4

# THE GREENHOUSE EFFECT, THE OZONE HOLE, THE LIGHT, THE HEAT AND THE GASSES

GLOBAL WARMING IS CAUSED by a greenhouse effect. This greenhouse effect is the conversion of light energy into heat energy, followed by the entrapment of that heat energy within the atmosphere of our planet.

## HOW A GREENHOUSE WORKS

A glass-enclosed greenhouse is used to create a warmer climate within the greenhouse than exists naturally outside the greenhouse. Tropical and subtropical plants can be grown in the warmer artificial climate. The entire air and surface temperature of the Earth is determined in a similar way. Our planetary temperatures are therefore described as resulting from a total world "greenhouse effect". Greenhouse effects result from the optical characteristics of the covering over the greenhouse; as was mentioned in Chapter 3.

White-hot surfaces, such as the surface of the sun, radiate white light. Slightly cooler objects, but still red-hot, radiate red light. Cooler objects still, objects cool enough to touch, radiate infrared light. "Infra red" means beyond red, and is not visible to human eyes, but we feel it as heat.

The glass in the walls and roof of a greenhouse is almost transparent to visible sunlight. The sun shines through the glass, and objects inside the greenhouse absorb the light energy and warm up. As the objects get warmer they radiate this warmth back out, but now they are radiating the energy as infrared light. Glass is transparent to white light but is not transparent to infrared light. The light, converted to heat energy is trapped.

Some of the infrared light coming from the objects within the greenhouse is simply reflected back off the glass and stays inside the greenhouse. Some of the infrared light is absorbed by the glass as it tries to get through. This now warmer glass in turn radiates energy. Some of the energy is radiated to the outside and escapes, but the rest is radiated back into the greenhouse. The temperature inside the greenhouse slowly rises. Eventually the glass, and the materials inside the greenhouse, get hot enough that as much heat is lost to the outside as the sun is pouring in. A warmer internal greenhouse temperature eventually stabilizes.

It depends on the conditions, but generally around 25% of the heat loss from a greenhouse is due to radiation from the glass. The rest is lost by conduction; for example, the heat might soak into the ground, or by convection, as outside breezes cool the glass walls. Such breezes blowing on the glass can increase heat loss dramatically. This is the reason why greenhouses are often doubleglazed. Usually in a greenhouse most of the heat loss results from this convection.

Our atmosphere acts like the glass in a greenhouse. It too lets the sunlight from space through and down to the ground. The ground warms up and radiates infrared light back into space. However, certain gasses in the atmosphere, the oxides of nitrogen, methane (the marsh gas that bubbles through your toes in swamps) and carbon dioxide (the bubbles in soda water and soft drinks) are opaque to infrared light. These gasses act exactly the same as the glass in a greenhouse. The infrared is re-reflected again to the ground. And so the Earth's surface warms up.

There is no air in space, and so there can be no convenient breezes in space to help cool the Earth down in the manner that glass is cooled in a greenhouse. Obviously, conduction and convection effects can't apply to a whole planet, as a planet resides in the vacuum of space. It is heat radiation alone that is relevant to overall planetary surface temperatures. Radiation is the sole way by which a planet can shed heat, or for that matter, any celestial body. Of course there are geological and nuclear energy phenomena occurring deep within our planet, but these have surprisingly negligible short-term or direct surface temperature effects.

The stream of solar energy that constantly bathes our planet has little variation. Weather and climate variations depend entirely on whether that sunlight energy stays in our atmosphere, our soil and our oceans, or is ultimately reflected or re-radiated back into space. The movement of the sun-derived energy through all these systems is called the "greenhouse effect". The prime controlling factor in the magnitude of the greenhouse effect is atmospheric carbon dioxide. The levels of carbon dioxide in our atmosphere, and the absorption of that carbon dioxide into the geology of the Earth's crust, into the oceans, into the planet's living biomass, and into soil fertility enrichment processes, are all intimately interrelated and determine the surface temperature of the planet.

All life on this planet controls, and is in turn controlled by, the relatively minuscule carbon dioxide content in our planet's atmosphere. We have to realize that by digging up and burning ancient buried carbon deposits, we are massively increasing that content.

## ELECTROMAGNETIC ENERGY AND THE GREENHOUSE EFFECT

Sunlight warms the Earth's surface and the Earth's atmosphere in a couple of different ways. The particular process is determined by the wavelengths of the incoming electromagnetic radiation. Light is simply visible electromagnetic radiation.

At an altitude of 275,000 feet or 52 miles (84 kilometres), the majority of the dangerous short wavelength gamma rays and X-rays in raw sunlight have been screened out by upper atmospheric effects. This happens in what is almost, but not quite, the vacuum of space. These effects are negligible as far as Global Warming is concerned. Infrared and visible light are the important ones. Starting with longer wavelengths, infrared radiation is in general absorbed by the gasses making up the atmosphere before it reaches the ground.

The greenhouse gasses in the atmosphere, having absorbed this heat energy, immediately re-radiate it out, but now in any random direction. What happens is that an individual molecule of the gas will absorb a photon, that is a single "particle" of light energy, and a little while later shoots another photon out at pretty much the same wavelength it came in at. Some of these photons will be re-absorbed, some will be re-radiated back into space, some will get all the way through the atmosphere and warm the planetary surface. Sometimes a molecule that has absorbed a photon collides with another molecule before it has a chance to shoot a photon back out. When this happens the energy is not re-emitted but instead ends up increasing the speed of the molecule. This increased speed manifests itself as an increase in temperature of the gas. Convection currents then distribute the heat through the surrounding air and warm the total mass of the atmosphere.

The other greenhouse warming process

involves shorter wavelength radiation. The majority of this radiation is visible light. The light, or more correctly photons of light come straight down through the atmosphere until they hit a cloud and are reflected directly back into space, or they penetrate straight through to the Earth's surface. During any one day it is usually a combination of both. The absorbed radiation warms the ground or the ocean. The heat soaks in. The temperature of the ground can then be warmer than the air in contact with it. So the air gets warmed by conduction. This warmer air moves away from the ground and in turn warms the atmosphere by convection.

All objects emit heat radiation, and the wavelength of that heat radiation is determined by the temperature of the radiating body. The ground is relatively cold and can only radiate infrared radiation. Infrared radiation has a lot more trouble getting past the greenhouse gasses to outer space and the heat is trapped.

Thus we have energy arriving from the sun in the form of visual light that easily penetrates our atmosphere. It hits the ground and is absorbed. As it is now trapped, things warm up. So the greenhouse effect basically depends on the optical qualities of our atmosphere. As more infrared absorbing gasses enter the atmosphere, the effect intensifies.

Optical processes can be affected by minuscule quantities of matter. For example, a household mirror reflects almost all light shining on it. That light is reflected back by the metallic coating on the back of the mirror. The coating can be mercury, silver, or aluminium and is usually between one and two-millionths of an inch (30 nanometres) thick. A nanometre, or nm, is one-billionth of a metre.

A piece of aluminium foil wrapped around a light globe won't let any heat or light radiation in or out. A thin coat of white paint, or a thin coat of black paint, will make an incredible difference to how much an object will heat up in the sun. The white paint is cool. You can fry an egg on the black paint. Smoke a piece of glass with a candle. The coating will be microscopically thin, yet the bright sun appears as a faint orange ball when viewed through the glass. A good 99% of the sun's energy has been blocked.

