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EMISSIONS OF CO₂ TO THE ATMOSPHERE DUE TO U.S.A. FOSSIL FUEL CONSUMPTION

V.D. DANG AND M. STEINBERG

June 1980

Research Sponsored by the
CARBON DIOXIDE AND CLIMATE RESEARCH PROGRAM
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Abstract

Analysis and projection of carbon dioxide emitted to the atmosphere are estimated based on the Brookhaven reference energy system. Some new results are given on carbon dioxide contribution to the atmosphere from U.S. fossil fuel consumption by different sectors including residential, commercial, industrial and transportation. The total weight of carbon as carbon dioxide emitted to the atmosphere and the additional CO₂ concentration over background by different subsectors in the years 1977, 1980, 1985, 1990, 2000 and 2020 are presented.

Introduction

Recent measurements and calculations [1,2] show that atmospheric CO₂ concentration has increased exponentially since the industrial revolution. It is estimated that a growth rate of 4.3% per year provides an excellent fit to the data except during the period of the two world wars and the great economic depression of the 1930s.

The CO₂ problem is generally being investigated in several areas:

(1) the carbon cycle, that is, a description of the sources and sinks of carbon and the transfers of carbon between the atmospheric, biospheric and oceanic reservoirs; (2) climatic effect of the increase of atmospheric CO₂; (3) methodology or technology of mitigating or controlling the increase in atmospheric CO₂ concentration.

According to the CO₂ theory of climatic change, surface air temperature rises due to the increase of the earth's atmospheric CO₂ concentration as a result of the moderating influence of CO₂ on the loss of terrestrial surface radiation to space. There is general scientific agreement about this potential temperature increase [3]. There are exceptions to this consensus [4,5] so that improved models with related field observations are still needed to test the models and resolve this issue.

Previous estimates [1,2] of CO₂ concentration increase in the atmosphere have been reported in total weight of carbon as carbon dioxide emitted annually. In this report, a detailed breakdown of the contribution of carbon dioxide by various sectors in the U.S.A. to the atmosphere is projected for recent and future years, 1977, 1980, 1985, 1990, 2000, and 2020.

Methodology, Results and Discussion

The methodology of estimation of CO_2 concentration from various fossil energy sources and its contribution to the atmospheric concentration is based on the reference energy system developed at Brookhaven National Laboratory [6] for the U.S.A. The concept of the reference energy system is a description of the major components of the energy system, specifying resource consumption, fuel transportation, conversion processes and end use. The energy system was developed for a base year 1969 and was projected for the designated future years. Projection of future energy demand and supply is based on energy use in the past and then extrapolated to the future years by using certain growth and reduction estimates for each sector [6]. A compilation of the major environmental effects of the system is also presented.

To determine the CO_2 emitted from a sector, one takes the product of the fuel demand for that sector and the emission coefficient of this fuel for carbon dioxide. For example, in 1972 the demand of distillate oil for space heat in the residential area is 7.80×10^{17} cal (3.09 quads) and the emission coefficient of distillate oil to CO_2 is 3.06×10^{-7} kg CO_2 /cal (8.5×10^7 tons CO_2 /quad) [6]. Thus the total CO_2 emitted from distillate oil consumption in the residential area is 2.39×10^{11} kg (2.63×10^8 tons). Several major sectors such as residential, commercial, industrial, electric utilities and transportation are considered separately. With the use of the reference energy system scenario for the U.S., the total annual carbon dioxide emission, its fractional distribution in different categories and the contribution to the concentration of carbon dioxide in the atmosphere are determined and tabulated in Tables 1 - 6 for the years 1977, 1980, 1985, 1990, 2000 and 2020.

