. The same can be said for a majority of the cities on the planet: noisy and crowded, with polluted air and water, and generally noticeably hotter than surrounding areas. This last phenomenon even has a name: The urban heat island effect.

It is not a new phenomenon; it was first documented in the 1830s. And it is not hard to understand why it occurs. The plant cover in modern cities can be lower than in many deserts. Pavement and buildings are everywhere, and none of those surfaces is water absorbent. What they absorb and store is heat from the sun. Rooftop temperatures can easily top 60C. Energy consumption for cooling soars. The heat soaks in and the water runs off. This situation needs to be reversed: the water soaks in and the heat reflects off and is removed through evaporative cooling! It can be surprisingly easy to do. All that is needed is a little imagination and some ingenuity. It is a question of greening the roofs and walls, and making reflective those surfaces that aren't. Evapotranspiration from the green roof or wall has a significant cooling effect, in addition to the direct shade provided and the insulation from the layer of soil. According to the American EPA, green roofs generally remain at ambient air temperature or even a bit cooler, while their bare counterparts can soar up to 40C or more above ambient air temperature (see illustration). Green roofs are already being installed in cities all over the world. With its world-class horticultural skills, Japan should be at the forefront of this green revolution!

グリーンルーフと従来の屋根の温度差

普段、シカゴ市庁舎の緑の屋根の温度は隣りの従来の屋根の温度よりおよそ40°C低いです。
屋上緑化がヒートアイランド現象の低減に役立つ新しいテクノロジーであります
グリーンルーフの植生が屋根に影を指すと、蒸発散により空気から熱を除去する

これら二つのメカニズムは屋根の表面と周囲の空気の温度を下げます。植生屋根の表面は周囲の空気よりも低温になることがありますが、従来の屋上の表面は周囲の空気の温度を最大50°C超えることがあります。

Green roofs are an emerging technology that can help communities mitigate urban heat islands. A green roof is a vegetative layer grown on a rooftop.

As with trees and vegetation elsewhere, vegetation on a green roof shades surfaces and removes heat from the air through evapotranspiration. These two mechanisms reduce temperatures of the roof surface and the surrounding air. The surface of a vegetated rooftop can be cooler than the ambient air, whereas conventional rooftop surfaces can exceed ambient air temperatures by up to 50°C.

Source: Reducing Urban Heat Islands: Compendium of Strategies

Estimates of reductions in summer energy demands for cooling range from 20% all the way up to 75%. What is clear is that the energy savings are significant. Implemented across a city, green roofs would reduce and even eliminate the urban heat island effect. They have many other benefits too: rooftop vegetation and soil work like sponges, absorbing and filtering water that would otherwise run off through gutters, wash through polluted streets and overload wastewater treatment plants. They also beautify cities, improve biodiversity, and provide areas for city dwellers to relax, and even to grow food. Green roofs can also last twice as long as conventional ones, for the soil and plant cover protect the roof material from harsh weather and UV radiation. A back-of-the-envelope calculation, assuming 25% of urban land surface could be greened, arrives at a figure of 400,000 km^2 of new plant cover in 2030. Imagine the energy savings from reduced air conditioning, and from reductions in water demand and in costs for treating wastewater! And, on top of all the emissions reductions related to cooling and wastewater treatment, green roofs also do their bit to drawdown and biosequester atmospheric carbon, which at over 40 million hectares would not be insignificant.

Internet screen grabs, provenance unascertainable

In a kind of a side note, pavements and sidewalks should be made of water-absorbent concrete and asphalt. This will go a long way towards replenishing groundwater, watering city gardens, reducing flood danger, and easing the burden on wastewater treatment plants. As it stands, city wastewater treatment plants are often overwhelmed by cloudbursts, and can even be forced to discharge large amounts of untreated sewage on such occasions. Water that drains through permeable concrete or asphalt also filters out myriad pollutants that accumulate on roadways and rooftops, and that would otherwise wash into nearby bodies of water and add to their pollution burden. There are already a number of products on the market. A new cement product called Topmix Permeable can absorb up to 1,000 liters of water per minute per square meter. Porous Asphalt systems have been around since the 1970s.   Good ideas are not what is lacking. What is lacking is the will to overcome human inertia and implement them!

