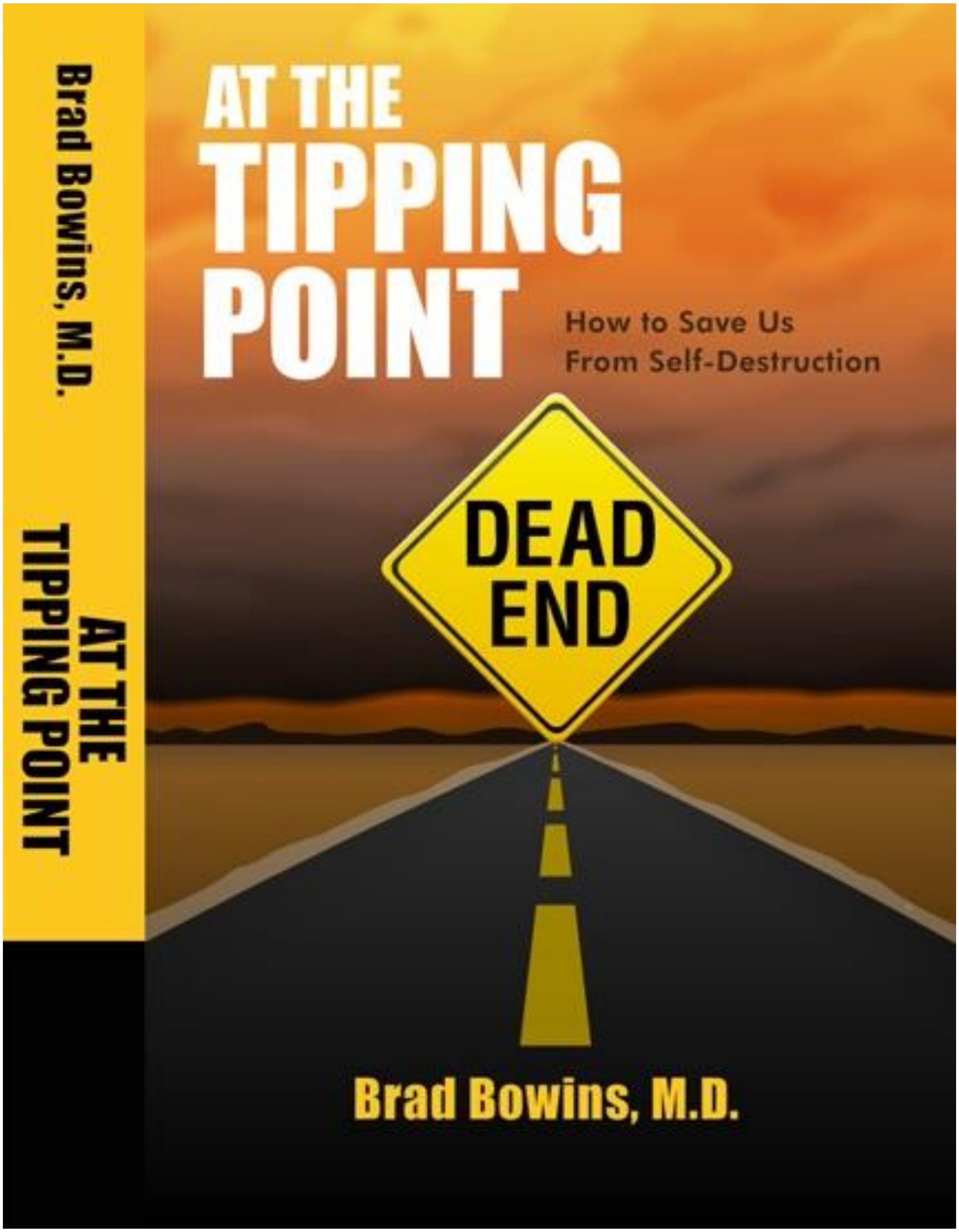

AT THE TIPPING POINT
How to Save Us From Self-Destruction
DEAD END
Brad Bowins, M.D.
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AT THE TIPPING POINT

TOO HOT TO HANDLE: GLOBAL WARMING (Sample Chapter)

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QUESTION:

The world is facing a major environmental challenge that is having a negative impact on your life now, and will have a much greater impact on future generations. What should we do?

A. Be optimistic that it will all work out in the end, as these things usually do.

B. Ignore the problem and let someone else take care of it.

C. Do whatever we can to fix the problem regardless of the costs.

D. Research until scientists are absolutely certain of what will work.

E. Appreciate the realities and proceed strategically.

If you answered A you show the capacity to put a positive spin on negative circumstance that is very good for mental health. Unfortunately, problems typically do not just take care of themselves and environmental issues are no exception. If you answered B, then you are engaging in another defensive response consisting of detaching from the problem. As with positive spins, this approach can limit suffering in the present, but allows problems to escalate. Answer C is the one given by many who care about the environment, but it simply does not work because unless a threat is dire and immediate people greatly limit what they are prepared to sacrifice. Answer D sounds good but shows a limited understanding of the way that science works. Uncertainty can rarely be fully eliminated, and waiting for the impossible ensures we will never get it done. If you selected answer E you are in the distinct minority, and have taken the first step on the path to solving most environmental problems. This approach makes optimal use of limited and valuable resources, thereby increasing the chances of success.

THE NATURE OF GLOBAL WARMING:

A Hot Topic:

Although there are many environmental problems, each with powerful consequences, the one that is on the mind of most people is global warming, or as it is often referred to, climate change. The latter name is a bit misleading, because it suggests that somehow the environment should remain stable, and that simply never occurs. Imagine if you woke up to the exact same weather every day of your life. The weather is always changing from day-to-day, or week-to-week, and even major fluctuations are the norm. Climate instability is a reality, and even the best weather forecast can go off. How many of us have set out on a day trip based on a forecast of sunny skies, only to encounter torrential rain? And that is for forecasts a day or so out. Try predicting the next month or two. Indeed, true climate stability would put weather forecasters and climate scientists out of a job. Another problem with the term climate change is that many natural fluctuations in weather are falsely attributed to this process. How many times have I heard something to the effect of, "This year we have had some bad storms, it must be climate change." Sounds good, but as we will see some of the problems attributed to "climate change" probably have other origins, and we are misleading ourselves by attributing everything to it.

So although climate change is a popular term it is not really helpful to the average person. Global warming captures the essence of what is happening to the world's climate, as it is slowly and steadily warming, with greater temperature increases at the north and south poles than the equator. One drawback of the term global warming is that it sounds good to many of us. I live in Toronto, Canada, where it is cold for about half the year. The term global warming conjures up images of not having to wear a jacket in winter, and perhaps only the odd day of having to shovel snow. I suspect that virtually everyone in a cold climate has had this fantasy, and even the leaders of some countries like Russia have expressed that it might not be such a bad thing for them. Let's face it if you live in a cold country global warming might sound okay. It is no wonder then that people seem unwilling to sacrifice a lot to deal with the problem. It has even been suggested that the best term might be global WARNING, as it conveys the message that there is a danger and something has to be done about it. However, I will use the term global warming as it more accurately reflects what is occurring, and allows readers to substitute an "n" for the "m" if so desired.

Global Warming Is Real:

Some question the validity of global warming reading political motivations into it. Others insist we are nearing the end of humanity due to global warming. Is it a true occurrence? YES! The answer is really this simple. The Earth has warmed about .75 Celsius over the last 100 years. Although difficult to predict, it is believed by scientists that we could end up with maybe a 3 degree Celsius increase in global temperatures. Not something to recoil in horror over, but as this story unfolds you will appreciate the self-destructive aspect, and why it is definitely worth applying limited resources in a strategic manner to deal with the issue.

Gases & Global Warming:

It is often said that without the sun there would be no life, but more accurately without the sun there would be no warmth, and then no life. Energy from the sun reaches the Earth and is radiated back into space. Gases in the atmosphere prevent a portion of that energy from leaving, thus keeping us warm. On Mars the atmosphere is very thin so almost all of the energy escapes back into space, meaning that it is far too cold for life, at least on the surface. So-called greenhouses gases are good then, at least in moderation. In excess too much energy is trapped overheating the planet.

A variety of gases contribute to the greenhouse effect, not just carbon dioxide (CO_2) that there is so much talk about. Methane and nitrous oxide are two additional greenhouse gases. Compared to CO_2 methane has about 25 times the ability to trap heat in the atmosphere, making it a truly potent greenhouse gas. Human activity including livestock farming, landfills, wastewater treatment, and the burning of fossil fuels, produces much of the methane released into the atmosphere. Increases in atmospheric nitrous oxide, another potent greenhouse gas, arise from fertilizer use, burning of forests and crop residues, and the combustion of fossil fuels. Several other gases produced exclusively by human activity such as PFC's and HFC's, also enter the atmosphere and trap in heat. Simple water vapor is another major contributor to the warming effect. So why is there so much emphasis on CO_2? First, CO_2 accounts for an incredible 80% of total greenhouse gas emissions, making it the most significant contributor. Second and very crucial to appreciate, CO_2 persists in the atmosphere, whereas the other gases clear rapidly. Methane actually undergoes a chemical change producing CO_2. Without removal from the atmosphere in some form, a process that might be thought of a scrubbing CO_2 from the air, it stays there.

Accumulation of CO_2 In The Atmosphere:

The amount of CO_2 in the atmosphere is presented as a concentration, or parts per million. Prior to industry the concentration of CO_2 was 280 parts per million; in 2011 it was 392, a very significant increase. Ice cores are taken from glaciers providing layers corresponding to years, as with the rings of a tree. Tiny bubbles of air trapped in the layers provide a sample from the past. Chemical analyses of these air bubbles show how much CO_2 there was in the atmosphere, and also the temperature at the time. The evidence is indisputable that first, CO_2 levels have been steadily increasing, and second, that temperatures are rising along with CO_2.

Al Gore in his book, An Inconvenient Truth, presents the relationship between CO_2 concentrations and temperature as a hockey stick with the long handle representing relatively flat CO_2 and temperature levels prior to industry, and then the blade sweeping upwards with industrial development. The atmospheric CO_2 concentration is now increasing at the rate of about 2 parts per million per year, meaning that in less than 100 years we will be near to or at 600 parts per million, greater than twice preindustrial levels, to produce a temperature increase of around 3 degrees Celsius. No one knows for certain what an acceptable level of CO_2 is, and as Roger Pielke Jr in his book The Climate Fix points out, focusing on a hypothetical limit can take away from more successful strategies to deal with the rise. What is clear is that CO_2 concentrations in the atmosphere and temperature are both rising. One might say that these events are only correlated and not linked in any cause and effect sense. This argument does not stand up, though, because it is known that CO_2 and the other gases mentioned do block solar energy from escaping back into space, thereby increasing the temperature. We might wonder why so much CO_2 is in the atmosphere in the first place, and how could we possibly contribute to it?

Much of the CO_2 in the atmosphere is naturally occurring from sources such as gaseous volcanic eruptions, the decay of vegetation, and breathing. Every time that you breath out you are releasing CO_2, so those who say mankind is not contributing to atmospheric CO_2 are actually doing so in the process of speaking those words. With billions of people on the planet we cannot help but contribute. However, the CO_2 released by our combined breathing is not significant relative to the activities we engage in. Many believe that the industrial era marked the start of mankind's contribution to rising CO_2 levels, but this is not true. Humans have existed for approximately 200,000 years and our predecessors much longer. For 95% of this time we were hunter-gatherers collecting vegetable matter and hunting. If an area offered abundant food and was not overly dangerous we stayed, but moved where the food was. Then around 10,000 years ago a remarkable change occurred, namely that we began to stay in one place and grow crops based on annual plants. Up until that time 95% or so of vegetation consisted of perennials, meaning plants that live for two years or longer. We picked what food perennials offered.

