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Introduction

We humans, Homo sapiens, are an improbable miracle.

If you are in open country where there are no city lights and look at the sky on a clear night, you see a magnificent display of stars similar to the sun that illuminates the planet we live on. Some of those stars have planets orbiting around them. Whether any of those systems sustain life is unknown. The nearest star is more than four light years from earth. That means that anything traveling at a speed of 186,000 miles per second would require more than four years to travel from earth to the nearest star. By contrast, light from our sun traveling at the same speed reaches earth in less than eight and a half minutes. To date, planet earth is the only known place that sustains life. Planet earth, our home, is a life sustaining refuge in a vast universe. But planet earth has a violent history. "Scientists estimate that at least 99.9 percent of all species of plants and animals that ever lived are now extinct."[1] And of all the many species that do exist, only one has the ability to build, engineer, and manipulate the planet where we live. That unique ability came into existence because humans have exceptional manual dexterity, that is, we have dexterous fingers. Manual dexterity made it possible to make tools, record information, and gradually accumulate a knowledge base that has become an intellectual powerhouse. The delicate finger dexterity that other species do not possess developed, it is believed, because we are bipedal; we walk on two legs, thus sparing fingers from brunt activity.[2]

The intensity of the solar energy emitted by the sun and the distance from the sun to earth both vary over time but remain within parameters that facilitate life. Too much or too little solar energy or a greater or lesser separation of sun and earth would be fatal. Gravity keeps the air we breathe from drifting off into space. A smaller planet would not have enough gravitational attraction to retain the air that keeps us alive.[3] Planet earth has been volatile and unstable in times past, and it has been impacted by objects from space that produced devastating consequences. The continuity of Homo sapiens is not assured. But our bank of scientific skills affords us an opportunity to understand ourselves and our planet.

Most of the human experience has been harsh, savaged by disease, starvation, and short life expectancy.[4, 5] The foundation for the transition to the wealth and grandeur of our contemporary age was the acquisition of energy, vast quantities of energy that could do massive amounts of work. That was carbon energy: coal, oil, and gas. Energy drives our 21st century world. Our human species has exhibited astonishing creativity producing a continuous flow of inventions and discoveries. But one weakness has also become apparent; we have failed to foresee the consequences of some of our activities. Everything we do has consequences. Consequences matter.

Climate Change

The sun provides the energy and warmth that allows life to exist on earth. But there is another factor involved. In the atmosphere above the earth there is a band of water vapor and gases including carbon dioxide and methane. Incoming sunlight passes through the band and strikes the earth. Scientists call sunlight electromagnetic radiation. When sunlight, visible to humans, strikes an object, it becomes heat. We can certainly feel that happening if we are outside on a bright summer day. All of that heat is eventually re-radiated back to space at an electromagnetic wave length that is not visible to humans. Consequently, we may not be aware that it is happening. The water vapor and gases in the atmosphere trap a significant part of the outbound energy. The heat captured by this band of atmospheric water vapor and gas is critical for life on planet earth. If it were not for this energy capture, called a greenhouse effect, the temperature on earth would be slightly below zero degrees Fahrenheit, and "most life as we know it could not exist," according to biologists Neil Campbell and Jane Reece.[1]

The amount of the sun's energy that is retained by the atmospheric band of water vapor and gases is influenced by the amount of carbon dioxide and methane in the atmosphere. The concentration of carbon dioxide in earth's atmosphere has been measured continuously since 1958 at the Mauna Loa Observatory on the island of Hawaii. Those measurements indicate a 25 percent increase in atmospheric carbon dioxide during the past 60 years. Scientific research indicates that the rapid accumulation of carbon dioxide in the atmosphere is a result of burning fossil fuels, i.e., burning coal and petroleum products.[2] When a carbon fuel burns, it combines with oxygen yielding carbon dioxide.

During the past century, our human population has increased from two billion to more than seven billion. There has been an intense demand for energy from fossil fuels to provide electricity, heating and cooling, transportation, and for industrial production activities. Since the beginning of the modern industrial era about 150 years ago, the average global surface temperature has increased by about 1.8 degrees Fahrenheit.[3] Although that is a small number, it represents a significant amount of heat. Only a small percentage of the heat returned to earth by the anthropogenic (human caused) greenhouse gases is held by the atmosphere and the land mass. About 90 percent of the heat is stored in the oceans.[4, 5] Because of the huge volume of the oceans, that heat doesn't increase water temperature very much, but the increased water temperature does affect weather conditions.

Greenhouse gases in the atmosphere above the surface of the earth act as a thermostat.[6] Carbon dioxide is the signature gas, the most important variable. Either too little or too much carbon dioxide would be fatal to life on the planet we call home. Venus, a planet in our solar system, has a dense carbon dioxide blanket; the temperature reaches over 800 degrees Fahrenheit.[7]

Methane is another gas that traps heat that would otherwise return to space. Methane is produced by microorganisms that decompose vegetation. It escapes, for example, from flooded rice fields.[8] There is a vast amount of methane stored in Arctic permafrost. Historically, this tundra has been permanently frozen but as the earth warms, it is beginning to thaw and release methane gas to the atmosphere. Livestock with ruminant digestive systems emit methane. Some methane escapes from petroleum extraction operations and some from waste deposit landfills.

Incoming sunlight can be blocked. The biggest bang since humans started recording their history occurred when the volcanic Mount Tambora in the Indonesian island chain erupted on April 5, 1815. The eruption was a monster. Several cubic miles of molten lava and rock were blasted five miles high, maybe higher. The noise was heard more than a thousand miles from the volcano. The volcanic dust began a journey around the earth filtering the sunlight and causing abnormally cool summer temperatures. But the maximum impact occurred the following year. People called 1816 the "year without summer." There was famine in China because the cold weather caused crop failure and because of extensive flooding. Abnormal rains in India caused a cholera epidemic that spread north as far as Russia.

Snow fell in June in eastern Canada and the northeastern United States. Lakes and rivers froze in Pennsylvania in July. Crops failed. Oats—fuel for horses—increased in price enormously, the equivalent, today, of a $2.50 gallon of gasoline rising in price to $19.00. There was an extensive migration of people from the northeastern U.S. to what was then called the "Northwest Territory," an area that included Ohio, Indiana, Michigan, Illinois, and Wisconsin. Eleven-year-old Joseph Smith and his family were uprooted by the volcanic eruption and began a westward trek. Their first stop was an area of New York where there was intense religious activity at that time. Joseph Smith's successors led his followers to Utah where they established the headquarters of the Mormon religion.

Europeans also experienced abnormally cold and wet summer weather. A group of friends went to Lake Geneva, Switzerland, in the summer of 1816 intending to enjoy boating on the lake. The persistent cold rain forced them inside where they entertained themselves telling ghost stories. Someone suggested that they each write a scary story, a contest to see who could write the scariest story. Mary Shelley wrote *Frankenstein*.

The volcanic dust from the Mount Tambora volcanic eruption prevented some of the sunlight from reaching earth, and that changed the weather but only for a few years. The volcanic debris soon fell out of the atmosphere. Both carbon dioxide gas and methane gas have longer atmospheric life expectancies. The carbon dioxide resulting from human activity remains in the atmosphere from 50 to 100 years, and a significant fraction may remain for 1,000 years or longer.[9, 10] Methane gas in the atmosphere traps heat far more effectively than carbon dioxide, but it has a shorter atmospheric lifespan, usually cited as 9 or 10 years.[11, 12] These gas accumulations in the atmosphere have the potential to alter seasonal weather and long-term climate on our planet. There is a naturally occurring large-scale exchange of carbon among rocks and soil, the atmosphere, and the oceans. That exchange has maintained equilibrium for thousands of years. But human activity is depositing an extra amount of carbon dioxide in the atmosphere and in the oceans.

The chemical symbol for carbon dioxide is CO_2. The symbol indicates that the carbon dioxide molecule has one carbon atom and two oxygen atoms. The chemical symbol for methane is CH_4. The methane molecule has one carbon atom and four hydrogen atoms. Water vapor is also a greenhouse gas, and the chemical symbol for water is H_2O. The water molecule has two hydrogen atoms and one oxygen atom.

