THE POTENTIAL IMPACT OF CONSERVATION AND ALTERNATIVE ENERGY SOURCES ON CARBON DIOXIDE EMISSIONS

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ABSTRACT

In this report, we examine two global energy consumption scenarios to determine how each will contribute to the greenhouse effect and global warming. A steady emissions trend scenario assumes only modest energy conservation and little change in the world's energy consumption patterns. A reduced emissions trend scenario assumes significant conservation and switching from a more carbon-intensive energy source mix to a less intensive mix. Based on the difference between the two scenarios' results, we conclude that it is possible to reduce carbon dioxide emissions by more than 50% by 2050 using a combination of conservation and efficiency improvements and increased use of nuclear, geothermal, and solar/renewable energy sources.

INTRODUCTION

The objective of this study is to develop a quantitative estimate for the potential reduction of energy related carbon dioxide emissions that might be achieved through making reasonable modifications to global energy consumption patterns. The modifications include increased conservation, efficiency improvements, and switching from fossil fuels to alternative energy sources such as nuclear, geothermal, and solar/renewable. We will estimate the magnitude of carbon dioxide emissions for two scenarios of global energy consumption starting with 1986 as a base year and progressing to the year 2050.

These scenarios are: a steady emission trend scenario, "Steady Scenario," where little is done to restrict the growth of energy consumption and little is done to change the mix of energy sources; and a reduced emission trend scenario, "Reduced Scenario," where, through conservation, increased energy efficiencies, and a general concern for alleviating the greenhouse effect, the growth of energy consumption and the mix of energy sources is considerably altered.

The most important greenhouse gases in the earth's atmosphere are water vapor (H_2O), carbon dioxide (CO_2), nitrous oxide (N_2O), methane (CH_4), tropospheric ozone (O_3), and the chlorofluorocarbons (CFCs): CFC-11 (trichlorofluoromethane, CCl_3F), and CFC-12 (dichlorodifluoromethane, CCl_2F_2). Figure 1 (Aronson, 1989) puts the relative importance of the various greenhouse gases and their anthropogenic sources (energy and nonenergy) into perspective. It was derived using the "Steady Scenario," described later in this paper. Carbon dioxide is the most serious of the greenhouse gases (accounting for nearly 40% of a projected greenhouse effect increase), due to its radiative effect and its atmospheric concentration, which may double in the next few decades. This gas is the natural product of burning carbon contained in all fossil fuels. In 1986 about 5.8 GtC (metric gigatonnes of carbon) was emitted into the atmosphere due to world energy consumption (WRI, 1989). It has been estimated that an additional 1.6 GtC was emitted from other anthropogenic activity, mostly deforestation (WRI, 1989).

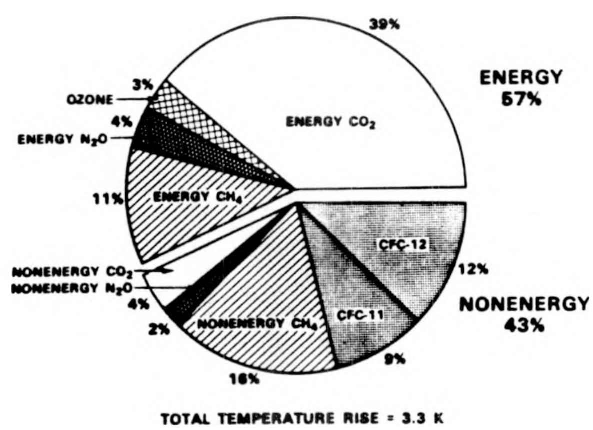

Figure 1. Relative anthropogenic contributions to an increasing greenhouse effect between 1986 and 2050 (no feedback).

This paper projects energy use and associated CO_2 emissions for the two scenarios described above. Based on these two scenarios, it estimates the relative contributions to reducing CO_2 emissions from conservation and efficiency improvements and from switching to less carbon intense energy sources including geothermal energy.

CURRENT ENERGY USE AND ENERGY USE PROJECTIONS

The global use of energy, in particular the burning of fossil fuels, is the largest single contributor (see Figure 1) to the anthropogenic emission of greenhouse gases; thus, estimating the magnitude of the greenhouse effect requires projecting global energy use. With the year 1986 as a starting point, we projected two global energy consumption scenarios and estimated CO_2 emissions for each.