With agriculture a massive shift occurred from perennials to annuals that only live for one growing season, devoting much of their energy to large seeds. Currently at least 80-90% of crops are annuals, representing a complete shift in percentage from pre-agricultural times. Our ancestors took the seeds of annuals and planted them each year. Seeds were selected from the most productive plants, stored, and used the next season introducing artificial selection. Natural selection increases the frequency of a gene in succeeding generations. For example, more acute close-up vision helped our very distant tree living ancestors see insects and small edible plant parts. Genes that fostered better close-up vision increased the chances of surviving, and these genes became more represented in future generations. Hence, we can see very small things thanks in large part to how our ancestors liked to snack on high protein insects—A yummy thought. Artificial selection is when humans (or conceivably other species) select organisms with desired traits, and facilitate their reproduction. For example, we have many types of dogs because humans have allowed ones with desired traits to breed. Retrievers are selected for retrieving skills, and pit bulls for attack ability. By selecting seeds from the most productive plants and using these for the next season, our agricultural ancestors were engaging in artificial selection of annual plants. All of our main crops including wheat, corn, rice, and soybean are annuals.

Now you might well wonder what this could possibly have to do with our contribution to CO_2 in the atmosphere? The answer is much more than what most people would ever suspect. The soil is a massive reservoir of carbon, a key component of carbon dioxide. In fact the top meter of soil holds more than three times the amount of carbon stored in either vegetation or in the atmosphere! With perennial plants the roots stay put for several years leaving the soil undisturbed. With annual plants the soil is always being disturbed due to yearly planting of seeds, and also soil erosion arising from limited roots and no roots, for at least part of a year, when the crop is harvested. So with the advent of agriculture we began disturbing the soil and releasing carbon. In addition, the indigestible parts of annual plants decay and release CO_2. Given the small size of the human population and limited scale of agriculture, the impact of this CO_2 contribution was very small, but is important to appreciate as it shows how we have been contributing to atmospheric CO_2 for a very long time.

The really big change in terms of the human contribution to atmospheric CO_2 involves the burning of fossil fuels, an event that ushered in the industrial revolution a few hundred years ago. Carbon is the basis of both animal and plant life. When plants and animals of ancient times died they became buried under land or underneath the sea. Heat, pressure, and time turned these long deceased microorganisms into coal and petroleum. Coal arises from the fossilized remains of plants, while oil and natural gas are derived from a mixture of ancient plants and animals. Burning of carbon based products produces energy, and energy is what powered the industrial revolution. We burn fossilized fuels as if there is no tomorrow, or perhaps more appropriately we burn it as if it's okay to push the consequences off to tomorrow.

Simply put, WE ALL LOVE ENERGY AND CANNOT GET ENOUGH OF IT!

Of the roughly seven billion people on the planet, virtually everyone relies on at least one industrial product. For example, the remote New Guinea villager who uses a machete to clear dense brush is tied into the industrial world. In modern societies we could not get by without a constant source of energy for heat, cooling, powering our computers and appliances, and making our cars run. Developing countries use less energy, but as the standard of living in these countries improves so will their energy consumption. In addition, approximately 1.5 billion people are off the power grid, and all of these people would like to be on it. It would be a very unfair scenario and a graphic violation of social justice to deprive these people of access, while those of us in the developing world use energy often with little or no restraint.

So who is to blame? All of us are or none of us are. The lesson to be learned is that we all love energy and will continue to use it. Trying to get the other person or group of people to use far less than what you do is not productive. Of course, those who seem determined to monopolize the world's supply might look at what is a fair intake, and revise their usage accordingly. But the key point is that we will continue to use energy and lots of it. With the rise in lifestyle of people in countries like China and India, the increase will be significant. If these countries had the 2006 emissions of France global CO_2 emissions would be 30% greater. Consider what will happen when the 1.5 billion without access to power are connected. Demonstrating how it is a problem that we all share blame in, hyper-consumerism practiced by so many people and hyper-growth promoted by industry, are depleting readily available fossil fuel supplies while adding to global warming. We are all to blame and have to take ownership of the problem.

SO WHAT'S THE BIG DEAL WITH RISING CO_2 LEVELS:

All sorts of problems have been attributed to global warming (do you hear warning), and fear induction based on this is a popular way environmentalists have of getting people motivated to do something about the problem. Furthermore, it is where science has fallen down trying to support claims that appear to lack substance. As pointed out by Roger Pielke Jr (The Climate Fix), this leads to a discrediting of science, and is not necessary because the majority of people believe in global warming and are willing to do at least something moderate about it. We are continually hearing how our climate is so destabilized with global warming that anything and everything can occur. That icicle that fell on my head from the roof this morning—"Oh, it must be global warming." But what can realistically be attributed to global warming? Here are some of the purported impacts with an evaluation of how likely it is that global warming is involved.

Ocean Acidification:

The oceans covering the majority of our planet absorb about a quarter of atmospheric CO_2, comprising a so-called carbon sink. That is good news for the rising CO_2 problem but bad news for the ocean environment. The problem relates to the acid-base balance of the oceans. Water becomes more acidic when hydrogen ions increase. Ions involve an imbalance of positive and negative charges, the negative provided by electrons and the positive by protons. Hydrogen ions occur when the sole electron is removed leaving only a positive charge (H^+). CO_2 reacts with water releasing hydrogen ions, thereby acidifying the water (technically it makes the oceans less basic because they are not actually acidic). From preindustrial times to the present the oceans have become 30% more acidic, occurring at a rate about a hundred times faster than the most rapid events in the geological past. This all sounds impressive, but why is it so bad?

Many marine organisms require a solid support structure if they are to survive. For example hard corals need walls around their soft bodies. When you look at coral while snorkeling or scuba diving you are really looking at the solid non-living support structure. Think of an apartment building that is viewed from the outside. The living organisms are inside and require that hard structure around them. If all the tenants of an apartment building were without the building and piled on top of each other, their survival from the pressure, elements, and predators (if we had any) would not be good. Likewise, the coral polyps with their soft bodies and tentacles for catching food particles are very vulnerable, and cannot survive without their solid apartment. Even soft corals that can be seen swaying with the current and surge require hard components within their structure to support the colony. Many other organisms beyond corals also need protection and support. The list is long and includes clams, snails, barnacles, sea urchins, sea stars, brittle stars, and tube worms.

You might now be wondering what makes up the hard part of these organisms? The answer is calcium carbonate. Calcium is a key component of hard structures found in living organisms, such as the bones in your body. Most of us can recall our parents saying, "Drink your milk, your bones need calcium," and we repeat it with our own kids. Calcium ions with a positive charge combine with carbonate ions having a negative charge (positive and negative attract), to produce the calcium carbonate that corals and other marine organisms require. Now think about all those H^+ ions in the water due to excess CO_2 absorption. They in a sense soak up the negatively charged carbonate ions, leaving calcium without enough carbonate ions to bond with. Hence, there is too little calcium carbonate for all the organisms needing it.

Without calcium carbonate the organisms requiring it becoming weaker and many die. Coral reefs around the planet are suffering, and many are dying off due to this calcium carbonate deficiency. I am an avid scuba diver and underwater photographer. In the Caribbean I have seen firsthand how hard and soft corals have died and been replaced by algae. Reefs I dove in the 1990's that were quite healthy and vibrant are now essentially dead with algae covering them. If anyone suggested to me 20 years ago that those corals will soon be gone, I would have told them they were crazy, not a term to throw around idly when you're a psychiatrist. However, my diagnosis would have been wrong, and the pessimist would have been right. This problem is barely discussed partly because it is hidden even to many divers lacking marine biology knowledge. I have heard some say how colorful the reef looks, when they are only seeing sponges that are much more resilient to ocean acidification.

In contrast to corals in the Caribbean that have largely been decimated, those in many other tropical areas have remained in fairly good health. How can this be if ocean acidification is a global event? All organisms that have survived over time have some degree of resilience, and corals are no exception. They can survive one punch as long as it is not too strong, much as we can usually survive one punch. However, when there are two, three, four, five, and even six blows, it is too much. This multiple blow scenario characterizes the Caribbean region. The first blow is ocean acidification due to global warming. The second punch is also likely due to global warming, namely rising ocean temperatures. Most corals survive best in a narrow temperature range, and their ability to survive falls off rapidly as the temperature either rises or falls. Ocean temperatures have been rising, and in 1998 the temperatures increased in some areas of the world's oceans such that corals suffered greatly. One of the worst hit regions was the Seychelles that I visited in 1999 to find the reefs decimated. The Caribbean was also hit hard by ocean warming.

A third blow is the removal of herbivores that eat algae and keep the reef clean. In many, or even most parts of the world, there is massive over-fishing, removing amongst other fish herbivores, such as surgeonfish and parrotfish. The Caribbean region has a large human population, many tourists, and a small area relative to some vast Pacific island nations. Not surprisingly, most of the medium-to-large size fish are harvested. In addition, fishing often occurs at spawning grounds ensuring too few juveniles to replace the harvested fish. The death of Caribbean spiny sea urchins, apparently due to a virus that might or might not be related to global warming (probably not), constitutes a fourth blow, because these urchins are major herbivores devouring huge amounts of algae. A fifth blow is nitrogen and phosphorous runoff from fertilizer use and untreated sewage, favoring the growth of algae and boring sponges that destroy corals. Excessive development, particularly along the shoreline, comprises a sixth hit because it results in too much silt in the water choking coral polyps. Very select regions in the Caribbean that have managed to avoid these problems have relatively intact reefs, one in particular being Cuba, where the absence of industrial fertilizer favoring organic farming, negligible shoreline development, and limited fishing have protected the ecosystem. However, due to the multiple blow scenario described, with global warming playing a major role in terms of ocean acidification and likely rising ocean temperatures, coral reefs are fading worldwide, with some regions such as the Caribbean more damaged than other areas. Although hard to predict for sure, all coral reefs might be gone in 30-70 years, a time frame that undoubtedly will be advanced if the other blows that have devastated most Caribbean coral reefs, also exert themselves in more remote regions.

Showing how everything in nature is interconnected, coral reefs have a much greater role than simply providing a source of recreation. It has been estimated that a quarter of all marine species spend a least some of their life on the coral reef. For several the benefit is protection as there are places to hide. Food is also more abundant, and many species spawn by coral reefs, ensuring the continuation of the their kind. Corals are the architectural basis of the whole ecosystem, and its collapse guarantees the demise of countless species. In addition, every marine organism that requires calcium carbonate will have trouble surviving due to ocean acidification, and creatures further up the food chain, such as sea lions feeding on shelled organisms, will suffer. Another very significant consideration is that the marine environment by far holds the greatest potential for new pharmaceutical products, given both the number of species and uniqueness of their chemicals. It is widely believed by scientists, pharmaceutical companies, and many government agencies, that most new drug discoveries are going to come from this realm. If we allow it to be destroyed we might well be giving up on drugs that could save many lives, maybe even your own.

I have presented the ocean acidification story in some detail because it illustrates several important processes. First, it provides a very clear example of how global warming has already damaged a major ecosystem. Second, it demonstrates how various influences linked to mankind can interact to produce severe consequences. Third, it reveals how all parts of an ecosystem are connected, such that if one major part suffers the whole system declines. These points are very important to keep in mind as we look at the other impacts, clear and less clear, of global warming.