The colour effects of a film of oil on water occur because the film of oil has thinned out to where it is no thicker than the wavelengths of the light shining on the oil. The differences in the thickness of the oil film trap different wavelengths. What you see is not actually a true spectrum but white light minus the particular colours of the true sunlight spectrum. You see that peculiar spectrum of not-quite-right colour.

If gold and mercury contact, a layer of mercury, as thin as a few atoms across will immediately coat the gold, and the colour of the gold vanishes. Those few atoms of mercury are extremely difficult to remove to expose the underlying gold, but eventually the mercury will evaporate into the air. Never let your gold wedding ring touch a drop of mercury.  What you actually see is a tiny opaque layer of mercury atoms. The coated gold looks a little like silver or platinum.

That's how little is required to alter optical phenomena. And so, it bears repeating. The entire greenhouse effect is an optical phenomenon; subject to control by seemingly insignificant quantities of matter. Because of this our power to change the temperature of our entire planet is awesome. We are now like small children innocently playing with fully loaded guns. And the fossil fuel industries keep telling us not to worry.

Greenhouse effects are not just confined to the backyard greenhouse and the atmosphere of planet Earth. Our two neighboring planets, Venus and Mars are excellent examples of planetary surface temperatures massively modified by greenhouse effects. The planets of our solar system have wildly different atmospheres resulting from the unique variations in their planetary evolution.

The atmosphere of Venus was originally assessed as probably 96% carbon dioxide and about 3% nitrogen; the rest a mixture of various gasses. Calculations based on this level of carbon dioxide predicted surface temperatures could be as high as several hundred degrees. Both predictions have since been confirmed by space probes.

In the unlikely event it ever existed, life on Venus was never able to entrap the planet's carbon dioxide and safely lock it away under the surface as limestone deposits, oil deposits, peat or coal beds, and certainly not as fertile soil. All the carbon dioxide that was ever in the atmosphere of Venus is still there. Its greenhouse effect, with all that carbon dioxide in its atmosphere, has established a completely stable but scorchingly hot, lifeless world. Ground temperatures on Venus were found to be around 475ºC (850ºF). The atmospheric pressure on Venus is about ninety times as high as here on Earth.

The planet Mars, on the other hand, was forecast as a place of extreme cold. Our space probe visit to Mars confirmed the forecast exactly. The actual composition of the atmosphere is virtually the same as on Venus. However the Martian atmosphere is so thin that the warming caused by a Mars' greenhouse effect is lost to space. The ground level atmospheric pressure on Mars is about 6 millibars, whereas on Earth it averages 1,013 millibars. In consequence, the surface temperatures of Mars range from a cold minus 20ºC at midday, to an extremely cold minus 120ºC at midnight.

Like Earth, the atmospheric temperatures and the ground surface temperatures on these planets are almost totally controlled by the quantity and composition of their atmospheres. The modelling of surface temperature modifications by greenhouse effects is well understood. The predicted surface temperatures on Mars and Venus were almost exactly the temperatures found when the inter-planetary space probes finally got there and checked them.

If planet Earth did not have an atmosphere containing gasses with significant greenhouse effects, the average temperature would not be plus 56ºF (15ºC) as it is now, but zero Fahrenheit (minus 18ºC) and with the same wild daily temperature variations found on other planets. This predicted temperature for our planet uses the same formula that so accurately predicted the temperatures of our neighboring planets. There are now no unexplained mysteries in the correlation of global temperatures with greenhouse gas levels in any planet's atmosphere.

If we had no atmosphere on Earth things would be very different. We can use the moon to illustrate this perfectly. The Earth and the Moon are both, on average, exactly the same distance from the sun. The night-time surface temperature of the Moon can drop below minus 150ºC and the day-time surface temperature can exceed 100ºC. The Moon's average surface temperature is about 33ºC cooler than the Earth's average. The Earth's atmosphere and its resulting greenhouse effect gives us the extra 33ºC of warmth and mitigates the inhospitable 250º C variation in daily temperature which would otherwise occur and make life on Earth, at least as we know it, impossible.

We know the temperatures that occur on Earth. We measure them all the time. We can forecast with confident accuracy and reliability how hot our changing atmospheric carbon dioxide level is going to make our atmosphere and our ground temperature. Just what these temperature rises will do to world climate, rainfalls and sea levels are the frightening unknowns. But we can be sure it won't be pleasant.

### **EXTRA:** HOW HEAT ENERGY MOVES.

Heat energy can be transferred, moved, or conveyed in three different ways.

The first is by radiation. All objects constantly absorb in and radiate out heat radiation. Heat radiation and light radiation are really the same. Heat radiation is usually considered as light radiation that is just outside our capacity to see. It is "invisible", although you can feel it.

The radiant heat emitted from an object is proportional to "the fourth power of its absolute temperature". So, if you double the absolute temperature of an object its radiation will increase sixteen-fold. If you increase the temperature threefold and it will radiate out, three by three by three by three times, as much radiation as it did at the cooler temperature. That is eighty-one times as much radiant heat.

If a surface is exposed to a similar adjacent surface with a higher temperature, both surfaces continue to radiate and both surfaces continue to absorb the radiant heat. Because of this quadruple multiplication factor, the cooler surface rapidly absorbs extra heat from the warmer surface. This happens until both reach the same temperature and radiating and absorbing effects become equal.

The heat we feel from a radiator, and the warmth we feel on our hand near a light globe is radiation, but to be more precise it is "electromagnetic radiation". Apart from quantity, the difference between radiation emitted from your hand and that from a light globe is simply the respective wavelengths of the electromagnetic radiation.

The second way heat energy moves is by conduction. Heat can be transferred from one object to another by conduction, if the objects are in contact. The molecules or atoms in a substance are always bouncing around a bit. The hotter the object the more they bounce around. When a hot object comes into contact with a cold object, the more violently moving molecules in the hot object "crash" into the molecules in the cold object and cause them to start bouncing more vigorously. So the cold object heats up. The process is called "heat conduction". Heat conduction burns your finger when you touch a hot electric iron.

Thirdly, heat can be transferred from one object to another by convection; that is when the actual object itself, containing the heat, moves. The hot electric element in a hair dryer warms the air in contact with the hot electric coils by conduction. The warmth, or the energy, in this now warm air is conveyed, or carried, to your wet hair as the air moves.

This process is convection. Convection can be "natural or un-forced" as in the case when warm air rises naturally warming the air above, or it can be "forced", as the example of the hair dryer where a fan pushes the warmed air along.

## THE COMPOSITION OF THE ATMOSPHERE

To understand what determines the extent of the greenhouse effect on Earth it's wise to have some basic knowledge of the properties and composition of our current atmosphere. Otherwise we are too easily fooled, and too many people want us to be.

The composition of our atmosphere is nitrogen 78%, oxygen 21% and argon 0.9%. All the rest of the gasses – carbon dioxide, neon, methane, krypton, helium, xenon, hydrogen, nitrous oxides, carbon monoxide, nitrogen dioxide, sulphur dioxide and ozone and various man-made gasses make up the remaining 0.1%. There is also both water and water vapour, which we'll count separately as atmospheric water content can vary enormously. It can vary from virtually zero to the huge quantities occurring during a storm.

The pressure in our atmosphere drops off with height, similar to the way water pressure drops off as you rise to the surface from a dive. Proportionally, air pressure does actually drop off faster as you ascend because air is compressible, so its density, or weight per unit volume, also drops off with height. Whereas, even under extreme pressure, the density of water varies little.