We constructed a 1986 energy flow chart for the world, Figure 2, using data from a World Resources Institute report (WRI, 1989). These data were used because they contain both aggregated global energy consumption and energy consumption broken down by world region and use sector. Our "agrescom" sector is the combination of agricultural, residential, and commercial energy use sectors. The differences between production and consumption in the WRI report are shown as "lost, stored, etc." in the figure. Electrical transmission losses were not included in the reference. They are not shown in the figure and are not expected to be large enough to change our results significantly. The "other" fuel category refers to wood and other organic fuels. Aronson (1989) gives a more detailed description of Figure 2. Energy consumption values are summarized in Table 1.

Our analysis explores two energy consumption scenarios: a steady emission trend scenario, "Steady Scenario," and a reduced emission trend scenario, "Reduced Scenario."

Steady Emission Trend Energy Scenario

Figure 3 compares five energy projections. The one labeled "ORIEA" is from Edmonds (1985) and shows the highest growth rate projection of the five. The two projections labeled "IIASA High" and "IIASA Low" are from Hafele (1981). The other two projections are from Mintzer (1987) and are labeled "WRI High Emission" and "WRI Slow Buildup." Each of these projections was based on rather detailed population growth, economic growth, and supply-demand scenarios. Without judging the relative merits of these and other scenarios, we selected a 2% per year energy growth rate as our Steady Scenario, which is very close to the WRI High Emission case. Based on data from EIA (1988) global annual energy growth was 1.8% for the 10 years preceeding 1987 and 2.8% for the 5 preceeding years; thus, a 2% growth rate is reasonably consistent with recent history. We do not wish to imply that it is a "most likely" or a "worst case" scenario. It is simply one of many possible scenarios.

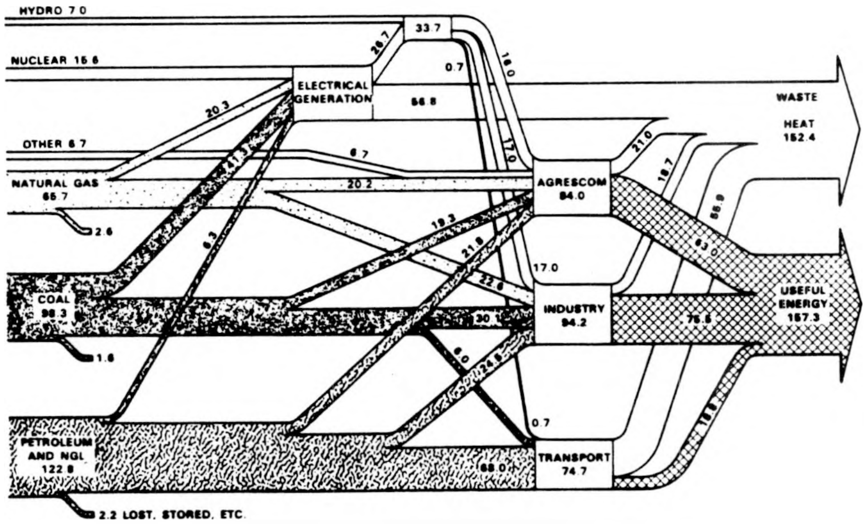

Figure 2. 1986 world energy consumption in Exajoules.

Table 1. 1986 world energy consumption (excluding other) in exajoules (EJ).

Oil	120.6
Coal	96.7
Natural Gas	63.1
Nuclear	15.6
Hydroelectric	22.0*
TOTAL	318.0
Geothermal	0.9**

* Equivalent thermal energy input.
** Not included in Figure 2.

Our Steady Scenario uses a 2% annual energy consumption growth rate without conservation or efficiency improvements. It also assumes that the pattern of future energy use will be very much the same as it is now, except that, as oil and gas are depleted, they will be replaced by synthetic oil and gas made from coal. At the same time, the oil and gas used to generate electricity will be replaced by coal. This scenario, while not a "worst possible case", does not attempt to reduce the demand for fossil fuel, nor does it attempt to reduce emissions of CO_2.