Melting of Ice Due To Global Warming:

We have all heard about how melting ice will raise sea levels causing flooding, but it is important to look at what might realistically occur. Sea ice will not raise ocean levels if it melts, because it is already in the water contributing to the current sea level. However, warmer water by being more expansive than cold water has raised sea levels 17 centimeters (just under 7 inches) since 1900. Due to global warming, sea ice in the Arctic and Antarctica is thinning and has been over several years. The Arctic is water covered by ice that is on average less than 10 ft. thick. The United States Navy has kept detailed records of the thickness of Arctic ice, as submarines can only surface from under the ice when it is thin enough. Since the 1970's the extent and thinness of ice in the northern hemisphere has declined markedly, and it is predicted that perhaps even by 2050, or earlier, the region might be ice free in summer, and maybe ice free period by 2100. While good for transportation with the opening of the Northwest Passage to shipping, it will be much less ideal for polar bears requiring sea ice to hunt.

Land-based ice raises sea levels if it melts, given that it adds to the oceans. Approximately 90% of land ice is found on Antarctica, 9% on Greenland, and only 1% on mountain ices sheets including glaciers. You can see why scientists are so concerned about what is happening to the ice sheets on Antarctica and Greenland. The ice sheets on Antarctica are up to 10,000 ft. thick. If all that land-based ice melts sea levels will rise by 65 meters! A reasonable prediction is that by 2100 sea levels will rise 1 meter. Although this does not sound too scary, consider that 200 million people and most of the world's largest cities live within that 1 meter. In areas with small populations rising sea levels have limited impact, but drastic and very expensive changes are unavoidable if the problem continues. Imagine closing down low lying sections of New York City and moving the population living there to higher ground, and fully shutting down cities like Miami that are now only slightly above sea level. Miami and other locations such as the Bahamas and Maldives, built on porous calcium carbonate (dead coral), cannot survive because water just percolates up through the foundation; imagine building on a rigid sponge with water washing onto the sponge. Perhaps an opportunity for shallow water scuba diving and snorkeling to replace dead coral reefs, but most other people will not be too thrilled.

To fully understand the connection between global warming, land-based ice, and rising sea levels, it is important to look closer at the melting process. When we picture melting ice most of us think of icicles dripping, or ground ice turning into a puddle. As with so many things in nature though systems are more complicated and interconnected, as evidenced by melting glaciers. In Greenland a fascinating phenomena has been observed, whereby a lake will form on a portion of the ice sheet. Interesting in itself, but the really amazing part of this story is how the lake will simply vanish in a matter of hours—Here one moment and gone the next! Where did the glacier lake go? These lakes drain out to the bottom of the glacier forming a lubricant for the ice sheet to slide on. Consequently, more ice reaches the open water and enters it. As air temperatures warm, more of the ice melts, more water drains out providing a lubricated surface for ice to slide along, and more enters the open ocean. This same process is occurring on the Antarctic Peninsula. Ice sheets the size of Rhode Island and hundreds of feet thick have broken off due to this process. Increasing ocean temperatures from global warming melt the portion of ice exposed to the sea. In Antarctica the vast ice sheets extending out to sea are melting. Ice sheets are not the only victims, though, as the adorable and inspirational Emperor penguins featured in March of the Penguins, have declined 70% in numbers since the 1960's.

The already bad situation to the north and south of the planet might get a lot worse due to a few so-called feedback loops, the first arising from the tendency of ice and snow to reflect the sun's radiation back into space, while open water absorbs it—The Albedo Effect. Greater ice cover then means cooler temperature, whereas more open water heats the planet. As the temperature increases with global warming, more ice melts enhancing the absorption of energy from the sun, thereby producing further temperature increases, melting more ice, and so on and so forth. The second involves warmer water evaporation leading to more cloud cover trapping in heat, thereby raising the temperature, and melting more ice. The third feedback loop concerns the Arctic permafrost, a deep layer of soil that remains permanently frozen so long as it stays cold enough. Billions of tons of carbon stored in this permafrost as methane might be released with thawing, thereby increasing greenhouse gases, that in turn will warm the planet further melting more permafrost and ice. What often at first glance appear to be simple and straightforward environmental changes have a way of being amplified in scope and complexity by these feedback loops, virtually ensuring that any predictions based on simplistic views will be underestimates.

Melting land-based ice has another profound effect on the environment, this one connected to the 1% found in mountains. Glaciers replenish fresh water supplies so vital to life. Snow and cold temperatures in mountain areas augment the ice in glaciers, and the melting of this ice at lower elevations during the spring and summer adds to rivers, streams, lakes, and underground water supplies. Unfortunately glaciers around the world are melting as if there's no tomorrow. One of the most picture perfect examples of global warming is to be found in photographs comparing glaciers now to a hundred years ago. In virtually all instances, the evidence is striking with the early 1900's one showing a healthy glacier, and the more recent picture the glacier vastly receded or even gone. For example, Mount Everest's East Rongbuk Glacier has lost about 350 vertical feet of ice during this 100-year period, now existing as a small remnant of its former self.

Asia relies on glaciers of the Tibetan Plateau, described as the roof of the world. The plateau and surrounding mountains contain the largest volume of ice outside of the polar-regions. Tens of thousands of glaciers give rise to and sustain Asia's largest and most important rivers, including the Yangtze, Yellow, Mekong, and Ganges. The Yangtze and its tributaries irrigate more than half of China's rice. Two billion people in more than a dozen countries, depend on these rivers that are in turn dependent on the glaciers of the Tibetan Plateau and surrounding mountains. Over 95% of the glaciers evaluated are losing ice, while at the same time water usage is increasing, the combination threatening the traditional balance between supply and demand. There has been some speculation about these glaciers melting entirely this century, but that appears unlikely. However, the imbalance between freshwater flow from these glaciers and increasing water usage will undoubtedly contribute to water shortages, particularly if current water usage strategies for agriculture continue.

Forest Fires:

In some regions warming of the climate appears to intensify forest fires. Warmer temperatures in some locations mean drier weather, with heat plus dryness increasing the risk of forest fires. These burning forests release more CO_2, understandable given that all vegetation releases CO_2 when dead or being combusted. Fire does not necessarily kill all vegetation and some trees have evolved resistance. Furthermore, fires have advantages such as returning minerals to the soil, clearing dead vegetation so that new growth can occur, and in some species (pine and oak) fire is needed to crack open the seeds. Like with so many things in life it is a matter of degree. Too limited forest fires, as happens with intense fire suppression, can leave a lot of dead and dry vegetation just ripe for creating a massive uncontrollable fire when conditions are right. Too intense fires can virtually destroy a forest producing a massive release of CO_2. In many parts of the world slash and burn agriculture is the norm, whereby vegetation is slashed down and burned to clear the land for planting. This practice contributes to the CO_2 we are pouring into the atmosphere.

A very interesting example of how global warming contributes to forest fires involves the mountain pine beetle. This 5 millimeter long beetle is found in the forests of western North America from Mexico to British Columbia. Although small in size, it has produced the largest forest insect blight ever in North America. Over vast swaths pine trees have died, with the dry decaying wood releasing CO_2. Forest fires appear to have increased as a result releasing CO_2 even faster, although this is not proven. In normal circumstances the mountain pine beetle actually contributes to the health of the forest by attacking old and weakened trees, thereby speeding up forest regeneration. Cold winters and wet summers keep the number of these beetles in check so they can really only damage the weaker trees. With global warming summers in some regions of western North America are drier, and perhaps of even greater significance, winters are not cold enough to limit their growth. Consequently, the outbreak that is occurring now is ten times that of previous ones.

Pine beetles spend most of their life cycle under the bark of pine trees where eggs are laid. The invading beetle releases a blue stain fungus that blocks the trees defenses, and also the flow of water and nutrients. Females invade first releasing chemical messages to attract other pine beetles, and with sufficient numbers the tree is overwhelmed and dies, cut off from water and nutrients. Huge swaths of forest in British Columbia and parts of Alberta are infected, with over 40 million acres in British Columbia alone! The Canadian Forest Service estimates that by 2020 the pine beetle outbreak will release 270 megatonnes of carbon into the atmosphere from Canadian forests alone. American forests are also affected with significant damage occurring in Colorado and Wyoming. As with any global warming issue there is controversy, with some people arguing that pine beetle forest kill might actually reduce available fuel for fires. Even if this perspective is shown to be true, it does not change the reality that pine beetle killed trees shift from CO_2 absorbers to CO_2 emitters.

Large healthy and mature trees excel at taking CO_2 out of the atmosphere to support photosynthesis (CO_2 + water in the presence of sunlight produces sugars) necessary for survival.

The larger and healthier the tree, the more photosynthesis and more CO_2 absorbed. Turning these CO_2 absorbers into dead CO_2 releasers is an obvious problem when it comes to managing greenhouse gases. The mountain pine beetle infestation adds to the transformation of mature trees from carbon removers to carbon contributors. This transformation is also occurring with slash and burn agriculture and industrial deforestation for timber and plantations (palm trees for palm oil and sugar cane for biofuel). These influences on the forests of the world are adding to atmospheric CO_2, with global warming producing the massive pine beetle infestation that in turn appears to be adding further to atmospheric CO_2 levels.

Hurricanes:

Also known as typhoons in most of the world, hurricanes can produce tremendous damage, making them the perfect poster child for environmentalists and environmentally concerned scientists and politicians trying to get a motivational rise, out of what sometimes seems to be a largely apathetic public. Unfortunately or fortunately, depending on your perspective, global warming does not seem to have a clear role in hurricane risk, as covered very well in The Climate Fix. One of the fascinating things with natural phenomena is that no one really seems to notice or care unless people are in the way. Imagine these two potential headlines in the news: “Hurricane wipes out palm trees!” “Hurricane destroys large town!” Any guesses as to the story that will sell more copies? If you picked the former do not consider a media career. Scary news sells and hurricanes fit into this very nicely given the potential for great damage. Linking global warming to forest fires involves an intrinsic logic. The same logic does not readily apply to hurricanes, and severe ones have been documented in the western Atlantic, Pacific, and Southeast Asia over the course of many years. It might be feasible that warmer surface water provides more energy to the hurricane in select instances, but there are undoubtedly many other factors influencing whether or not a weather system starting off the coast of Africa has a major, minor, or negligible impact on North America.

So if hurricanes and typhoons are not worse due to global warming, why does it seem to resonate with so many people? As Roger Pielke Jr (The Climate Fix) argues, the real issue is development and people living in the path of hurricanes that even our recent ancestors avoided. For example, the coastline of Miami has become vastly more developed then it was a century ago. A hurricane back then might only have produced the, “Hurricane wipes out palm trees” headline, but now it produces “Hurricane kills people” type headline. The latter phrase catches the attention of the public, and also that of insurers having to pay out large settlements. Supporting the role of development in our perception of hurricane severity, the most hurricane damage occurred in the United States during 1991-1994, a period that was also the quietest for hurricanes! People are getting in the way of natural events, such as hurricanes, and this amplifies public perception of the intensity of these events. The same problem seems to apply to flood damage, not surprising considering that when safer prime land is exhausted developers turn to riskier areas. They are not required to absorb the cost, or any portion of it, for building in the path of severe weather events. The profits are for developers while costs are for taxpayers and insurance companies, although the latter ultimately transfer these costs on to individuals in terms of higher premiums.

IS THERE ANY WAY TO SEE WHAT A GLOBALLY WARMED ENVIRONMENT IS LIKE?

So far we have seen what greenhouse gases and global warming appear to contribute to, and what they likely do not. It would be nice if we had an example of a globally warmed world that we can look at and observe the changes. That example is the Paleocene-Eocene Thermal Maximum (PETM) occurring some 56 million years ago, long before we arrived on the scene. Over a period of 20,000 years or so greenhouse gases rose dramatically and the planet warmed. The reason for this warming obviously could not have been mankind, but seems to have involved the release of carbon stores that occurred when the supercontinent Pangaea broke up. Molten rock and intense heat rose up through a landmass encompassing what is now Europe and Greenland. Baked carbon rich sediments released CO_2 into the atmosphere.