Contribution of CO_2 by the U.S. to the atmosphere was 27% of that contributed by the world in 1974 [2]. However, the U.S. contribution is estimated to be about 9% of the world contribution in 2025 [2]. Results for 1977 are from the latest information developed at Brookhaven National Laboratory. In Table 1 for 1977, the CO_2 emitted from the commercial and residential sectors is combined. This is different from the other years where the residential sector is separated from the commercial sector. As a result of Tables 1 - 6, the coal burning electric utilities is the largest emitter of carbon dioxide to the atmosphere ($\sim 25\%$) followed by the emission from automotive sources, automobiles, buses and trucks ($\sim 20\%$). Industrial gas is generally the third emitter of carbon dioxide ($\sim 10\%$). The industrial coal sector, as well as air and ship transportation, each run as the fourth largest carbon dioxide emitters to the atmosphere ($\sim 8\%$). The total U.S. carbon dioxide emission ranges from 1.22×10^9 to 5.24×10^9 metric tons of carbon, between 1977 and 2020. With the total mass of dry air as 5.12×10^{21} gm [1], it is then possible to estimate the CO_2 concentration in the atmosphere as tabulated in Tables 1 - 6. It is seen that additional CO_2 increase in the atmosphere over background (330 ppm CO_2) is 0.626 ppm in 1977 and 1.529 ppm in 2020. The average carbon dioxide growth rate is about 2.1% per year over this forth-three year period. This is smaller than the 4.3% per year in the past [2]. It is possible to obtain different growth rates with different scenarios. For example, substitution of fossil fuel burning power plants with nuclear power plants can reduce the carbon dioxide emission over 30% in the future. Recycling of atmospheric carbon dioxide for synthetic liquid fuel production [7], instead of continuing consumption of petroleum and natural gas resources, may also lead to reduction of carbon dioxide emission in the atmosphere.

A further detailed breakdown of the carbon dioxide source in 1985 is shown in Table 7 as a representative example. It is seen that coal fired power plants and passenger cars alone are, respectively, the first (24.5%) and the second (13.0%) highest contributors of carbon dioxide to the atmosphere. Emission of carbon dioxide from the electric utilities and industrial subsectors can be considered centralized sources. Emission of carbon dioxide from the residential, commercial and transportation subsectors can be considered as diffusive sources. Diffusive sources are those released near ground level in quantities proportional to the population density. Thus these emissions are heavily concentrated in populated areas. In 1985, emission of carbon dioxide to the atmosphere from the electric utilities and industrial sectors is estimated to be 31.7% and 22.5% respectively. Thus the total carbon dioxide emission to the atmosphere from the concentrated source (a combination of the electric utilities and industrial sectors together) is estimated to be 54.2%. Emission of carbon dioxide to the atmosphere by the diffusive sources (a combination of the residential, commercial and transportation sectors together) is thus estimated to be 45.8%. For the concentrated source, it may be possible to remove and recover carbon dioxide by various technologies such as absorption/stripping, adsorption [8,9] or disposal in the bottom of the ocean [10]. For a diffusive source, control technology may be more difficult to apply. Further discussion of control technology options for carbon dioxide are given in [8,9 and 11] and will be subject of further evaluation in future reports.

Summary and Conclusion

Estimates of total carbon dioxide release and its additional concentration to the atmosphere for the years 1977, 1980, 1985, 1990, 2000 and 2020 by U.S. fossil fuel consumption have been tabulated for different sectors

of the economy including residential, commercial, industrial, power plant utilities and transportation. A detailed breakdown of carbon dioxide for different subsectors for the year 1985 is also reported. Coal fired power plant and car/bus/truck transportation are the first and second largest carbon dioxide contributors to the atmosphere with the former contributing about 25% and the latter contributing about 20% of the total U.S. carbon dioxide emitted to the atmosphere. Additional CO₂ concentration over background (330 ppm) due to U.S. fossil fuel consumption, was 0.626 ppm in 1977 and is estimated to be 1.529 ppm in 2020.

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Table 1

RESIDENTIAL, COMMERCIAL, INDUSTRIAL, UTILITIES AND TRANSPORTATION
EMISSION OF CO₂ FROM VARIOUS SECTORS OF U.S. ECONOMY
AND CONTRIBUTION TO ATMOSPHERIC CO₂ CONCENTRATION

1977

	<u>Emission of C as CO₂</u> <u>(metric tons C)</u>	<u>%</u>	<u>CO₂ in World</u> <u>Air (ppm)</u>
<u>Residential and</u>			
<u>Commercial</u>			
Oil	6.51 x 10 ⁷	5.33	.034
Gas	9.89 x 10 ⁷	8.10	.051
Subtotal	1.64 x 10 ⁸	13.43	.084
<u>Industrial</u>			
Oil	1.04 x 10 ⁸	8.55	.054
Gas	1.06 x 10 ⁸	8.70	.054
Coal	6.13 x 10 ⁷	5.03	.032
Subtotal	2.72 x 10 ⁸	22.28	.140
<u>Electric Utilities</u>			
Oil	7.59 x 10 ⁷	6.22	.039
Gas	5.37 x 10 ⁷	4.40	.027
Coal	2.82 x 10 ⁸	23.12	.144
Subtotal	4.12 x 10 ⁸	33.74	.211
<u>Transportation</u>			
Car, Bus and Truck	3.12 x 10 ⁸	25.58	.160
Air and Ship	5.94 x 10 ⁷	4.87	.031
Subtotal	3.72 x 10 ⁸	30.45	.191
TOTAL	1.22 x 10 ⁹	99.90	.626