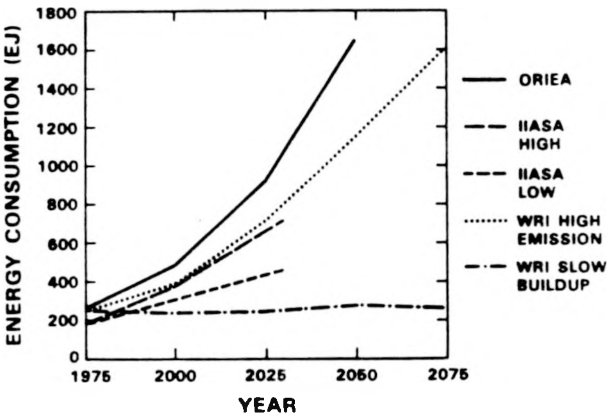

Figure 3. Global energy consumption projection comparisons.

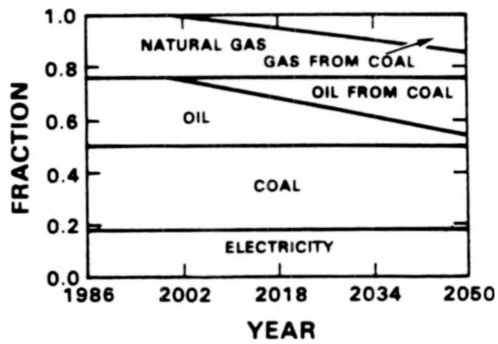

Figure 4b. Steady Scenario fractions for industrial energy consumption.

Figures 4a through 4d show how the fractional mix of energy sources progresses with time for the Steady Scenario. These figures illustrate our scenario that little change is made to the energy mix and that synthetic oil and gas produced from coal will gradually displace fossil oil and gas beginning in the year 2000. The Steady Scenario will deplete fossil oil by 2038 if synthetic oil is not substituted. This is based on the global fossil energy resources shown in Table 2. The information in Table 2 was derived using data from Hafele (1981) and represents what they call recoverable resources; for example, the oil figure is recoverable at $20 (1975 dollars) per barrel or less. For comparison, Table 2 also shows the world geothermal resource (Bath, 1990). The quantity of a recoverable resource will, of course, depend on the cost of competing resources.

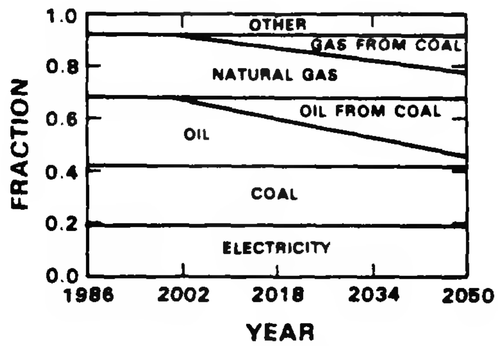

Figure 4c. Steady Scenario fractions for agrescom energy consumption.

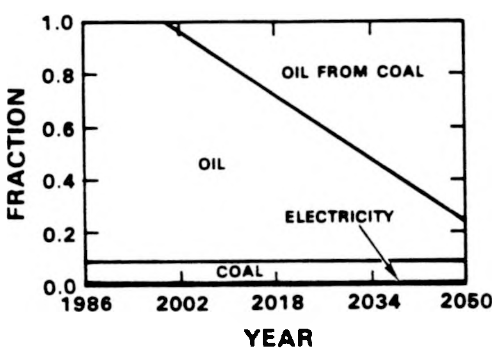

Figure 4a. Steady Scenario fractions for transportation energy consumption.

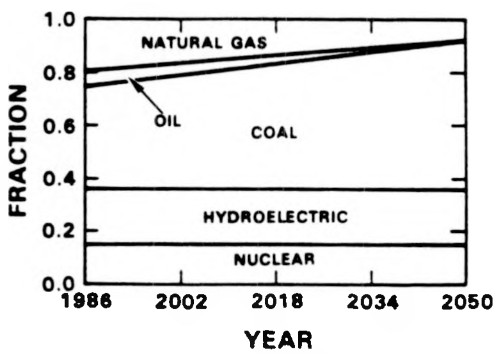

Figure 4d. Steady Scenario fractions for electrical generation.

Table 2. World recoverable fossil fuel and geothermal resources, EJ.