The sun delivers an immense amount of heat to earth in the form of shortwave radiation, much of it visible light that we can see. The solar energy that heats the earth is returned to space as longwave infrared radiation that we cannot see. Some of the solar energy is absorbed by the earth and retained temporarily. But ultimately, the earth must lose as much heat as it gains. Otherwise, planet earth would have become a cinder long ago. However, if earth received no heat from the sun or any source, the temperature on the planet would eventually approach absolute zero, about 459 degrees below zero on the Fahrenheit scale.

Most of the inbound shortwave solar radiation passes through the belt of greenhouse gases unimpeded. But when the outbound longwave infrared radiation strikes a molecule that has three or more atoms (CO_2, CH_4, H_2O), it agitates the atoms generating heat that is again released in the infrared spectrum and some of the heat remains in the earth environment. That process has been more or less in a state of equilibrium for thousands of years. It is the thermostat that allows life to exist on our planet.

Solar radiation and infrared radiation are forms of electromagnetic radiation. Wave length and frequency are determined by the heat of the object that emits the electromagnetic radiation. The sun is intensely hot, and it emits shortwave, high frequency radiation. The earth which has much lower heat emits longwave, low frequency radiation. Electromagnetic radiation changes to heat when it impacts an object and is absorbed. Some of the inbound solar radiation is not absorbed by the earth environment because it is reflected back into space by white ice or snow or other reflective matter.

The sun also emits shortwave ultraviolet radiation. Ultraviolet radiation is impeded by ozone O_3 and by oxygen O_2 in earth's atmosphere. That is important because exposure to ultraviolet radiation causes skin cancer, eye damage, and damage to the human immune system.[13]

There are other chemicals that may act as greenhouse gases including nitrous oxide, nitrogen dioxide, and halocarbons. Nitrogen is converted to nitrous oxide by bacteria. Nitrogen is a vital plant food, and farming for a large population requires factory production of nitrogen fertilizer which, ultimately, increases the amount of nitrous oxide in the climate system. These nitrogen chemicals are symbolized by NO_x. The NO_x chemicals are also produced by combustion of fossil fuels. The halocarbons are air conditioning and refrigeration chemicals. These chemicals are potent greenhouse gases, but as long as they enter the atmosphere in limited quantities, they are not major climate change generators.[14, 15] Methane CH_4 could become a more important greenhouse gas in the future. Large amounts of methane are contained in permafrost. If the climate warms enough to melt the permafrost, substantial amounts of methane could escape into the atmosphere. If the permafrost bogs are moist after they thaw, methane enters the atmosphere. If the permafrost is dry after it thaws, much of the methane will chemically change to carbon dioxide. Both chemicals are greenhouse gases. Water vapor is a natural greenhouse factor. Water evaporates extensively in the equatorial regions of the ocean and circulates in the atmosphere. The evaporation rate depends on sea surface temperature. Warmer water increases the evaporation rate, and sea surface temperature has increased during recent decades.[16] Warm air can transport more water than cooler air. The water vapor falls as rain or snow, generally within 10 days.

The word *atmosphere* is a general term we use to describe the air above the surface of the planet. Scientists define atmospheric zones. The zone from the surface of the earth to approximately six to 12 miles elevation is the troposphere. The vertical extent of the troposphere is variable and depends on location. The top of the troposphere is higher near the equator and lower in the polar areas. The zone above the troposphere is called the stratosphere. The separate designation for each zone facilitates understanding of earth's climate. Ozone, for example, yields different effects in each zone. Ozone in the stratosphere protects us from harmful ultraviolet radiation. At ground level, ozone is an irritant that can cause health problems.[17]

Carbon dioxide is the centerpiece of climate change discussion. Scientists have instruments that can count the molecules of gases in a given volume of air. The first scientific instrument count of carbon dioxide at Mauna Loa in 1958 registered 315 molecules of carbon dioxide per million gas molecules. That is expressed as 315 ppm (parts per million). As of 2019, Mauna Loa measurements exceed 400 ppm. The U.S. National Aeronautics and Space Administration (NASA), now operates a satellite—the Orbiting Carbon Observatory-2—that measures atmospheric carbon dioxide with an accuracy of (+/-) one part per million molecules of gas. Atmospheric carbon dioxide is not distributed evenly around the planet, and it varies seasonally. The count is greater in the spring and lower in the fall. Since carbon dioxide lingers in the atmosphere for a long time and since most of the heat that atmospheric carbon dioxide captures is stored in the ocean, the ultimate impact on climate is delayed. This fact makes it difficult for non-scientists to judge the severity or importance of the issue. Scientists, however, are concerned because they understand that a tremendous amount of heat energy is accumulating in the system and, sooner or later, it will manifest in some manner. There is, though, an array of measurable evidence of change including ice melt, sea level rise, sea temperature change, and more. Additionally, carbon dioxide, the pivotal heat capture gas in the atmosphere, is accumulating at an accelerating rate. Our news media sometimes report that the latest severe weather event is evidence of climate change, citing the physical damage and human suffering. But that is not a reliable measure or indicator. Those news reports reflect vulnerability. For example, a hurricane that strikes a beach community on the U.S. Gulf of Mexico may do tremendous damage, but a hurricane at the same location and of the same size, intensity, and duration 500 hundred years ago may have caused very little damage because the coast was then a primitive area. Coastal areas of the United States and other countries are now extensively populated and have all of the structures that support human activity. That makes coastal areas vulnerable to severe storms, sea level rise, flooding, salt water contamination of fresh ground water, and demise of vegetation that cannot tolerate salt.

Natural processes put carbon dioxide into the atmosphere and remove it, and that has been happening for thousands of years. Now, human activity is adding to the concentration of carbon dioxide in the atmosphere. It is a result of burning fuels that contain densely packed carbon including coal, oil, and gas. Solving the problem is a significant challenge. The first reason is that our modern society depends on utilization of immense amounts of energy. Secondly, billions of people want the same benefits derived from energy that are enjoyed by the wealthier countries. And, we do not yet have an adequate alternative energy system.

Dr. Frank P. Incropera, former Dean of Engineering at Notre Dame University: ". . .energy. . .is the lifeblood of our modern life and economy." "It would be difficult to overstate the importance of energy to the well-being of humankind. It is the resource that sustains all life and economic activity." "While developed nations are responsible for most of the cumulative emissions, it will not be long before developing economies achieve this distinction. . . ." "The reality is that, for decades to come, global energy demand will continue to increase in concert with population and average energy consumption per capita."[18]

Dr. Anthony D. Barnosky, Professor, Department of Integrative Biology, at the University of California, Berkeley: ". . .the only reason we humans can exist in such high numbers—numbers that are far above Earth's normal carrying capacity for big land animals—is that we add a huge amount of energy to the global ecosystem, mostly through the extraction of fossil fuels. Without that extra energy, a lot of people would have to die, and the high quality of life that billions of people now enjoy and billions more aspire to would evaporate."[19]

Dr. Vaclav Smil, Distinguished Professor Emeritus at the University of Manitoba: "Modern society has been created by the. . .combustion of fossil fuels. . . ." "More than in any other modern nation, the power and influence of the United States have been created by its extraordinarily high use of energy. . . ." "What can be seen with great certainty is that much more energy will be needed during the coming generations to extend decent life to the majority of a still growing global population whose access to energy is well below the minima compatible with a decent quality of life."[20]

Planet earth is finite and, like a lifeboat, there is a *maximum population* that the earth can support in some rudimentary manner. We don't know what that number is. There is also an *optimum population* that the earth can support, in perpetuity, without exhausting our resources, contaminating the environment with our waste, extinguishing other species, or adversely altering the climate. We don't know what that number is. We do know that nature has a remedy for overpopulation: starvation and disease.

The adoption of fossil fuel energy was innocent. No one understood that burning these high energy products would eventually alter the climate of the planet. There are no moral grounds for faulting the fossil fuel production companies; they produce products because we consumers demand the products. If we were suddenly deprived of our energy resources, our economy would not merely decline, it would collapse, and those who survived would quickly revert to a primitive existence.

