RENEWABLE TECHNOLOGIES AND THEIR ROLE IN MITIGATING GREENHOUSE GAS WARMING

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Human activity has led to an increased atmospheric concentration of carbon dioxide (CO_2), methane (CH_4), and other gases which resist the outward flow of infrared radiation more effectively than they impede incoming solar radiation. This imbalance yields the potential for global warming as the atmospheric concentrations of these gases increase. For example, before the industrial revolution, the concentration of CO_2 in the atmosphere was about 280 ppm, and it is now about 360 ppm. Similarly, CH_4 atmospheric concentrations have increased substantially, and they are now more than twice what they were before the industrial revolution, currently about 1.8 ppm. Recent data also suggest that airborne particulates have increased significantly in the post-industrial period and have contributed to a counteracting cooling impact.

In this paper we will discuss the role that renewable and other mitigation approaches could play in ameliorating such projected warming. In order to put this issue in context, the following issues will be discussed:

-What is the range of projected warming?
-What is the relative importance of the various greenhouse gases?
-What are the major and projected sources of CO_2?
-What emission controls achieve what level of greenhouse gas warming mitigation?
-What are candidate mitigation technologies - on both the end use side and the production side?
-Focusing on one particular renewable technology, the Hynol process, what are some of the economic, institutional, and other barriers that hinder commercialization?

A model (Glowarm 3.0) that the author has developed to help evaluate these questions is a spreadsheet (Lotus 1-2-3) model which calculates global concentrations and their associated global warming contributions for all the major greenhouse gases. The model calculates atmospheric concentrations of greenhouse gases based on projected emissions in 10-year increments. For CO_2, look-up tables are used to relate the fraction of CO_2 remaining in the atmosphere as a function of time after emission for two alternative CO_2 life cycles. For the other gases, an inputed lifetime value is used. Average global equilibrium temperatures are calculated by adding contributions of each gas, using lifetimes and radiative forcing functions described in Intergovernmental Panel on Climate Change (IPCC), 1990, along with an assumed input atmospheric sensitivity. Realized (or actual) temperature is estimated using an empirical correlation algorithm we developed based on general-circulation model (GCM) results presented in IPCC, 1992. This approach uses a correlation which relates the rate of equilibrium warming over the period between the target year and 1980 to the ratio of actual to equilibrium warming. The greater the rate of equilibrium warming, the smaller is the ratio of the actual to equilibrium ratio. Note that it is much easier to calculate average global warming than it is to estimate warming on a geographical or seasonal basis. Such geographical or seasonal projections require more complex models which are subject to a much greater degree of uncertainty.

Figure 1 shows fields for the model. Note that equilibrium and transient (realized or actual) warming can be calculated for any year (to 2100) for a variety of emission and control scenarios, two CO_2 life cycles, an assumed atmospheric sensitivity to a doubling of CO_2 concentration, CH_4 lifetime, and both sulfate cooling and CFC phaseout assumptions. Under the same assumptions, the model output temperatures fall generally within 10% of values calculated by other more complex models (IPCC, 1996b; NAS, 1991; Krause, 1989).

UNCERTAINTIES IMPACTING DEGREE OF WARMING EXPECTED

There are many uncertainties associated with the expected magnitude of global warming. The following are major uncertainties which will be considered and quantified:

1. Atmospheric Sensitivity. This critical variable is generally defined as the equilibrium temperature rise associated with a doubling of CO_2 concentration. GCMs are utilized by climate modelers to forecast the impact of CO_2 warming. Unfortunately, the range of their results is wide and not converging (Dornbusch and Poterba, 1991). The IPCC (IPCC, 1996a) has concluded this range to be between 1.5 and 4.5°C.

2. CO_2 Life Cycles. The Earth's carbon cycle, which involves atmospheric, terrestrial, and oceanic mechanisms, is complex and not completely understood. Yet, in order to estimate CO_2 atmospheric concentrations and subsequent warming, it is necessary to assume a relationship between CO_2 remaining in the atmosphere and time after emission. For this analysis, two CO_2 life cycles were utilized, one based on IPCC (1992) and the other described by Walker and Kasting (1992). The Walker model yields longer atmospheric lifetimes leading to higher CO_2 concentrations.

3. Projected Growth of CO_2 Emissions Over Time for a "Business as Usual" Case
Attempting to predict the future is a risky business, at best. Yet, to scope the magnitude of the warming issue, it is necessary to estimate emissions of greenhouse gases as far in the future as one wishes to project warming. As we discussed and quantified in a previous paper (Princiotta, 1994), the following are key factors which will determine a given country's emissions of CO_2, the most important greenhouse gas:

   - current emission rate
   - population growth
   - growth of economy per capita
   - growth rate: energy use per economic output
   - growth rate: carbon emissions per energy use unit

Since future global CO_2 emissions will be the sum of an individual country's emissions, all subject to varying factors listed above, it is clear that even for "business-as-usual" (or base case) there is a large band of uncertainty.

4. Methane Lifetime. A variety of investigators have provided a range of estimates for the atmospheric lifetime of CH_4. The longer the lifetime, the greater is CH_4's contribution to global warming.

5. Projected Growth of Methane Emissions. There is an incomplete understanding of the current contributions of the major anthropogenic sources of CH_4. They include: landfills, rice production, coal mines, natural gas production and distribution systems, and the production of cattle. There is even more uncertainty regarding the likely growth of such emissions over time as population grows, industrialization accelerates in developing countries, and agricultural practices change.