Temperatures don't follow that simple pattern. Starting from ground level and rising we are initially in the troposphere, where just about everything that directly concerns human life happens, from growing our food to flying our planes, from drizzling rain to towering tornadoes. In the troposphere, temperatures constantly decrease with height at an average of about 1.1ºF (2ºC) per 1,000 feet (300 m) to about minus 69ºF, or about 101ºF below freezing (-56ºC). At this point the temperature stops dropping and we enter the stratosphere. The behaviour in temperature nominates the boundary. The boundary between the troposphere and the stratosphere is called, appropriately enough, the tropopause. This boundary can be as low as 25,000 feet (8 km) over the poles and as high as 50,000 feet (15 km) over the equator.

The troposphere contains 80% of all the air on this Earth of ours. When you look out the window on that inter-city jet flight we previously considered, 80% of all the world's air is underneath you and that air controls the temperature of the entire planet. It is a sobering thought.

The area defined as the stratosphere tops out at about 160,000 feet, or 30 miles (50 km). In the stratosphere the temperatures stay at their low readings until slowly rising again to about 50ºF (10ºC) in a thin band called the mesosphere. At a height of around 60 miles (100 km) temperatures again fall to low readings. They then start to rise again as we merge into interplanetary space where temperatures rise to as high as several thousand degrees. At these heights however, there is so little mass involved that such temperatures are almost purely academic. Our skin can't tolerate boiling water but we sit in saunas with air temperatures well above that of boiling water. The air may be hot but being so light there is little heat energy in it. Variations in temperatures of thousands of degrees would not even be felt in the thinness of space.

At an altitude of 30 miles (50 km) or so, only about 0.1% of the world's air is still above you; yet this thin air is still sufficient to protect us from incoming meteors. We see them as shooting stars as friction burns them up travelling through this high thin air.

## WHAT IS CLIMATE MODELLING?

Climate modelling is the simulation on computer of most of the variables involved in predicting weather patterns and climatic change.

In climate modelling relating to the greenhouse effect, usually all the greenhouse gasses and their effects are given a "carbon dioxide equivalent" rating. The quantity of each gas is converted into the quantity of carbon dioxide that would give the same greenhouse effect. Apart from CFCs most of the greenhouse gasses are fossilized-carbon use related and therefore fairly intimately related to pure carbon dioxide concentrations. The simplification therefore does not distort the essential validity of calculations. Changing greenhouse gas concentrations can then be studied as an exercise in one variable – the equivalent total of $CO_2$.

Climate and weather modelling works something like this.

First you might get the temperature of the local ocean current, and let's say, you already know that it's moving south. There might be a high pressure system sitting off to the east and you know air revolves around a high pressure system in a certain way, counterclockwise in the Southern Hemisphere, clockwise in the Northern. You have collected measurements, the humidity of the air and its temperature and pressure at various heights. At the time of the year the warmth from the sun is a known quantity. The air maybe has a measured quantity of dust from a recent dust storm, and that will affect heat getting through to the ground. This too must be allowed for. Summer is approaching. You know that the ground is much wetter than it normally is because of recent rain showers. You have a whole stack of records that show what happens when similar readings occurred in the past. In addition you have worked out some rules that give you a rough idea how each of the conditions you've measured affects other phenomena. You then put all this information, and as many rules as seem applicable, into a computer and press "go".

Because there are so many variables, the bigger and faster the computer is, the better. What you want the computer to do is to move all these variables around according to your rules, and give you back what all these readings will be, let's say, a week ahead. Short-term, this is called weather forecasting. Long-term, it's called climate modelling. Climate modelling implies covering a much larger area than that taken into account in weather forecasting.

In practical terms, with weather forecasting in most parts of the world, the most accurate weather forecast for tomorrow is firstly that it will be the same as today. To this is added modifications based on information gleaned from weather maps, satellite cloud images, and even the location of recent rainfalls. A final forecast is then made. This method is hardly climate modelling, but is generally reliable in the short-term.

Prior to the advent of powerful computers, long-term forecasting was based on considering what similar weather patterns in the past had produced and basing a forecast on history repeating itself.

This method of forecasting is difficult without a mass of accurate records. Of course for long-term climate forecasting in a Global Warming scenario, the records themselves unfortunately now come from a somewhat cooler world. With modern powerful computers there is now less reliance on simply looking at “patterns” in the past weather. Both weather forecasting and climate modelling now depend more on knowing how all the variables interact and using these “rules” to let the computer work out what will happen. The accuracy is improving constantly.

## THE GREENHOUSE PROPERTIES OF THE ATMOSPHERIC GASSES

The greenhouse effect of an individual gas is determined not only by how much of that gas is up there, but also how well the gas absorbs and then re-radiates energy or simply scatters it. Those wavelengths of electromagnetic radiation, that a gas molecule absorbs best, are determined by the size of the gas molecule and how strongly the atoms within the molecule are bound together, or how “flexible” the molecule is. Each gas has its own unique capacity to absorb sunlight at particular wavelengths. Additionally, the significance of the effect will vary if it occurs at a high altitude or a low altitude because of previous screening. The gasses that make up the atmosphere are evenly and totally mixed throughout all altitudes. The only exception being at altitudes where particular gasses are being chemically or structurally modified by some external influence and mixing is not yet complete.

The molecules of oxygen and nitrogen in the atmosphere are too small and too rigid to interact with either visible or infrared light and do not have any greenhouse effects. The molecules that comprise the gasses that concern us most are slightly bigger, more flexible and a little more complex. They can interact with infrared light and so have an important part to play in the greenhouse effect.

These gasses are, carbon dioxide ($CO_2$), methane ($CH_4$), nitrous oxide ($N_2O$) and various other compounds of nitrogen and oxygen, loosely labeled $NO_x$. Then there is ozone ($O_3$), and finally the compounds of carbon combined with chlorine and fluorine and generally labelled chlorofluorocarbons, or CFCs. Although ozone is a potent greenhouse gas, the quantities involved are too tiny for its greenhouse effect to be of any real significance.

CFCs are the man-made gasses used in such things as refrigerators and spray cans. The CFCs are important both because of their interaction with ozone and because of their not totally insignificant greenhouse effects. Ozone and the Ozone Hole are discussed later in this chapter.

Some of the wavelengths in solar radiation are absorbed by a few greenhouse gasses, some are absorbed by only one and some are not absorbed at all. One of the reasons that the refrigerant gasses, the CFCs, are a significant greenhouse gas is that they affect wavelength ranges that are otherwise unaffected by the main greenhouse gasses. This effect of the CFCs is in addition to their ability to destroy the high altitude ozone layer that helps in shielding us from cancer causing ultraviolet radiation.

All the greenhouse gasses combined currently make up less than one-tenth of one percent of the atmosphere. Water however is a wild card. When water evaporates into the air, it becomes humidity or water vapour. And atmospheric water vapour acts as a very powerful greenhouse gas.

Of course the greenhouse gasses are thoroughly mixed and dispersed throughout the predominately nitrogen-oxygen atmosphere.

For an exercise to appreciate the relative quantities and importance of the atmosphere’s constituents, let’s imagine that we take all the greenhouse gasses combined and separate them out. We then put them in separate layers away from the main nitrogen-oxygen mix. Imagine them as individual self-contained layers on the surface covering the whole planet and then let's measure them. For this exercise we will omit humidity and cloud formations and also assume the gasses are at normal ground temperature and pressure. We are talking about gasses not liquids.