Oil	11,000
Natural Gas	8,900
Coal	250,000
Geothermal	100,000,000

To avoid a discontinuity in oil supply, we required a smooth transition from fossil to synthetic oil. The slopes of the synthetic oil and gas displacements were established by requiring that the fractions be linear with time and that the fractions of fossil oil and gas consumption reach zero at the same time the resource is depleted. With this transition from fossil to synthetic oil, fossil oil will be depleted in 2068 under the Steady Scenario. The real progression will be considerably more complicated and will be driven by economic and political considerations.

Our Steady Scenario, which replaces fossil oil and gas with synthetic oil and gas, requires that the capacity to produce 1.2 million barrels of synthetic oil and 1.8 billion cubic feet of synthetic gas daily must be installed in the year 2000. The capacity added each year must increase to five times that rate by 2050. These synthetic fuel production capacity additions are possible if the global community recognizes the impending depletion of conventional oil and gas reserves and reacts accordingly; however, delaying additions or reducing additions, under the Steady Scenario, will require higher capacity additions at a later date if a discontinuity in the oil supply is to be avoided.

Reduced Emission Trend Energy Scenario

Our Reduced Scenario, like the Steady Scenario, starts with the energy consumption pattern shown in Figure 2 and with an annual energy consumption growth rate of 2%; however, it allows energy conservation and efficiency improvements to reduce the 2% baseline energy consumption growth rates to the growth rates specified in Table 3.

Table 3. Reduced Scenario energy consumption growth rates due to conservation and efficiency improvements, percent per year.

Transport	1.00
Industry	1.85
Agrescom	1.65

While greater and smaller growth rate reductions are quite possible, the values presented above are our assessment of what may realistically be accomplished between 1986 and 2050. They are not based on specific technological, sociological, or political changes, nor are they limitations. If all technically possible improvements are realized and if they completely penetrate the world's economy (we believe this is unlikely), conservation and efficiency could reduce growth rates far more than we have assumed. A more detailed explanation of these energy consumption growth rate reductions is given by Aronson (1989).

For the Reduced Scenario, we have also assumed that electrical generation efficiency will improve by 0.2% each year from 32% in 1986 to 36.4% in 2050. Some analysts look at today's most efficient electrical generation plants, which have efficiencies near 40%, and project that these efficiencies can be achieved for all generation systems in the future. This improvement will probably not be realized because electrical generation is a mix of base, intermediate, and peak load plants. Base plants tend to have the highest efficiencies because of the economic trade-off between capital cost and operating cost. We expect that future electrical generation will continue to use a mix of more and less efficient plants.

The above energy consumption, conservation, and efficiency growth rate scenarios allow us to make energy consumption projections, but we must also specify which energy sources will be used to meet the demand for energy. Our assumed mix of energy sources is shown in Figures 5a through 5d. The beginning mix is that shown in Figure 2. Like the conservation and efficiency improvement scenarios, these mixes are our estimates of how the world's consumption of energy may progress. The Reduced Scenario gradually replaces fossil fuels with geothermal, solar and other renewable, and nuclear sources. Again, this is not the most optimistic scenario imaginable, but it does project what we believe is an aggressive but realistic evolution to nonfossil energy forms.

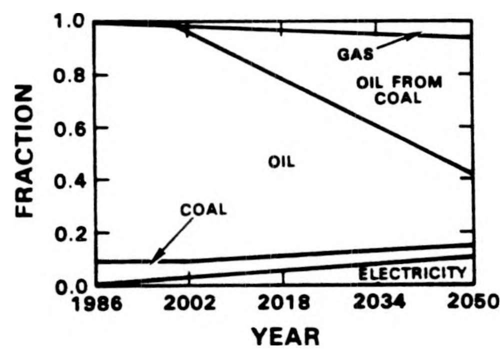

Figure 5a. Reduced Scenario fractions for transportation energy consumption.

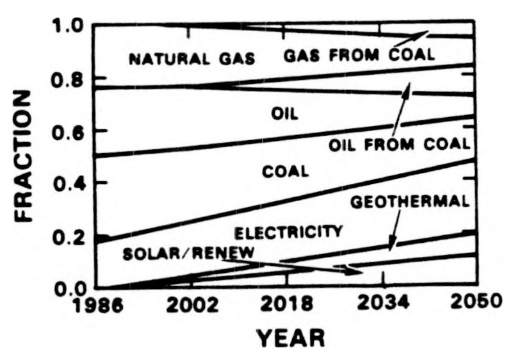

Figure 5b. Reduced Scenario fractions for industrial energy consumption.