Another source of greenhouse gases during the PETM consisted of methane, the simplest hydrocarbon consisting of a single carbon atom surrounded by four hydrogen atoms. Methane hydrate is an ice-like compound with water molecules surrounding a single molecule of methane. This compound is stable only within a narrow range of pressure and low temperatures. Deposits of methane hydrate are found in Arctic permafrost, under the sea floor, and on slopes linking the continental shelves to the deep abyssal plains. With the tearing apart of landmasses and formation of the North Atlantic Ocean, massive amounts of methane hydrate were likely released. With 25 times the warming power of CO_2, and conversion to CO_2 after a decade or two, this methane release was a major factor, something to keep in mind when we consider current global warming and its impact on Arctic permafrost. It also appears that man-made global warming is now heating up cold ocean water, and releasing methane from the slopes linking the continental shelves to the deep abyssal plains, as occurred during the PETM.

Let us now look at environmental change associated with the PETM. Beyond any doubt things were very warm with a temperature increase of about 8 degrees Celsius. The region of the world including China, India, southern Europe, and the United States, that now includes half of the current population, scorched at over a hundred degrees Fahrenheit day and night. Animal and plant life migrated to the colder regions to the north and south. Ocean temperatures increased from top to bottom, such that the bottom was around 60 degrees Fahrenheit (F), up from the normal temperature of just above freezing. Arctic ocean temperatures in the summer rose to 74 degrees F. All that nice land ice keeping sea levels down was completely melted and sea levels increased by 220 ft! Recall I mentioned that a rise of about 1 meter (just above 3 ft.) is a reasonable estimate for what might occur by 2100 or so. Maybe that reasonable estimate is not so reasonable.

Acidification of the oceans evident with current global warming characterized the PETM, resulting in the virtual elimination of sea creatures relying on calcium carbonate. Goodbye corals and most shelled organisms. Oxygen levels on the sea floor were greatly reduced, leading to the death of additional marine organisms. Forests appear to have dried out in some areas likely contributing to increased forest fires, and insect populations grew. Consider how the mountain pine beetle might flourish in such a world. Clearly the PETM suggests that we might consider formally changing the term global warming to global warning. Some might question whether or not we can compare the PETM to the present. The evidence indicates that such a comparison is wise.

The burning of fossil fuels since the eighteenth century with the advent of industrialization, has released more than 300 billion tons of carbon into the atmosphere. Sounds like a lot but it only represents a tenth of that still in the ground transferred to the atmosphere during the PETM. Estimates suggest that if fossil fuel burning continues unabated we will be at the same place by 2400 as the PETM, making it an ideal model of what advanced global warming will look like. Interestingly, the situation might end up being worse than the PETM, because the time frame for change is a crucial factor in the ability of ecosystems to adapt. Prior to the PETM during the Cretaceous period, that ended 65 million years ago when an asteroid impact killed the dinosaurs, the world was a hothouse. Research indicates that species adapted better to this warming because it occurred over millions of years instead of the 20,000 of the PETM. Imagine if global warming and related changes were to occur over only 500 hundred or so years! Oh, but that is precisely what we are into now with global warming.

CAN WE DO ANYTHING ABOUT GLOBAL WARMING?

I sincerely hope that by this point no reader seriously doubts that we need to do something about global warming. If the problem continues unabated we are all in trouble. We are engaging in self-destruction, and certainly as pertains to our children and grandchildren. Anyone thinking that all is well should consider donating their brain to medical science, as it might go a long way in helping us understand how some people place massively positive spins on experience, even in the face of truly negative evidence. I know a person who was diagnosed with a form of blood cancer that few people survive. He never doubted he would live and sailed through chemotherapy remaining free of cancer ever after. Unfortunately, with global warming we are talking about a much more extensive system not likely to be profoundly, or even slightly, influenced by our best positive spins. I will assume that the majority of readers are with me that we should do something about global warming. Please note that I have not said what we should do or how much of it, just that we do something.

Surveys and just everyday conversation backs up the position that people are interested in doing something. The problem is that people are very confused about what to do and how much of it. Pessimism enters the picture with many hearing how it will all be too little too late. The failure of governments to address any of the global warming issues in a constructive fashion reinforces this pessimism. There is also opposition to any substantial change, such as opponents of wind farms arguing that our health suffers from wind turbines, and that too many birds and bats are killed. Then there is the hyper-growth focus of the economy with hyper-consumerism supporting it, requiring ever increasing fossil fuel consumption. Understandably the average person, and even those familiar with the issues, are doubtful we can do much, or that much will ever get done.

Fortunately, optimism is warranted based on a realistic option that will involve limited upfront expenditures and overall cost savings, plus many side benefits. As with any solution this one is going to take time, in the range of 20 to 50 years, so the sooner we start the better. First, however, let us consider the various things that we might try and do in response to global warming. Three general types of strategies have been proposed: Prepare so we can adapt, reduce CO_2 emissions, and remove CO_2 from the atmosphere. These types of action are not mutually exclusive, and any sensible person will agree that working on all three is the best way to go. This latter statement is important to keep in mind because often when a viable solution is proposed for a problem, people forget all others that can play a major role in the final outcome.

Prepare:

Be prepared as the Boy Scouts like to say, and prepared is what many parts of the world will have to be. Already some nations vulnerable to rising sea levels are taking action. In the Netherlands floating homes are being built and people are already living in them. Images of houses floating around come to mind (do I see a comedy movie here?), perhaps with piloting capacity so you can drop the kids off at school and then float to the office. Of course the school might float as well, so it could come to your house. Humor aside, these solutions are highly innovative and might allow a low-lying nation such as the Netherlands to survive, as opposed to becoming a scuba attraction. Along the same line, the Maldives has embarked on a highly ambitious project to build floating islands! A Dutch company has been partnered with bringing their experience and ingenuity to the project. Diagrams of the islands are stunning with multilevel green spaces and accommodations underneath the terraces. The price tag for even one of these islands must be incredible, making it hard to imagine how this could be done for the whole country, but at least they are trying. Beyond this ambitious project the Maldives government is buying up land in nearby countries in anticipation of moving some of the population, and has gone carbon neutral to limit their own contribution to global warming.

On a somewhat more modest note, countries might try to restrict development to areas elevated enough to survive at least a one or two meter rise in sea levels. Of course development is difficult to control, and as we have seen more people are getting in the way of unpleasant natural events, with developers only focused on profits more than happy to accommodate these desires, and even create the market. However, to be developing in areas that will be underwater without heroic measures is certainly either very shortsighted, plain crazy, or both. People must consider these issues when thinking of building in a given area, and politicians and regulating agencies need take this into account when approving projects. Pushing costs down the road is a popular strategy, but the costs might prove far too great favoring a more conservative approach, such as simply not developing regions that are projected to be submerged in several decades.

Forest fires are a consequence of global warming in some settings, and dead tree removal is a strategy to reduce this risk. In Colorado where trees tend to be densely clumped, removal in select areas where people frequent such as parks is ongoing. Governments in western Canada and the United States are trying to provide incentives for companies to harvest beetle-killed trees. The commercial timber life of these dead trees is about 8 to 10 years. Some effort is even being directed towards using these trees for biofuel or biopower. As with the flooding consequence of global warming, preparation strategies for forests are important. Unfortunately, a major problem with this approach is that it only works for some of the global warming impacts, and to a limited extent. Acidification of the oceans is an example of a global warming impact that we are really powerless to do anything about. Floating homes or islands are a very costly solution that might work to a limited extent for some wealthy individuals and nations, but are out of reach for most people of the world. Likewise, it will likely prove impossible to remove and market all the pine-beetle killed timber.

As is evident from the examples provided a lot of ingenuity is being applied to manage and prepare for global warming related events. Our ability to devise and modify technology suggests that further steps can and will be taken. Regrettably, these might prove to be grossly inadequate if we get to the point where sea levels rise above 200 feet, and most of the currently inhabited world is baking. In addition, it is a sad state of affairs given human ingenuity and technological ability to let it come down to preparing as best we can. Sure for earthquakes this does make sense, as we cannot predict when and where they will occur to any great degree of accuracy. Since buildings kill and not earthquakes, constructing earthquake resistant buildings has proven very successful. The 2010 Haiti earthquake was so devastating not because of the event itself, but due to the interaction of the event with shoddy construction and the high-density population in the capital city. So while global warming preparation is important, hopefully we will not rely on this approach as our major one.

Reducing CO2 Emissions:

Most attention by far has been directed to this category of global warming response, and you would have to be living in the most remote part of the world, or perhaps moon, to not have heard of many of these options. Generally speaking ways of reducing CO2 emissions can be divided into improved efficiencies and switching to greener sources of power.

Improved Efficiencies: We all are aware of much more efficient light bulbs that can save a great deal of energy, and hence money, for both individuals and businesses. Appliances of old were energy consuming monsters compared to the greater efficiency of modern units. Efficiency certifications such as Energy Star indicate that a product is a winner in terms of the energy required to operate it. Many individuals and businesses have already made the switch to more energy efficient lighting and appliances. Even entire houses and building have been designed based on principles of energy efficiency, with the LEED (Leadership in Energy and Environmental Design) representing the highest of green standards. One component of LEED design is high efficiency windows that quadruple the thermal performance of double pane glass, and can be made from regular glass. Windows of the Empire State Building have been converted. Other innovative strategies applied to buildings and homes include white roofs reflecting heat thereby lowering cooling costs, and green roofs insulating against heat and cold while absorbing storm water.

Great improvements in energy efficiency have also been made in transportation. Efforts are focused both on improved mileage using regular fossil fuels, and use of greener strategies such as hybrid and purely battery-operated cars. Currently the gas-guzzling beasts of the recent past are being replaced with vehicles with a much reduced carbon footprint. So-called Smart City Technology can assist in the energy efficiency of transportation, such as by informing drivers of what roads, or even sections of a parking lot, are crowded to prevent congestion and unnecessary burning of fossil fuel. All these efforts are to be applauded both for the designers of the technologies and users, because overall they are significantly reducing our carbon footprint.

Greener Sources of Power: Green energy provides lower carbon energy than burning fossil fuels. Wind turbines harness the power of the wind in a similar fashion, but at a much larger scale, than farmers of the past using energy from windmills. There is solar power taking sunlight and converting it to energy, either solar-thermal or solar-photovoltaic. Solar-thermal is more for large-scale applications with focused sunlight heating water or oil based fluids. The heated fluid is carried in pipes to a heat exchanger, where it is converted into steam to drive turbines. Solar-voltaic generates an electric current using two layers of semiconducting material. When sunlight is absorbed, excess electrons move from one layer to the other generating an electric current. This type of solar power is suitable for smaller-scale applications such as on rooftops.

A major issue with wind and solar energy is that they are not always available, and the energy generated has to be stored for when the supply diminishes. Even placing wind turbines in very windy areas and solar power devices in sunny locales, does not guarantee a constant supply of the natural ingredient. At night solar power is of course inactive, and cloudy days cannot be controlled. Storage of the energy is a major limitation, as there is currently no cost effective way to store the energy until when it is needed. With coal fire plants the burning of fossil fuels can just be increased or decreased to align with demand. An interesting option is to create a high voltage backbone akin to major highways for the power grid. The existing grid in North America cannot reliably handle huge bulk transfers, as with an inflow of green energy from wind turbines or solar power. A new high voltage system could handle this input shunting the power to where it is needed. No new technology is required, but the cost is about 2.6 million dollars per mile, and in the United States alone 19,000 miles of transmission are involved. Another impediment is the lack of commitment on the part of the relevant governments to integrating the electrical system on a continental scale.