That layer of greenhouse gasses would be about nine feet (3 m) high. The layer of gas would not reach the ceiling in a one storey bungalow. If we then condense the gas layers into our hypothetical liquid form, the total layer of greenhouse gasses would be no more than about an eighth of an inch (3 mm) deep. Of that only a very tiny but very dangerous added fraction is causing our world to overheat.

## CARBON DIOXIDE ($CO_2$)

Carbon in the form of carbon dioxide is the most critical component in the greenhouse effect. All the gasses in the atmosphere that influence the Earth's greenhouse effect interrelate and overlap in their ability to absorb and affect sunlight, but carbon dioxide is the key. In the atmosphere carbon dioxide lasts for ever. It doesn't break down into something less able to cause greenhouse heating. It can only be physically removed. Some soaks into oceans, but the rest can only be extracted by the processes within living things.

Over millions of years in our world's long geological history huge quantities of carbon have been transformed via biological processes into oil, gas, coal and limestone. It must be clearly appreciated that in the short-term, in terms of a few hundred years or less, it can only be extracted by the creation of additional biomass and increased soil fertility.

It must also be noted that the man-made sources of carbon dioxide on Earth are either closely connected, or often identical to, the sources of the other major man-made greenhouse gasses. In general they are derived from producing and burning fossil carbon for fuel, or from destroying soil organic matter and microscopic soil life by excessive use of chemical fertilizers generally exacerbated by other damaging agricultural practices. In a similar manner the production of almost every minor greenhouse gas is associated with a carbon dioxide producing process, gasses such as methane, nitrous oxide, the CFCs and ozone. Conveniently and for simplicity the minor gasses are given a "$CO_2$ equivalent" rating. The measure of carbon dioxide accumulation in our atmosphere, either itself only or including the minor gasses is thus an excellent measure of, and correlates exactly with, the constantly rising levels of "natural" disasters we are now experiencing.

In the beginning, carbon dioxide, being one atom of carbon combined with two atoms of oxygen (dioxide = two oxygen), belched out of volcanoes in huge quantities where it became a major component of Earth's primal atmosphere. It is still being discharged from the thousands of active volcanoes under the oceans and across the Earth's surface.

The whole process of life started by taking some carbon from the air, mixing in some water, adding tiny traces of other elements for variety, and then warming it all with sunlight energy. There were probably a few lightning flashes thrown in to kick-start the life-developing chemical processes. (Alternatively, some believe life may have initially started using carbon dioxide coming from undersea volcanoes and vents which dissolved in the surrounding seawater, and the energy of the geothermal activity to power up the life generating process.)

Multiple reactions occurred in these processes, and complex organic compounds were formed. These complex compounds then became the building blocks for even more of the complex chemicals of life. In this process the oxygen in the original carbon dioxide was released into the atmosphere to eventually support the development of aerobic metabolic processes, i.e. life based on oxygen use or consumption.

There was once much too much carbon dioxide in the air for humans to breathe the stuff. However over hundreds of millions of years, primitive plants, microbes and bacteria absorbed the carbon dioxide from the air. They also absorbed the sunlight energy that shone on this primitive world. Most of these complex carbon compounds, with their entrapped solar energy, became part of the rocks that form the Earth's upper crust.

Two billion years after the formation of the Earth, the carbon dioxide levels had been massively reduced and oxygen, because of living processes, became a significant ingredient in the atmosphere. The oxygen-consuming life forms then developed rapidly. After another two and a half billion years, the atmosphere and the Earth's environment changed towards generally what we know today. These new types of environments suited the evolution of well-developed life forms. Mammals eventually evolved, then came the evolution of the primates, and finally mankind.

As plant life grows, sunlight energy becomes trapped as chemical bonds within carbon-containing molecules. When we burn a piece of wood, the complex organic material that makes up the wood, recombines with the oxygen in the air to re-form the original carbon dioxide. The energy released as heat and radiation from the fire is the energy of the sunlight, originally utilized to grow and form the wood.

In our bodies, we can combine oxygen with the complex carbon molecules at much lower temperatures and at much slower and controlled rates. This produces the energy we need to function. In the process, we also produce carbon dioxide, which we discharge in our exhaled breath. This energy producing system is extremely compact. It is twenty times more effective at energy production than that used by most lower life forms, especially those primitive, microscopic life forms that need to rely on carbon compounds that are only randomly formed.

Despite its importance to our Global Warming problems there is actually very little carbon dioxide in our world's atmosphere, relative to the other gasses. Recalling our liquefied carbon dioxide example, all the liquid $CO_2$ in the atmosphere would be about one-tenth of an inch thick; that's about two and a half millimetres. The crazy and dangerous weather changes we are now experiencing are occurring because we have added just twenty-thousandths of an inch, or half a millimetre, to that imagined liquefied carbon dioxide blanket covering the Earth.

## METHANE ($CH_4$)

Methane is the second most influential greenhouse gas following carbon dioxide. It is at least 20 times more potent, but relatively small quantities are involved.

Both methane and nitrous oxide (considered next) have one special importance when considering Global Warming. In the longer wavelengths, carbon dioxide and water vapour don't have much effect on planetary re-radiation. Methane and nitrous oxide do. They trap many of the infrared wavelengths that are missed by carbon dioxide. This gives them an importance way in excess of what would be expected by their relatively small quantities.

Methane is composed of one atom of carbon and four atoms of hydrogen. Its chemical formula is $CH_4$. Methane is constantly being produced on the planet both naturally and anthropogenically. It is constantly being broken down by oxidation into carbon dioxide and water. Methane's life in the atmosphere as methane is short, only about 10 years, but the resulting carbon dioxide lasts indefinitely.

Apart from its contribution to Global Warming, excess methane in the atmosphere has other downsides. Methane migrates up into the stratosphere where it breaks down to water and carbon dioxide. The water from this breakdown then forms thin whispy clouds. The sequence of events in these breakdown processes exacerbates the destruction of our ozone shield.

A constant build-up of water vapour and ice crystals in the otherwise very stable upper stratosphere suggests all kinds of very unpleasant but likely scenarios as the ice crystals can catalyze any number of reactions. We don't know what the consequences might be. Unfortunately, research on these effects is quite noticeably not well supported. Just possibly because it would be to the detriment of the fossil carbon industries' image.

Atmospheric methane had previously been produced almost entirely by anaerobic bacteria digesting dead plant material. Anaerobic bacteria don't require and often can't tolerate the presence of oxygen. Methane is also formed this way in the stomach of all herbivorous animals. This factor gets a lot more publicity than its relative quantity warrants.

Herbivorous animals as a source of methane have definitely risen with the increase in world cattle and sheep populations. However, the increase is not nearly as significant as is constantly insisted, for grazing lands have always been inhabited by grazing animals, whose populations have only ever been limited by grass growth, and of course the carnivores that inevitably move in and hunt the herbivores.

Vegetation decomposition produces methane in any situation when air supply is restricted. Methane is thus formed in large quantities by vegetation decomposing underwater. The so-called marsh gas in swamps and rice fields is methane. Big increases in rice production have meant significant increases in the discharge of methane into the air. At the same time however, large areas of swamps or "wetlands" have been cleared and turned into grazing land. This reduction in swamps and wetland areas has just about compensated for the extra methane from the world increase in rice production. Wetlands and rice fields contribute about equal quantities of methane to the atmosphere. Most of these wetlands are in the Earth's northern hemisphere. Incidentally "dry land rice", which is the majority of rice grown in Australia, produces very much smaller quantities of methane.