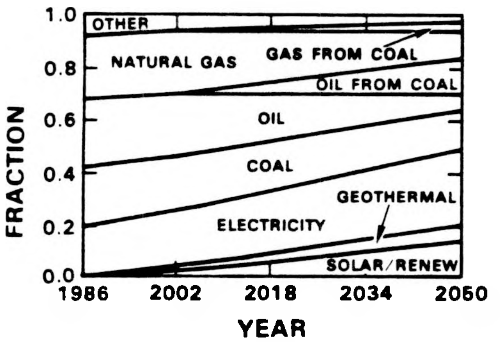

Figure 5c. Reduced Scenario fractions for agrescom energy consumption.

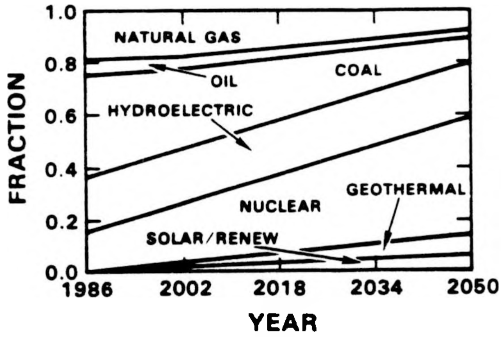

Figure 5d. Reduced Scenario fractions for electrical generation consumption.

This scenario projects that geothermal energy sources will satisfy roughly 8% of global energy needs by the year 2050. The estimated accessible energy resource from hydrothermal convection systems, 2500 EJ, exceeds the oil resource in the U.S. (Muffler, 1979). If potentially accessible magma and hot-dry-rock geothermal sources are included, the world has a very large geothermal resource; 100,000,000 EJ has been estimated (Bath, 1990). The geothermal fractions shown in Figures 5a through 5d roughly correspond to a 7% annual growth rate for both electrical and thermal energy. The world's geothermal electric capacity was 5 GWe in 1987 and direct thermal consumption was 0.5 EJ. The 7% growth rate is consistent with projections from Bath (1989) which had a U.S. geothermal-electric growth rate of 7% and a U.S. thermal growth rate of 9% for its most optimistic scenario. Geothermal fractions are put into perspective in Table 4.

We also assume that solar/renewable (which includes solar, wind, ocean, and biomass) energy sources will satisfy roughly 10% of global energy needs by 2050. Like the geothermal resource, the potential for using solar/renewable energy sources is huge; but, we also assume that, while their potential is large, exploitation expense will limit their use. They will make a significant, but not a dominant, contribution.

Table 4. Global geothermal energy use for the Reduced Scenario

	Electric primary energy (EJ)	Electric capacity 100% cap fac (GW)	Direct use (EJ)
1990	0.7	7.3	1.1
2000	3.0	31.	4.5
2010	6.1	65.	8.2
2020	10.7	120.	13.
2030	17.	190.	20.
2050	38.	440.	39.

We did not include the use of oxygenated fuels to displace oil. These fuels can be produced from biomass using renewable energy sources and their own bagasse, which would give them no net CO_2 emissions. We did not include them because of our uncertainty in their potential; however, they may prove to be important.

The Reduced Scenario assumes an increasing use of nuclear power that requires construction of 14 new 1 GW nuclear power plants somewhere in the world each year during the near term and 115 each year around 2050, assuming a capacity factor of 0.65 and a generation efficiency of 32% in the near term, increasing to 36.4% in 2050. To put this construction rate in perspective, 13 new plants came on line in 1986 (the number has decreased since then) and 44 came on line in 1979, the peak year. The number of new nuclear plants required for the future is easily within the world's capacity, but the present trend would have to be reversed.

The fractions in Figure 5, which indicate switching from one energy source to another, and the conservation and efficiency improvements projected for the Reduced Scenario assume making changes without indicating what mechanisms may motivate the changes. Significant changes will not occur without motivating mechanisms. Creating this scenario was an interesting exercise, but the real challenge will be to define mechanisms which can motivate the desired conservation and efficiency improvements and energy source switching.

The energy mix fractions directly consumed by each sector and from electrical generation are compared for the two scenarios in Table 5. They are assumed to change linearly between the dates shown.