e) Oceans

Phytoplankton in the oceans are responsible for generating at least half the oxygen in the atmosphere through photosynthesis. They capture about 37 billion metric tons of CO_2 in the process, about 40% of all CO_2 produced. The IMF article cited here[15] estimates that this would be the equivalent to the CO_2 captured by 1.7 trillion trees – four Amazon forests' worth. A large portion of this captured CO_2 sinks to the ocean bottom through several mechanisms and is thus sequestered. First, much dead phytoplankton gradually sinks to the bottom, as demonstrated by large geological deposits of diatomaceous earth worldwide. Second, zooplankton that graze on the phytoplankton near the surface during dark hours, migrate downwards to avoid predators during daylight. Their fecal pellets, and those of animals that prey on them, excreted at depth, transport carbon fixed by phytoplankton near the surface down to abyssal depths. Third, the bodies of larger animals that prey on zooplankton (some sharks and rays, penguins, and most notably whales) sink to the bottom when they die. This whole process is called the 'biological pump' and it operates at such a scale that without it, almost twice as much CO_2 would remain in the atmosphere. Clearly, positive and negative human impacts on this biological pump must be taken into consideration as a significant part of the photosynthetic solution to Global Warming. The scale of phytoplankton impact on the carbon cycle is briefly described above, but the scale of zooplankton impacts, and that of megafauna, particularly whales, needs more elaboration.

The zooplankton vertical migration is called the diel vertical migration (DVM). It is possibly the largest natural daily movement of biomass on the planet. The zooplankton is preyed upon by diverse predators as it moves up and down in the sea water, and the resulting chains of predation and fecal pellet production move carbon and other elements deeper and deeper, fairly rapidly. In this way DVM is a major factor in the 'biological pump', or the biologically mediated sequestration of CO^2 down to the ocean depths. [16]For the purposes of this discussion, the focus will be on krill. Strictly speaking, krill are classed as zooplankton only in their egg and larval stages, when they lack locomotion. This type of zooplankton is called meroplankton. Krill are perhaps the most abundant animal on the planet. It is estimated that peak populations of krill reach up to 6 billion tons just in Antarctic waters. Krill swarms can be seen from space. Their cumulative shuttling of carbon to the ocean depths,

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where it is sequestered, is huge in scale. They are also the primary food of the great baleen whales.

Whales work to sequester carbon in several ways. First and foremost, they are crucial for the abundant growth of phytoplankton. This point cannot be stressed strongly enough. The diving movements of whales stir up nutrients and help bring them to the surface. Whales also excrete, and at the surface, in what are euphemistically termed “fecal plumes”. These fecal plumes are rich in nitrogen and in iron, both elements crucial to plankton growth. Wherever whales are found, so are large concentrations of phytoplankton and of the zooplankton that feed on them. Whales cycle nutrients, in other words. Without a healthy population of whales, plankton levels would be severely impacted. Abundant plankton, thanks to the whales, means significant CO^2 biosequestration. And, as a side benefit, also rich fisheries, as these are directly or indirectly dependent on the total planktonic biomass. Whales also function as carbon sinks, both during their long lifetimes, and also when they die. This is because their bodies generally descend to the sea floor.

The world’s population of great whales is only about 25% of what it was prior to the industrial whaling of the 19^{th} and early 20^{th} centuries. The present population of Blue whales, the largest animal to have ever lived, is only 3% or so of historical levels. Andrew Pershing, a research scientist working with the University of Maine and the Gulf of Maine Marine Research Institute, makes this loss of carbon biosequestration capacity easier to comprehend: “A century of whaling equates to the burning of more than 28 million hectares of forest or 28,000 SUVs driving for 100 years.” It should be obvious that a very significant portion of carbon biosequestration begins with the photosynthetic activity of oceanic phytoplankton. It continues with the carbon movement provided by zooplankton. And it is sustained by an abundant and thriving population of great whales. Whales are an essential component of a large and thriving biomass of oceanic plankton. This is the biological carbon pump.