6. Use of High Global Warming Potential Compounds (e.g., HFC-134a) to Replace Chlorofluorocarbons (CFCs).
As the international community phases out of CFC production, due to concerns associated with stratospheric ozone depletion, hydrofluorocarbon (HFC)-134a and other compounds with significant greenhouse warming potential are being utilized as replacements. The importance of the extent to which compounds such as these are utilized will be evaluated.

7. Actual Temperature Response Versus Calculated Equilibrium Warming. GCMs often calculate projected equilibrium warming rather than transient or actual warming. Equilibrium warming can be defined as the temperature the Earth would approach if it were held at a given mix of greenhouse gas concentrations over a long period of time. Transient (also called realized or actual) temperatures are those that would actually be experienced at a given point in time, taking into account the thermal inertia of the Earth, especially its oceans. There is only an incomplete understanding of this thermal inertia effect and its quantitative impact on actual warming.

8. Aerosol (Sulfate) Cooling. A recent development (IPCC, 1992) has been the availability of evidence that emissions of sulfur dioxide (SO_2), other gases, and aerosols have contributed to a significant cooling impact, counteracting greenhouse gas warming. There is significant uncertainty over the magnitude of the direct impact of such fine particles and even more uncertainty over their secondary impact on clouds (generally thought to be significant and in the cooling direction).

In order to attempt to understand the impact of these variables, we have estimated warming for five scenarios spanning what we believe are reasonable ranges of values for these variables. For certain factors, such as atmospheric sensitivity, there is a reasonable consensus regarding the possible range of values. For other factors, there is no such consensus. It should be recognized that the credibility of this uncertainty analysis is only as good as the variable ranges assumed. Table 1 shows the assumed range of values from the "lowest" scenario, which assumes that all of these variables are at values which will yield the lowest degree of warming, to the "highest" case, which assumes those values which will yield the highest projected warming. These can be characterized as representing best versus worst case scenarios, respectively. In the middle is the base case which is generally consistent with the IPCC (1992, 1996b) and represents current conventional wisdom regarding the most likely scenario.

Figure 2 graphically summarizes the results of model calculations for the five scenarios examined. Also included in this figure is the actual warming estimated in 1980 relative to the pre-industrial era (NAS, 1991). As indicated, the range of projected global warming varies from significant to potentially catastrophic. We believe a more likely range of uncertainty is represented between the low and high scenarios. The predicted warming at 2100 for these cases is 2.1 and 5.7C°, respectively. The magnitude of these values and the difference between them support the contention that we are dealing with an issue not only of unprecedented potential impact, but also of monumental uncertainty. It is noteworthy that, even for the "low" scenario, temperature increases of 2.1C° over pre-industrial values (1.6C° over 1980 levels) are projected by 2100. According to Vostock ice core measurements (Dornbusch and Poterba, 1991), the last time the Earth experienced such an average temperature was 125,000 years ago.
As a basis for comparison, recently the IPCC (IPCC, 1996b) has projected warming at 2100 to range from 1.8 to 3.0°C depending on the projected emission scenario, with the base case warming at 2.5°C. This warming includes the 0.5°C warming experienced from the pre-industrial era to the current time. On the same basis, the Glowarm model calculates a base warming of 2.6°C.

It is important to note that uncertainty influences not only the predicted degree of future warming, but also the effectiveness of a given mitigation strategy. Figure 3 illustrates this point. Realized warming versus time is plotted for the "low," "high," and base scenarios. In addition, two stringent mitigation cases are included. Both assume that, by the year 2000, worldwide mitigation is imposed to decrease emissions of all greenhouse gases by 1% annually. However, the first mitigation case assumes all of the "high" variables summarized in Table 1 . The second, imposes a mitigation program assuming base (or "most likely") variables. The results are dramatic. They show that, even with a stringent emission reduction program, if the "high" case values are assumed, warming will be **greater** for all years before 2100 than for the uncontrolled base case! Note that, if a mitigation program (1% per year reduction for this "high case") were initiated further in the future, 2010 for example, the results would be even more dramatic. In this case, the controlled temperature at 2100 is now about 2.4°C versus the 2.1°C for the uncontrolled base case.

WHICH GASES ARE IMPORTANT?

Let us now examine the important greenhouse gases and their potential warming contributions. Figure 4 shows the projected contribution by greenhouse gas over the period 1980-2050 for the base scenario. CO_2 and CH_4 are clearly the most important contributors to warming, with CFCs and their substitutes, nitrous oxide (N_2O), and tropospheric ozone (O_3) [1] playing small but significant roles. Noteworthy, is the projected cooling impact of aerosol sulfates.

However, again, uncertainty is significant, this time in determining the relative contributions of the greenhouse gases. Such uncertainties are considered in Table 2. For each greenhouse gas, this table summarizes: atmospheric lifetime, the ratio of current to pre-industrial atmospheric concentrations, projected contributions to realized warming, and the projected impact of mitigating emissions. Also included is a judgment regarding the relative confidence of the predicted warming impacts, along with major uncertainties and the major human sources. Uncertainty is important for all gases, but especially for aerosols and tropospheric ozone.