The constant call for the preservation of swamps and wetlands in effect becomes a call to increase Global Warming and sadly therefore a call that harms the total ecology of the whole planet. Filling in swamps or wetlands will do more good than harm. Our priorities have to be seriously, and not irrationally reconsidered.

The tundra areas of Siberia and Alaska are frozen swampland and contain incredible quantities of methane that has been trapped in the ice over countless centuries. This methane is starting to be released into the air as the tundra thaws due to global temperature rises. Another positive feedback loop is thus being created, forcing further global temperatures rises. In addition the seawater flooding of fresh water based coastal lowland vegetation will also contribute to methane generation.

We now dump our rubbish in landfills where there is no oxygen supply. It ferments to form methane. In the past our rubbish used to end up in the top few inches of soil where it broke down aerobically and didn't produce methane. It did produce some carbon dioxide but more importantly, it improved and produced soil. We don't do that now.

The methane from airless landfills is now sometimes extracted by driving steel pipes into the landfill mass to tap this gas. It is then collected and burnt as an energy source. The burnt methane is finally discharged into the atmosphere as water and carbon dioxide. This carbon dioxide production is a far less undesirable outcome than having the methane escape directly into the air.

This sequence is actually sustainable. The rotting material in landfills was once plant life. This plant life grew by utilizing atmospheric carbon dioxide. The whole process from atmospheric carbon dioxide to plants, to trash, to landfill, to methane and finally back to carbon dioxide, although tiny, is a reasonably sustainable energy recycling system. This is only provided there are no fossilized carbon inputs, either as fuel or as agricultural chemicals to overload the cycle.

Food waste and sewage waste is better recycled to produce rich soil, but collecting methane from food waste dumps for energy production is an excellent second choice.

Methane also resides in huge quantities in coal seams. This dates back to the original formation of the coal seams from vast ancient swamps. So methane, along with some carbon dioxide, is commonly the main constituent of coal gas. In the general mining of coal, these gasses are constantly being released into the atmosphere.

The additional worldwide methane release that is now overloading natural atmospheric methane breakdown comes from the production and treatment of fossil fuels. Radiocarbon analysis of atmospheric methane reported in *Nature* Vol. 332, pp 522-525 indicated that even as far back as 1988, at least one-third of all the atmospheric methane then existing in our world came from fossil fuel productions and use. Atmospheric methane concentration is now rising at around 1% of its current level per year, as measured at the Cape Grimm Observatory, Tasmania. That's almost exactly in line with the numbers for fossil fuel usage.

In grim confirmation, ice core samples taken at the Russian Vostok station in Antarctica show past variations in world methane levels to have fluctuated between 350 ppbv (parts per billion by volume) to 650 ppbv over the last 160,000 years. That is more than *Homo sapiens'* total time in existence. But just in the last few years we have increased those concentrations to 1,700 ppbv. The rate of increase in atmospheric methane levels is now between 14 and 17 ppbv each year, as reported by Houghton, Jenkins and Ephraums in *Climate Change*, IPCC *Scientific Assessment* (Cambridge University Press). Ten years ago both French and Soviet researchers were warning that atmospheric methane levels were already rising 50 times faster than at any time in the previous 160,000 years.

What do these numbers mean by comparison? The figure of 1,700 parts per billion is another way of writing 1.7 parts per million (ppm). Carbon dioxide levels have risen 80 ppm but methane has at least twenty times the greenhouse effect of $CO_2$ so it has the warming equivalent of 34 ppm of carbon dioxide.

The public relations ploy of blaming all methane build up on cows is a giant red herring. The press produces more wind than the cattle.

## NITROUS OXIDES ($NO_X$)

The oxides of nitrogen are potent greenhouse gasses. Fortunately they are there in relatively small quantities. In addition to Global Warming effects, nitrous oxide in the atmosphere readily combines with moisture to form nitric acid, one of the more deadly components of acid rain. Until man's relatively recent industrialization, the levels of nitrous oxides in the atmosphere had been quite stable.

There are natural sources of atmospheric nitrous oxides. Some soil bacteria and termites produce nitrous oxide. These have not changed much. But we know that nitrous oxide levels in the atmosphere are rising dangerously and dramatically. One quite reasonable estimate suggested that the level of nitrous oxides will rise to ultimately become a ten percent contributor to total Global Warming within 30 years. These additional nitrous oxides entering our atmosphere come from fossil fuel power stations and automotive exhausts.

The other and equally significant source of the nitrous oxides comes from our massive use of nitrogenous fertilizers and other nitrogen based agricultural chemicals. These chemicals not only release their own nitrogen compounds into the atmosphere, but by breaking down soil organic matter, they excessively release the nitrogen that is a constituent of all good fertile soil. This soil nitrogen enters the air generally as nitrous oxides.

## ATMOSPHERIC WATER, THE WILD CARD

The amount of water ($H_2O$) and water vapour in the atmosphere varies widely. In the dry air over hot parched deserts, water content can be almost zero. Whereas in the tropics, in thunderstorms, the total water content could well weigh more than the total dry air mass itself. Normally, localized atmospheric water content is constantly varying from day to day, while the average world total stays constant.

The amount of water vapour in the air is usually expressed as relative humidity and written as a percentage rather than "parts per million" as is the case with other gasses. At 100% relative humidity no more water can evaporate into the air at the particular air temperature – the water vapour in the air has reached "saturation". If the relative humidity is very low we have nearly dry air. The air's total water content can only exceed 100%

relative humidity if the air also contains solid or liquid water, such as snowflakes, raindrops, minute droplets like those we see as a warm breath in cold weather, or as cloud formations.

Another term used to describe atmospheric water content is "absolute humidity". Absolute humidity is the actual mass of water vapour present, and provided no water is added or no moisture is forced to condense out by cooling, the absolute humidity will not vary with temperature.

The maximum weight/mass of water vapour that a volume of air can hold rises as the air temperature rises, and falls as air temperature falls. If a parcel of air containing some quantity of water vapour is cooled, its relative humidity will rise to 100%. Any further cooling will cause some of the water to condense out and form clouds, or dew. The temperature at which this happens depends on the absolute humidity and is called the "dew point".

Often you might notice, all the clouds in the sky appear to have flat bottoms and all at the same altitude. This is the altitude at which the temperature has dropped to the dew point and moisture condenses out of any rising warm air and forms clouds. For any large mass of air the cloud base will rise during the day as the air mass warms. At high altitudes tiny ice crystals can form out of wet saturated air and persist in the upper atmosphere for hours, and sometimes even days. Being ice they won't readily evaporate back into the parent air. This phenomenon produces the common "anvil" formation on the top of thunderstorms. While the droplets in the rest of the towering thunderstorm can evaporate away, or fall as rain to the ground, the frozen misty anvil top will spread and form a thin layer of high cirrus cloud, sometimes covering the whole sky.

Water has a molecular structure with just the right size and flexibility to absorb and re-radiate infrared energy and so must be considered as a greenhouse gas. Because of the huge quantity in the atmosphere, water is far and away the most powerful and influential of all the greenhouse gasses. On a normal comfortable day at 25ºC or 77ºF and 50% relative humidity, there are about 15,000 parts per million of water vapour in the air at sea level, or almost 50 times the mass of carbon dioxide.

The effect of atmospheric water as a blanket stopping heat radiating back into space can be felt when cloud cover moves in during the night. Overnight frosts can't form if an overnight cloud or fog covers the area and entraps the daytime solar heat under the blanket. A cloudy night after a warm sunny day always means the next day will be considerably warmer than otherwise expected.