Table 2

RESIDENTIAL, COMMERCIAL, INDUSTRIAL, UTILITIES AND TRANSPORTATION
EMISSION OF CO₂ FROM VARIOUS SECTORS OF U.S. ECONOMY
AND CONTRIBUTION TO ATMOSPHERIC CO₂ CONCENTRATION

	<u>1980</u>		
	<u>Emission of C as CO₂</u> <u>(metric tons C)</u>	<u>%</u>	<u>CO₂ in World</u> <u>Air (ppm)</u>
<u>Residential</u>			
Oil	6.44 x 10 ⁷	4.83	.033
Gas	8.18 x 10 ⁷	6.16	.043
Subtotal	1.46 x 10 ⁸	10.99	.076
<u>Commercial</u>			
Oil	5.51 x 10 ⁷	4.14	.029
Gas	3.82 x 10 ⁷	2.86	.020
Subtotal	9.33 x 10 ⁷	7.00	.049
<u>Industrial</u>			
Oil	6.60 x 10 ⁷	4.96	.034
Gas	1.54 x 10 ⁸	11.55	.080
Coal	7.99 x 10 ⁷	6.00	.042
Subtotal	3.00 x 10 ⁸	22.51	.156
<u>Electric Utilities</u>			
Oil	5.56 x 10 ⁷	4.19	.029
Gas	5.51 x 10 ⁷	4.13	.029
Coal	3.03 x 10 ⁸	22.75	.157
Subtotal	4.14 x 10 ⁸	31.07	.215
<u>Transportation</u>			
Car, Bus and Truck	2.92 x 10 ⁸	21.95	.152
Air and Ship	8.65 x 10 ⁷	6.49	.045
Subtotal	3.79 x 10 ⁸	28.44	.197
 TOTAL	 1.33 x 10 ⁹	 100.01	 .693

Table 3

RESIDENTIAL, COMMERCIAL, INDUSTRIAL, UTILITIES AND TRANSPORTATION
EMISSION OF CO₂ FROM VARIOUS SECTORS OF U.S. ECONOMY
AND CONTRIBUTION TO ATMOSPHERIC CO₂ CONCENTRATION

	<u>1985</u>		
	<u>Emission of C as CO₂</u> <u>(metric tons C)</u>	<u>%</u>	<u>CO₂ in World</u> <u>Air (ppm)</u>
<u>Residential</u>			
Oil	6.87 x 10 ⁷	4.59	.035
Gas	8.15 x 10 ⁷	5.46	.042
Subtotal	1.50 x 10 ⁸	10.05	.077
<u>Commercial</u>			
Oil	6.30 x 10 ⁷	4.22	.033
Gas	3.87 x 10 ⁷	2.58	.020
Subtotal	1.02 x 10 ⁸	6.80	.053
<u>Industrial</u>			
Oil	5.67 x 10 ⁷	3.80	.029
Gas	1.52 x 10 ⁸	10.19	.079
Coal	1.27 x 10 ⁸	8.50	.066
Subtotal	3.36 x 10 ⁸	22.49	.174
<u>Electric Utilities</u>			
Oil	5.26 x 10 ⁷	3.52	.027
Gas	5.62 x 10 ⁷	3.77	.029
Coal	3.65 x 10 ⁸	24.45	.189
Subtotal	4.74 x 10 ⁸	31.74	.245
<u>Transportation</u>			
Car, Bus and Truck	3.19 x 10 ⁸	20.51	.166
Air and Ship	1.11 x 10 ⁸	8.42	.058
Subtotal	4.30 x 10 ⁸	28.93	.224
 TOTAL	 1.50 x 10 ⁹	 99.95	 .773

Table 4

RESIDENTIAL, COMMERCIAL, INDUSTRIAL, UTILITIES AND TRANSPORTATION
EMISSION OF CO₂ FROM VARIOUS SECTORS OF U.S. ECONOMY
AND CONTRIBUTION TO ATMOSPHERIC CO₂ CONCENTRATION