The total energy consumption resulting from our two scenarios is shown in Figure 6. Figures 7 and 8 show the energy consumption breakdowns for the Steady and Reduced Scenarios, respectively. Less fossil fuel, coal in particular, is consumed in the Reduced Scenario.

Table 5. Assumed energy mix fractions for the Steady (Stdy) and Reduced (Redc) emission scenarios.

	1986 Both	2000 Stdy	2050 Stdy	2000 Redc	2050 Redc
Transportation					
Oil	.91	.91	.15	.89	.27
Synthetic Oil	.00	.00	.76	.00	.52
Natural Gas	.00	.00	.00	.02	.06
Synthetic Gas	.00	.00	.00	.00	.00
Coal	.08	.08	.08	.06	.04
Electricity	.01	.01	.01	.03	.11
Industry					
Oil	.26	.26	.04	.24	.08
Synthetic Oil	.00	.00	.22	.00	.12
Natural Gas	.24	.24	.10	.24	.10
Synthetic Gas	.00	.00	.14	.00	.06
Coal	.32	.32	.32	.28	.16
Geothermal	.00	.00	.00	.02	.08
Solar/Renewable	.00	.00	.00	.02	.12
Electricity	.18	.18	.18	.20	.28
Agrescom					
Oil	.26	.26	.04	.24	.06
Synthetic Oil	.00	.00	.22	.00	.14
Natural Gas	.24	.24	.10	.24	.10
Synthetic Gas	.00	.00	.14	.00	.04
Coal	.23	.23	.23	.21	.15
Geothermal	.00	.00	.00	.02	.06
Solar/Renewable	.00	.00	.00	.02	.14
Other	.08	.08	.08	.06	.02
Electricity	.19	.19	.19	.21	.29
Electrical Gen.					
Oil	.06	.05	.01	.05	.03
Natural Gas	.19	.16	.07	.18	.07
Coal	.39	.43	.56	.31	.10
Hydroelectric	.21	.21	.21	.21	.21
Nuclear	.15	.15	.15	.21	.45
Geothermal	.00	.00	.00	.02	.08
Solar/Renewable	.00	.00	.00	.02	.06