Eighty-five percent of the world's energy is derived from fossil fuels that we burn producing carbon dioxide as a by-product.[21, 22] Citizens and government officials sometimes aspire to eliminate dependence on fossil fuels by specified dates. The technology to eliminate dependence on fossil fuel energy on a worldwide basis does not exist as of 2019. Since carbon dioxide does not respect political boundaries, a worldwide solution is required.

Coal is an abundant energy resource and is used, extensively, to generate electricity. Coal-fired electric generating plants contribute about 45 percent of the carbon dioxide produced by human activity.[23] Several technologies have been developed or envisioned that would extract a significant percentage of the carbon dioxide from the coal burning process. One of the principal methods is called carbon capture and sequestration (CCS). The problems, to date, are that it is too costly to be competitive; the captured carbon dioxide must be transported to an underground storage site; the underground storage site must be permeable enough to accommodate the carbon dioxide, and the area must be capped with a thick layer of rock that will prevent the carbon dioxide from escaping into the atmosphere. A significant amount of energy is required which means that the electric power plant must reduce its output of electric energy to the electrical service grid, or the plant must produce additional electricity to power the carbon dioxide capture process. There are other processes to accomplish the elimination of carbon dioxide from entering the atmosphere, but they all have the high cost problem. If the technical and financial problems can be solved, it would allow the continued use of coal, but at the present time, it appears that other sources of energy are more promising.

Natural gas is being used to generate electricity, and it is replacing coal in some countries. Natural gas, primarily methane CH_4, produces about half as much carbon dioxide as coal when it is burned. That is a significant advantage. As can be observed from the chemical symbol, methane has four hydrogen atoms but only one carbon atom. However, to realize the potential advantage of natural gas as a fuel for electric generating plants, it is necessary to prevent leakage of the natural gas from the producing wells, transportation systems, storage systems, and utilization as a fuel. If three percent or more of the natural gas is allowed to escape into the atmosphere, the advantage over coal is lost. Useful gain requires limiting leakage to less than one percent.[24] Natural gas is not visible to humans, and the human olfactory nerve does not detect a natural gas odor. Instrument detection is required. Natural gas delivered to residential users has a chemical additive that emits an odor that humans can detect. The technology to prevent leakage exists. Effective use of the technology requires government inspection and enforcement of natural gas leak prevention operations. That means that governments must have both the political power and the political will to do the job. Some governments have that capability and others do not. Natural gas is, of course, a carbon fuel, and eventually, it must be replaced unless some new technology facilitates prevention of carbon dioxide release to the atmosphere when natural gas is burned. Worldwide, natural gas accounts for approximately 23 percent of electricity generation.[25]

Hydroelectric generating stations do not emit carbon dioxide. The sun heats and evaporates ocean water and ground water that soon falls as rain or snow elsewhere. Where drainage basins are appropriately configured, dams can be erected forming large lakes. The weight of the water (gravity), causes water to flow through turbines in the dam that generate electricity. It is a good system for generation of electricity, but it can only be utilized where topography and rain or snowfall are sufficient. A prolonged drought may require reduction of electrical output. There are several, perhaps many, places where additional hydroelectric facilities could be constructed. Almost always, that involves disruption or displacing people who live upstream or downstream from a new hydroelectric project. From a carbon dioxide standpoint, hydroelectric generation of electricity is an excellent solution. Hydroelectric systems currently supply approximately 16 percent of the world's electricity.[26]

Wind force can be used to generate electricity. Wind farms, on land or off-shore, utilize large turbines to power generators. The system does not produce carbon dioxide. Wind farms need to be located where the wind is relatively continuous and has sufficient velocity to propel the turbine blades. Wind farms can make a useful contribution to energy supply, but they are not a stand-alone system, because winds are variable.

Geothermal energy can be used in a few places, and it produces very little carbon dioxide. Geothermal can be utilized where the crust of the earth is thin, usually in places where the earth's interior heat causes volcanic eruptions. Steam produced by the earth's interior heat is used to power electric generators. A very small percentage of the world electricity supply is produced by geothermal energy.

Ocean waves or tidal forces hold potential to provide energy for electricity generation, but this is currently an undeveloped idea.

Nuclear reactors produce approximately eleven percent of the world's electricity. Nuclear generators are reliable and capable of flexible output, but they have two serious flaws. They produce radioactive waste for which no satisfactory permanent storage system has been developed. Storage of radioactive nuclear waste needs to be managed for thousands of years. Nuclear electric generating stations are very expensive, too expensive to be profitable for private investors. The plants usually require government subsidies, loan guarantees, or protection from liability in case of accidents. In the U.S., the Price-Anderson Act limits the dollar amount of liability that the nuclear plant owners are responsible for. Dismantling an aged nuclear power plant is also very expensive. Development of a different type of nuclear electricity generating plant that does not produce radioactive waste is underway, but decades of experiment and development to determine technical and financial feasibility will be required before such plants could be deployed. Expansion of nuclear energy may depend on availability of cooling water.

Biowaste/biomass can be used to generate energy. Currently, biowaste/biomass is not a significant factor for generation of electricity. Biomass is vegetation and animal waste.

The sun is a source of energy. ". . .every hour the sun beams down more energy than the world uses in a year."[27] Solar powered electricity generation is our under-exploited opportunity. The sun delivers an immense amount of energy to our planet, and it is widely distributed across most of the densely populated geographical areas of the earth. The technology that is extremely promising is solar panels that convert sunlight to electricity. It is a technology that warrants generous funding for research and development. Solar panel electricity generation has some flaws that need to be addressed. Solar panels do not work the night shift, and they do not function when the sunlight is obscured by clouds. Solar panel electricity requires backup by "baseload" generating stations. Baseload generators are fossil fuel, nuclear, and hydroelectric. Baseload generators can operate 24/7/365. Currently, solar panels produce maximum output during mid-day and feed the electricity into a baseload system. The baseload generator must cut back electricity production to accommodate the solar field input. When clouds suddenly obscure the solar field or as the sun sets in the evening, the baseload generator must rapidly increase generation of electricity. The rapid rate of production change is expensive and hard on equipment. The process may require that the baseload generator be connected to other baseload generators by a wide area grid to distribute the burden of rapid solar field production variations.[28, 29] Generally, baseload operations can accept no more than approximately 20 percent of their electricity from solar panel fields. But solar energy has enormous potential, and the Holy Grail for solar panel electricity generation is an electricity *storage* system.[30, 31]

Research and development for electricity storage needs to be funded. The United States has some historical precedents that could be a guide for electricity storage R & D. During World War Two, the scientists at the secret Manhattan Project developed nuclear weapons. While that may be a dubious accomplishment, the method used to achieve the goal is significant. The method was funding, concentration of intellectual talent, and singular purpose. During the subsequent "cold war" era, a program was launched to put an astronaut on the moon in competition with Russia (USSR). Again, it was successful because of funding, concentration of intellectual talent, and dedicated purpose. Both examples cited above were driven by fear. Fear is a prime motivator. At some future time, climate change may induce fear, but if we wait for that motivation, we may have waited too long. We need a research effort to learn how to store solar energy. That research effort needs to be massively *funded*, implemented by a concentration of *intellectual talent,* and driven by dedicated *purpose*.

Research and development is not a profit center; it is a cost. The R & D effort will require government financing and incentives to induce private enterprise investment for an electricity storage system. Electrical grids need to be connected to enable distribution of electricity, both intermittent and baseload, from places where it is available to places where it is needed. Wind and solar energy systems do not emit carbon dioxide, but they produce electricity intermittently and will provide a significant solution to our energy problem only if a storage system for electricity is developed and wide area grid connections are established.

Political leadership is essential. International cooperation will be required to prevent an excessive accumulation of carbon dioxide or other greenhouse gases in the atmosphere. Billions of people are striving to acquire the benefits of energy enjoyed by the wealthier nations. The governments of the wealthier nations should exhibit prudence and moral leadership to assist and guide the energy acquiring populations to an energy frontier that does not cause our atmospheric carbon dioxide thermostat to malfunction.