What are the threats to this essential healthy population of whales? Much has been made of the activities of nations that persist in whaling, despite a general ban. Japan is chief among them. Actual numbers of whales taken by Japan, Iceland and other whaling nations are small compared to historical catches. The indirect impact of these whaling activities is likely to be much greater. Whales have extraordinary hearing because they depend on it, the way we depend on vision. They can hear sounds, especially low frequency sounds, over astonishing distances. The distress calls of hunted whales can possibly be heard by other whales hundreds of kilometers away, and undoubtedly stress and even terrorize these highly intelligent creatures. This brings us to a threat to the world’s whales probably far greater than whaling.

That is acoustic pollution, which is increasing exponentially in the world's oceans. It is not just ships' motors. The most damaging forms of acoustic pollution are sonic booms in the range of hundreds of decibels. These are extensively used both for seabed oil exploration and by the US and other navies to hunt for the submarines of potential enemies. These sonic booms can be deafening, and a deaf whale, functionally blind, is a dead whale. Whales that are far enough away that their hearing is not permanently destroyed are still terrorized by the overwhelming sound and flee in panic. There is even evidence that this panic overrides their instinctive timing of ascent from deep dives, and they wind up suffering the bends, just as human divers do. Whales also have to deal with pollution of a more insidious kind: the bioconcentration of persistent organic pollutants, such as dioxin, PBCs, organic mercury, etc. By virtue of being at the top of the food chain, concentrations of these potential endocrine disruptors and carcinogens have now reached hazardous levels in the bodies of whales, far exceeding safety limits set by governments. As a side note, this situation should make us think twice before consuming whale meat, whatever other opinions we may have for or against commercial whaling! The long-term impact of this chemical pollution on the health of the world's whale population is yet unknown, but it can't be good.

What is obvious from the above paragraphs is how essential a large healthy population of whales is to the global carbon cycle. It is also clear how they continue to be adversely impacted by human activities even long after the end of the large-scale industrial whaling that nearly drove them to extinction. A discussion of managing the oceans for photosynthesis, to mitigate Global Warming, is almost by definition a discussion on how to protect great whales and foster their population recovery.

5) CONCLUSION

The potential for catastrophic change in the planet's climate is very real, particularly if feedback loops that release methane locked in the permafrost and in methane hydrates are triggered on a large scale. 4 out the past 5 mass extinction events in geologic history can arguably be attributed, wholly or in significant part, to the effects of global warming triggered by runaway greenhouse effects. The most disastrous of these was the end-Permian mass extinction, when over 90% of species became extinct. We are already seeing significant impacts of the current global warming trend. These include prolonged droughts and devastating wildfires, more destructive storms, heavier rainfall and more frequent and destructive floods, melting ice at the poles and in the mountains, sea level rise, insect infestations, significant shifts north and south of animal and plant species, and a skyrocketing extinction rate. All of these are happening at a far faster rate than even during the end-Permian mass extinction, and represent an existential threat to humanity.

The need for urgent action is getting clearer by the day. Unlike previous mass extinction events related to runaway greenhouse effects, the current crisis is primarily the result of anthropogenic emissions of greenhouse gases. We are causing it. The urgent action needed is two-fold: one, reduce the sources of those anthropogenic emissions and two, initiate a global campaign to drawdown the excessive carbon in the atmosphere, in every way possible. However, the global community, with very few exceptions, is only focused on reducing carbon emissions resulting from the burning of fossil fuels. This is problematic for several reasons. One, we are failing to do so; emissions from fossil fuels have increased significantly over recent decades, instead of being reduced. Two, even if we were to miraculously eliminate fossil fuel emissions overnight, the ‘legacy carbon’ already in the atmosphere virtually ensures at least 2C of warming. There are no technological means of drawing down sufficient carbon that can be implemented fast enough (let alone economically enough) to be effective in avoiding widespread climatic disaster and even possibly triggering the apocalyptic release of the vast amounts of methane stored in permafrost and oceanic methane hydrates. Three, and most importantly, anthropogenic emissions are not just the result of burning fossil fuels. Other sources of anthropogenic emissions exist, and, though generally ignored, are as or even more significant in causing global warming.