When one considers the importance of a given greenhouse gas, it is informative to evaluate warming prevented for a given mitigation scenario. Figure 5 shows results of model calculations for the period 1980-2050 comparing equilibrium base scenario warming to warming prevented assuming a stringent mitigation program. In this case, a 1% annual reduction in emissions is assumed for each gas (or its precursor), exclusive of sulfates, starting in the year 2000. The main result here is that a higher fraction of their base warming can be mitigated for the short-lived gases such as CH_4 and O_3. For example, whereas less than half of CO_2's base warming is mitigated in this case, about three-quarters of CH_4's base warming is mitigated. When viewed from a mitigation (or warming prevented) viewpoint, CH_4 is about half as important as CO_2; whereas, from an emission viewpoint, it is less than a third as important.

Figure 6 shows additional model results to help shed light on this point. In this case, the effect of annual mitigation rate (starting in 2000) on equilibrium warming mitigated by gas is illustrated. An interesting observation that can be made is that a stringent 2% per year mitigation program for CH_4 could have almost as much benefit by the year 2050 as capping (0% growth) CO_2 emissions. Of course, such conclusions are subject to the uncertainties previously discussed.

WHICH COUNTRIES ARE MAJOR CONTRIBUTORS TO EMISSION OF GREENHOUSE GASES? WHAT ARE LIKELY TRENDS?

It is useful to look at recent histories of CO_2 emissions for key countries. Figure 7 derived from NAS, 1991, illustrates growth in CO_2 emissions from 12 key countries between 1960 and 1988. As indicated, the U.S., USSR (now Russia, Ukraine, and other independent countries), and China are by far the major sources of CO_2. However, when one considers the recent (1980-1988) growth rate, China and India are especially significant since this portends

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[1] This value assumes volatile organic compound (VOC), nitrogen oxide (NO_2), and carbon monoxide (CO) precursors contribute to O_3 formation. However, the small component of O_3 warming associated with CH_4 emissions is included in the CH_4 value.

future contributions to CO_2 emissions. Table 3 summarizes 1988 CO_2 data (NAS, 1991) for key countries listed in order of overall emissions, per capita emissions, and per gross national product (GNP) emissions. Although, the U.S. leads the world in overall and per capita emissions, China easily has the largest per emissions GNP.

In order to provide insight into the various sectors contributing to 1990 CO_2 emissions for key countries, Figure 8 was generated based on Oak Ridge National Laboratory (ORNL) calculated data (Bowden, et al., 1993). This figure illustrates that each country has a distinctive mix of activities yielding CO_2 emissions. In the case of the U.S., coal combustion (for electricity and steam), petroleum for transportation, and natural gas combustion (primarily for power generation and space heating) are the three most critical contributors. The pattern is similar in the former Soviet Union with the major difference in the automobile sector; much less CO_2 is generated by a much smaller fleet of vehicles. In China, coal combustion is the dominant source of CO_2 emissions, helping to explain why China's CO_2 unit of GNP is so high; coal is by far the most CO_2-rich fuel source per unit of useful output energy. Germany, the fourth most important source of CO_2, is also dominated by coal use: in their case, brown coal (lignite) is indigenous to their country. Japan, with few indigenous fossil fuel resources, is heavily dependent on imported coal and residual oil for power generation. It is interesting to note that India, the second most populous country in the world and likely a major future contributor, has a pattern similar to China, with steam coal the dominant source.

We have already discussed the uncertainties associated with future emissions of CO_2. Such emissions will depend on country-specific factors: population growth, rate of industrialization, energy use per economic output, and carbon use per energy utilized. Table 4 (Princiotta, 1994) shows a projection of growth of these factors for the developed (Organization for Economic Cooperation and Development--OECD) and relatively undeveloped Asian countries for the period 1990-2025. This projection is derived from information presented in IPCC, 1992. For the OECD countries, the key driver yielding increased CO_2 emissions is expected to be economic growth, whereas population growth is projected to be quite modest. For the Asian countries, the key driver is likely to be economic growth, with population growth also significant. For both regions, in the absence of a CO_2 mitigation program, energy efficiency gains and a decrease in carbon-intensive energy use are projected to be modest over this time period.

It is useful to examine the likely results of these drivers on projected emissions of CO_2 from selected countries. Figures 9 and 10 show such a projection assuming economic, population, and energy use trends summarized in IPCC, 1992. Projections for the years 2030 and 2100 are combined with actual CO_2 emission data (NAS, 1991) from the 1960-1988 time period. These graphics show that the Asian countries, especially China and India, driven by high projected economic growth and large populations, will be dominant CO_2 emitters by the middle of the next century.

MITIGATION: HOW MUCH AND WHEN TO START?

Figure 11 illustrates the projected results of two hypothetical mitigation scenarios compared to the base case which assumes current expectations for greenhouse gas emissions. If emissions were held constant at year 2000 levels, the rate of projected warming could be slowed substantially; although significant warming would continue for the foreseeable future. However, if emissions for all greenhouse gases were reduced 1% annually, post-1980 warming could be stabilized below about 1° C by the year 2100. Therefore, in order to mitigate warming over the long term, it will be necessary to reduce greenhouse gas emissions substantially over time. This will be a difficult goal, considering projected rates of economic and population growth which are key drivers for greenhouse gas emissions. Figure 12 illustrates this point by showing on one graphic, projected economic activity, population, base case CO_2 emissions, and mitigated CO_2 emissions unitized at 1990.

Figure 13 illustrates the impact of the year control starts on realized warming projected in 2050 for two mitigation scenarios (1% of annual control and an emission cap). As indicated, early emission control allows for a larger degree of climate stabilization. These results suggest that there can be major stabilization benefits for early initiation of mitigation.