Electricity generation is the leading source of human produced carbon dioxide accounting for approximately 42 percent of worldwide emissions. The second category is industrial production, which accounts for about 24 percent of global carbon dioxide emissions. That is a very broad spectrum of activities that includes agriculture and every product that we manufacture or process. Among these products, cement is noteworthy. Cement, the basic adhesive for concrete, is made by heating limestone to 2700 degrees Fahrenheit. The process emits carbon dioxide even if the source of the heat is carbon dioxide free, e.g., electricity from a hydroelectric plant. Cement production accounts for about five percent of the carbon dioxide we humans pump into the atmosphere. The modern world is built of concrete, staggering amounts of concrete. We have poured so much concrete that there is a developing shortage of sand for future concrete construction. Anyone who has been in a desert might say that we have plenty of sand, but desert sand has been rolled by the wind for centuries, and it has rounded edges. Sand for concrete needs jagged edges that bind to make a strong building material.[32] Industrial activities require energy to power machines, perform chemical processes, move objects, and for heating, cooling, and lighting. That energy is obtained from the least costly source or the most suitable source or the available source. Any energy system that eliminates or captures carbon dioxide will enable manufacturing and processing industries to reduce their carbon dioxide contribution. Beyond that, some industries may be able to reduce carbon dioxide output by re-engineering their processes and products. Cement is an example. Research is being conducted to find a new way to make concrete.[33]

Transportation vehicles are the third major source of human caused carbon dioxide emissions. Worldwide, all types of transportation account for about 23 percent of carbon dioxide emissions. United States citizens operate more than 250 million automobiles and trucks and drive three trillion miles each year. Worldwide, there are more than 1.2 billion cars and trucks and more being produced every day. Most vehicles are currently powered by fossil fuels. Vehicles can also be powered by ethanol alcohol produced from vegetation. The United States adopted the practice of producing alcohol from corn and blending the alcohol with gasoline. The practice is condemned because corn is a major food product. Using top quality farm land to produce transportation fuel increases the price of food. Alcohol has lesser energy density than gasoline which requires burning more per mile than would be required for fossil fuel. Energy for automotive fuel is frequently expressed in British Thermal Units (BTU). Gasoline contains approximately 114,000 BTU per U.S. gallon. Ethanol contains approximately 76,000 BTU per U.S. gallon. Ostensibly, burning ethanol does not increase the amount of carbon dioxide in the atmosphere. The reasoning is that corn, from which the ethanol is produced, previously absorbed the carbon from the atmosphere and burning the ethanol merely recycles the carbon back to the atmosphere. However, if we consider the energy required to produce the seed corn, the nitrogen fertilizer required to grow the corn, and the energy required to harvest the corn, dry the corn, and transport the corn to the ethanol plant, ethanol fuel is not carbon dioxide neutral. Brazil, South America, produces alcohol from sugar cane for use as a vehicle fuel additive. Sugar cane contains about eight times more sugar than corn, and it is the sugar that converts to alcohol.[34, 35]

Automobiles and trucks can also be powered by hydrogen. Hydrogen would be an ideal fuel if it were readily available. When hydrogen burns, it unites with oxygen producing heat, and the by-product is water H_2O. There is no carbon dioxide emission. The problem is that hydrogen is bonded with another chemical as, for example, water H_2O. Breaking the bond to free the hydrogen requires energy making the process impractical, at least, with currently available technology. However, research, including the use of solar energy to break the bond, may lead to a practical solution eventually.[36] The greater problem for new portable vehicle fuels may be developing a distribution system that makes the product easily obtainable by consumers.

Electric vehicles are being promoted as a solution for the elimination of carbon dioxide from vehicle emissions. Technical problems including the availability of charging stations and the time required to charge vehicles will surely be solved. But there is a key factor that we need to remember. Electric vehicles eliminate carbon dioxide emissions only if the electricity generating plant that supplies the electricity does not emit carbon dioxide.[37, 38] Currently, more than two-thirds of the world's electricity is produced with carbon fuels.[39] Additionally, a large-scale switch to electric automobiles and trucks would require a large increase in electric plant generating capacity. Given current technology, those plants would have to be fossil fuel or nuclear.

The land we live on and the way we live on that land affect the carbon dioxide concentration in the atmosphere. By the year 1600 AD (CE), England was an aspiring sea power. Construction of a naval sailing ship required two thousand mature oak trees for the hull and additional tall pine or fir trees for the masts. England's once extensive forests had been cut for firewood, farming, ship building, and for construction material. England's King James I chartered the for-profit Virginia Company, and that company established a colony in 1607 at Jamestown, Virginia, on the east coast of what is now the United States. It was a commercial venture, and the purpose was to obtain timber.[40] The process of removing trees has been in progress for centuries, and it is estimated that half the temperate and tropical forests that once existed on our planet have been cut or burned.[41] This is a concern because trees absorb carbon dioxide from the atmosphere. Re-establishing forests would sequester some of the carbon dioxide that currently becomes greenhouse carbon dioxide.[42]

Daniel Fahrenheit invented the mercury thermometer in 1714. It became a popular instrument and, by 1880, temperatures were being systematically recorded in enough places to constitute a record that scientists can use. Degrees of temperature on the Fahrenheit scale are expressed with the symbol ^{o}F. In recent decades, mercury thermometer measurements have been supplemented by other scientific instruments and by satellite observations. In the years since 1880, the average surface temperature on our planet has increased approximately 1.8^{o}F[43]. The rate of change has increased during the past four decades. The National Oceanic and Atmospheric Administration reports that the air temperature increase, per decade, at the surface of the earth during the 40 years from 1980 to 2020 has been twice the rate of increase, per decade, that occurred during the 100 years between 1880 and 1980.[44] Currently, the global surface temperature is increasing at the rate of three degrees Fahrenheit per century. The current average surface temperature is approximately 58^{o}F. Note that this is written in 2020, and these numbers may change in the future.

Ocean temperature has also increased. ". . .the increases in ocean heat content that have occurred deep below the surface in all the ocean basins reflect a persistent and globally pervasive period of warming."[45] The average ocean surface temperature increase during the past 140 years is approximately 1.8 degrees on the Fahrenheit scale.[46] Most of the temperature increase has accumulated in the top 600 feet of ocean water. However, some temperature increase has been measured to a depth of 6000 ft. The amount of the increase seems trivial, but it is not. The oceans cover 70 percent of the planet and have an average depth of 2.3 miles. Considering the volume of the oceans, the water temperature increase is significant. It represents a tremendous amount of heat. It is a concern of scientists because they understand that, at some future time, the heat will exit. What is unknown is how, when, and at what rate it will manifest. We do know that the oceans play a pervasive role in earth's climate system.

Sea level has increased since 1880 by approximately 8.8 inches. Since 1993, the rate of sea level rise has nearly doubled.[47, 48] Between 1900 and 1990, sea level rose at not more than 1.7 millimeters per year. As of the year 2016, sea level was rising at a rate of about 3.4 millimeters per year—double the earlier rate of rise—according to the Smithsonian Institution (Ocean).[49] Approximately 90 percent of the heat captured by human produced greenhouse gases deposits in the oceans. That accounts for the increased water temperature, and it contributes to sea level rise because the ocean water expands as it warms. A lesser contribution to current sea level rise is attributable to land-based ice melt. If there is significant future sea level rise, it will be mostly a result of land-based ice melt.

Sea level is not uniform, and the sea is not level if that means flat. We generally think of sea level in relation to the coastal land area. In that sense, sea level is affected by wind, ocean currents, gravity, rotation of the earth, water temperature, and salinity. Sea level is higher on the west coast of the United States than it is on the east coast.[50] In addition to any sea level rise, some places are affected by coastal subsidence. Jakarta, Indonesia, with a greater metropolitan area population of 30 million people, is sinking from three to six inches per year.[51] Local measurements of sea level are not an adequate means to determine general sea level or changes in sea level. However, we now have satellite instruments that make accurate sea level measurements at many ocean locations. That provides a capability to detect change in sea level. Altimetry satellites determine the distance from the satellite to the earth's surface by measuring the time it takes a radar pulse to travel from the satellite to the sea surface and back. The Jason-2 satellite is an example. Jason maps 95% of the world's ice-free oceans every ten days.[52] The Jason-3 satellite is now in low orbit at 830 miles altitude. The two Jason satellites and their predecessor, TOPEX/Poseidon, recorded a 2.8 inch sea level rise in a 23 year period subsequent to the 1992 launch of TOPEX/Poseidon.[53]

Measurement of carbon dioxide in the atmosphere is an appraisal of the cause of climate change, i.e., the capture of heat via interception of outbound infrared radiation. Atmospheric and sea temperatures and sea level rise are indicators of the primary result of that additional heat. There are some other indications of climate change. Carbon dioxide routinely deposits in the oceans through a natural process. However, the additional carbon dioxide produced by human activity is changing the acidity of the sea water. On the chemical pH scale of 0 to 14 with 7 being neutral, ocean water is typically alkaline (base) at 7.5 to 8.5.[54] Carbon dioxide chemically changes to carbonic acid when it reacts with sea water. There is concern that some marine life, including corals and animals with exoskeletons, may be adversely affected if sea water continues to change to a more acidic state. This topic is further addressed in the section on species stress.