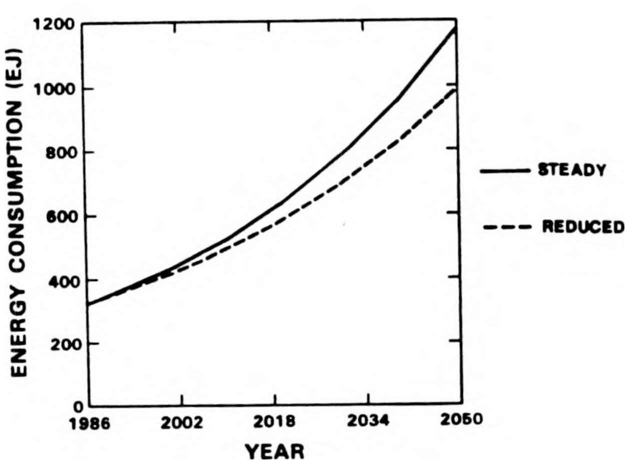

Figure 6. Energy consumption scenarios

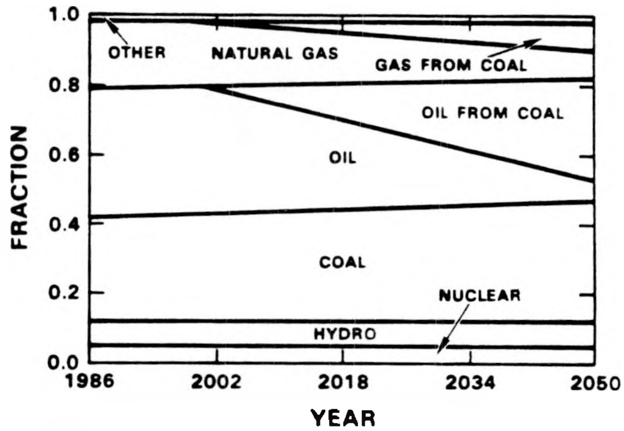

Figure 7. Total energy consumption fractions for the Steady Scenario

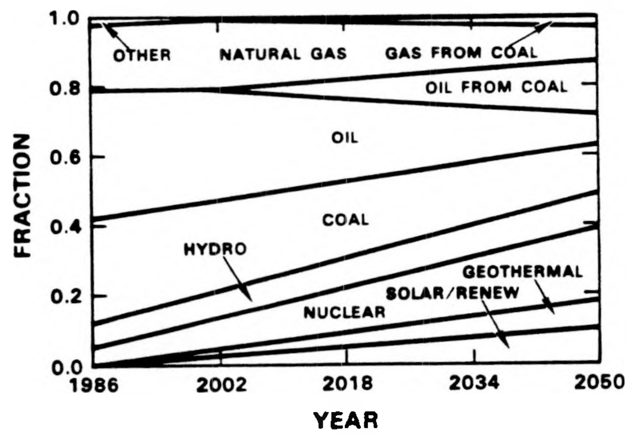

Figure 8. Total energy consumption fractions for the Reduced Scenario

Energy Related CO2 Emissions

Carbon emissions per unit energy of coal, oil, and gas are shown in Table 6, along with emission estimates for synthetic oil and gas made from coal, shale, and tar sand (Mintzer, 1987). Of the natural fuels, coal produces the most carbon, with natural gas producing about half and oil about three-quarters the carbon that coal produces on a per unit energy basis. The synthetic fuels generate considerably more carbon emissions because of the substantial amount of energy required to produce them, in addition to the carbon emitted in their consumption. Figure 9 shows a CO_2 flow chart constructed using Table 6 and the 1986 energy consumption values form Figure 2.

Table 6
Carbon Emissions of Fossil Fuels, MtC/EJ

Natural Gas	13.8
Oil	19.7
Coal	26.9
Synthetic Oil	38.6
Synthetic Gas	40.7
Shale Oil	47.6

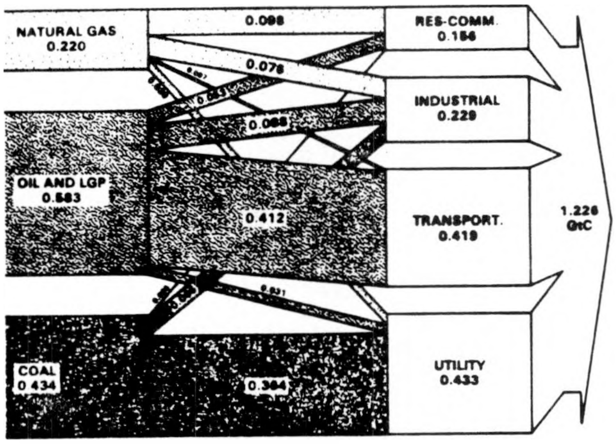

Figure 9. 1986 CO_2 emissions from global energy consumption, GtC.

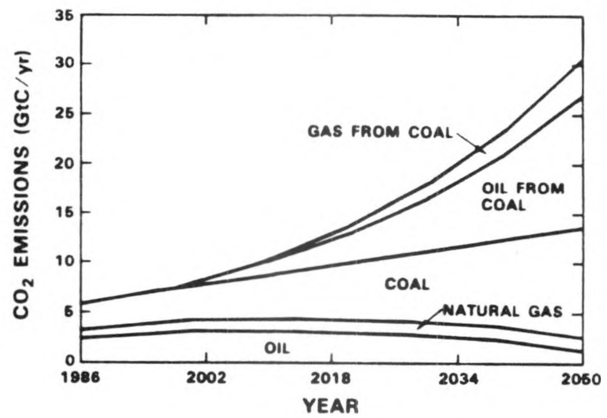

Figure 10. Steady Scenario CO_2 emissions from energy consumption

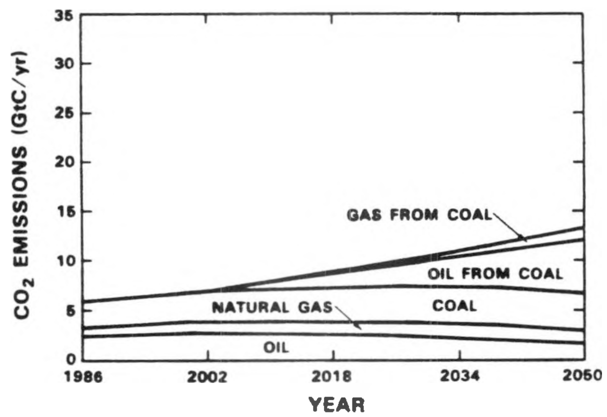

Figure 11. Reduced Scenario CO_2 emissions from energy consumption

Geothermal energy can also emit CO_2, which is dissolved in the working fluid. The quantity of CO_2 being emitted depends on the geothermal field being used and the energy conversion mode. The currently operating Geyser field in California emits CO_2 at the rate of 2.2 MtC/EJ (Randerson, 1984). For a geothermal plant operating in the "binary" mode, there should be essentially no carbon emissions.