Geothermal and ocean wave power are additional sources of green energy. Geothermal power relies on so-called hot rock within the earth that is fortunately present in many areas. In the best scenario heated water flows up by itself, but most areas with geothermal potential have "hot dry rock" requiring fresh water to be injected down and then recovered. The additional effort required with the latter type of rock reduces the efficiency of the system, as power is needed to inject the water, and valuable fresh water is consumed. With either wet or dry hot rock the heated water is typically converted to steam that drives turbines. An advantage of geothermal power over wind and solar is that it is always available, and the flow can be turned on and off to align with demand. Ocean wave power is more in its infancy than wind, solar, and geothermal, but has real potential in select areas. As the name implies, the immense power of waves is the basis of this green source of power. Strategies can vary, one being to build steel or concrete columns open below to the water and closed at the top. Wave action alternately pressurizes and depressurizes air at the top driving a turbine. Given that wave action in certain areas, such as the Pacific Northwest, is quite constant it could provide a steady source of energy.

Two green sources of energy that have been around now for quite some time are hydroelectric and nuclear. Hydroelectric involves harnessing the power of rivers and waterfalls to turn turbines that generate power. Frequently a dam is built to control the flow of water to turbines, such as at the impressive Hoover Dam. Unfortunately, this green source of energy appears to have reached its peak in almost all areas. In Canada, an amazing 61% of total electricity consumption (as of 2008) is provided by hydroelectric power, making it difficult to imagine increasing reliance on it further, although a new Niagara Falls project is providing power to about 160,000 homes. The United States meets only about 3% of its electricity needs with hydroelectric power, and there are few options for increasing this percentage short of buying Canadian generated hydroelectric power. Many argue that hydroelectric power is already overdone, being responsible for environmental damage related to altered and reduced water flow, and flooding of areas above dams. Major expansion of this green source of energy is unlikely, and in some instances dams are being decommissioned.

We are all familiar with nuclear power and the potential risks. Nuclear power is really nuclear fission, whereby atoms are split releasing enormous amounts of energy. Nuclear fusion is a process occurring in the sun involving two or more atomic nuclei fusing to produce a single heavier element, such as hydrogen nuclei combining to make helium. The formed element is slightly lighter than the ones creating it, and the extra mass is transformed into energy. Nuclear fusion is the holy grail of clean energy, in essence giving us the power of the sun in a much more limited, and hopefully contained manner. However, by any reasoned estimate we are a long way from developing nuclear fusion as a viable and cost effective source of energy, perhaps even centuries, so it is not reasonable to consider it as a source of green energy we can expect to have any time soon.

The green sources of energy mentioned so far have been those contributing to the power grid, but what about switching from fossil fuels to greener fuel. Biofuels seem to be the most popular answer and ethanol from corn and sugar cane has entered gas tanks. It's all good, right? Let us take a closer look. To make biofuel plant material has to be fermented, much as with making the alcohol that we drink. Yeast or bacteria is mixed with the plant material in large tanks, and as the little organisms digest the plant material they release ethanol. The desired product must be distilled as with beverage alcohol, a process consisting of heating the mixture to boil off the ethanol and trap it in a separate container. You might ask where does the energy come from to boil off the ethanol? Good question, and as it turns out from fossil based fuels like coal or natural gas.

The energy that is derived from biofuel turns out to be only somewhat greater than the energy that goes into producing it! The input-output ratio is much better for sugar cane than for corn, however rainforests that absorb CO2 from the atmosphere are being cut down in some instances to grow the sugar cane. Weighing into the equation the energy consumption involved in land clearing and the overall impact of deforestation, it turns out that the CO2 release and consequent global warming resulting from sugar cane, and some other biofuels, actually appears to exceed any reduction achieved by replacing good old gasoline. Furthermore, a gallon of ethanol only provides two-thirds the energy of a gallon of gasoline. Corn-based ethanol produces another problem, namely that corn for food is diminished, diverting it from the mouths of the billion or so people who are hungry each day. In the United States 40% of corn cropland has been diverted for biofuel driving up corn prices. This intensive industrial farming has also produced a massive dead zone in the Gulf of Mexico, caused by fertilizer runoff in the Mississippi River favoring the growth of algae. It has been suggested that what will destroy the planet is not global warming, but changes resulting from biofuel development. Sometimes it seems like we just cannot win.

A potential solution that seems great on the surface is so called grassoline—Instead of using crops like corn and sugar cane, fast growing grass and waste vegetation like the discarded remains of annual crops are used. The major problem here is that nature has evolved great strength in the cellulose walls of plant material, and chemically breaking down those walls to produce a fermentable solution is extremely expensive and energy intensive. Another option is using algae to produce fuel in the form of plant oil. Some strains of microscopic algae can harness 3% of sunlight to make plant material, as opposed to 1% for corn and sugar cane. Ponds of algae could conceivably produce plant oil for fuel. Although this is a potentially solid option requiring further work, there are numerous problems the first being how to preserve the algae against the elements and predators. To ensure that algae grow well nitrogen and phosphorous must be provided, adding cost and environmental impact issues. Furthermore, mature algae cell walls will not give up the oil easily and must be broken down using fossil fuel energy. As with corn and sugar cane, the overall cost-benefit ratio might not be that favorable.

While biofuels do seem to present an option for greener energy to put in our gas tanks, the promise might be a false one. The best-case scenario is that they will offer an alternative source of fuel with a poor input-output ratio, particularly when several undesirable byproduct effects on the environment are taken into account. Despite hopes, scientific and business knowledge, and massive government subsidies, no biofuel has come close to the cost of fossil based gasoline. Without the financial subsidies the costs are so much higher that few will switch to biofuel. Using electricity to fuel cars is a promising option, but of course the power must come from the largely fossil fuel based power grid, and batteries capable of providing long-range capacity are difficult to produce.

What Might Green Sources of Energy Achieve? We have looked at green sources of energy and how there are significant limits on some, such as furthering the use of hydroelectric power and the poor input-output ratio of biofuels. However, the important question remains of what can green energy achieve in terms of reducing CO2 emissions? I will focus on sources contributing to the power grid and not fuels, because as we have seen gasoline is not going to be replaced by biofuels any time soon, and the net benefit of biofuels to the environment and the level of atmospheric CO2 is highly questionable. In addition, the preference of many people for large vehicles worsening global warming does not seem to be disappearing.

How much energy do we actually use? It is very crucial to understand our real energy usage if we are to arrive at a way of dealing with it. I will apply the analysis conducted by Roger Pielke Jr. in The Climate Fix, as it is both very comprehensive and revealing. As of 2006 the world consumed about 472 Quads of energy per year. To give a feel for how much power this is, a Quad is 11,000 megawatts and the average nuclear power station generates about 750 megawatts of power per year. Hence, it takes about 15 nuclear power plants to generate 1 Quad of power, or about 7,080 nuclear power plants to meet the worlds current energy needs. There are presently only 430 nuclear power plants with 474 planned. Clearly we love energy, and in nuclear power plant equivalents we are far short of what is needed.

Planning for energy usage cannot stop at what we currently use because demand is increasing. Gross Domestic Product (GDP) is the value of all goods and services produced within a nation in a year, and an indicator of economic growth. As the GDP increases so do carbon emissions according to an analysis by, Maddison and the US Energy Information Administration. Assuming a modest increase in energy consumption of 1.5% per year, based upon ongoing economic growth, we have to add 206 Quads of energy used per year for the entire world by 2030. In nuclear power station equivalents that means adding about 3,090 more such power generation facilities. Oh, and we forgot about the 1.5 billion people who do not have access to electricity currently, but should have it. We will obviously need a lot more energy in the future.

To give another perspective on the need and what it will take in terms of green energy, if we were to reduce 2006 fossil fuel consumption levels by 10%, it will require 692 new nuclear power stations, 157,000 solar thermal plants, and 625,000 wind turbines to achieve it! That is for a 10% reduction, and we are not factoring in increasing energy consumption with economic growth, and those 1.5 billion people that have to be granted access to power. What about achieving the Copenhagen Consensus on Climate Change of 50% below 1990 levels by 2050? Between 1990 and 2012 the world's use of fossil fuels only decreased from 88% to 87%, and renewable sources now comprise just 3.35% of the total, according to energy researcher Yaclav Smil. Factoring in ongoing economic growth and those 1.5 billion people not on the system currently, it would take the equivalent of something like 12,000 nuclear power stations, requiring us to build one per day until 2050. It is difficult enough to get one built in most countries let alone 12,000 worldwide.

At this point some astute readers will suggest that the problem is economic growth, and that if we reduce it our power consumption needs go down. The IRON LAW as Roger Pielke Jr. refers to it kicks in at this point—Whenever, economic growth and global warming concerns counter each other economic growth always wins. Presently, no country is going to voluntarily give up on economic growth. But is endless economic growth inevitable? In an ideal world no, and such growth ultimately requires cheap and abundant resources that are rapidly dwindling. Biological organisms do not grow forever and endless growth is impossible as we learned in the Taking The "Devil" Out Of Development chapter. Many businesses like family owned small-scale operations make a profit, but one that remains relatively consistent over time. So there is no absolute reason why endless economic growth should be required. However, so long as it is insisted upon by corporations, shareholders, and politicians essentially working for corporations and the financial elite, we have no chance of controlling global warming via green energy, or likely by any alternative or combination of options for very long. Furthermore, if the unsustainable drive for endless growth requires that all global warming moderation strategies fully align with economic considerations, there will be very few if any options available to us.

For the present we have to assume that economic growth will not be sacrificed voluntarily. Leaders of developing countries like India have been very public about this reality, and if you look at what has happened since global warming became a concern, it is obvious that economic growth never loses to global warming. Hence, global warming moderation strategies must align with economic growth if they are to succeed. For example, many companies have adopted green policies not because they are being altruistic and willing to sacrifice financial growth. No, they make the switch because the economics favor it. For example, recycling waste cuts way down on the costs of disposing garbage. Even if there is a small up front economic hit there are compensating benefits in other ways, such as attracting environmentally conscious consumers who will buy their products over those of less green competitors, or tax advantages. The second iron law of global warming might then be—Global warming moderation strategies must align with economic growth considerations if they are to succeed. Although it follows directly from the first iron law, it emphasizes what must be present in any global warming moderation proposal if it is to be a winner, at least within the current endless growth economic world.

Anyone concerned about the environment has to feel some degree of frustration about the agonizingly slow switch to green energy. We have been hearing about global warming and related climate change for many years now, but nothing really changes. If anything we seem to be building more coal fire plants and relying more on fossil fuels. Are we insane? Well perhaps we are but the iron laws of global warming show us why the shift to green energy is not taking place—Simply put, it costs too much and hence does not align with economic considerations. China burns more coal than the United States, Europe, and Japan combined, because its economy is growing with manufacturing requiring cheap energy. Manufacturing as a component of the economy is declining in North America and Europe, but we are still increasing our energy consumption. We can blame China, but this is pointless because they are doing what we all are, putting economic growth before global warming considerations. Take yourself for example, while you might be willing to spend slightly more for green energy, if you are like the vast majority of people, slight will be the operative word, because even a modest increase in your energy costs will not be accepted. In 2009 a poll was conducted in the United States asking respondents about their willingness to support a proposed climate bill in Congress, at three different levels of annual cost per household. At $80 a majority supported it, at $175 support dropped by half, and at $770 ten times more respondents opposed than supported it. Even $770 per year per household could be seen as moderate but opposition was enormous, with support really only found for the low amount of $80 per year. So how can we expect China or any country to accept much higher energy costs that counter economic growth? We simply cannot in the context of our current economic model.