Developing a solution for the planet's changing climate is an extraordinarily difficult challenge. It is difficult because it requires worldwide cooperation. It is difficult because non-carbon dioxide emitting technologies that can safely meet world energy requirements do not yet exist. It is difficult because we are dependent on massive amounts of energy, and the demand for energy is increasing. Energy consumption increased 40 percent during the first 16 years of the 21st century.[55] Consider the fact that 40 percent of the world food supply depends on manufactured nitrogen fertilizer. Manufacturing nitrogen fertilizer requires substantial energy usually obtained from natural gas or other fossil fuel.[56] Surprising as it may seem, it is expected that data centers (cloud computing) may consume 20 percent of the electricity supply in the near future.[57, 58] More than 6000 products are made from plastic, and plastic is made from fossil fuels.[59] And 60 percent or more of the clothing we wear is made from fossil fuel.[60]

In 1306 England's King Edward I issued a proclamation banning the burning of coal in London. He did so because the elite and wealthy citizens objected to the smoke. The wealthy could afford to burn the declining supply of wood in their large fireplaces. The poor people began burning coal.

The modern increase in atmospheric carbon dioxide began in the 1500s with the burning of coal in England. ". . .almost all of [England's] coal fields were opened up between 1540 and 1640."[61] The carbon dioxide emissions regime intensified as a consequence of the beginning of the Industrial Revolution, circa 1750 to 1850.

Recognition that the anthropogenic carbon dioxide problem justifies government action is fairly recent. Spencer R. Weart, Director of the Center for History of Physics of the American Institute of Physics writes: "Issued in 1990, the first IPCC [Intergovernmental Panel on Climate Change] report concluded that the world had indeed been warming. The report predicted (correctly) that it would take another decade before scientists could say with any confidence whether the warming was caused by natural processes or by humanity's greenhouse gas emissions."[62] "The discovery of global warming—that is, plain evidence that the greenhouse effect really operated as predicted—would come sometime around the year 2000."[63]

If climate change advances to a degree that exceeds human willingness to adapt, then Homo sapiens may attempt geoengineering. The climate of planet earth is complex and not fully understood. Attempts to engineer the climate of the planet could easily produce unforeseen consequences and should be approached with skepticism and utmost caution. "The Earth's climate system is so irreducibly complicated that we will never grasp it completely, in the way that one might grasp a law of physics."[64]

The numbers cited in this document are crucial measurements of the status of the planet. The numbers reflect 2019/2020 data. These numbers will very probably change with the passage of time.

*Atmospheric carbon dioxide increase: 25% since 1958
*Average global surface temperature: 58°F; increase during the past 150 years: 1.8°F
*Sea surface temperature change; increase since 1880: 1.8°F
*Ocean pH change since 1880: decline from 8.2 to 8.1
*Sea level rise since 1880: 8.8 inches; currently rising at 3.4 millimeters per year; 13.3 inches per century
*Decline in atmospheric carbon-14 (^{14}C) since 1900: 2 percent
*Ocean oxygen decrease during the past 50 years: 2 percent
*Glacier melt in Glacier National Park since 1910: 120 of 150 glaciers have melted
*Japanese cherry blossom bloom date: 10 days earlier than any time during the past 1200 years

Environment

Boundaries of arid zones have shifted. Habitat boundaries for vegetation and animals have moved poleward or vertically to cooler areas. Seasons have changed. Ancient ice has melted.

The 100th Meridian—runs through Dodge City, KS—was identified in 1878 as a natural boundary between the arid western plains and the eastern U.S. where rainfall is sufficient for farming. That boundary has shifted eastward 140 miles.[1] The Sahara Desert, which is about the size of the United States, has expanded about 10 percent since 1920.[2] Not all of the expansion is attributable to climate change, but climate change is a significant factor. Twenty percent of China is desert. China's deserts have expanded 21,000 square miles since 1975.[3] Desert expansion can be caused by decreasing rainfall or by increasing heat. The additional heat evaporates the meager quantity of soil moisture in desert border areas thus depriving vegetation of a necessity and causing the area of the desert to expand.

In Glacier National Park in Montana, 120 of the 150 glaciers that were there when the park opened in 1910 have melted.[4] Glaciologists have defined 19 glacial regions on the planet. All have lost ice. Six hundred glaciers have "disappeared."[5]

The Japanese have recorded the dates in spring when their cherry trees blossom. They have kept those records for 1200 years. The blossoms began to appear earlier starting about 1980. They now (2019) appear 10 days earlier than anytime during the past 1200 years.[6]

"Water, water everywhere/Nor any drop to drink." These lines of poetry are from The Ancient Mariner by Samuel Taylor Coleridge. Fresh water is a profoundly critical environmental asset. The oceans contain 97 percent of the water on planet earth. The remaining three percent is freshwater (no salt), and approximately 69 percent of the freshwater is held in the polar icecaps. Slightly less than one percent of the water on the planet is available to support animal and plant species that require fresh water. Seventy percent of that fresh water is used to irrigate agricultural crops.[7, 8] Forty percent of the world food supply is produced on irrigated agricultural land.[9, 10] Aquifers are the water source for a significant amount of agriculture. "**. . .**over half of the world's biggest aquifers are being depleted. They are past sustainability tipping points, and a third of those big aquifers—13 of those—are seriously distressed," according to Jay Famiglietti, professor of earth science at UC Irvine and senior water scientist at NASA's Jet Propulsion Laboratory.[11] In the United States, the Ogallala aquifer underlies eight states in the Great Plains. More than a hundred million acres of these former grasslands have been converted to cultivated cropland by pumping irrigation water from the Ogallala aquifer. The aquifer also supplies drinking water for two million people.[12, 13] The Ogallala and other aquifers accumulate water slowly over thousands of years. A substantial number of countries must import food products because they cannot produce enough to feed their population. When countries import food, they are utilizing *water* from another geographical location.

Water supplies are routinely contaminated with industrial waste. The Environmental Protection Agency lists 85,000 chemicals as required by the Toxic Substances Control Act.[14] Very few of those chemicals have been tested for human safety or harm to the environment, and traces of 500 of those manufactured chemicals are present in the bodies of people who live in the

United States.[15] During the five years from 2004 to 2009, the U.S. Clean Water Act was violated more than 506,000 times.[16] The United States has 1343 Superfund sites where the federal government has accepted responsibility to oversee and, if necessary, finance the cleanup of toxic chemicals. Additionally, 413 Superfund sites have been remediated or sealed. Forty-three more sites have been proposed for Superfund status.[17] Generally, the main purpose of Superfund sites is to prevent contamination of ground water. Ninety percent of the wastewater discharged by developing countries is discharged untreated.[18]

One response to water shortage is desalination, the extraction of usable water from sea water. Desalination is expensive and requires substantial energy, but the most difficult problem is that there is no good disposal method for the salt brine waste.[19, 20]

Uncontaminated fresh water is a critical resource. The demand is increasing; the availability of safe, fresh water is inadequate. Contaminated water is a major source of disease.