The majority of water in the atmosphere comes from evaporation off the surface of oceans so there is absolutely no shortage of water on this planet to create humidity and to form clouds. If all the air in the world's atmosphere somehow absorbed its maximum possible quantity of water and thus all the air would have a 100% relative humidity, the process would have used up less than three inches (75 mm) of the oceans' waters. The average depth of the world's oceans is over two miles. Three inches is nothing.

We might ask, why doesn't water vapour itself lead to a runaway greenhouse effect? The answer is that water vapour content fortunately is self-regulating. If the water content of the atmosphere increases then there will tend to be more clouds. Clouds are very effective at stopping the escape of heat but they also have a very high albedo, meaning they reflect most of the sunlight that hits them back into space.

Long continuous cloudy periods, even in summer, will cause the average temperature to drop. When the temperature drops, so does the dew point and the water simply falls out of the air as rain or snow. The average water content of the atmosphere will therefore regulate itself about some norm, some average. But that norm is determined by the other greenhouse gasses.

While water is a powerful greenhouse gas, it is more like a draught horse; it's big but it's controlled by others. The water content of the atmosphere will always rapidly settle down to an average world level. That level is determined by the prevailing level of the more stable greenhouse gasses. Carbon dioxide is by far the most significant of these and so carbon dioxide levels ultimately control atmospheric water content. Atmospheric carbon dioxide levels are now 360 parts per million, whereas the water content in humid air can be as high as 15,000 parts per million. But carbon dioxide still holds the reins.

The problem is, when we change the carbon dioxide level we just have no idea what the water vapour content is going to settle down to. Maybe we can steer the draught horse. But that is of little use if we are the ones wearing the blinkers. Browbeaten by the oil companies' PR people, we humans are the ones avoiding an honest observation of where the road is really heading. Alas, we are shirking our responsibility, and the draught horse is almost at full gallop.

The amount of water in the atmosphere as water vapour, or humidity, or clouds, in all their significant and sometimes majestic forms, is ultimately determined by world temperatures and these are determined by the "thickness" of our greenhouse gas blanket. Change the thickness of the blanket, and a totally new world climate and atmospheric stability will have to re-establish itself. But unfortunately no future stability is at all possible while we continue to modify the thickness of our blanket. And even if we stop at some new blanket thickness, any hypothetical stability will be delayed for decades, or even for centuries, while the world waits for the ocean temperatures to slowly catch up.

Again, in simple terms, we used to have three blankets keeping our world stable and liveable and now we have four. Even if we pegged it at four blankets, it would still take a few hundred years for ocean temperatures, sea levels, ocean circulations, world climates and world weather to catch up, and then to finally settle down to some new pattern. We are guaranteed unpredictable weather and unpredictable rainfall for at least hundreds of years. Additionally, there is absolutely no guarantee that a meaningful stability is even possible, ever. Unstable and continuous massive climate fluctuations for thousands of years are likely.

It was O.K. when natural carbon dioxide, nitrogen oxides and methane levels oscillated slightly over hundreds, or more likely thousands of years. But now, with our massive burning of fossil fuel and our massive destruction of soil fertility with "fertilizers", we are changing these greenhouse gas levels at extreme rates and to extreme levels. In the past these changes have only occurred associated with catastrophic events such as meteorite impacts, or massive widespread volcanic activity, but afterwards things would settle down. It took a few hundred years, or a few thousand years, or sometimes a few million. But the inevitable tendency was to creep back to the prior norms. This cannot happen while we continue to pump $CO_2$ and other greenhouse gasses into the atmosphere. Destructive instability itself becomes the norm.

## CFCs AND THE STORY OF A BRILLIANT CHEMIST

1930 was approaching. It was the time of the great depression. General Motors owned Frigidaire, and the refrigeration industry was starting to boom. Various substances were used as the refrigerant. Frigidaire was using sulphur dioxide. The American Medical Association was highly critical of the poisonous nature of sulphur dioxide. Methyl chloride had also been used but methyl chloride was also a toxic substance. Industrially, ammonia was the preferred refrigerant. However, even then a few people had already died in industrial accidents from ammonia poisoning.

Frigidaire needed a substance that would not burn, was not toxic, would be a good refrigerant and would be cheap to produce. They went to General Motors. General Motors Research Corporation lent them one of their most brilliant industrial chemists. His name was Thomas Midgley Jr. He had joined General Motors during World War I.

Thomas Midgley Jr. was indeed a brilliant chemist. The rapid development of aeroplane engines during World War I, demanded fuels with higher and higher octane ratings. One of Midgley's tasks while at General Motors was to somehow increase the octane rating of petrol and therefore increase its efficiency. He succeeded. He invented tetraethyl lead. It wasn't long before every car engine in the world was designed to run on leaded fuels. His brilliance in creating the fuel additive tetraethyl lead was the reason General Motors sent him to Frigidaire to solve the refrigerant gas dilemma.

Midgley solved this problem too. He actually designed a suitable chemical compound on paper, based on the desired characteristics and chemical nature of its components, and then synthesized his molecular design in the laboratory. It worked. He called his chemical dichlorodifluoromethane. He was then able to synthesize a whole group of compounds based on the same chemical constituents. The group of chemicals he called chlorofluorocarbons and abbreviated the name to CFCs.

They were magical chemicals. They were perfect for cleaning circuit boards and radio valves, they were a great foaming agent and were ideal as a propellant in spray cans and they were an incredibly efficient refrigerant. It was 1974 before any significant scientific paper was published suggesting that CFCs could damage the ozone shield that protects land life from harmful ultraviolet radiation.

In those days, we didn't even know that high altitude ozone protected us from ultraviolet light. It was also quite inconceivable that civilized man could modify the whole planet's atmosphere. Midgley was a chemist. There were no high altitude meteorologists – no atmospheric physicists there to tell him what CFCs might do. An ozone shield wasn't even a theory in those days. There weren't a lot of motor vehicles around either to burn his leaded petrol. Thomas Midgley Jr. was indeed a great chemist. He had well over one hundred patents credited to him when he died in November 1944.

## OZONE, THE OZONE HOLE AND CFCs

Ozone has almost nothing to do with Global Warming. Ozone and the Ozone Hole is a totally different story.

Unfiltered sunlight, the raw sunlight of space, contains ultraviolet light of various wavelengths. Some can break down organic chemical bonds and all life is structured using organic chemical bonds. That's why ozone and the ozone shield is important. It filters out a high proportion of the more damaging wavelengths. The ozone shield was already in place when life moved up onto land. Land life evolved to handle the UV wavelengths not stopped by the ozone shield.

Oxygen in the upper atmosphere stops short-wave ultraviolet light up to a wavelength of about 190 nm (nanometres – a billionth of a metre). It does this by absorbing its electromagnetic energy. Three oxygen ($O_2$) molecules get converted into two, semi-stable ozone ($O_3$) molecules. This becomes a shield.

The screening effect of oxygen peter out at wavelengths much above 240 nm but the effect on these lower wavelengths ensures that ozone is continuously being formed.

Above those wavelengths, ultra violet light is given names. Above a wavelength of 240 nm, up to about 290 nm, the ultraviolet is described as UV-C.

The ozone formed in the stratosphere blocks out the UV-C. At the high quantities involved, UV radiation with wavelengths below 290 nm is very damaging. It easily destroys proteins and DNA. Life on our planetary surface cannot survive when continuously exposed to UV-C. As soon as oxygen was available in quantity an ozone shield was created. An evolutionary adaptation to live with UV-C was never needed.