Green energy costs far more than coal, much as unsubsidized biofuels do compared to gasoline. Of course if full environmental accounting was required, and producers and consumers of "dirty" energy paid for negative externalities, the cost of green energy sources would be closer to that of coal and gasoline. Something referred to as, the green paradox, adds another layer of complexity to the situation. The green paradox reflects how markets actually work focusing on what would happen if green energy all of a sudden dropped in cost. Some people assume that everyone would rush to buy green energy and that would be that. Market forces, however, dictate that suppliers, of let us call it dirty energy, would cut the cost of their product to outcompete green energy, ensuring that most customers will not switch over to the latter product. Can you imagine suppliers of dirty energy saying, "Well that's it then, let's just shut the doors for good." No, they will fight for their survival. Of course if the cost of green energy dropped greatly, such that the costs of dirty energy cannot compete, then green energy wins in regards to the iron laws. Unfortunately, we are a long way from this scenario. Vastly increasing the supply of green energy will reduce the cost due to improved efficiencies, but this will not be enough to successfully compete with dirty energy. Some argue that natural gas and fracking to bring it to the surface are a key part of the solution, but there is a lot of debate regarding the safety and environmental impacts.

Fracking involves drilling into shale deposits and injecting millions of gallons of water, chemical lubricants, and sand at high pressure to fracture the shale and allow trapped natural gas (or oil) to travel up the well. The main component of natural gas is methane, and the possibility exists that disturbing deposits of natural gas will allow methane to escape into the atmosphere, mitigating any pluses in reducing global warming by burning natural gas (from fracking) over coal. There have been numerous reports of methane emerging from taps in homes located near to fracking areas, providing support for this assertion. In addition, groundwater is often contaminated due to the chemical lubricants used, adding a massive environmental cost.

The rush is on to maximize this source of natural gas (and oil) without due diligence in testing for health and environmental impacts.

We Are All In A Very Big Bath Tub:

Let us assume for the moment that we live in an ideal world where the iron laws do not apply. Would everything be fine with us simply switching to green energy and driving atmospheric CO_2 levels right down? The answer appears to be no. First, there is the matter of how great the increase in green energy would have to be covered earlier, keeping in mind the provision of power to the 1.5 billion people lacking it now. Also, we might want to consider that the population of the world is growing, and these extra people will also want affordable power. Second, and more profound is what is known as the bathtub analogy. When water is run into a bathtub there are input-output forces to consider, although I suspect most of us look at a bathtub as a place to get clean or relax. Science is everywhere, including in your bathtub, but please resist the temptation to imagine a scientist peering up from the drain. If the water is running and the plug is in, the tub will overflow. When the plug is removed the water drains, but what if the plug was only partially removed or plugs with varying sized holes substituted. Also, we will adjust the flow rate. Whether the water volume in the tub increases, remains the same, or decreases, depends on the rate of inflow compared to outflow. In the same way atmospheric CO_2 levels depend on the relationship between emissions and CO_2 removal by so-called carbon sinks, or natural ways that the earth reabsorbs CO_2 from the atmosphere.

The concept that I am about to present is one that even graduate students at MIT have trouble understanding, according to John Sterman, an expert on this process, who cites it as a cognitive limitation blocking effective global warming solutions. So if you follow this you are ahead of many graduate students and on the path to solving the global warming problem. It is often assumed that if we substantially cut CO_2 emissions atmospheric levels will plummet, analogous to simply pulling the plug out of the large bathtub we are all in. Unfortunately, this large bathtub has a plug containing only a small hole limiting the overall capacity of the environment to remove CO_2 from the atmosphere in a given time frame. CO_2 levels will not plummet and might even continue to rise. The reason has to do with the capacity of carbon sinks.

Different natural carbon sinks exist, the major ones being plants and soil, oceans, and mixing with rocks and minerals. Plants and soil absorb CO_2 rapidly, but this carbon sink is currently limited due to deforestation and the agricultural system we have adopted, the latter a topic we will get to shortly. The ongoing deforestation of the world does not help at all, because large trees provide some of the best CO_2 absorption there is. Since deforestation fosters economic growth, stopping it to moderate global warming violates the iron laws, meaning that we cannot expect it to end with the current endless growth economic system. Oceans can absorb a massive amount of CO_2, but it is a slow process over decades and centuries. CO_2 laden ocean water sinks depositing the CO_2 deep down, but this sinking process only occurs at the poles limiting the speed, as with a bathtub plug possessing a couple of very small holes. Rocks and minerals that are broken up through weathering and other processes can absorb all the CO_2 we are putting out. Even calcium carbonate will be returned to the sea as atmospheric CO_2 binds with calcium leeched from rocks by rain. The only problem is that CO_2 absorption by rocks and minerals occurs over centuries and millennia, so it will all be good in about 10,000 years. Think of a microscopic hole in our bathtub plug.

We are all in this large tub that is overflowing with CO2, and even if we get around to radically reducing CO2 emissions (very unlikely), the concentrations of this global warming gas will remain elevated, and maybe even increase for years to come. BOY, ARE WE IN TROUBLE! At this point most of you are likely feeling somewhat down, maybe even depressed, and not seeing much hope. Perhaps some of you have taken a break and gone on line to see if you can volunteer your children or grandchildren to be the first to colonize Mars. But are things hopeless? Should we be investing in massive arks to carry civilization as the seas rise? There is one more option available to us, that being to scrub or artificially remove CO2 from the atmosphere.

Scrubbing CO2:

Artificial removal of CO2 from the atmosphere can be achieved by technology. For years CO2 from human respiration has been scrubbed on submarines, spaceships, and by scuba rebreathers using filters. Building machines that can scrub CO2 right out of the air is a brilliant idea. Although designs vary the basic principle is the same. Wind enters the machine through inlets and comes into contact with filters laced with an absorbing agent. CO2 is acidic and a base such as sodium carbonate is used in the absorbing agent. Contact with the absorbing agent draws CO2 out of the air, forming sodium bicarbonate or baking soda. Through chemical means the CO2 is recovered and compressed to a liquid. Once in liquid form it can be stored deep underground where it will remain, at least theoretically, being absorbed by rocks and minerals.

Wow, does that sound great! It actually sounds more than great, and maybe too good to be true. As it turns out there are several problems with this option, the main one being the cost-benefit ratio. A detailed economic analysis by Jennifer Wilcox of Stanford University and colleagues, published in the Proceedings of the National Academy of Sciences in 2011, found that the cost-benefit ratio does not justify these approaches. Substantial energy and associated costs go into these machines, with manufacturing of the housing and materials, and powering of the unit so that CO2 can be captured, separated, and compressed into a liquid. Then there is the cost of storing the liquid CO2 with another analysis showing that the amount of metal piping required to do so would be virtually astronomical. Where would all the energy come from to manufacture the scrubbing machines and piping to store the liquid CO2 underground, and power the process? If it comes from fossil fuels the benefit is not there as CO2 emissions from the required fossil fuels are far too great. If the energy comes from green sources, it is best to apply it right to the grid to reduce our reliance on coal and natural gas.

Even the economic cost itself is too great amounting to $1,000 per ton of carbon, equivalent to a $10 per gallon tax on gasoline to cover it. In contrast the cost to scrub CO2 right from the smoke stacks of coal fired power plants is only $50-$100 per ton, and these are crucial point sources of CO2 emissions. Ah, so why do we not add scrubbers to smokestacks of coal plants? The why is that it costs too much raising the price of previously cheap energy. China has indicated that it is too expensive to add these to the coal fired power plants it has, and is producing more of these plants every day. Once again we see that when global warming moderation efforts counter economic considerations, the latter wins every time. If the much lesser cost of point source CO_2 scrubbing will not wash, excuse the pun, then there is no way that the much more expensive CO_2 air scrubbers will ever fly.

We do seem to be running out of options and colonization of bleak Mars is looking brighter. Perhaps due to desperation, human creativity, or a bit of both, some more let us say oddball solutions have been proposed, and even tried. One such scheme arose from the realization that phytoplankton (plant marine organisms) blooms in the ocean are limited by not nitrogen and phosphorous, but by iron. Dust rich in iron blown from African deserts and falling in the Atlantic, has triggered phytoplankton blooms. The logic went, that if we add a large amount of iron to the ocean we might induce more phytoplankton growth that in turn absorbs CO_2 for photosynthesis. As the phytoplankton sinks down it takes the CO_2 with it, thus taking care of our atmospheric CO_2 problem. As you might imagine the project failed because of unforeseen consequences. As the plankton sank it also took with it nitrogen and phosphorous, reducing the amount available in other parts of the ocean, thereby limiting the growth of CO_2 absorbing marine plant life in more distant areas.

The spraying of aerosol particles into the atmosphere to reflect sunlight has been another solution of this type. Observations of ash sent into the high atmosphere from the 1991 Mount Pinatubo eruption, revealed that even though there was a sunshade cooling effect it was very brief, because the particles settled out of the atmosphere very quickly. So any aerosol strategy would require ongoing seeding at a staggering cost, and even then there could be unanticipated and dangerous consequences we cannot predict. Interestingly, over the last couple of years the pace of global warming has slowed slightly, largely due to the high number of volcanic eruptions and the reflecting of sunlight by the released ash. Unfortunately, as the ash settles out of the sky global warming will return to its normal pace, and maybe even make up for the delay.

In evaluating the potential of any so-called, geoengineering project, the criteria proposed by Dan Sarewitz and Dick Nelson, published in Nature (December 2008) are useful to consider. First, the strategy must have an established base of knowledge and experience, improving upon what already exists. Second, there must be a clear link between what the strategy is designed to do and what it actually does. Third, the results must be clearly measurable. Based on these criteria iron to grow phytoplankton and spraying aerosols into the atmosphere fail miserably. There is no solid knowledge or experience other than somewhat related observations of natural phenomena, what they actually achieve is not always what they are intended to, and it is difficult to assess impacts. In contrast, scrubbing CO_2 from the atmosphere with filters is based on existing technology, there is a clear link between what it is intended to do and does, and the results are fairly easy to measure. Unfortunately, the cost-benefit balance is not at all favorable.

So where does this leave us? Are we out of options? There is one more possibility that actually involves returning the earth to how it was prior to our changing it with annual plant agriculture. This strategy offers the possibility of massively ramping up the plant and soil carbon sink, and given the rapid absorption of CO_2 via this route atmospheric, levels could actually plummet. It brings to mind War of the Worlds where all our sophisticated technology, nuclear included, could not stop the invading Martians, but simple and natural common cold viruses could. Let us consider this hopeful scenario.

CONVERTING AGRICULTURE FROM ANNUALS TO PERENNIALS:

Annual plants add CO_2 to the atmosphere, whereas perennials remove it. It has been estimated that while annuals add about 410-1140 kg of CO_2 per hectare per year, perennials remove from 200-1050 kg of CO_2 per hectare per year. Common (or previously so) perennial grasses can even absorb and store a staggering 500-2,000 kilograms of carbon per hectare! To place the CO_2 scrubbing capacity of perennials in a more meaningful context, the United Kingdom's Biotechnology and Biological Services Council has calculated that if we replaced only 2% of annual crops with perennials, we could remove enough carbon from the atmosphere to halt the increase in atmospheric CO_2! If we were to replace all farmland with perennials we would sequester about 118 parts per million of CO_2, enough to return the world to preindustrial levels! In addition, plants and soil sequester atmospheric CO_2 very quickly compared to the other major carbon sinks. This is amazing, particularly considering the dismal scenario for managing global warming that we were looking at until this point. But how can this be?