River water disputes between upstream countries and downstream countries currently exist and will probably become more intense as demand for fresh water increases. The Indus River is a specific example. India needs the water, and Pakistan cannot survive without it. Life in Egypt depends on the food produced in the Nile River valley and electricity generated at the Aswan Dam. The Nile receives water from eleven countries. Upstream Ethiopia has designs for the river that could threaten Egypt. The Mekong River Delta is the rice bowl for Vietnam. Upstream Laos and Cambodia would like to establish hydroelectric dams on the Mekong, and that would affect the flow and timing of the river water reaching Vietnam. China has established several dams on the tributaries for the Mekong that cause severe water and silt shortage down river. The Tigris and Euphrates Rivers originate in Turkey but are the historical source of irrigation water for Syria and Iraq. What Turkey does with the water is of great significance to the downstream countries.

People traditionally settled adjacent to rivers because the fertile soil and water facilitated food production. When rivers flood, they replenish the fertility of the soil and flush the harmful minerals that would otherwise accumulate in the soil. But river floods are also a threat to human and animal life and unseasonal floods destroy planted crops. The solution was dams. Today, there are not fewer than 45,000 large dams on the planet and a much larger number of small dams.[21] Some of them are designed to produce electricity, some are a water source for irrigation. We now know that when agricultural land is deprived of rain or floods, the soil accumulates toxins and eventually requires chemical fertilizer. Wildlife is deprived of its habitat.

Were it not for the invention of a new material, we might be running out of trees and metal ores, two of our traditional raw materials. That new material is plastic, and plastic is our champion waste product. Americans purchase approximately 50 million tons of plastic each year, and a huge percentage of it ends up littering the planet where we live including the oceans.[22] In 1601, the English sent a sailing expedition to the East Indies to purchase spices. The sailors returned to England two and half years later with, among other things, a million pounds of pepper. Those sailors, at sea for so long, could not have imagined that it would be possible for humans to throw away enough of anything to pollute those vast oceans, but now it is happening.[23] Plastic does not readily decompose; no one knows the life span of plastic. It does, however, break into smaller pieces. Those small pieces are too often ingested by aquatic creatures. Some types of plastic absorb toxic substances from sea water and, if ingested, the toxins become concentrated as they ascend the food chain.[24] Seafood is a major component of the human diet.[25] A lot of our plastic products are one-time use. It is difficult to recycle plastic because the products must be separated by chemical composition which varies depending on the design purpose. Sixty percent of the clothing we wear, the equivalent of clothing for 4.5 billion people, is made from fossil fuel. We do not have the land and water resources to replace that fabric with the traditional plant and animal fabrics, e.g., cotton and wool.

We are even trashing the space hundreds of miles above the earth. The U.S. Strategic Command now tracks 17,000 "man-made" objects in earth orbit.[26, 27]

Some of our vulnerability to severe weather and natural events is acquired by where we live and the way we build structures. That statement does not imply fault. We do, however, need to address these acquired vulnerabilities. We can relocate to less hazardous areas, or we can construct buildings and infrastructure that can withstand severe shocks. Earthquakes, volcanic eruptions, fires, floods, drought, and severe storms on land and sea have always existed. Some of these events may be more intense because of changing climate. But even if they are not more intense, our vulnerability needs to be addressed. The structures we build become a part of the environment, and that environment affects the quality of life.

Cities absorb heat and can be warmer than the surrounding area. It is called the heat island effect. Environmental scientist Ming H. Wong reports that several cities in China sustain temperatures from five to eight degrees Fahrenheit warmer than the surrounding area.[28] The heat island effect of a city is, to a great extent, determined by its location. Some cities benefit from prevailing winds that remove heat. Rain can also have a cooling effect. Large, modern cities are constructed of materials that readily absorb and hold heat. When night falls, the area surrounding a city cools, but the urban core retains heat. The temperature differential between the city and surrounding countryside is greater at night than during the day. According to the U.S. Environmental Protection Agency, an urban core can remain as much as 22^{o}F warmer at night than the surrounding area.[29] Energy to operate air conditioners is required to cool those urban cores. There are some measures that cities can take to mitigate the heat island effect. Those measures include coating surfaces with heat reflective paint and installing trees or other vegetation where possible.[30] The Solar Reflectivity Index is a measure of the quantity of solar energy reflected back into space by a surface, e.g., a roof. The SRI for a white roof is considerably better than for a green roof, i.e., a roof covered with growing vegetation.[31] The engines of automobiles and trucks produce heat. Measures that reduce the automotive traffic in urban cores also reduce the amount of heat in urban areas.

City officials and private citizens are planting vegetation where ever they can to moderate the heat island effect and to make their cities more pleasurable. Entomology professor Douglas Tallamy advocates planting only native species, reasoning that those species have worked out predator-prey relationships and mutually beneficial relationships with other species over thousands of years whereas non-native species lack these balancing features.[32] Evolutionary biologist Menno Schilthuizen argues that cities need vegetation that thrives in difficult conditions and, if non-native species can thrive in cities and are otherwise satisfactory, they should be utilized.[33] The following agricultural plants are successfully cultivated in the United States, but none are native to the U.S. Almonds; apples; apricots; cantaloupes; corn; cotton; oranges; peaches; peanuts; pears; potatoes; rice; soy beans; tomatoes; watermelons; and wheat.

Trees extract carbon dioxide from the atmosphere, use it for energy, and store some of the carbon in their wood structure where it remains out of circulation during the life of the tree. Because there is currently an excessive amount of carbon dioxide circulating in earth's atmosphere, large scale reforestation of the planet is viewed as one means to improve the environmental health of the planet. Old growth forests established by nature are the model for reforestation projects. The trees that survive and thrive in old growth forests are well-adapted to the soil, water availability, sunlight, temperature variations, insects and diseases in the geographical region where they grow. Trees, like other vegetation, need soil that contains the appropriate nutrients. Diversity of tree species provides protection from pests. Carbon capturing forestation projects need to be permanent, never harvested for lumber. They need to be planted incrementally over several decades so that the trees are not the same age. And, to be effective as a carbon sink, millions of square miles of forest need to be planted.

Fossil fuels emit not only carbon dioxide when burned, but also release ground level chemicals and particulates that can impair human health and cause "smog." Various technical advances reduced these emissions, but increased demand for energy and, especially, increasing automotive congestion in cities has extended this problem. The worldwide improved air quality resulting from decreased economic activity in early 2020 that was induced by the COVID -19 pandemic revealed the effects of air pollution in real time. Noise reduction was also noted. Carbon dioxide emissions that trap heat in the atmosphere are another matter. Even though the economic downturn was severe, carbon dioxide emissions were reduced by only eight percent or less for the year 2020. This is a clear signal that solving the energy problem is going to be difficult. Additionally, the decline in economic activity and the accumulated governmental debt will probably make it more difficult to prioritize investment in "green" energy systems in the near future.

Some countries may not have laws to prevent discharge of industrial chemicals and waste products. Others have laws that are not successfully enforced. Equally significant are accounting systems that allow profits to be declared and passed to owners and shareholders while costs of processing waste products and remediation of habitat are passed to society. But we must also acknowledge that we citizens bear responsibility for our personal conduct and, in a democracy, we also bear responsibility for the performance of government.

Walking and bicycling to destinations, when and where feasible, reduces greenhouse gas emissions if it substitutes for driving, and physical activity promotes personal health. If that works for you, then consider persuading the public servants in your community to invest in safe and practical bicycle and walking facilities.

Species Stress

Adapt or Die is a fundamental requirement for biological organisms.

Sometimes adaptation is an unrealistic option. Alan Weisman writing in *The World Without Us* relates that the North American passenger pigeon existed in such great numbers that they darkened the sky at mid-day and formed "flocks 300 miles long." The last bird flew in 1914. The North American passenger pigeon was a victim of an invasive predator species, Homo sapiens.[1]

Bird populations in the United States have been substantially reduced by human activity including use of insecticides required for farming, wind turbines used for generation of electricity, electrical transmission lines, tall buildings, communications towers, and habitat loss. As many as a billion birds die annually because of these issues.[2, 3] Cities and supporting infrastructure are alien features on our planet. Temperature increase is apparently causing some bird species to lose body mass and increase wingspan.[4]

We generally think that insects are undesirable pests, but insects are vital for maintenance of human life. "Insects pollinate 87.5 percent of all plants, and 90 percent of all flowering plants. . ..."[5] All animals, even carnivores, depend on plants for food supply. Carnivores prey on other animals, but the animal food chain starts with plant eaters. During the past 50 years, worldwide insect population has declined approximately 45 percent.[6] ". . .humans would last only a few months if insects were to disappear from the earth. . .," according to entomologist Douglas W. Tallamy.[7]

Biodiversity is a life sustaining necessity. Habitat loss and human exploitation of species are the two main reasons that biological diversity is diminishing. To remain healthy and survive, a species must maintain genetic diversity. If a population becomes too small because of habitat loss, exploitation, or other reasons, it loses reproductive vitality and may become extinct. Lack of genetic diversity has appeared in the human species among, for example, European hereditary monarchies where inbreeding produced physically and mentally defective offspring.

