December 9, 1982

David McMurrey, Chairman
Coastal Real-Estate Developers
400 Baywater Blvd.
Corpus Christi, Texas

Dear Mr. McMurrey:

As agreed in our September 21 contract, we are submitting the attached report entitled *The Effects of Increased Atmospheric Carbon Dioxide*.

This report examines the problem of CO_2 accumulation in the earth's atmosphere. The climatic changes caused by excessive CO_2 concentrations in the atmosphere, and the implications of these changes, will be discussed. Also discussed are the mechanisms of the greenhouse effect, the sources of atmospheric carbon dioxide, and some possible remedies to the problem.

I hope you find this report satisfactory.

Sincerely yours,

William R. Waters, President

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1212 Trace Dr., Suite 3
Austin, Texas 78741

WRW:mb
Enclosures

Report
on

THE EFFECTS OF INCREASED ATMOSPHERIC CARBON DIOXIDE

Submitted
to
Mr. David McMurrey, Chairman
Coastal Real-Estate Developers Association
Corpus Christi, Texas

by

Environmental Research Associates, Inc.
December 9, 1982

The report examines the effects of increased CO_2 concentrations in the earth's atmosphere. The shifting of local weather patterns, the mechanisms of the greenhouse effect, and the sources and sinks of CO_2 are also discussed. A list of possible remedies to the problem concludes the report.

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ABSTRACT

Since the Industrial Revolution, man has introduced tremendous amounts of carbon dioxide into the earth's atmosphere. While some of this CO_2 is assimilated into natural reservoirs, approximately 50% remains airborne. This increase in CO_2 concentration causes what is commonly known as the greenhouse effect. The greenhouse effect is a result of the absorption of infrared radiation by the surface of the earth. This absorption causes an increase in the atmospheric temperature. Increasing the earth's temperature in turn increases the amount of water vapor in the atmosphere. Since water vapor is also a strong absorber of infrared radiation, a positive feedback mechanism is created, leading to further infrared-radiation absorption. As temperatures increase, atmospheric circulation patterns are altered which will change local weather patterns.

These changes could have an enormous impact on agricultural production. Attendant to a rise in the mean global temperature is a melting of small but significant portion of the polar ice caps. This will result in a rise in sea level which would flood coastal areas including major population centers. The problem of the greenhouse effect might be remedied by a reduction in the use of fossil fuel, large scale reforestation to increase the capacity of the biotic sink, and development of alternate energy sources such as solar and nuclear fusion. However, not much hope is held out for these remedies.

Report on
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I. INTRODUCTION

Before the year 2020, the climate of the earth may be warmer than any time in the past thousand years. This change, which is incredibly fast by geological time scales, will be brought about by increased levels of carbon dioxide in the earth's atmosphere. The most important source of excessive CO_2 is the burning of carbon-based fossil fuels for energy production. Carbon dioxide is a by-product of all living systems and is normally considered harmless. It is a minor element in the earth's atmosphere comprising only about 0.03% of the total atmosphere. However, this small amount of CO_2, along with water vapor, is responsible for what is commonly known as the greenhouse effect.

The fact that changes in CO_2 concentrations in the atmosphere could cause changes in the earth's climate has been known for over one hundred years. However, only in the last 5 to 10 years has significant research been done in this field. The most ominous of the effects of a warmer climate will be the shifting of local weather patterns. This shifting will have profound effects on agricultural production in a world that is already unable to adequately feed its citizens today. There will also be an accompanying redistribution of wealth which will likely lead to dangerous social conflicts. It is obvious that the continued introduction of CO_2 into the atmosphere will have consequences far worse than producing a slightly balmier climate.

The purpose of this report is to examine the climatic changes caused by increased carbon dioxide in the atmosphere and their implications for society. Also discussed will be the mechanisms of the greenhouse effect, the sources and reservoirs of carbon dioxide, and some possible methods to reduce the magnitude of the problem. Note, however, that the most we can do at this point is lessen the severity of the situation. That the mean global temperature will increase in the next few decades is certain. The only questions are how much and how fast.