The planet appears to require perennial vegetation to sequester carbon from the atmosphere. CO_2 is absorbed for photosynthesis and the carbon enters the soil via the roots. In forests virtually all vegetation consists of perennials, including trees and shrubs. Roots that commonly spread twice the height of the tree, and in many cases fairly deep in the ground, deliver carbon to the soil, the most significant carbon reservoir. On prairies, steppes, and the tundra, virtually all vegetation consists of perennial grasses and plants. Perennial plants have roots extending about 8-12 feet, as opposed to 1 ft for annuals. The capacity of perennials to transfer carbon to the soil is then much greater; perennial crops can transfer 320-440 kilograms of carbon per hectare per year, compared to from 0-300 kilograms by annuals. Douglas Kell, professor of chemistry at the University of Manchester and Chief Executive of the Biotechnology and Biological Sciences Research Council, estimates that by increasing soil carbon just 15%, atmospheric carbon levels could be lowered by 30%.

Beyond their carbon transfer ability perennials survive for several years, leaving the soil undisturbed and the carbon trapped inside. With annual agriculture the soil is frequently disturbed for seed planting each year, and plowing the plant refuse underneath after the harvest releases carbon. Of course, decaying plant material itself returns carbon to the atmosphere. Hence, with annuals crops carbon is released, and with perennials carbon is stored in the soil. A massive benefit then ensues from the conversion of our major annual crops to perennials, in terms of cutting CO_2 emissions while at the same time vastly ramping up CO_2 absorption! Nature had it worked out, until we changed it. Readers knowledgeable about farming might argue that some annual farming does not disturb the soil and release carbon. With high quality farmland there is still a low-to-moderate risk of soil degradation, but only 12% of farmland worldwide is high quality. An incredible 33% of the world's farmland, supporting 50% of the population, is marginal in quality.

Another major problem related to the release of carbon from soil is the washing away of soil by rains. Perennial roots being so deep and extensive keep the soil intact, acting like rebar in concrete. With annuals the roots are shallow and limited, plus they die off each year. Rain can then wash the soil away, and wind can blow off the top layer if loose. On completely level fields the washing away of soil is limited, but a staggering 45% of the world's farmland is on an angle of 8% or greater, and 135 million hectares on an angle of 30% or greater (think ski hill). These inclined slopes are not compatible with annual plants, because the soil rapidly washes away with rainfall. Even targeting farmland on the steepest slopes for perennials would sequester 3.3 billion tons of carbon, a third of what we emit annually. A hundred years of comparing the relative capacity of annuals and perennials to retain topsoil, reported by Gantzer and colleagues in 1990, found that perennials were 50 times better at it.

The water part of the equation is important to consider. With sloping fields not only soil washes away but fresh water, an increasingly valuable commodity, and one that is only going to become more important with an expanding population. Currently we are rapidly depleting groundwater reserves worldwide to supply annual crop agriculture. When these freshwater supplies run out these crops are finished. Even level high quality farmland loses water with annuals because the root system is so limited. The roots of perennials act like a sponge absorbing water during times of plenty, and releasing it when conditions are dry. Hence, perennials are crucial to fresh water conservation. Related to this function they play an important role in reducing floods that kill people in many parts of the world, via their ability to stabilize the soil.

A further advantage of perennials is nutrient retention. Nutrients such as nitrogen and phosphorous, are absorbed from the soil by fungus in the plant's root system, and transferred to the above ground portions of the plant. The extensive root system of perennials is incredibly well suited for nutrient retention and conservation. Annuals on the other hand are really poor performers in this regard, and soils become depleted of crucial nutrients very quickly. Even with flat high quality farmland where soil erosion can be limited, nutrients are still lost with water runoff. The same applies to fields where conservative tillage (leaving crop residue) and no tillage are applied to conserve topsoil. So how do annuals survive? They only do so with our intensive help in terms of, adding fertilizer to provide nutrients, pesticides to protect the crops, and water via irrigation techniques. These inputs in turn rely on the burning of fossil based fuels, further adding CO2 to the atmosphere. Without our artificial help involving very costly CO2 emitting fossil based fuels, annuals would never provide us with the food we need. Much of Africa is currently caught in a vicious cycle, whereby due to food scarcity high yield annual crops like corn and rice are planted, but lack of availability and the high cost of commercial fertilizer greatly limit its application. Consequently, the soil becomes progressively more depleted of nutrients, resulting in diminishing crop yields, more hunger, and further reliance of nutrient depleting high yield annual crops.

One of the more interesting aspects of this story is that without a chemical process invented by the German chemist Fritz Haber early in the 20th Century, 30-40% of the population would not be here given our reliance on annual crop agriculture. Although arguable the most important scientific discovery of modern times, few people are even remotely aware of the Haber-Bosch Process. Haber invented it and Bosch helped commercialize the process, whereby atmospheric nitrogen is converted into ammonia for fertilizer. In the absence of this chemical process annuals could never supply the food needs of the world, given their poor nutrient retention capacity. Perennials with their excellent nutrient capacity do not require fertilizer, or in the worst-case scenario, only 3% of that required by annuals.

Given the poor nutrient retention of annuals it is not surprising that most of the added nutrients are lost with rainfall, only to accumulate further away. Global data for corn, rice, and wheat annual crops indicate that only 18-49% of nitrogen applied as fertilizer is taken up by crops while the rest is lost. Nitrogen losses from annual crops are 30-50 times higher than for perennial crops. Currently, there are hundreds of dead zones along coastal waterways. The largest of these covers 70,000 sq km, with perhaps the most well known one in the Gulf of Mexico being around 22,000 sq km, this one due to fertilizer runoff from the Mississippi River. They are called dead zones because oxygen is depleted, thereby killing animal species requiring oxygen. When fertilizer enters the sea the nitrogen and phosphorous contained within it promote the growth of small plant organisms (phytoplankton). Bacteria proliferate to eat dead phytoplankton that sinks to the bottom, and these bacteria use up all the oxygen. Consequently, fish and other marine animals die off. Fertilizer based phytoplankton growth also contributes to the die off of corals, such as in the Caribbean. In addition to water-based runoff of fertilizer nitrogen, much of it evaporates to nitrous oxide, a potent greenhouse gas adding further to atmospheric CO_2 levels.

Now you might say, okay I'm convinced that we must switch from annual to perennial agriculture, and wonder why we did not think of it earlier? When looking ahead the solution lying behind can often be missed. We are so used to annual crops that we do not consider alternatives, including what came before them. Our early ancestors saw annuals as the best option because the seeds are larger, and by planting the best seeds from each crop they could increase their yield with succeeding generations (artificial selection). Seeds of perennials are smaller producing a lower yield. Now at this point the skeptics will be thinking that perennials will not work due to the lower yield. Fortunately for us, the small seeds of perennials are not inevitable, but the result of natural selection in stable and competitive environments favoring longevity. In most natural setting plants compete for resources, such as sunlight, water, and nutrients. Diverting the plants energy to the root system where water and nutrients are absorbed, and making sure that the roots grow stronger over years is the best way to compete. In a setting aided by man that reduces this competitive pressure, larger seeds are definitely possible. Of course, the large seeds of annuals are in large part due to the artificial selection provided by man.

What will it take to switch from annual to perennial agriculture? Presently virtually all of our major grain crops are annuals, the thirteen most common being wheat, corn, rice, soybean, sunflower, oat, barley, chickpea, common bean, peanut, pearl millet, rape, and sorghum. Perennial fruits include apple, apricot, avocado, banana, blackcurrant, grape, kiwi, pear, pineapple, plum, strawberry, and raspberries. Perennial vegetables include eggplant, broccoli, asparagus, leek, potato, rhubarb, spinach, taro, sweet potato, and watercress. Perennial herbs consist of alfalfa, basil, dill, garlic, ginger, horseradish, lavender, mint, onions, oregano, sage, and thyme. Clearly perennials are a type of plant we are familiar with, so the conversion of our most abundant grain crops from annuals to perennials is not radical.

While we are more familiar with perennials than most of us realize, it will take some effort to switch our main grain crops from annuals to perennials. What will be required is a combination of techniques, including artificial selection, hybridization, and genome derived knowledge. Researchers believe that applying artificial selection in a properly managed agricultural environment can produce a good seed yield in perennials. Four characteristics of perennials contribute to this potential, the first being the long growing season. In warmer climates perennials grow all year round providing ongoing food production. In colder climates parts of the root and exposed portion recede or die off during winter, but some of the root remains. Consequently, growth tends to occur earlier in the spring than it does with annuals. For example, in the Land Institutes research breeding nurseries in Kansas, shoots emerge from underground stems (rhizomes) of perennial sorghum a month earlier than shoots emerge from seeds of annual sorghum. Intermediate wheatgrass (a perennial) maintains a photosynthetically active leaf between July and September, when annual wheat plants are not growing at all.

The second characteristic of perennials giving them the potential to provide good seed yields with artificial selection is the very efficient use of nutrients. As reported by Cox and colleagues, in Kansas perennial hay has been grown adjacent to wheat and the nitrogen balance in each has been carefully measured. Both have been harvested for about 75 years, and yield similar amounts of nitrogen in the form of hay or grain. However, 70 kg of fertilizer nitrogen has to be added per hectare per year to the wheat fields, while none is added to the hay fields. Nitrogen levels are far greater in soil growing perennial hay than annual wheat, and the same result has been found for phosphorous and potassium. The third characteristic is that perennials yield a greater amount of overall above ground biomass than do annuals, and through artificial selection some of the carbon can be shifted to grain production. Fourth, perennials with their soil stabilization, and nutrient and water retention ability, are ideally suited to challenging growth environments where annuals do not do well, at least without intensive assistance. Even with human assistance, the soil in many of these regions is not sustainable due to ongoing erosion. Perennial species with high and consistent seed production and other traits suited to robust grain crop yields need to be identified. Then these species can be bred to further increase the frequency of genes for traits such as, large seeds that resist shattering, provision of a high seed yield per unit of land, and synchronous flowering and maturity.

In addition to artificial selection hybridization can be applied to convert our major annual grain crops to perennials. Hybridization is a very complex topic, but it basically involves crossing species, such as annuals and perennials, to increase genetic diversity. In some cases these crosses are infertile and not at all valuable, but in other instances they produce a more effective species. It is really taking advantage of genetic diversity that would be difficult, if not impossible, to achieve through artificial selection alone. Maize was one of the first crops to benefit from hybridization techniques. Fortunately for us, ten of our thirteen most common annual grain crops have perennial relatives, and have already been hybridized. This research is still relatively young and has a long way to go, but we have started the process. So far it has been discovered that hybrids tend to be perennial only when at least 50% of their genome is derived from a perennial parent. By hybridizing an annual grain crop like wheat to a perennial relative, we might end up with a fully perennial form of wheat that yields large robust seeds. Artificial selection is then applied to a promising hybrid species to further its desired traits, in this case productive and enduring crop yields. So far cycles of hybridization, propagation, and selection in wheat, wheatgrass, sorghum, and sunflower, have produced perennials with characteristics intermediate between wild and cultivated species, yielding improved grain production. Genome mapping is either complete or underway for annual grain crops. This research will likely indicate the genes that are most linked to desired traits. We can then quickly assess the genetic constitution of hybrids to see if they have the most promising genes. This strategy will cut down on the length of time it takes to evaluate the effectiveness of a hybrid through strictly experimental crop yields.