Some species exploit a particular niche in the habitat. But when a species becomes highly specialized, adaptation to a changing environment is difficult, perhaps impossible.

Almost all species have some necessary relationship to another species. Some animals depend on trees for nesting sites or shelter. A plant may depend on microorganisms to fix nitrogen in the soil, or it may depend on insects to transmit pollen. Some plants depend on birds to scatter their seeds. In the United States, 96 percent of birds that live on land are omnivores or carnivores; they feed their young insects, especially caterpillars. The leaves of oak trees are an important food source for caterpillars.[8] A food chain can have several links, each one important to other species. Living things have become accustomed to these relationships and may not survive if they are lost. The expansion of human population to 7.6 billion people and the development of modern technologies and lifestyle have led to wide scale habitat destruction, and that process is continuing.

Habitat change in the northeastern U.S. has contributed to an unforeseen spread of tick vectored diseases that affect our human population. Ticks spread Lyme disease and 15 other diseases. The greatest incidence of Lyme disease in the U.S. is among boys ages five to ten, probably because of their outdoor play activities where they are exposed to ticks.[9] Chipmunks, short-tailed shrews, masked shrews, and white-foot mice are prime transporters of ticks, especially white-footed mice. In their original natural habitat, tick populations were moderated by foxes, hawks, owls and other predators that pursued the smaller animals thus limiting the tick population. Opossums are champion tick destroyers through their grooming process. Real estate development, infrastructure development, and land clearing for farming reduced the population of predator animals and opossums thus allowing the tick population to increase. Loss of biodiversity is a factor in the incidence of tick vectored diseases.[10] Acorns are a favorite food of white footed mice. Acorns were also a favorite food of the extinct North American passenger pigeon. According to David E. Blockstein and Stanley A. Temple, the feeding activity of the three to five billion North American passenger pigeons that previously lived in North America limited the food supply and thus the population of white footed mice. Fewer white footed mice attracted fewer ticks that vector Lyme and other diseases.[11] This is an example of a harmful loss of biodiversity. Also, climate change may be expanding the length of the season that ticks are active.[12]

Invasive species are a serious threat to biological diversity. Human beings are a global species. We bring plants, animals, viruses, bacteria, and fungi along with us during our travels and commerce. The number of alien “invasive species” introduced in the United States is estimated to be in the thousands including, for example, the Burmese Python in the Florida Everglades and the Lionfish along the Florida Atlantic coast and the Gulf of Mexico. Neither species has a natural enemy in its new habitat, and both devastate native species. Spanish explorers inadvertently brought diseases to the native American Indians who had no immunity and no medical scientists to work out solutions. The Indians suffered serious population decline. According to Charles C. Mann writing in his book *1493*, the Europeans brought smallpox, influenza, hepatitis, measles, encephalitis, viral pneumonia; tuberculosis, diphtheria, cholera, typhus, scarlet fever, and bacterial meningitis to the Western Hemisphere killing about seventy-five percent of the native population.[13] The Irish potato blight, *Phytophthora infestans,* moved from the Americas to Europe where it caused the Irish potato famine resulting in the starvation of a million people and the migration of two million people.

There is a tremendous amount of living matter, both flora and fauna, in the oceans. Those organisms are sensitive to their environment. The sensitivities include acidity, water temperature, light, oxygen, noise, industrial chemicals, salinity, and predator pressure. That predator pressure includes human commercial fishing. The open oceans are “commons,” not owned or controlled by any government. As a result of that problem, oceans are severely overfished. Seafood is a major source of animal protein for human sustenance.[14]

About 230,000 species of ocean dwelling plants and animals have been identified.[15] Because only about five percent of the deep ocean has been explored, scientists estimate that another two million ocean dwelling species may exist.[16] Carbon dioxide cycles, naturally, from atmosphere to the oceans and, eventually, back to the atmosphere. A part of the process of moving carbon dioxide from the atmosphere to the deep oceans is performed by living micro-organisms, phytoplankton (plant) and zooplankton (animal).[17] But the ocean is changing, and it is uncertain how these living organisms will adapt. Oxygen content of the oceans has declined by two percent during the past half century.[18] Sea surface temperature has increased 1.8°F[19], and the water has become less alkaline, a pH decline from 8.2 to 8.1.[20] It is not yet clear how these environmental changes will affect the function of the carbon recycling plankton or the many other species that reside in the ocean. Warm water corals are an exception. They have demonstrated their sensitivity to environmental stress.[21] Warm water corals are home to a huge number of ocean plant and animal species. Corals are animals that have a symbiotic relationship with zooxanthellae, another animal, that provides nutrients for the coral. But when the zooxanthellae are heat stressed from a warming ocean, they abandon the coral.[22] The corals lose the coloration provided by the zooxanthellae and become white, a process called bleaching. If the water temperature normalizes within a few months, the symbiotic process resumes and the coral survives. The Great Barrier Reef near Australia suffered a major bleaching event in 2016. Declining pH is a concern for marine animals that calcify exoskeletons or shells, but it is too soon to be certain how that will develop.

Another type of destabilization of ocean life that presents with clarity is the dead zone phenomenon. Approximately 95,000 square miles of ocean are mostly devoid of living plants and animals, either seasonally or continuously.[23] Chemical fertilizer from farm fields that is not absorbed by the roots of farm crops leaches into rivers and moves down stream to the coastal area of oceans as does sewage discharge from cities and towns.[24] Fertilization stimulates excessive algae growth. When the algae die, decomposition consumes the available oxygen supply in the water making it impossible for other life forms to exist. The United States has a large dead zone where the Mississippi River empties into the Gulf of Mexico.

Plastic waste ocean contamination, briefly addressed at pages 15 and 16, is no mystery. It is a result of careless human behavior. The world produces 395 million tons of plastic annually (359 million metric tons).[25] A huge percentage of that plastic becomes unmanaged trash contaminating every part of the planet. Plastic doesn't decompose. It courses through ocean waters where larger pieces cause injury or death to sea turtles, sea birds, and about 43 percent of marine mammal species that ingest plastic or become entangled in it.[26] Plastic doesn't readily decompose, but it does break into ever small pieces, as small as one nanometer, one billionth of 39.37 inches. Small plastic particles are inadvertently ingested by filter feeding marine animals. The plastic accumulates in the organism's system. Most plastics contain chemical additives, some of which are toxic. Some types of plastic act like a sponge, soaking up toxins from the sea. These toxins work their way up the food chain where they concentrate in large fish that humans consume. Pieces of plastic are transport systems for micro-organisms, including pathogens (disease causing). They ride free where ever the current takes them, thus becoming a new form of invasive species.[27]

Many plastic items are one-time use and are not recycled. Americans use an average of 500 plastic bags per person per year after which the bags often become litter carried by wind and oceans currents to every part of the planet. A Florida law prohibits cities or counties from enacting bans on plastic bags and other consumer plastic items. Some other states have similar legal codes.[28, 29]

Plastic is useful. It is a versatile and inexpensive fabrication medium. But management of plastic waste is a problem, and it is an international problem. Plastic pollution doesn't readily degrade, and it is harmful to many living organisms. Asian countries produce 51 percent of the world's plastic.[30] The countries that generate the most plastic waste are China, the United States, Germany, Brazil, Japan, Pakistan, and Nigeria.[31] The countries contributing the greatest amount of plastic pollution to the oceans are China, Indonesia, Philippines, Vietnam, and Sri Lanka.[32] The United Nations Environmental Program estimates that there is an average of 46,000 pieces of plastic in every square mile of the oceans.[33] A survey of the Atlantic ocean to a depth of 650 feet found as many as 7000 plastic micro-particles per cubic meter of seawater.[34, 35] A current assessment of ocean plastic pollution is addressed by M. Debora Iglesias-Rodriguez in *The Future of Marine Life in a Changing Ocean.*[36]

A mass extinction of species is underway. Some species may not be missed; other species may be vital to the function of the planet. The problem is that scientists have not had the time and the resources to evaluate or even identify all of earth's living entities. Some of them may benefit our well-being. Humans cannot exist without plants, animals, and microbes, but all of those living organisms can exist without humans. Humans are the dispensable species.