This discussion is focused on this third problem, the lack of recognition of the scale and importance of non-fossil fuel emissions. An increasing body of evidence indicates that emissions resulting from destructive land and ocean management over time can rival and even possibly exceed those of fossil fuel emissions. These various forms of mismanagement, discussed above, have resulted in the mass release of carbon previously bio-sequestered in organic matter, and simultaneously have greatly reduced the capacity of the biosphere to continue bio-sequestering carbon in beneficial organic forms. It should be obvious that no effective strategy is possible to reduce greenhouse gas emissions, and to drawdown from the atmosphere excessive carbon in the form of CO_2, without a recognition of this fact. In fact, the only realistic strategy to slow down and subsequently reverse global warming, **in the time frame available**, is the harnessing of the potential of photosynthesis to biosequester carbon. Globally, photosynthesis, on a daily basis, moves roughly nine times as many carbon atoms as all human activity, and it moves them in the right direction: into organic forms where carbon is beneficial to life. If we could enhance photosynthetic activity to where it moves ten times as many carbon atoms, we would solve global warming. In other words, to save the planet, we are talking about a mere 10% or so increase in photosynthetic production. Surely that seems doable.

Three figures, more than any others, have advanced this understanding. First is Dr. Rattan Lal, at Ohio State University, who pioneered methods to measure the loss of soil organic carbon. His research and that of others established that world soils have lost between 50 and 80% of their soil organic carbon, mostly in the past two centuries. This is a staggering amount. Significantly, Dr. Lal has also clearly stated that restoring soil organic carbon is a viable strategy to limit climate change. But his claims probably do not go far enough. Because his methods of estimating soil carbon loss are limited in application, and don't take into account losses from wild rangelands, urban areas, forests, or the oceans, the total amount of organic carbon lost to the atmosphere is, in all probability, far higher. Consequently, strategies to restore that organic carbon through photosynthetic sequestration can have a correspondingly greater impact. The second figure is the wildlife and grasslands restoration ecologist Allan Savory. Savory has pioneered a method of livestock and rangeland management he termed 'Holistic Range Management' that can reverse desertification, all while restoring rangeland and multiplying by several times the livestock numbers that can be sustainably grazed on a given area of rangeland. Savory has claimed that if his methods were to be implemented on half the world's grasslands, atmospheric carbon levels could be reduced to pre-industrial levels in a few decades. His pilot projects and those of his emulators certainly have shown that amazing recoveries of degraded land are possible in a short time. The third figure is Dr. Christine Jones, noted Australian soils ecologist. She has helped elucidate and worked to further the understanding of the crucial relationships between plants and the soil microbiome. These relationships work to bio-sequester carbon in vast quantities and at speeds that are not yet generally recognized. She coined the expressions 'carbon pump' and 'liquid carbon pathway', which encapsulate those relationships and provide useful new terminology to help build understanding of the workings of bio-sequestration of carbon. She has worked tirelessly to advance the recognition that plants are not just takers of nourishment from inert soil, but that plants give back to the soil in significant quantity. This two-way interaction among plants, mycorrhizal fungi and microbes forms a soil symbiotic net that works to actively bio-sequester carbon in astonishing amounts, enriching the soil and improving its water retention capacity in the process. This understanding helps underpin Savory's claim that grasslands can reverse climate change.

Many have derided Savory's claims as wildly improbable and, without providing any real counterproof, dismissed his tangible results. But he is not the only one making these sorts of claims or achieving these types of results. With regards to forests, ecologist Thomas Crowther and colleagues at Swiss university ETH claim in a study published in 2019 that an additional 1.2 trillion trees can be planted worldwide without impinging on agricultural lands, thus locking up hundreds of gigatons of carbon, or at least 10 years of anthropogenic emissions at our current rate. In regard to agricultural lands, research conducted at the New Mexico State University Institute for Sustainable Agricultural Research by David C. Johnson and his colleagues found that with a method of soil management they developed that maximizes healthy fungi and bacteria in soil, "you can grow more crops faster, better and with less water. . . The carbon sequestration is the icing on the cake." They have stated that "The rates of biomass production we are currently observing in [their] system have the capability to capture enough CO_2 (120+ tons per hectare) to offset all anthropogenic CO_2 emissions on less than 11% of world cropland." These two studies are making the same argument as Savory, that on properly managed lands, enhanced photosynthetic activity can by itself eliminate anthropogenic emissions. It behooves us to implement all these strategies to the extent possible. The methods and strategies that these and many other visionaries are pioneering have, without exception, very desirable side benefits: reversing desertification, improving agricultural production, enhancing flood and drought prevention, cooling our cities, rebuilding social cohesion, restoring ocean fisheries, restoring biodiversity, and more. These side benefits make those strategies worth implementing by themselves, even without the major benefit of mitigating and even reversing global warming. This demonstrates, as well, how interconnected and related to climate change all these other problems are.