II. NATURAL WEATHER PATTERNS

The earth's climate naturally changes over extended periods of time. Temperatures have been much warmer for 80 to 90 percent of the last 500 million years than they are today. The polar ice caps, for example, are actually a relatively new phenomenon. They were formed 15 to 20 million years ago in the Antarctic and perhaps as recently as 3 to 5 million years in the Arctic.

The climate is still dominated by natural cycles of warming and cooling. The most influential of these natural weather patterns is the 180-year cycle. The 180-year cycle predicts that temperatures in the Northern Hemisphere reach a minimum every 180 years. (Climate records for the Southern Hemisphere are incomplete.) The bottom of the last cycle was in the early 1800s, which suggests that we may now be in a period of peak coldness. The winters of 1976 through 1979, which were unusually bitter, seem to reinforce the theory behind the 180-year cycle. This current cooling trend would mask any warming caused by an increased greenhouse effect.

However, the 180-year cycle predicts a natural warming trend will begin shortly before the end of this century. At the same time, the effects of elevated CO_2 levels on atmospheric temperatures will have increased to new high levels. Figure 1 shows the combined effects of these warming trends. Therefore, temperatures could reach their highest level in several hundred years shortly after the year 2000, and they will reach their highest level in the last 125,000 years by mid-century [1:7-11].

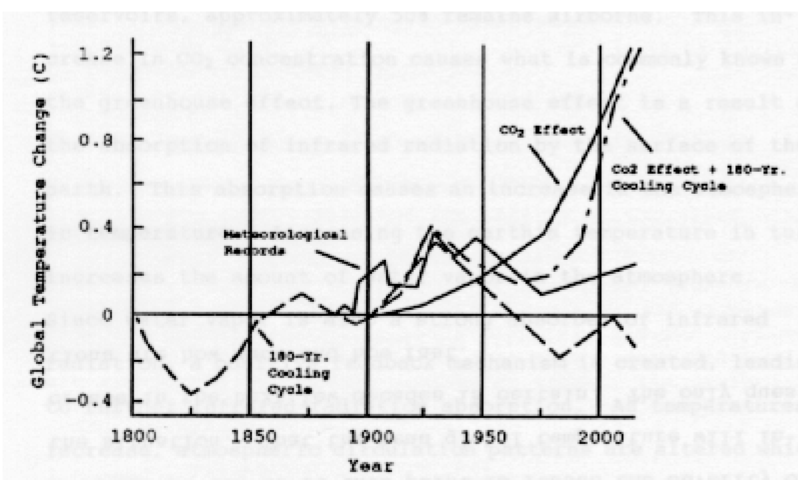

Figure 1. Combined Effect of the 180-Year Cycle and Increased CO_2 Concentrations. Source: Harold W. Bernard. *The Greenhouse Effect* (Cambridge: Ballinger, 1980), 10.

III. MECHANISMS OF THE GREENHOUSE EFFECT

For the mean global temperature to stay constant, the earth-atmosphere system must be in radiative equilibrium with the sun. In other words, the incoming solar radiation must match the outgoing thermal radiation from the earth. Of the incoming solar radiation, 35% is reflected back into space. The reflectivity of the earth is its albedo. The albedo is taken into consideration when the total energy flux of the earth-atmosphere system is calculated. Of the remaining 65% of solar radiation that is not reflected back, 47% is absorbed by the surface and 18% is absorbed by the atmosphere. For the temperature of our system to remain constant, this energy that is absorbed by the atmosphere must be radiated back out. This radiation primarily takes place in the 5-micron to 30-micron range of wave lengths, which is in the infrared portion of the electromagnetic spectrum. A micron is one millionth of a meter [2:755].