	<u>1990</u>		
	<u>Emission of C as CO₂</u> <u>(metric tons C)</u>	<u>%</u>	<u>CO₂ in World</u> <u>Air (ppm)</u>
<u>Residential</u>			
Oil	6.71 x 10 ⁷	4.08	.035
Gas	8.05 x 10 ⁷	4.90	.042
Subtotal	1.48 x 10 ⁸	8.98	.077
<u>Commercial</u>			
Oil	6.63 x 10 ⁷	4.03	.034
Gas	3.98 x 10 ⁷	2.43	.021
Subtotal	1.06 x 10 ⁸	6.46	.055
<u>Industrial</u>			
Oil	7.04 x 10 ⁷	4.28	.037
Gas	1.60 x 10 ⁸	9.77	.083
Coal	1.44 x 10 ⁸	8.73	.074
Subtotal	3.74 x 10 ⁸	22.78	.194
<u>Electric Utilities</u>			
Oil	4.61 x 10 ⁷	2.81	.024
Gas	5.24 x 10 ⁷	3.17	.027
Coal	4.15 x 10 ⁸	25.10	.214
Subtotal	5.14 x 10 ⁸	31.08	.265
<u>Transportation</u>			
Car, Bus and Truck	3.63 x 10 ⁸	21.95	.187
Air and Ship	1.44 x 10 ⁸	8.74	.075
Subtotal	5.07 x 10 ⁸	30.69	.262
 TOTAL	 1.64 x 10 ⁹	 99.99	 .853

Table 5

RESIDENTIAL, COMMERCIAL, INDUSTRIAL, UTILITIES AND TRANSPORTATION
EMISSION OF CO₂ FROM VARIOUS SECTORS OF U.S. ECONOMY
AND CONTRIBUTION TO ATMOSPHERIC CO₂ CONCENTRATION

	<u>2000</u>		
	<u>Emission of C as CO₂</u> <u>(metric tons C)</u>	<u>%</u>	<u>CO₂ in World</u> <u>Air (ppm)</u>
<u>Residential</u>			
Oil	7.66 x 10 ⁷	3.87	.040
Gas	7.28 x 10 ⁷	3.68	.038
Subtotal	1.49 x 10 ⁸	7.55	.078
<u>Commercial</u>			
Oil	7.64 x 10 ⁷	3.85	.040
Gas	4.25 x 10 ⁷	2.15	.022
Subtotal	1.19 x 10 ⁸	6.00	.062
<u>Industrial</u>			
Oil	9.95 x 10 ⁷	5.03	.052
Gas	1.81 x 10 ⁸	9.16	.094
Coal	1.99 x 10 ⁸	10.04	.103
Subtotal	4.80 x 10 ⁸	24.23	.249
<u>Electric Utilities</u>			
Oil	4.45 x 10 ⁷	2.24	.023
Gas	4.04 x 10 ⁷	2.04	.021
Coal	5.29 x 10 ⁸	26.77	.275
Subtotal	6.14 x 10 ⁸	31.05	.319
<u>Transportation</u>			
Car, Bus and Truck	4.23 x 10 ⁸	21.42	.220
Air and Ship	1.93 x 10 ⁸	9.76	.100
Subtotal	6.16 x 10 ⁸	31.18	.320
 TOTAL	 1.98 x 10 ⁹	 100.01	 1.028

Table 6

RESIDENTIAL, COMMERCIAL, INDUSTRIAL, UTILITIES AND TRANSPORTATION
EMISSION OF CO₂ FROM VARIOUS SECTORS OF U.S. ECONOMY
AND CONTRIBUTION TO ATMOSPHERIC CO₂ CONCENTRATION

	<u>2020</u>		
	<u>Emission of C as CO₂</u> <u>(metric tons C)</u>	<u>%</u>	<u>CO₂ in World</u> <u>Air (ppm)</u>
<u>Residential</u>			
Oil	8.10 x 10 ⁷	2.75	.042
Gas	8.97 x 10 ⁷	3.04	.047
Subtotal	1.71 x 10 ⁸	5.79	.089
<u>Commercial</u>			
Oil	9.41 x 10 ⁷	3.20	.049
Gas	4.53 x 10 ⁷	1.54	.024
Subtotal	1.39 x 10 ⁸	4.74	.073
<u>Industrial</u>			
Oil	1.41 x 10 ⁸	4.80	.073
Gas	2.75 x 10 ⁸	9.31	.142
Coal	2.14 x 10 ⁸	7.25	.111
Subtotal	6.30 x 10 ⁸	21.36	.326
<u>Electric Utilities</u>			
Oil	5.89 x 10 ⁷	2.00	.031
Gas	3.16 x 10 ⁷	1.08	.017
Coal	1.11 x 10 ⁹	37.65	.575
Subtotal	1.20 x 10 ⁹	40.73	.623
<u>Transportation</u>			
Car, Bus and Truck	5.54 x 10 ⁸	18.74	.286
Air and Ship	2.55 x 10 ⁹	8.65	.132
Subtotal	3.10 x 10 ⁹	27.39	.418
 TOTAL	 5.24 x 10 ⁹	 100.01	 1.529