An important point regarding all these claims needs to be made here: Even in our age of exalting scientific certainty, the overwhelming majority of decisions are based on empirical knowledge. In other words, 'It works, so let's do it, and figure out why later'. And so it has to be with our response to global warming. **For too long, the demands for absolute proof of the anthropogenic cause of global warming, and of the effectiveness of any strategy to deal with it, have just served as an excuse to do nothing.** The clear and already present danger of global warming is bearing down on us so fast that we do not have the luxury of demonstrating the scientific validity of a strategy completely beyond all doubt before beginning to implement it. If it is working, we have to empirically accept and implement it. No other possible realistic solutions to our climate emergency have been found, and time is running out. The astonishing results being achieved worldwide by managing for photosynthesis, on grasslands, agricultural lands, forests and urban areas, and potentially the oceans, are already sufficient empiric proof that our answers lie here, and that even just their side benefits make implementing them worthwhile.

It might be useful to frame the discussion in economic terms. Dr. Christine Jones has called carbon the currency for most transactions within and between living things. According to ecologist John Todd, “Humanity has always been carbon based. The carbon that supported us through most of history was slow carbon embodied in trees, other plants, and animals. Since the Industrial Revolution we have shifted to using fast carbon in the form of oil and natural gas. Fast carbon is finite and non-renewable”. Put differently, we are now operating on an ‘oxidizing’ economy, undoing the photosynthesis of the past through burning **and** the photosynthesis of the present through destructive land management. Pollution, wars, destroyed social fabric, and the uber-crisis of global warming are the disastrous results. To save ourselves and make the world green and blooming with life again, we have to ditch the oxidizing economy and return to a slow carbon photosynthesis economy. To promote the land management strategies that can accomplish this, we will also have to alter our economic order and put a proper value on both the fast carbon of death (make people pay to use it) and the rich life-giving organic slow carbon of life (reward people for building it). Therefore, we will need to rethink our presently flawed economic management parameters along with our land management parameters to succeed.

The time to implement our only realistic hope, the photosynthetic solution to climate change is running out. Global warming will, if unchecked, remove the places on earth where the solution can be implemented. Rain bands will move north and south, creating Sahara-like deserts in southern Europe, North America and indeed around the globe. Forests will burn down and grasslands turn to desert, as will agricultural lands everywhere. Sea level rise will inundate vast areas. Heating and acidifying oceans will turn into the oceanic equivalent of deserts as well. Coral reefs will disappear. The apocalyptic catalogue goes on. We have two to three decades at most to succeed in implementing the photosynthetic solution to climate change.

And succeed we must. It has been demonstrated through both scientific investigation and, even more crucially, through practical application all around the world, that enhancing photosynthetic activity can both heal damaged lands and waters, and, most importantly, contribute enormously to reversing climate change. The work and the results described above give humanity hope in the midst of an exponentially growing crisis where hope is in short supply. The world has no choice but to apply these discoveries and methods as fast as possible, and on as large a scale as possible, to make that hope a reality. The alternative is grim beyond all imagining.