Natural Greenhouse Effect

The effective radiating temperature is the temperature the earth should have for the amount of solar radiation it absorbs. Calculation of the effective radiating temperature gives a value of -200° C. However, the observed mean global temperature is 140° C. The difference of 340° C is caused by a natural greenhouse effect that takes place in the atmosphere [11] . As the earth tries to lose heat into space, the atmosphere absorbs infrared radiation emitted by the surface. Specifically, the atmosphere allows 50% of the incoming solar radiation to reach the surface but only 10% of the longwave radiation from the surface to escape. This causes the temperature of the earth-atmosphere system to increase. The magnitude of the greenhouse effect is defined as the difference between the upward infrared radiation from the surface and the upward infrared radiation from the top of the atmosphere [2:755].

Radiation Absorption by Carbon Dioxide and Water Vapor

The greenhouse effect is caused by minor constituents in the atmosphere, mainly carbon dioxide and water vapor. The earth must radiate in the 5-micron to 30-micron region. However, water vapor is a strong absorber of radiation over the entire thermal spectrum except in the 8-micron to 18-micron interval. The 12-micron to 18-micron interval is largely blocked by CO_2 absorption. In fact, current CO_2 levels are sufficient to make the 15-micron band virtually opaque to infrared radiation. The earth is, therefore, constrained to radiate its excess thermal energy in a nearly transparent window from 8 microns to 12 microns. As anthropogenic carbon dioxide is introduced into the atmosphere, mostly by combustion of fossil fuels, absorption of infrared radiation in the 10-micron band and in the wings of the 15- micron band is increased. This increased absorption results in an overall warming of the earth-atmosphere system.

Positive Feedback Mechanisms

As the climate becomes warmer, positive feedback mechanisms tend to exacerbate the problem. Elevations in temperature decrease the solubility of CO_2 in the oceans. Therefore, as temperature increases, the oceans release more CO_2 into the atmosphere, which causes another increase in temperature. Even more threatening is the greenhouse water vapor coupling. The atmosphere tends to attain a definite distribution of relative humidity in response to a change in temperature. If the temperature is increased, the relative humidity, which is a measure of the amount of water vapor in the atmosphere, is also increased. At the same time, the vapor pressure of water is raised. The result is more water vapor in the atmosphere, which causes more greenhouse effect, which raises temperatures even higher, which again increases the water vapor in the atmosphere. This positive feedback mechanism approximately doubles the sensitivity of surface temperature to a change in the amount of energy absorbed by the earth [1:19].

IV. THE CARBON CYCLE

The annual increase of carbon dioxide in the atmosphere is dependent on several factors. First is the amount of carbon dioxide produced by consumption of carbon-based fuels. Subtracted from this amount is the carbon dioxide that is removed from the atmosphere and stored in reservoirs, or sinks. The most prominent sinks of carbon dioxide are the atmosphere, the oceans, and the biosphere. Also contributing to a net increase in CO_2 is the deforestation of large land areas each year. The amount of carbon dioxide produced from fossil fuels and the annual increase in atmospheric concentrations are both well known. Approximately 50% of the CO_2 produced from fossil fuel remains in the atmosphere. The rest is absorbed into sinks. The proportion of CO_2 that goes into each sink and the mechanisms of CO_2 removal are poorly understood.

CO_2 From Fossil Fuel

Since the advent of the Industrial Revolution, about 154.4 gigatons (G ton) of carbon have been added to the atmosphere. One gigaton is equal to one billion tons. Even more alarming is the fact that of this 154.4 G tons, about 27%, or 45 G tons, were produced from 1970 to 1978. Overall, the use of carbon-based fuels has increased at an exponential rate of 4.3% per year from 1860 to the mid-1970s. (See Table 1.) High energy costs should help to slow the use of fuels, although no significant reductions in demand have yet been observed.

Table 1. Estimated Carbon Added to the Atmosphere by the Burning of Fuels (G tons per year)

Year	Carbon Added (G tons)
1950	1.63
1960	2.16
1970	3.96
1975	4.87
1978	5.62

Source: Gordon J. MacDonald. *The Long-Term Impacts of Increasing Atmospheric Carbon Dioxide Levels* (Cambridge: Ballinger, 1982), 152.