From 290 nm to 320 nm we have UV-B. The "B" is for biological. This is the band that land life was mainly exposed to and evolved to live with. These wavelengths are still effective enough to stimulate mutation changes, and as such have contributed to evolution. UV-B gives us a suntan. It can also give us skin cancers if we get too lackadaisical. Ozone does screen out some UV-B even up to wavelengths as high as 350 nm. Ozone absorbs its longer UV in a similar fashion to how oxygen absorbs its shorter UV. The power of the incoming radiation is "soaked up" by being used to break the $O_2$ molecules into $O_3$ molecules. The $O_3$ is then available to absorb longer wavelengths and return to being $O_2$. This cycle normally continues endlessly.

From 350 nm to 420 nm is the band described as UV-A. It was once considered as almost totally harmless but that's not quite true. UV-A is more penetrating and produces a deeper sunburn but it also produces skin aging effects, wrinkles and skin sagging. In general, sun creams do not screen out UV-A unless they are so marked, eg. "broad spectrum". Neither ozone nor oxygen shade us from UV-A and land life has evolved to handle this unimpeded radiation.

Above 400 nm it's no longer ultraviolet and no longer dangerous, it's violet or indigo, and it's visible. Light from 400 nm through to red light at 760 nm comprises the total visible spectrum. Above 760 nm it becomes invisible again. It's called infrared, i.e. beyond red.

In summary, oxygen ($O_2$) stops very short wavelength UV light, and becomes ozone, ($O_3$). The $O_3$ stops UV-C and some UV-B, and in doing so turns back into $O_2$.

Unfortunately for us, ozone is very unstable and very vulnerable to contaminants in the air. It can pop back into $O_2$ before it has its chance at preventing too much harmful UV-B and UV-C getting through to the ground. For example, if, as sometimes happens, a molecule of nitrogen gets extremely close to a molecule of ozone, a rapid series of chemical reactions occur. Initially the ozone is broken down and reforms into oxygen, which UV-B sees as transparent. Finally, the nitrogen is free to go off and destroy another bit of ozone if it gets close enough. This constant inter-reaction becomes a never-ending juggling act maintaining just enough ozone to give us our "ozone shield".

Some rise and fall in ozone levels in the upper atmosphere occur naturally. For one thing the levels change with the seasonal variation in incoming sunlight. In addition, recent evidence indicates that the eleven-year cycle of sunspot activity does play a small part in ozone formation. If it was really significant then recent solar activity should have prevented, or minimized the destruction of our ozone shield.

But it didn't. The shield is slowly deteriorating. It now appears that variations in solar activity have a very much smaller influence on our ozone shield than the CFCs we make and allow to leak into our atmosphere.

CFCs, chlorofluorocarbons, contain the elements chlorine, fluorine and carbon. When a CFC molecule leaks out of a refrigerator and ultimately drifts up into the upper atmosphere, ultraviolet rays break down the CFC, releasing chlorine gas. The chlorine then breaks down the ozone. Chlorine molecules are incredibly destructive to an ozone molecule. A coffee mug full of CFCs taken from a household refrigerator, or a car's air conditioner, contains enough chlorine atoms to destroy twenty-five acres (10 ha) of the Earth's ozone shield and the destructive effect will last for two hundred years. The AAAS journal *Science* compiled an excellent and sobering series of reports on CFCs and their effects in their Issue Vol. 261.

Reiterating, the raw sunlight in space hits the first traces of oxygen in our high upper atmosphere and the impossible to live with, very short wavelength UV gets screened out. This process produces ozone from the battered oxygen. Oxygen's role in ultraviolet shielding then ceases. Ozone molecules then screen out UV-B and some of the UV-A radiation. These are the UV frequencies that are difficult to live with. This screening reduces the incidence of skin cancer. In these processes there are no significant greenhouse warming repercussions.

How much ozone in our atmosphere are we talking about? To put it into perspective let's go back to our model where we magically condensed all the atmospheric gasses into liquids with the same weight. Now let's do that with ozone. If all the ozone in the atmosphere became a layer of liquid covering the planet it would amount to no more than a thin smear one ten-thousandth of an inch thick (0.0025 mm). Is that all there is, to protect us from excessive UV solar radiation? Yes. But just as a thin film of sun-screen lotion is enough to prevent sunburn, that thin film of ozone has, to date, been enough to protect surface life on Earth.

The tiny quantity is also ozone's vulnerability. Because it is so thin, or really because there is so little of it, it is extremely vulnerable to the effects of strange and new chemicals that have never before existed on the planet.

The physics and chemistry of the upper atmosphere and the formation and breakdown of ozone are difficult to study, and the conditions up there are difficult to simulate in a laboratory. The processes are full of complexities and uncertainties. But one thing we know with absolute certainty is that our ozone shield is deteriorating. It's got holes in it. What is happening? How big are the holes?

The Antarctic Ozone Hole is an area the size of Australia or China. It is as big as the contiguous 48 states of the US. It is an area where total destruction of the ozone shield is now a massive annual event. The hole is not fixed over the Antarctic continent. It can drift. It often drifts up over Australia and New Zealand and maybe soon, over South America.

Actually there has always been a small ozone hole over Antarctica that formed regularly every year. It would last a few weeks and then close up again and do no damage, but what we have now is different indeed. It is much bigger and is no longer a short-lived insignificant phenomenon restricted solely to the high southern polar latitudes.

The United Nations Panel on Environmental Effects of Ozone Depletion claimed that a one percent decrease in the world's ozone screen would result in a three percent increase in skin cancer. That means thousands of extra cases and hundreds of extra deaths, particularly in fair skinned people that regularly frequent the outdoors.

Today, people in the northern hemisphere can also no longer feel complacent. The 1980s and 1990s saw a marked depletion in protective ozone between latitudes thirty degrees north and fifty degrees north. That's from North Africa to London. Just in the 1980s the depletion approached 10%.

It looks as if we can almost count on an Arctic ozone hole – a zero protection hole – to form and meander over Europe and North America in the very near future.

Ozone formation and ozone effects are not confined to high altitudes and high latitudes; there is a downtown variety.

Photochemical smog is the unpleasant cocktail comprising natural fog, exhaust gasses from petroleum fuelled automobiles and the range of chemicals, such as nitric acid, produced by the action of sunlight on this cocktail of gasses. Hence "photochemical". When raindrops fall through this mix and absorb the chemicals, the result is "acid rain". Ozone is another product produced in photochemical smog.

At these ground levels, ozone still acts as an ultraviolet filter. Although the ozone concentrations near the ground are now dangerously high in our cities, the depth of this ozone-containing layer is relatively small, generally less than a few hundred feet. Because of this, its overall ultraviolet screening effect is small.

Ground level ozone gas is considered to be a major factor in the death of trees in Europe and North America, as ozone is poisonous. Ozone and acid rain undoubtedly kill more trees than clear felling forests for timber.

Sadly, when the trees are dead, poisoned by acid rain, they are quite dangerous to harvest as the dead limbs fall unpredictably. So their wood is wasted. Plastics and steel get used instead.

Ground level ozone concentrations were once around 10 ppb (parts per billion). Currently these levels have doubled to 20 ppb, and in many areas concentrations exceed 200 ppb. Environmental protection levels in the US were, conveniently for the fossil fuel producers, allowed to be inflated to 120 ppb. Maybe the justification being that data indicated that ozone induced lung tissue damage does not appear to occur at levels just below 120 ppb. Adopting this upper limit would then not interfere with the sales of petroleum fuels. In England, during a warm summer, readings can well exceed 250 ppb, and stay there for long periods. No action is taken to prevent such occurrences.