MITIGATION: WHICH SOURCES/WHICH TECHNOLOGIES?

It is useful to examine recent CO_2 energy use patterns in order to ascertain which sectors and fuels are significant CO_2 emitters and candidates for mitigation. Table 5 (adapted from IPCC, 1996a) illustrates that all major energy categories are important emitters of CO_2, so that all major energy sectors will require major improvements in end use efficiency <u>and</u>, in the longer term, migration away from fossil fuels if stabilization efforts are to be successful.

Since it is clear that fossil fuel use is the key driver for greenhouse gas warming, a relevant question is: how much fossil fuel is available and how long will it last?

Table 6 adapted from IPPC, 1996a, and augmented by the author, summarizes the prevailing view on this subject. Basically, oil appears to be the least abundant fossil fuel with reserves plus most likely discovered conventional oil estimated to be 8500 EJ. Such an amount would be depleted by about 2035, if oil use rate were to increase by 1.5% per year. If unconventional reserves which, include heavy oil, oil shale, and oil tar deposits, are included, the availability of oil could be extended to about 2080, again assuming 1.5% increase in use per year until depletion. For conventional gas, the reserves plus expected discovered resources are estimated to be 9200 EJ . If gas use rate would increase 1.5% annually, these resources would be depleted by 2065. If unconventional gas sources are considered, gas resources wouldn't be depleted before about 2135 under the assumptions described above. As indicated, known reserves of coal are much larger, with depletion estimated at 2195 under the 1.5% annual growth assumption. Taken together all fossil fuel resources appear to be sufficient to last until about 2150. From a greenhouse warming viewpoint, gas is the most desirable fossil fuel since it has a high hydrogen to carbon ratio and generates substantially lower quantities of CO_2 than do oil and coal.

A reasonable scenario, then, is that sometime during the first half of the next century conventional sources of oil and later gas will become scarce and more expensive. Unconventional sources will likely become available but at substantially higher prices than for more easily extracted conventional sources. At the same time, depending on economic conditions, political policies, and technology availability, coal and/or alternative sources of energy, (e.g., biomass, solar) will fill the gap left by the depletion of relatively inexpensive oil and gas resources.

Since fossil fuels are the key driver for greenhouse gas warming, and their resources are limited, especially for oil, a key question is what renewable resources are potentially available to displace oil, gas and coal. Table 7, adapted from IPCC, 1996a, and augmented by the author, shows the potential renewable resource available in the 2020-2025 time frame and for the longer term. Also included is information estimating the fraction of total projected global energy use that these resources could supply. As can be seen, in the nearer term horizon (2020-2025) only biomass, hydro, and solar (in that order) appear to be available in sufficient quantities to displace a major component of fossil fuel use. In the longer term only solar and biomass appear to offer the potential for wide scale displacement.

Any successful mitigation program dealing with the critical energy sector must aggressively deal with the two fundamental components of the energy cycle: end use efficiency and production. Tables 8 and 9, adapted from NAS, 1991, list and briefly summarize candidate mitigation options for the end use and production sectors, respectively. Since electricity production and use, residential, commercial and industrial combustion, and transportation energy use are all major current and projected generators of CO_2, all these sectors must make fundamental end use and production improvements if a stabilization program is to be successful.

The author is convinced that meaningful mitigation can be achieved only with an aggressive program aimed at using less energy in all sectors in the near term, supplemented by new technologies capable of displacing fossil fuels in the longer term. This contention is supported by one of the most detailed assessments of its kind (EPA, 1990), in which a multitude of options were evaluated for their quantitative potential in mitigating greenhouse warming in the 2050 and 2100 time frame. Table 10 is adapted from that study and compares the mitigation potential of those options which can reduce emissions of CO_2. As can be seen, both end use and production strategies can be effective in mitigating greenhouse gas warming in these time frames. Of particular potential importance are end use efficiency in transportation and stationary source combustion systems, and in the production side via extensive displacement of fossil fuels by biomass. Also, potentially significant would be a forest sequestration strategy to reverse the current trend of deforestation with wide-scale reforestation.

When one considers the potential problem posed by long term fossil fuel use from a greenhouse warming viewpoint, and the likely depletion of cheap fossil fuels, especially oil and gas, within a few generations, one might expect a massive worldwide effort to develop renewable alternatives and energy conservation technologies. This is not the current situation. Table 11 (IPCC, 1996a) summarizes energy research in the IEA countries (industrialized) from 1983 to 1994. As can be seen, R&D expenditures have been generally decreasing during this period, especially when calculated as a fraction of Gross Domestic Product (GDP). Also, by far the largest component of such research has been focused on nuclear fission, a commercial technology with many economic and political problems not likely solved with research. It is interesting to note that the U.S. military research budget alone in the post cold war era is about 3.5 times greater than the combined energy research for all the IEA countries!

Focus on Hynol Process Utilizing Biomass and Methane to Yield Transportation Fuels

In order to consider some of the real world difficulties of developing and commercializing a potentially significant CO_2 mitigation technology, we will discuss the Hynol process. This process, which was innovated at DoE's Brookhaven National Laboratory, has been under development via EPA sponsorship with contributions from the California Energy Commission and DoD's Strategic Environment Research and Development Program (SERDP).