[17] This assertion is based on a number of sources. One is the landmark work carried out by Dr. Rattan Lal at Ohio State University. Based on a methodology he established to measure Soil Organic Carbon (SOC) depletion, he has demonstrated that agricultural soils worldwide have lost between 50 and 80% of their organic carbon. He has also by extension shown that re-sequestering SOC can both restore degraded soils and, crucially, mitigate Global Warming, as laid out in the following paper:

Global Potential of Soil Carbon Sequestration to Mitigate the Greenhouse Effect
By R. Lal (https://doi.org/10.1080/713610854)

It is crucial to note that Dr. Lal's methodology for estimating SOC loss is limited to agricultural lands that were originally forest, and thus his estimates for the potential to mitigate global warming are also far lower than the true potential of photosynthetic biosequestration of carbon when rangelands, oceans, urban areas and forests themselves are collectively taken into account.

For oceanic loss to the atmosphere of organic carbon AND of atmospheric carbon biosequestration capacity, my source is an article in the July 29, 2010 edition of Scientific American entitled "Phytoplankton Population Drops 40 Percent Since 1950" by Lauren Morello. A 40% of Oceanic phytoplankton since 1950 is an enormous quantity!

For loss of SOC from rangeland (also described as drylands or grasslands) I have relied on widely available data from the internet on the extent of desertification of those rangelands. Estimates vary widely, but in every case, they are enormous and relentlessly ongoing, and my contention is that this desertification has to be seen as a) a major source of carbon emissions to the atmosphere, and b) an equally major loss in photosynthetic biosequestration capacity. In making these assertions here and throughout this paper, I have also relied on the TED Talk and published work of Alan Savory, and on the reportage on activists at the front line of what has been termed the "Photosynthetic Revolution" in "Cows Save the Planet" by Judith Schwartz, "The Soil will save us" by Kristin Ohlson, and other similar publications.

Taken together, all these sources document a staggering loss of organic carbon to the atmosphere from non-fossil-fuel sources, and point the way to a photosynthetic solution to Global Warming.

[18] This assertion is backed in part by the following study:

Terrestrial Gross Carbon Dioxide Uptake: Global Distribution and Covariation with Climate
Beer et al.

This study "used a combination of observation and calculation to estimate that the total Gross Primary Production (GPP) by terrestrial plants is around 122 billion tons per year: in comparison,

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[18]

burning fossil fuels emits about 7 billion tons annually."   I took this fact, and calculating very roughly, doubled those anthropogenic emissions to account for all the non-fossil-fuel emissions due to land and ocean mismanagement (one of the major points in my article). Thus, I arrived at the conclusion that photosynthetic output *by terrestrial plants alone* moved approximately 9 times as many carbon atoms as all anthropogenic emissions, and it moved them in the right direction: sequestered in organic form. This leads to the assertion that by increasing photosynthetic production by 10% we can offset ALL anthropogenic emissions. If we manage to increase photosynthetic output by terrestrial plants alone by 20% we are well on our way to drawing down excess carbon in the atmosphere and reversing Global Climate Change. If we include the activity of oceanic phytoplankton and implement policies to restore oceanic phytoplankton levels, we can achieve this goal that much faster, and the section on Oceans discusses in some detail approaches to doing exactly that.

[19] As quoted in:

https://www.bloomberg.com/news/articles/2013-11-04/kyoto-veterans-say-global-warming-goal-slipping-away

[20] "Are We Falling Off the Climate Precipice"'   by Dahr Jamail

https://oilprice.com/The-Environment/Global-Warming/Are-We-Falling-Off-the-Climate-Precipice.html

Links providing sources to each item in the timeline included in the online article

[21] Ibid.

Graph on Page 6: Graph from "The Siberian Traps and the End-Permian mass extinction: a critical review" by Andy Saunders and Marc Reichow

Graph on Page 10: From: Global Changes in Drought conditions Under Different Levels of Warming" by Gustavo Nauman, Lorenzo Alfieri et al. in Geophysical Research Letters, March 2018

Double graph on page 15:   European Environment Agency (EEA) report No 12/2012
Climate Change, impacts and vulnerability, and quoted in Grist, Nov. 21, 2012:
"The 16 scariest maps from the E.U.'s massive new climate change report" by Phillip Bump

[22] Carve: The carbon in Arctic Reservoirs Vulnerability Experiment, Charles E. Miller
Conference Paper, IEEE Aerospace conference Proceedings, March 2012

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