So far everything seems great about converting all our annual crops to perennials, but is there a major downside? Based on the criteria proposed by Dan Sarewitz and Dick Nelson, it fairs extremely well. There is an extensive body of knowledge and expertise pertaining to crops, perennial vegetation, natural selection, hybridization, and genome mapping. A clear link exists between what perennials are proposed to do and what they actually do, in that they do absorb CO_2 from the atmosphere and deposit carbon in the soil. Finally, the results are measurable, and we already have values for their CO_2 absorbing capacity. Okay, that's great but artificially scrubbing CO_2 from the air with filters met these criteria and failed based on the cost-benefit balance. Maybe the same problem will occur with conversion of annual crops to perennials. If the costs are too excessive economic growth suffers and we violate our iron laws—Whenever, economic growth and global warming concerns counter each other economic growth always wins, and the related (but worth emphasizing), global warming moderation strategies must align with economic growth considerations if they are to succeed.

FINALLY, WE HAVE A TRUE WINNER, because the cost-benefit balance is vastly in favor of converting annual crops to perennials. The iron laws align extremely well given that economic prosperity is actually enhanced by this conversion. Farming whether small or large scale is a business, and a very energy and resource intensive one. Annual crops require precisely timed new seed planting ever year and plowing under of prior crop waste, both with significant labor and fossil fuel costs. If there is less machinery involved labor costs go up, and if there is less labor then fossil fuel and machinery costs go up. Then there is all that fertilizer, costly both in terms of the direct expense and the hidden costs of runoff, such as dead zones killing commercial and pleasure fishing. Readily accessible and hence cheap phosphorous, a key element in fertilizer, is being depleted worldwide and thus the costs of fertilizer will likely rise in the future.

Oh yes, and then there is the tremendous amount of fresh water that is wasted with annual crops, particularly on the vast amount of farmland that is sloped. Freshwater must often be delivered to fields, via expensive irrigation processes reliant on the burning of fossil fuels for pumping and manufacture of the irrigation equipment. Furthermore, water usage for irrigation often reduces the amount available for other purposes. Perennials make much better use of natural freshwater, acting like a sponge when it rains and releasing it when conditions are dry. Global warming will probably further reduce groundwater supplies that are currently nearing depletion in many areas, resulting in deficient amounts of this most valuable of resources. Due to their more natural evolution, and resulting genetic variation, perennials are much more resistant than annuals to challenges from harsh conditions, diseases, insects, and weeds. Perennials can survive in conditions that annihilate annuals, and resist diseases better. There will then be fewer costly crop failures with perennials. The lesser vulnerability to insects reduces the need for expensive pesticides that exert costs in terms of toxicity-related human and animal health effects, and rising CO_2 levels associated with their production and application. Given the much more extensive and permanent root system of perennials, they are superior at outcompeting weeds compared to annuals, greatly reducing the need for costly herbicides, thereby providing an additional cost savings.

From a cost perspective there is then a tremendous benefit to converting our major crops from annuals to perennials. This advantage is even greater if we take into account the cost of all the excess CO_2 in the atmosphere, and how perennials will scrub it out. By switching from annual to perennial crops CO_2 emissions are vastly reduced, based on both cutting the release that arises directly from annual crops, and that derived from the massive amount of fossil fuel required to support this form of agriculture. Combine the greatly reduced CO_2 emissions with the vast and rapid CO_2 absorption capacity of perennials, and it is easy to picture CO_2 levels plummeting. In terms of the negative externalities associated with farming, perennials do very well and certainly relative to annuals, given the vastly reduced fertilizer, pesticide, herbicide, and irrigation needs, that all have negative impacts far removed from the farm. As it stands now efforts are underway to develop perennial grain crops, but 10,000 years of going the wrong way does not reverse in a minute. It will take both time and money. Scientists indicate that the time frame is in the region of 20-50 years, with full conversion feasible sometime in the latter part of this range. Ed Buckler, an Agriculture Department scientist at Cornell University in New York, believes that whereas with prior technology it would have taken 100-plus years, we can now do it in 20 years with a concerted effort. This might seem like a long time, but it is realistic and will take care of the carbon we have placed into the atmosphere, hopefully even to that point. In addition, there are really no other viable options that align with the iron laws.

The actual financial cost of converting our major annual crops to perennials is a very important consideration, beyond the time frame. Research is not cheap for anything of significance. The United States alone spends about $30 billion annually on medical research, and $80 billion annually on military research and development. In 2009-10 the United States Department of Agriculture provided $1.5 million dollars in grants for perennial research, and asked Congress for $1 million for 2012. Carefully note the difference between $30-$80 billion and $1-$1.5 million. Ed Buckler indicates that $10-$20 million a year and dozens of scientists are required to breed perennial corn that could be commercialized. It sounds like a lot and just for corn, but when we compare it to $80 billion for weapons of destruction and defense it is an insignificant amount.

I encourage the required sums be provided by all governments to ensure the conversion of annual to perennial crops. To cover these costs, I further propose two small taxes at the individual and commercial level. Given that sentiment is high for doing a little to assist with the global warming problem, a yearly income tax of $100 per working person, with the option of voluntarily contributing more, be instituted in all countries with such taxes. A global system of taxation as proposed in the Greed: More Is Never Enough chapter can include this tax. At least 90% of this money is to be spent on research and implementation, and a maximum of 10% on related administration costs. In addition a $5 per metric ton of carbon tax be collected at the end point, much of it diverted to this research, the remainder to green energy initiatives. Support for a green tax of this amount on carbon has come from the CEO of ExxonMobil. Many see this company as the evil villain, but remember no one or everyone is to blame, and we all are enjoying the ultimately self-destructive orgy of fossil fuel energy consumption. The latter tax would raise about $150 billion per year, providing enough money to successfully convert all our major annual crops to perennials, and further the conversion to green energy.

Regarding the conversion to green energy, it is important that readers do not assume we can go on burning fossil fuels like there is no tomorrow, or there might not end up being a tomorrow that is livable. While perennials excel at scrubbing CO_2 from the atmosphere, there are limits and vastly increased atmospheric CO_2 might well overwhelm this capacity. In addition, readily accessible fossil fuel sources are limited and our society relies on them for needs way beyond cheap energy. The chair you are sitting on probably has plastic parts derived from fossil based sources of carbon, as does pretty much everything you rely on. If we use up reasonably available fossil fuels for energy, then we will all suffer. Gradually converting to greener energy will save fossil fuels for these other uses and reduce CO_2 emissions.

The global warming story that has unfolded is one that seemingly had no happy ending. The conversion of our major crops from annuals to perennials provides a very happy ending, if we rise to the challenge. In contrast to the other potential solutions, that either will not work or have a poor cost-benefit balance, this strategy is a winner. It is the only one that does not violate our iron laws, because based on the highly favorable cost-benefit balance economic prosperity is actually enhanced by it. The relatively low amount of financial investment over a 20-50 year period will be more than offset by the advantages accruing, beyond the main benefit of scrubbing CO_2 from the atmosphere. Undoubtedly, there will be significant challenge and opposition from the current agriculture industry, including manufacturers of annual seeds, fertilizer, and pesticides, and biotech companies producing genetically modified annual crops. They will undoubtedly apply intense lobbying pressure to oppose research efforts that might undermine their fortunes, and drum up the marketing message that annual crops are the best way to go emphasizing any limitations to perennials. A key argument likely to be made by those who wish to see annual crop agriculture remain firmly in place is how it has fostered the Green Revolution.

With increasing populations after WWII severe food shortages appeared inevitable. To the rescue was industrial agriculture based on monocultures of annual seeds. Large fields utilizing one seed type produced tremendous amounts of food for the hungry mouths of the world. This Green Revolution has been described as a miracle even by highly scientific publications. However, taking a closer look at the situation reveals a somewhat different picture. Indeed large amounts of food are produced by strategies including intensive fertilizer and pesticide application, irrigation, and genetic modifications to produce high-yield seeds, but what about the ratio of input to output? Green Revolution monoculture is highly dependent on fertilizers to facilitate growth, and pesticides to control pathogens that these crops are vulnerable to. Manufacturing all the required fertilizer and pesticides consumes a tremendous amount of energy and resources. The machinery involved in this type of agriculture and the delivery of water for irrigation also consumes a lot of energy. As it turns out to produce a 100 units of food, 300 units of input is applied, as presented in From Naked Ape To Superspecies (David Suzuki and Holly Dressel), a losing scenario for the natural capital of the planet, but a winning scenario for industry given all the fertilizer, pesticides, equipment, and seeds that have to be produced.

Standing in stark contrast to industrial Green Revolution agriculture is so-called, biodiversity-intensive agriculture, a form of agroecology. There are many components to this form of agriculture, such as combining crops. By planting a diversity of crops vulnerability to a devastating pathogen targeting a particular species is limited. Even this outcome is less likely given that natural protection against pathogens is present in the plants grown. For example marigolds, niger, amaranth, pepper, and even marijuana, have natural resistance to certain pathogens, that in isolation or combination can protect more vulnerable plants such as beans. In addition, the insects that accompany biodiversity-intensive farming often eat those that target plants, providing another layer of natural protection. The need for pesticides is then markedly lower or nil. Some of the crops applied such as legumes can stabilize the soil, translating into the retention of soil nutrients and greatly reduced fertilizer requirements. Soil stabilization also retains water reducing the need for intensive irrigation. In the final analysis biodiversity-intensive agriculture produces 100 units of food, using only 5 units of input! Wow, talk about a great input-output gain for the natural capital of the planet, and one that is far superior to the 300 units of input for 100 units of output characterizing Green Revolution annual seed agriculture.

Traditional agriculture techniques developed over thousands of years, and well before industrial fertilizers and pesticides were available, have been largely biodiversity-intensive. Tax records from pre-colonial India suggest that real agricultural yields (considering the input-output ratio) were 7-8 times higher than during the Green Revolution. Research by the World Bank and the International Food and Agriculture Organization, reveal that maximum productivity occurs on small fields up to 3 acres in size applying traditional agriculture. Third world colonization by first world nations transformed this highly productive and sustainable form of agriculture, and modern day industrial monoculture annual seed agriculture has virtually eliminated these advantageous agroecology practices. Imagine if we combined biodiversity-intensive agriculture practices with fully perennial crops. The input-output ratio would be amazing. All too often the crucial matter of the input-output ratio is ignored by industrial agriculture, because the results do not favor the strategies they are promoting. When the negative externality of rising atmospheric CO_2 levels from these practices are accounted for, along with the highly beneficial CO_2 absorption by perennials, the true input-output ratio is tremendously in favor of converting our annual crops to perennials, and utilizing agroecology techniques wherever and whenever feasible.

By considering the input-output ratio, the miracle of the Green Revolution fades to a more mundane story of unsustainable hyper-production based on intensive resource usage. The natural capital of the planet is diminished, while the artificial capital of agriculture-related corporations is enhanced. Consequently, if the agricultural industry waves the Green Revolution flag to support the value of monoculture annual seed crops, they can only do so by excluding any discussion of the dismal input-output ratio. In line with the optimism that perennials give for our future, it is feasible that the annual seed industry will step up to the plate and share its vast expertise and experience. A portion of the research funding for conversion of annual to perennial crops could even go to such firms if they come on board, compensating them for losses associated with the conversion, and bringing us closer to the goal of full perennial agriculture. Each of us as individual citizens will need to make politicians aware of this perennial option for managing global warming, and support related actions. Advocates of perennial agriculture will have to be vigilant for the inevitable opposition and counter it. Considering that we are all in the same big bathtub together with ongoing global warming representing a form of self-destruction, a concerted effort to convert our major grain crops to perennials does make sense. In addition, there is something very conceptually appealing to returning the world to its natural state in the process of managing global warming.

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