Bench scale work over a 4 year period has been performed at Brookhaven and at EPA's Research Triangle Park, NC, facility to provide fundamental design information. This process could be used to provide fuel to dedicated light and heavy duty vehicles designed for methanol fuel as well as fuel-cell powered vehicles. Figure 14 is a schematic of the process.

Analysis of technological options for converting biomass to liquid fuels showed that methanol, produced by the Hynol process, could displace more gasoline at lower cost--and with greater effect on the net CO_2 emissions--than other process options (Borgwardt, 1997). Methanol from the Hynol process cost is estimated at \$0.48/gallon (\$0.13/liter) for a 7870 tonne/day plant with 15.45% Capital Recovery factor, \$61/tonne biomass cost, and natural gas at \$2.50/10^6 Btu (\$1.055/GJ). It is currently estimated to be competitive with current equivalent gasoline prices in conventional vehicles.

A patent for the Hynol process was issued on September 6, 1994. A 50 lb/hour (23 kg/hour) pilot test facility has been constructed for testing the critical gasifier and will commence operation soon. University of California, Riverside, has the lead research role via a cooperative agreement with EPA. Figure 15 illustrates the projected cost of Hynol methanol as a function of natural gas price.

The following are the author's observations and opinions regarding the difficulty of developing and ultimately commercializing such a process under the current economic and political situation.

- Despite the potential of a process such as Hynol to displace oil and/or to reduce greenhouse gas emissions, there is no commercial incentive to develop biofuels as long as their cost exceeds, or even is equivalent to, that of fossil fuels. Situations where biomass can compete economically with fossil fuels are very few and have insignificant potential for affecting global greenhouse gas emissions.

- If greenhouse gas emissions is the only factor justifying biofuel utilization, development of biofuel technology is improbable without support by the government for the R&D that is necessary to demonstrate the technology and for providing incentives for renewable energy use.

- In the U.S., despite a robust economy, funding for renewable energy R&D is constrained to a modest level because of concerns about budget deficits and the absence of any imminent energy or environmental emergency. In the case of Hynol, it has been difficult to convince federal and private research sponsors to provide the resources for comprehensive testing of an integrated pilot of the process. The current pilot program is limited to gasifier evaluation.

- As long as petroleum is one of the lowest-cost sources of energy, and there is no global commitment to greenhouse gas reduction, only market forces will determine the fate of any effort to develop a biofuel alternative. The current basic cost of petroleum production is so low that it could undercut any attempt to start a major biofuel industry.

- If either petroleum displacement or greenhouse gas reduction is to be appreciably affected by biofuel, a very large plant must be considered, like 9000 tonnes/day of biomass feed. This is simply a matter of the number of plants that would be required to displace a significant portion of the current consumption of fossil fuel. The logistics of producing and delivering 9000 tonnes of biomass per day is formidable, given the land area, transport system, storage, etc., that are required. Capital investment in the plant alone would be over \$1billion ($1 x 10^9$); raising such an amount would be quite difficult unless risks were very low and potential profits high.

- Convincing landowners of the merits of investing and establishing dedicated energy plantations on a large scale, even before a conversion plant is built, will be difficult. Building a conversion plant before the energy crops are in production, will also be a risk. Government guarantees would likely be necessary.

- Even at 9000 tonnes/day, leveraging of the yield of liquid fuel from biomass will be necessary for practical consideration, given the amount of fuel needed, the number of plants required, and the production cost. Hynol methanol provides a means of such leveraging by use of natural gas as cofeedstock. Further leveraging will be achievable when high efficiency fuel cell vehicles become commercialized, probably about the same time as a viable biofuel industry could be established.

- Energy companies have billions of dollars invested in infrastructure for the petroleum fuel cycle; therefore, there is a tremendous amount of inertia to make fundamental changes in this area. Energy companies have a considerable vested interest in the status quo, considering this investment.

- As a new fuel to be potentially used in unprecedented quantities and in locations all around the country, the following issues will have to be evaluated and resolved before such widescale use is practical: (1) potential toxicity; (2) potential for groundwater contamination; and (3) corrosiveness to vehicle components.

SUMMARY AND CONCLUSIONS

- A spreadsheet model has been utilized to calculate both equilibrium and realized greenhouse warming as a function of key variables including: greenhouse gas emission growth rates, CO_2 life cycles, CH_4 lifetime, current aerosol cooling, and CFC phaseout assumptions.

- Model calculations for the three most credible cases, assuming a varying range of assumptions, yield projected warming at 2100 from a substantial 2.1C° to a potentially catastrophic 5.7C°. The most likely case yields 2.6C° projected warming from pre-industrial values; such warming is consistent with the most recent IPCC (IPCC, 1996b). Such uncertainty also impacts the estimates of the effectiveness of a mitigation program. Model results suggest that, even assuming a stringent mitigation program, if key uncertainties all align toward maximum greenhouse warming, warming will be greater than it would be for a business-as-usual case assuming the mid-range of the key variables contributing to uncertainty.

- Aerosol/sulfate cooling is an important phenomenon, with recent data suggesting cooling comparable to the warming associated with CH_4, the second most important greenhouse gas. Again, uncertainty in current and projected cooling is substantial.

- CO_2 is the largest potential contributor of the greenhouse gases, with CH_4 the second most important contributor. Warming associated with tropospheric ozone could be important, but the underlying science allowing a quantitative judgment is weak.