It is expected that industrialized countries will be able to significantly reduce the use of fossil fuels for energy production by using clean energy sources such as solar and nuclear. However, a growing world population will place heavy pressure for increased energy use, especially in developing countries. The percentage of CO_2 produced by geographical regions in 1974 and the projected contribution expected in 2025 is listed in Table 2. Even though the United States will reduce its contribution from 27% to 8%, the amount produced by developing regions in the same time will more than triple [4].

Carbon Dioxide Produced by Different Fuels

The amount of carbon added to the atmosphere depends on the type of fuel being burned. Fuels with a high hydrogen- to-carbon ratio produce the most energy for each unit of carbon released. The dirtiest fuels, in terms of carbon dioxide, are the various synthetic fuels that are produced from coal. Synfuels release large amounts of CO_2 because energy must be expended to extract them from coal. Therefore, the carbon dioxide generated from producing the synfuel must be added to that released by combustion. Because the world has very large coal reserves, research into synfuel production has increased greatly. Although synfuels could significantly reduce the dependence of the United States on petroleum, they would tend to accelerate the buildup of carbon dioxide in the atmosphere. Table 3 lists the amount of CO_2 released by each type of fuel.

Table 2. Percent of Atmospheric CO_2 Contribution by Nation and Continent

Nation or Continent	1974	2025
USA	27	8
USSR & Eastern Europe	25	17
Western Europe	18	10
Central Asia	8	19
Japan, Australia, N. Zealand	7	4
Developing Asia	--	4
Developing America	4	40
Developing Middle East	--	3
Developing Africa	--	2

Source: Committee on Governmental Affairs, U. S. Senate. *Carbon Dioxide Accumulation in the Atmosphere, Synthetic Fuels and Energy Policy* (1979), 451.

Table 3. CO_2 Contribution by Fuel Type. Carbon released per 100 quads of energy produced (1 quad=1015 Btu).

Fuel	Carbon in 10[-15] Grams
Oil	2.00
Gas	1.45
Coal	2.50
Synfuels	3.40

Source: Committee on Governmental Affairs, U. S. Senate. *Carbon Dioxide Accumulation in the Atmosphere, Synthetic Fuels and Energy Policy* (1979), 451.

Future Levels of Carbon Dioxide

Future inputs of carbon from fossil fuels are dependent upon world energy consumption and on the mix of fuels used. Two models have been devised to estimate the world consumption of carbon-based fuels in the future. The first model is based on the historical growth rate of 4.3% per year.

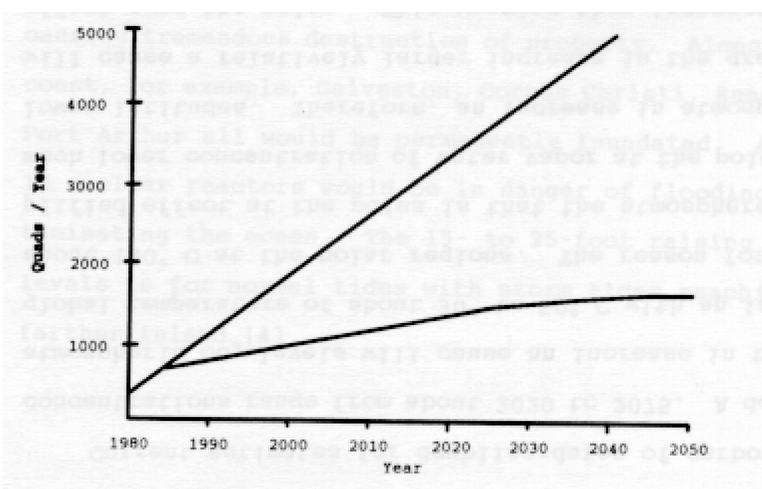

Figure 2. Growth Rate of Fuel Use Computed With Two Different Models. Source: Gordon J. MacDonald. The Long-Term Impacts of Increasing Atmospheric Carbon Dioxide Levels (Cambridge: Ballinger, 1982), 34.