RESULTS

With our two energy consumption scenarios and the emissions given in Table 6, we quantified energy related CO_2 emissions associated with each scenario. The CO_2 emissions for the Steady Scenario are shown in Figure 10 and those for the Reduced Scenario are shown in Figure 11. Starting with the same CO_2 emission in 1986, the Reduced Scenario emits less than half as much CO_2 as the Steady Scenario in the year 2050. Cumulative emissions from 1986 to 2050 are reduced by 38%. Emissions are reduced by a combination of energy conservation, efficiency improvements, and switching among energy sources. In addition to reducing energy demand, conservation and efficiency improvements extend the use of oil and natural gas, thereby displacing synthetic (made from coal) oil and gas, which emit more CO_2 per unit energy than "natural" oil and gas. Increased use of hydroelectric, nuclear, geothermal, and solar/renewable energy also displace coal and synthetic fuels. Oil and natural gas are credited with a small CO_2 displacement because they displace some coal. The relative contributions made to CO_2 emission reduction by conservation and efficiency improvements and by switching among energy sources are shown in Table 7. These percentages apply to the reduction of cumulative, energy related CO_2 emissions from 1986 to 2050. Conservation and efficiency improvements play the major role, but nuclear, geothermal, and solar/renewable energy are all also very important.

Table 7. Relative contributions to the reduction of CO_2 emissions

Conservation and Efficiency	48%
Oil	2%
Natural Gas	3%
Hydroelectric	5%
Nuclear	20%
Geothermal	10%
Solar/Renewable	12%

CONCLUSIONS

Energy related CO_2 emissions, nearly all due to the consumption of fossil fuel, will contribute nearly 40% (for the Steady Scenario) of an increased greenhouse effect. Mitigating global warming will require reducing energy related emissions; however, nonenergy anthropogenic emissions contribute nearly half and must also be reduced.

The results of this study illustrate that energy related CO_2 emissions can be significantly reduced by a combination of conservation, efficiency improvements, and switching from fossil fuels to energy forms which release less CO_2 and other greenhouse gases. Based on our two scenarios, emissions were reduced by more than 50% in 2050, and cumulative (1986 to 2050) energy related CO_2 emissions were reduced by 38%. Of this cumulative reduction, conservation and efficiency improvements contributed 48%, the increased use of nuclear contributed 20%, solar/renewable contributed 12%, and geothermal energy sources contributed 10%. Thus, according to the scenarios we considered, geothermal energy can be a significant contributor to reducing energy related CO_2 emissions.

Also of great importance is the fact that conservation, efficiency, and energy source switching can extend the availability of fossil oil and natural gas. Under the Steady Scenario, oil and natural gas will diminish rapidly between now and 2050. They will be replaced by synthetic oil and gas, made from coal, both of which are very rich sources of CO_2. Under the Reduced Scenario, synthetic oil and gas are required, but in much smaller quantities than in the Steady Scenario.

Under the Reduced Scenario, this study has assumed changes in the pattern of energy consumption--conservation, efficiency improvements, and energy source switching--without regard to the mechanisms which may motivate these changes. Some changes will be the result of natural market forces. As fossil fuel resources are depleted, they will become more expensive, motivating conservation and switching to less expensive alternatives. But, it is not clear that natural market forces will be sufficient to motivate the desired reduction of emissions which cause an increased greenhouse effect and global warming. We cannot assume that the desired pattern of energy consumption will be achieved spontaneously. Mechanisms which lead to the desired result must be identified, evaluated, and integrated into the world's economy. These mechanisms should include both domestic and international governmental policies. Careful market dynamics studies should be undertaken to find those policies which best motivate and achieve the desired changes in energy consumption patterns. These studies should include within them quantified estimates of the global costs associated with pollution and an increased greenhouse effect, costs which have previously been considered exogenous to energy economics.

ACKNOWLEDGMENTS

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