- Mitigating CH_4 emissions can achieve substantial benefits, in the near term, in light of its relatively short atmospheric lifetime. In fact, a 2% per year CH_4 mitigation program can be almost as effective as placing a cap on CO_2 emissions, assuming mitigation started in 2000 and the target year is 2050.

- The United States, the former Soviet Union, China, Germany, and Japan are the largest emitters of CO_2 (in rank order). Each has a distinctive profile with regard to contributions per fuel-use sector. Developing countries in Asia, such as China and India, are expected to have exponential growth in greenhouse gas emissions, driven primarily by projected economic growth and dependence on coal as a major fossil fuel.

- Model analysis shows that the time mitigation is initiated has an important impact on the degree of mitigation achievable. For example, a program to cap (hold constant) greenhouse gas emissions can be equally effective as a more stringent mitigation program initiated 10 years later.

- Mitigation of greenhouse gas emissions will be a major challenge, since it may be necessary to dramatically decrease emissions over time. This would run counter to very strong trends toward progressively increasing emissions, driven by projected economic and population growth and widescale use of coal. Such mitigation may require major enhancements in end use efficiency in the short term and a major transition to renewables in the longer term.

- Fossil fuels are a finite source of energy. Oil and gas are projected to become scarcer and much more expensive during the middle portion of the next century. Among the renewable energy resources, only biomass and solar appear to have the potential for large scale fossil fuel displacement. Despite this, research on renewable technologies is at a constrained level, and, in the author's view, unlikely to provide technology capable of displacing large quantities of fossil fuel at competitive costs anytime in the foreseeable future.

- The Hynol process is a potentially attractive technology generating methanol (or hydrogen) for the transportation sector. However, as for other renewable technologies, a host of political, economic, and policy factors inhibit commercialization.

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Table 1: Five Scenarios Impacting Degree of Global Warming

Variable Impacts on Predicted Warming		*Range of Impacts---->Greater Warming*			
	Lowest	Low	*Most Likely*	High	Highest
Atmospheric Sensitivity	1.5	2	*2.5*	3.5	4.5
CO2 Life Cycle Model	IPCC	IPCC	*IPCC*	Kasten	Kasten
CO2 Growth Rate:1990-2030	1.4%	1.6%	*1.85%*	2.00%	2.2%
Co2 Growth Rate:2030-2100	0.5%	0.65%	*0.78%*	1.85%	2.2%
Methane Lifetime, years	7	8	*11*	12	13
CH4 Growth Rate:1990-2030 / 2030-2100	0.67%/0.32%	0.77%/.52%	*1.17%/.82%*	1.27%/.92%	1.37%/1.02%
Penetration of HFC-134a	15%	25%	*35%*	45%	55%
Actual/Equil. Temp.Ratio @ 0.35 C degree/yr	0.3	0.4	*0.505*	0.6	0.7
Current Sulfate Cooling, degree C	-2.5	-2	*-1.65*	-1	-0.1
Sulfate Cooling Emission Ratio Exponent	1	0.9	*0.8*	0.7	0.6
OUTPUT Calculations,Degree C.					
Equilibrium Temperature @ 2050	0.5	1.2	*2.3*	5.1	7.8
Realized Temperature @ 2050	0.5	0.9	*1.2*	2.6	4.4
Equilibrium Temperature @ 2100	1.1	2.4	*4.3*	10.3	15.9
Realized Temperature @ 2100	0.9	1.7	*2.2*	5.2	9.1

Table 2: Greenhouse Gases -- What is Known and What is Not

CHARACTERISTIC	CARBON DIOXIDE	METHANE	AEROSOLS	HFC-134a	TROPO. OZONE	N2O
1. Atmospheric Lifetime (yrs)	50-100	10-12.5	<<1	16	<<1	150
2. Current Concentration/	1.26	2.15	Uncertain	New CFC Substitute	>1, But Poor Data	1.08
Pre-Industrial Concentration						
3. Projected Realized Warming/						
By Gas at the Year 2100	+1.8	+0.5	-0.5	+0.2	+0.1	+0.1
Most Likely Case: Total Warming = 2.2		Incl. Indirect Effects			(Excludes CH4 source)	
4. Impact of 1% /Yr Mitigation:	60%	31%			4%	4%
Control starts at 2000, the impact at 2050:						
Calculated as % of total mitigation						
5. Confidence in Warming Calculations	Fair/Good	Fair	Poor	Good	Poor	Fair
for Items 3. and 4. Above						
6. Major Uncertainties	Carbon Cycle Influence on	1. Quantification of Natural and	1. Current Extent of Cooling	Extent to Which Will	1. Atmospheric Chemistry	Atmospheric Concentration
	CO2 Atmospheric Lifetime	Human Sources and Sinks	2. Relationship of Emissions	Substitute for CFCs	Models Insufficient	Rising Faster Than Known
		2. Explanation Needed for Decelerat-	to Atm. Aerosols		2. Data on Tropo. Ozone	Sources/Sinks Predict
		ing Growth in Atm. Concentrations	3. Impact on Cloud Formation		Trends Poor	
					3. Emission Data for NOx,	
					Hydrocarbons and CO	
					Precursors Poor	
7. Major Human Sources	Fuel Combustion	Coal Mining	Fossil Fuel Combustion	Refrigeration Cycles	Mobile Sources: VOCs, NOx,	Biomass Burning
	- Electric Power	Natural Gas and Oil Production and	Biomass Combustion		and CO	Adipic Acid and HNO3 Prod.
	- Mobile Sources	Transportation			Stationary Combustion:	Mobile Sources
	- Industrial Deforestation	Landfills			NOx and CO	Farming
		Rice Paddies			Biomass Burning: CO and	Stationary Source
		Ruminants			VOCs	Combustion
		Biomass Burning & Decomposition				