If the world use of fossil fuels is maintained at that level, the proven energy reserves would be exhausted by 2010 to 2015. The second model, and probably the more accurate one, postulates that the current growth rate will continue until 1990, and then the rate of growth will decline to zero over a fifty-year period. Figure 2 graphically compares growth rates from both models. This tapered growth scenario would postpone the exhaustion of proven reserves by ten to fifteen years. However, actual use of carbon-based fuels could continue for some time after this, since the total amount of recoverable reserves is much greater than the proven reserves. Obviously, these estimates are greatly simplified, since they were devised to give minimum times to exhaustion of energy reserves.

As conventional fossil fuels become more expensive, it is likely that world fuel usage will shift to a different combination of fuels than used today. Changes in this fuel mix causes more uncertainty in estimates of future CO_2 inputs into the atmosphere. Table 4 gives the dates for doubling of CO_2 concentrations for various fuel use combinations [9].

Table 4. Doubling-Dates for Carbon Dioxide Concentrations for Different Fuel Use Combinations.

Fuel	**4.3% Exponential Growth**	**Tapered Growth**
Current Fuel Mix	2035	2055
All Coal After 1990	2030	2045
All Synthetics After 1990	2022	2030
All Natural Gas After 1990	2043	2075

Source: Gordon J. MacDonald. *The Long-Term Impacts*, 84.

V. CLIMATIC EFFECTS OF INCREASED CO_2 CONCENTRATIONS

Current estimates for doubling-dates of carbon dioxide concentrations range from about 2020 to 2075. A doubling of atmospheric CO_2 levels will cause an increase in the mean global temperature of about 30° to 50° C with an increase of about 120° C at the polar regions. The reason for the amplified effect at the poles is that the atmosphere has a much lower concentration of water vapor at the poles than at lower latitudes. Therefore, an increase in atmospheric CO_2 will cause a relatively larger increase in the greenhouse effect over the poles. This warming then increases the water vapor present by melting ice, which causes the process to be self-enhancing.

Changes in Local Weather Patterns

As the temperature of the atmosphere is increased, the global circulation patterns will be shifted. This will cause widespread changes in local weather patterns. Although mathematical models devised by meteorologists can describe overall climatic changes, they are not able to predict these small-scale variations in local conditions. One method that can be used is to examine weather records for a period when the temperature was higher than it is today.

The 1930s As Climate Analog

The most recent global peaked in the 1930s. The 1930s averaged about 10° C warmer than recent decades have. In the United States, a greater number of state records for high temperatures were set in the 1930s than in any decade since the 1870s. The 1° C increase is analogous to the initial decade of CO_2-induced warming which should occur shortly after the turn of the century.

Drought

The most significant feature of a warmer climate is the absence of adequate precipitation. The drought of the 1930s has been called the greatest disaster caused by meteorological factors. Research into climate records by studying tree rings has determined that 1934 was the driest year in the western United States since 1700. If the atmospheric circulation patterns of the 1930s return early next century because of warmer temperatures, agricultural production and water supplies could be seriously affected. Even though food production would decline, modern agricultural practices would probably prevent a catastrophe like the dust bowl of the 1930s. Water supply, however, is a different situation. Particularly hard hit will be the region of the West that draws water off the Colorado River basin. This region, which is already plagued by water shortages, could be devastated by a drought that lasts several years.

Increased Tropical Storm Activity

The warming of the atmosphere will cause the sea temperature to rise as well. This will result in more tropical storms being generated. The 1930s were a period of increased tropical storm activity. Twenty-one tropical storms blew up in 1933, seventeen in 1936; the current average is nine per year. These storms will also be able to reach higher latitudes because of warmer seas [1:35-50].

Sea Level Increase

Researchers have suggested that conditions similar to those of the 1930s could persist for as long as 25 years. During this time the earth's temperature will still be increasing and a longer range problem will become evident. The polar ice caps would begin to melt, raising the sea level. This will be a slow process, but one that will be irreversible once the greenhouse threat is fully realized. A rise in ocean levels of between 15 to 25 feet is possible in as little as 100 years. Coastal regions would be flooded causing tremendous destruction of property. Along the Texas coast, for example, Galveston, Corpus Christi, Beaumont, and Port Arthur all would be permanently inundated. As many as 10 nuclear reactors would be in danger of flooding and contaminating the ocean. The 15- to 25-foot raising of sea levels is for normal tides with storm tides reaching even farther inland [4].