Annex A

Temperature conversion

This text uses the Fahrenheit temperature scale that is familiar to most of us. However, the scientific community prefers the centigrade scale.

Convert centigrade temperature to Fahrenheit:

$F = 9/5\ C + 32$

Convert Fahrenheit temperature to centigrade:

$C = 5/9\ (F – 32)$

Scientists also use the Kelvin temperature scale. The Kelvin scale starts at absolute zero. One degree Kelvin is equal to one degree on the centigrade (Celsius) scale.

	Water freezes	Water boils*
Fahrenheit	32	212
Centigrade	0	100
Kelvin	273	373

*At sea level atmospheric pressure (14.7 psi)

Land area conversion

Convert hectares to acres:

Number of hectares multiplied by 2.47 equals the approximate number of acres.

Example: 10 ha x 2.47 = 24.7 acres

Linear distance unit conversion

Convert kilometers to miles:

Number of kilometers multiplied by 0.62 equals the approximate number of miles

Example: 100 km x 0.62 = 62 miles

Annex B

Oxygen isotopes

Oxygen atoms can have different numbers of neutrons in the nucleus. ^{16}O is standard, that is, 8 protons and 8 neutrons in the nucleus. But ^{17}O and ^{18}O occur in small quantities. ^{17}O has one extra neutron. ^{18}O has two extra neutrons. The symbol δ is pronounced *delta*, and is used to express the ratio of ^{18}O to ^{16}O.

Geologic history of climate can be determined by analyzing the $\delta^{18}O$ content of the shells of benthic foraminifera in the core samples of ocean sediments. During ice ages, ocean water accumulates on the polar ice caps and sea level declines. Under those conditions, the shells of benthic foraminifera reflect a higher concentration of $\delta^{18}O$ than during inter-glacial periods. The core samples of ice from the polar ice caps reflect the opposite, a lower concentration of $\delta^{18}O$ during ice ages.

Scientists use this system and other data to determine that the earth has experienced eight ice ages during the past million years.

Carbon-12, carbon-13, and carbon-14

Most carbon atoms have six protons and six neutrons in the nucleus yielding carbon-12. A few carbon atoms have seven neutrons yielding carbon-13. Very rarely, a carbon atom has eight neutrons yielding carbon-14. Carbon-14 is radioactive. The rate of radioactive carbon-14 decay allows dating of objects as old as 50,000 years. Fossil fuels—coal and petroleum—do not have carbon-14 because those products have been buried for millions of years. When a fossil fuel is burned, the emissions do not contain carbon-14. The ratio of carbon-14 in the atmosphere is declining. The concentration has decreased by two percent since 1900. Scientists conclude that the decline is because the carbon dioxide from fossil fuels does not contain carbon-14. The symbols for these carbon atoms are: ^{12}C, ^{13}C, and ^{14}C.

Annex C

Approaches to Reduction of Greenhouse Gases

Primary non-carbon dioxide energy sources

<u>Examples</u>

Wind, solar, hydrogen, hydroelectric, nuclear

Removal of carbon from the atmosphere

<u>Examples</u>

Re-forestation
Direct withdrawal of carbon dioxide from the atmosphere (an attempt to do what trees do)

Research for improved technology

<u>Examples</u>

Electricity storage system
Carbon capture and sequestration (from flue gasses)
Nuclear fusion
Concentrated solar power

Frugality

<u>Examples</u>

Forego automobiles
Small houses
Vegetarianism
Reduced night activity

Efficiency

<u>Examples</u>

Improved automotive fuel mileage
Low energy demand electrical appliances
Work from home via electronic technology
Walk, bicycle, or use mass transit

Disruption of fossil fuel production

Examples

Disinvestment
Taxation

Population control

Examples

Education for females
Birth control measures
Improved economy
Urbanization

Geoengineering

Examples

Seeding clouds with chemicals to promote reflectivity
Seeding the ocean with chemicals to promote phytoplankton growth
Pumping nutrient bearing deep ocean water to the surface to promote phytoplankton growth
Placing reflective mirrors in space
Irrigating a desert to promote tree growth

Passive Cooling

Examples

Solar reflective surfaces
Urban trees and other vegetation (ground level cooling)

Other

Example

Climate change education

NOTE: This is not an all-inclusive list of approaches to climate change.

Glossary

These are terms that are used by scientists and writers when the subject is climate change or environmental issues or stress on living species of plants and animals.

afforestation

Afforestation is planting a forest where one did not previously exist.

albedo

The word albedo originally meant white. The word is used by climate change writers to express the amount of sunlight that is reflected back into space by a surface. A white surface (ice or snow) reflects a lot of the incoming solar energy; a black surface absorbs a lot of the incoming solar energy (heat).

Anthropocene

(Anthropo) is a prefix that means human, and (-cene) is a suffix that means era or period. Climate change writers use the word Anthropocene to indicate that we live in an era when climate change is caused by humans.

Does it seem reasonable that human beings could alter the climate of the planet? Once upon a long time ago, a type of bacteria called cyanobacteria began producing oxygen. Without that oxygen there would be no carbon dioxide CO_2. There would be no animals, at least, none that breathe oxygen. If cyanobacteria can alter the planet and its climate, perhaps Homo sapiens can also do it.

cryosphere

The cryosphere is the ice on planet earth including the polar icecaps, the glaciers, and the sea ice. Ice is a result of climate, but ice changes can also affect climate, environment, and human activities.

ecology

Ecology is the study of the relationships among living things and the environments they inhabit.

hydrosphere

The hydrosphere is the water on planet earth including oceans, lakes, rivers, and the water vapor in the atmosphere.

insolation

Insolation is the amount of solar energy per unit of area that reaches the earth over a specific amount of time. A square foot where the sun is directly overhead receives more solar energy than a square foot where the sun is low in the sky.

intermittency

Solar panels and wind turbines deliver energy intermittently, i.e., not consistently. That deficiency requires that backup baseload electric generating plants—hydroelectric, fossil fuel, or nuclear—provide electricity when the sun doesn't shine or the wind subsides. The intermittency problem may eventually be resolved by development of a storage system for electricity. That may be improved batteries, but it could also be other technology. Lakes behind hydroelectric dams are a storage system. Other storage technologies are being considered.

irradiance

Irradiance is a measure of the amount or intensity of the sun's energy falling on planet earth and may be measured as watts per square meter. W/m^2

isotope

Isotope refers to the variable number of neutrons in the nucleus of some atoms.

lithosphere

The lithosphere is the crust of the earth. It varies in thickness but may be as much as sixty miles thick, below which is the molten core of the planet.

phenology

Phenology is the science dealing with climate influenced biological processes, e.g., bird migration dates, insect hatch dates, leaf bud and flower dates, and aquatic species migration. A warming climate can induce changes in these activities.

radiative forcing

Radiative forcing (RF) is any factor that changes the amount of heat transmitted as electromagnetic radiation from the sun to earth or from earth to space. Debris from a volcanic eruption that impedes incoming solar radiation would be a natural radiative forcing. Human activities also induce radiative forcing. Positive radiative forcing warms the planet, e.g., carbon dioxide from fossil fuel burning. A negative radiative forcing cools the planet, e.g., some manufactured aerosols.

thermohaline ocean circulation

(Thermo) is a prefix that means heat, and (haline) refers to salt. The oceans are salt water. However, the concentration of salt varies. A greater concentration of salt increases density (weight per cubic unit) of the water, and that causes the higher density salt water to sink below ocean water with a lesser salt content. Temperature also affects density. Warm water has a lesser density than cold water. Scientists have identified ocean circulation patterns that are driven by differentials in salt content and water temperature. That is called thermohaline circulation.

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