Table 3: 1988 CO_2 Data for Key Countries
(Note: 1 ton = 0.9078 metric ton)

CO2 Emissions-1988		CO2 per capita		CO2 per GNP	
(Million of Tons)		(tons per person)		(Mt CO2 per $1000 GNP)	
United States	4804	United States	19	China	6.0
USSR	3982	Canada	17	South Africa	3.6
China	2236	Czechoslovakia	15	Romania	2.8
Germany	997	Australia	15	Poland	2.7
Japan	989	USSR	14	India	2.5
India	601	Germany	13	Czechoslovakia	1.9
United Kingdom	559	Poland	12	Mexico	1.7
Poland	459	United Kingdom	10	USSR	1.5
Canada	438	Romania	10	Korea	1.2
Italy	360	South Africa	8	Canada	1.0
France	320	Japan	8	United States	1.0
Mexico	307	Italy	6	Australia	1.0
South Africa	284	France	6	United Kingdom	0.8
Australia	241	Korea	5	Germany	0.7
Czechoslovakia	234	Spain	5	Brazil	0.6
Romania	221	Mexico	4	Spain	0.6
Korea	205	China	2	Italy	0.4
Brazil	202	Brazil	2	Japan	0.3
Spain	188	India	1	France	0.3

Table 4: Assumed Annual Growth Factors Influencing CO_2
Emissions (1990 - 2025)
(Derived from IPCC, 1992)

FACTOR	OECD	ASIA
Growth of Economy Per Capita	2.2%	3.5%
Population Growth Rate	0.3%	1.5%
Growth Rate: Energy Use Per Economic Output	-1.1%	-0.8%
Growth Rate: Carbon Emissions Per Energy Use Unit	-0.7%	-0.3%
Annual CO_2 Growth Rate (Sum of above factors)	+0.7%	+3.9%

Table 5: 1990 Global Energy Use and CO2 Emissions from Energy Sources

Carbon expressed in Gt C; Energy as EJ

	Energy Used	CO2 Emitted
Electric Generation	96	1.3
Direct Use of Fuels by Sector		
Resid./Comm./Inst.	47	0.9
Industry	68	1.4
Transportation	51	0.9
TOTAL	**262**	**4.5**
Demand Side		
Resid./Comm./Inst.	86	1.4
Industry	123	2.1
Transportation	53	1.0
TOTAL	**262**	**4.5**
By Source		
Solids	77	1.9
Liquids	90	1.7
Gases	61	0.9
Other	34	0.0
TOTAL	**262**	**4.5**

Table 6: Global Fossil Energy Reserves and Resources, In EJ

	Consumption 1860-1990	Consumption 1990	Reserves Identified	Conventional Resources Remaining to Be Discovered at Probability 95%	50%	5%	Unconventional Resources Currently Recoverable	Unconventional Resources Recoverable W/Techno-Logical Progress	Resource Base [a]	Year Resource Is Depleted (at 1.5% annual growth rate)
Oil										
Conventional	3343	128	6000	1800	2500	5500			8500	2035
Unconventional	-	-	7100					9000	16100	2080
Gas										
Conventional	1703	71	4800	2700	4400	10900			9200	2065
Unconventional	-	-	6900				2200	17800	26900	2135
Coal	5203	91	25200				13900	86400	125500	2195
Total	10249	290	50000	>4500	>6900	>16400	>16100	>113200	>186200	2150

Notes: All totals have been rounded: - = negligible amounts: blanks = data not available

[a] Resource base is the sum of reserves and resources. Conventional resources remaining to be discovered at probability of 50% are included for oil and gas

Table 7: Global Renewal Energy Potentials by 2020-2025, and Maximum Technical Potentials in EJ Thermal Equivalent [a]

	Consumption		Potential by 2020-2025[b]	Fraction Global Energy By 2050 [c]	Long-Term Technical Potentials[d]	Fraction Global Energy by 2100 [e]
	1860-1990	1990				
Hydro	560	21	35-55	5-8%	>130	>9%
Geothermal	-	>1	4	0.5%	> 20	>1%
Wind	-	-	7-10	1-1.5%	>130	>9%
Ocean	-	-	2	0.2%	>20	>10%
Solar	-	-	16-22	2-3%	>2600	100%
Biomass	1150	55	72-137	9-19%	>1300	>87%
Total	1750	76	130-230	18-32%	>4200	100%

Notes: All totals have been rounded; - =negligible amounts; blanks = data not available
[a] All estimates have been converted into thermal equivalent with an average factor of 38.5%.
[b] It represents renewable potentials by 2020-2025, in scenarios with assumed policies for enhanced exploitation of renewable potentials.
[c] Based on potential by 2020-2025 and assuming 709 EJ utilized in 2050.
[d] Long-term potentials are based on the IPCC Working Group II. This evaluation is intended to correspond to the concept of fossil energy resources, conventional and unconventional.
[e] Based on long-term potentials by 2100, assumed 1492 EJ in 2100.