VI. WAYS TO REDUCE GREENHOUSE EFFECT

The severity of the consequences of this major climatic change requires that action be taken to lessen man's input of carbon dioxide into the atmosphere. The greenhouse threat is a global problem that calls for global action. Unfortunately, the political structure of the world tends to impede cooperation on a global scale. Even with these difficulties, it is imperative that the use of carbon-based fuels be reduced significantly. The United States, as the world's leading consumer of energy, could influence world opinion and stimulate action by taking decisive measures. Some of the steps that need to be taken are:

1. A concerted effort must be made to conserve fuel with a goal of reducing global consumption 20% worldwide by the year 2000. Public knowledge of the effects of CO_2 on the climate is needed. A tax on fossil fuel would provide an extra incentive to conserve. The revenue from such a tax could be used to further development of alternate energy sources.

2. The use of a combination of fossil fuels that will minimize the input of CO_2 into the atmosphere must be emphasized. Natural gas is the cleanest of the fossil fuels and large reserves of gas have been found. Coal is also found in abundance in the United States and is therefore likely to be increasingly used for energy production. However, coal releases 75% more CO_2 into the atmosphere per unit of energy produced than does natural gas. Because of this, use of coal should be de-emphasized and use of natural gas emphasized.

3. Alternate energy sources, such as solar and nuclear, should be developed. There is a substantial amount of emotional opposition to nuclear power, which will impede the expansion of its use. Solar power, as are wind and wave power, is ideal in that it is constant and non-polluting. The technology is not quite at a stage where solar power is economically feasible. A strong effort must be made to develop this highly attractive source of energy.

4. Reforestation on a massive global scale is needed to provide a large biotic sink in the next few decades. The total respiration of CO_2 should be less than the total photosynthesis on a regional and worldwide basis. Fast- growing trees, such as the American Sycamore, can absorb as much as 750 tons of carbon per square kilometer per year. Water hyacinths can absorb 6000 tons of carbon per square kilometer per year. The growth of biomass for energy production could serve as an additional method of reducing CO_2 accumulation because it would

only involve recycling between carbon pools of the biosphere and the atmosphere.

5. Research into the carbon cycle is needed to reduce the uncertainties surrounding predictions of climatic changes. Although the amount of carbon dioxide that is released and the amount that remains airborne is well known, the method by which CO_2 is assimilated into sinks, such as the ocean and the biosphere, is poorly understood. Typical estimates of the amounts of CO_2 absorbed annually by the ocean and the biosphere are 2 G tons and 1 ton, respectively [4].

VII. SUMMARY

Carbon dioxide accumulation in the atmosphere is the most dangerous pollution problem today. This excess of CO_2 will cause an increase in the mean global temperature which should be detectable shortly before the end of this century. This warming is caused by the greenhouse effect. CO_2 allows incoming radiation from the sun to enter the atmosphere. The heat from the earth's surface, which must radiate in the infrared region of the spectrum, is absorbed by CO_2 and water vapor, thereby raising the atmospheric temperature. The greenhouse water-vapor coupling provides a strong positive feedback mechanism. Fossil-fuel use increases at an exponential rate of 4.3% annually. This should cause a doubling of CO_2 concentrations by between the year 2020 and the year 2075. This doubling of atmospheric CO_2 will cause an increase in the mean global temperature of about 30° to 50° C. Warmer temperatures will cause a shift in atmospheric circulation patterns. This will cause local weather patterns to change. The results for the United States could be intensive drought, increased tropical storm activity, and a rise in the sea level caused by melting of the polar ice caps. To lessen the severity of the problem, fossil fuel consumption must be curtailed and alternate energy sources developed. Also, a global reforestation program should be undertaken to provide a large biotic sink for CO_2 in the new few decades.

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