Table 7

DETAILED BREAKDOWN OF U.S. EMISSION OF CO₂ FROM VARIOUS SECTORS OF U.S. ECONOMY
AND CONTRIBUTION TO ATMOSPHERIC CO₂ CONCENTRATION

	<u>1985</u>		
	<u>Emission of C as CO₂</u>	<u>%</u>	<u>CO₂ in World</u>
	<u>(metric tons C)</u>		<u>Air (ppm)</u>
<u>Residential</u>			
<u>Oil</u>			
Space Heat	6.35 x 10 ⁷	4.24	.033
Water Heat	5.21 x 10 ⁶	0.35	.002
Subtotal	6.87 x 10 ⁷	4.59	.035
<u>Gas</u>			
Space Heat	5.43 x 10 ⁷	3.64	.028
Water Heat	2.19 x 10 ⁷	1.47	.011
Cooking	5.32 x 10 ⁶	0.36	.028
Subtotal	8.15 x 10 ⁷	5.46	.042
<u>Commercial</u>			
<u>Oil</u>			
Space Heat	6.30 x 10 ⁷	4.22	.033
<u>Gas</u>			
Space Heat	2.84 x 10 ⁷	1.90	.075
Air Conditioning	4.83 x 10 ⁵	0.03	.000
Water Heating	7.50 x 10 ⁶	0.50	.004
Cooking	2.27 x 10 ⁶	0.15	.001
Subtotal	3.87 x 10 ⁷	2.58	.020
<u>Industrial</u>			
<u>Oil</u>			
Process Heat	4.83 x 10 ⁷	3.23	.025
Cement	2.68 x 10 ⁶	0.18	.001
Iron	5.05 x 10 ⁵	0.03	.000
Steel	4.01 x 10 ⁵	0.03	.000
Industrial Electric Generation	4.96 x 10 ⁶	0.33	.003
Subtotal	5.67 x 10 ⁷	3.80	.029
<u>Gas</u>			
Process Heat	1.28 x 10 ⁸	8.54	.067
Aluminum	1.51 x 10 ⁶	0.10	.001
Cement	5.81 x 10 ⁶	0.39	.003
Iron	9.65 x 10 ⁵	0.07	.000
Steel	1.27 x 10 ⁷	0.85	.007
Industrial Electric Generation	3.55 x 10 ⁶	0.24	.002
Subtotal	1.52 x 10 ⁸	10.19	.079

Table 7 - (Cont'd)

	1985		
	Emission of C as CO ₂ (metric tons C)	%	CO ₂ in World Air (ppm)
<u>Coal</u>			
Process Heat	9.44 x 10 ⁷	6.32	.049
Aluminum	4.23 x 10 ⁶	0.28	.002
Cement	8.78 x 10 ⁶	0.59	.005
Industrial Electric Generation	1.96 x 10 ⁷	1.31	.010
Subtotal	1.27 x 10 ⁸	8.50	.066
<u>Electric Utilities</u>			
Gas	5.62 x 10 ⁷	3.77	.029
Oil	5.26 x 10 ⁷	3.52	.027
Coal	3.63 x 10 ⁸	24.45	.189
Subtotal	4.72 x 10 ⁸	31.74	.245
<u>Transportation</u>			
<u>Gasoline & Jet Fuel</u>			
Bus	8.86 x 10 ⁵	0.06	.001
Truck	2.53 x 10 ⁷	1.70	.013
Car	1.93 x 10 ⁸	12.95	.100
Air	8.67 x 10 ⁷	5.80	.045
Subtotal	3.08 x 10 ⁸	20.51	.159
<u>Oil</u>			
Bus	2.36 x 10 ⁶	0.16	.001
Truck	8.70 x 10 ⁷	5.82	.045
Railroad & Subway	1.18 x 10 ⁶	0.79	.006
Ship	2.47 x 10 ⁷	1.65	.013
Subtotal	1.26 x 10 ⁸	8.42	.065
TOTAL	1.50 x 10 ⁹	100.01	0.773