Ozone gas at ground levels is an unpleasant story and, conveniently for some, rarely discussed.

Ozone is a slightly bluish, highly reactive, and extremely poisonous gas. In the rarefied atmosphere of the stratosphere, its importance lies in its optical properties. At ground level its chemical properties take precedence. Ozone is poisonous even in quite small quantities.

In the lower atmosphere ozone is produced naturally by lightning activity. Life on Earth obviously evolved to handle the levels produced by such weather phenomena. Much more dangerous quantities of near-ground ozone are formed from photochemical smog. This ozone formation and its harmful effects are rarely mentioned in the media.

One of the great ironies is, while we are destroying upper level ozone with consequent increases in dangerous UV levels, we are concurrently generating large quantities of ozone at ground levels. As we have seen, ozone is extremely reactive with a consequentially short lifetime. So, unfortunately, it is too long and too time-consuming a journey for exhaust pipe ozone to move up to the stratosphere and shore up our ozone shield.

The same cannot be said for CFC's ozone destruction. The main concern with CFCs results from their exceptional chemical stability and resultant long lifetimes. CFCs do drift up to very high altitudes and enter the stratosphere, and do play havoc with our ozone shield.

Global Warming is a different issue. The ozone shield itself is almost totally unrelated to Global Warming and has no significant role whatever in trapping heat and changing the surface temperature of the planet. Many confuse the two effects, possibly because the distinctions are deliberately never made clear.

Up until just recently, when one read all the press releases and the general literature on the changing atmosphere, it was amazing how much was devoted to CFCs and their affect on upper level ozone. In collecting references on the greenhouse gasses, the volume of references to CFCs and ozone and their interrelationships outstripped everything else. That one phenomenon accounted for more references than all the other greenhouse gas references combined. Yet ozone, against all other comparisons, is a totally insignificant contributor to Global Warming. The references infer a relationship to Global Warming although they always refer to upper atmospheric ozone concentrations and CFC related effects. Should we wonder why? It is an obvious reality that if the world production of CFCs stopped tomorrow, the producers of oil, coal and natural gas would experience next to nothing in sales reductions. However if calls were made to reduce ozone levels at ground level – only done by reducing automotive fuel use – then things would be different and ozone would vanish as a topic of interest in the media.

CFCs are being replaced by other more benign industrial chemicals so objections to their reduced use is not a marketing issue for the petrochemical industries, for who else will manufacture the substitutes?

The media emphasis away from Global Warming and onto ozone and ozone holes has only declined because finally larger numbers in the general public started demanding more information on Global Warming disasters.

Totally independent of their role in the drama of the ozone shield, CFCs are also greenhouse gasses. They are actually extremely powerful greenhouse gasses, but their low atmospheric concentrations make them a minor force in Global Warming. Ironically, because of the media emphasis on ozone shield effects, CFCs are already being phased out of widespread use, especially as a refrigerant and in aerosol sprays. As a result, their concentrations in the upper atmosphere began declining in the mid 1990s.

There is one serious problem however with reductions in CFC levels. Figures came out in 1999 that showed that while the rest of the world has been showing considerable responsibility, China was not. Production of CFCs in China expanded and China singularly has now reversed the short-lived welcome decline in world CFC levels. When massive production and use of CFCs finally stops as substitutes are adopted, it will still take a long time before levels become insignificant.

Ground level ozone results from our use of petrol and diesel to fuel our transport systems. Ozone at ground level can be a killer. Cancer and respiratory disease, cataract formation and blindness caused by high ozone gas concentrations have killed and maimed more people than have ever been, or are ever likely to be killed or maimed from atomic energy nuclear accidents and radioisotopes. In contrast, ozone in the stratosphere keeps us alive by screening out harmful ultraviolet radiations. CFCs and some agricultural chemicals migrate up to the stratosphere and destroy this beneficial ozone.

As always with all things, common sense must apply. It should be applied for nominated specific uses for CFCs. It must be recognized that in some industrial applications, where quantities and leakages are of minor significance, it would be quite irrational to ban these very specific uses on purely emotive grounds. There is a big difference between CFC's relatively tiny use in a few sealed and protected manufacturing laboratories, and their use in millions of car and home air conditioners, household refrigerators, spray cans and fire extinguishers. CFCs must cease being used for such applications.

## WE MUST RETURN THE COMPOSITION OF OUR ATMOSPHERE TO NEAR NORMAL

Fair skinned humans are very vulnerable to skin damage in tropical localities. With depletion of the ozone shield and the massive enlargement of the areas over the Poles, where no protection exists, the Ozone Hole and the annual drift of this hole out over inhabited areas, both fair skinned and dark skinned humans are becoming frighteningly vulnerable to skin damage. But skin damage and resulting skin cancers pose a very small threat to people on this Earth compared to the damage and deaths Global Warming is already causing. We must also recognize that the frequency and severity of Global Warming related havoc and destruction are rising endlessly.

The average surface temperature of Planet Earth was recently 15ºC or 56ºF. Our then familiar, stable and livable world climatic conditions result from the greenhouse phenomenon and its sensitive balancing act. This balancing act has been relatively stable for a good million years or so. The last quarter of this period saw the evolution of mankind. With the two or three degree temperature rises now expected, world weather will be in chaos with sea level rises destroying cities and nations across the planet.

In this last million years the world has experienced tiny fluctuations in atmospheric carbon dioxide levels resulting from volcanic and biological activity. And this, in conjunction with, or resulting from, tiny fluctuations in the Earth's orbit, created eight separate ice ages. Remembering that the ebb and flow of ice ages is associated with a movement of only few degrees in average world temperatures. Up until now it has generally taken tens of thousands of years for these changes to manifest.

For the last several thousand years greenhouse gasses, acting like blankets on a bed have maintained a relatively stable and pleasant world temperature. But in the period from just before World War II through till now, we have been loading our vulnerable atmosphere with greenhouse gasses at an alarming rate. We must never forget that before World War II, we had three blankets on the bed and today we have four. The only reason the world is not sweating excessively today is that our enormous oceans act like a bedroom hot water bottle, except it's filled with cold water. That's what's holding down world temperature rises. But like any other cold water bottle, the oceans can only slow the warming process until they themselves warm up.

To maintain fossil fuel sales, we are being conditioned by the media and public relations people to accept that a doubling of carbon dioxide levels in the atmosphere is inevitable, and somehow acceptable. That's six blankets. The enormous public relations machinery of the oil and petrochemical industry is trying to convince us that a greenhouse gas level that hasn't been seen on this planet for a hundred million years is really O.K.!

It is very fortunate, as we shall see, that our civilization finally has the technology to totally and economically replace fossil fuels. But we must also have the desire and take the responsibility to do so.

We had better wake up, before it's too late.

If we endeavour to change our society to create an atmosphere in which the major greenhouse gasses are normalized back to near pre-industrial levels, as we must, we are then creating a frontal attack on the fossil fuel petrochemical industries. And they won't like it. They have been happily fooling us for too long. And they like it that way, but…

> *You can fool all the people some of the time,*
> *and some of the people all the time,*
> *but you can not fool all the people*
> *all of the time.*
>
> Abraham Lincoln
> September 8  1858

**We must hope!**