Table 8: **Brief Descriptions of End Use Mitigation Options For the United States (NAS, 1991)**

END USE: RESIDENTIAL AND COMMERCIAL ENERGY MANAGEMENT

Electricity Efficiency Measures	
Residential Lighting	Reduce lighting energy consumption by 50% in all U.S. residences through replacement of incandescent lighting with compact fluorescents.
Water Heating	Improve efficiency by 40 to 70% through efficient tanks, increased insulation, low-flow devices, and alternative water heating systems.
Commercial Lighting	Reduce lighting energy consumption by 30 to 60% by replacing 100% of commercial light fixtures with compact fluorescent lighting, reflectors, occupancy sensors, and day lighting.
Commercial Cooling	Use improved heat pumps, chillers, window treatments, and other measures to reduce commercial cooling energy use by 30 to 70%.
Commercial Refrigeration	Improve efficiency 20 to 40% through improved compressors, air barriers and food case enclosures, and other measures.
Residential Appliance	Improve efficiency of refrigeration and dishwashers by 10 to 30% through implementation of new appliance standards for refrigeration, and use of no-heat drying cycles in dishwashers.
Residential Space Heating	Reduce energy consumption by 40 to 60% through improved and increased insulation, window glazing, and weather stripping along with increased use of heat pumps and solar heating.
Commercial and Industrial Space Heating	Reduce energy consumption by 20 to 30% using measures similar to those for the residential sector.
Commercial Ventilation	Improve efficiency 30 to 50% through improved distribution systems, energy-efficient motors, and various other measures.
Oil and Gas Efficiency	Reduce residential and commercial building fossil fuel energy use by 50% through improved efficiency measures similar to the ones listed under electricity efficiency.

(continued)

Table 8 (continued)

Fuel Switching	Improve overall efficiency by 60 to 70% through switching 10% of building electricity use from resistance heat to natural gas heating.

END USE: INDUSTRIAL ENERGY MANAGEMENT

Cogeneration	Replace existing industrial energy systems with an additional 25,000 MW of co-generation plants to produce heat and power simultaneously.
Electricity Efficiency	Improve electricity efficiency up to 30% through use of more efficient motors, electrical drive systems, lighting, and industrial process modification.
Fuel Efficiency	Reduce fuel consumption up to 30% by improving energy management, waste heat recovery, boiler modifications, and other industrial process enhancements.
New Process Technology	Increase recycling and reduce energy consumption primarily in the primary metals, pulp and paper, chemicals, and petroleum refining industries through new, less energy intensive process innovations.

END USE: TRANSPORTATION ENERGY MANAGEMENT (Note: 1 mpg = 0.42 km/liter)

Vehicle Efficiency	
Light Vehicles	Use technology to improve on-road fuel economy to 25 mpg with no changes in the existing fleet.
	Improve on-road fuel economy to 36 mpg with measures that require changes in the existing fleet such as downsizing.
Heavy Trucks	Use measures similar to those for light vehicles to improve heavy truck efficiency up to 31 mpg.
Aircraft	Implement improved fanjet and other technologies to improve fuel efficiency by 20% to 130 to 140 seat-miles per gallon.
Transportation Demand	Reduce solo commuting by eliminating 25 % of the employer-provided parking spaces and management placing a tax on the remaining spaces to reduce solo commuting by an additional 25 %.

Table 9: Brief Descriptions of Production-side Mitigation Options for the United States (NAS, 1991)
(Note 1 Quad = 1.055 x 10^{18} J)

ALTERNATIVE FUELS FOR TRANSPORTATION	
Methanol from Biomass	Replace all existing gasoline engine vehicles with those that use methanol produced from biomass
Hydrogen from Nonfossil Fuels	Replace gasoline with hydrogen created from electricity generated from nonfossil fuel sources such as nuclear and solar energy directly in transportation vehicles.
ELECTRICITY AND FUEL SUPPLY	
Heat Rate Improvements	Improve heat rates (efficiency) of existing plants by up to 4% through improved plant operation and maintenance.
Advanced Coal	Improve overall thermal efficiency of coal plants by 10% through use of integrated gasification combined cycle, pressurized fluidized-bed, and advanced pulverized coal combustion systems.
Natural Gas	Replace all existing fossil-fuel-fired plants with gas turbine combined cycle systems to both improve thermal efficiency of current natural gas combustion systems, and replace fossil fuels such as coal and oil that generate more CO_2 than natural gas.
Nuclear	Replace all existing fossil-fuel-fired plants with nuclear power plants such as advanced light-water reactors.
Hydroelectric	Replace fossil-fuel-fired plants with remaining hydroelectric generation capability of 2 quads.
Geothermal	Replace fossil-fuel-fired plants with remaining geothermal generation potential of 3.5 quads.
Biomass	Replace fossil-fuel-fired plants with biomass generation potential of 2.4 quads.
Solar Photovoltaics	Replace fossil-fuel-fired plants with solar photovoltaic generation potential of 2.5 quads.
Solar Thermal	Replace fossil-fuel-fired plants with solar thermal generation potential of 2.6 quads.
Wind	Replace fossil-fuel plants with wind generation potential of 5.3 quads.
CO_2 Collection and Disposal	Collect and dispose of all CO_2 generated by fossil-fuel-fired plants into the deep ocean or depleted gas and oil fields.

Table 10: Selected CO_2 Emission Global Mitigation Policy Strategies: Decrease in Projected Warming (Equilibrium) Relative to Base Case (Adapted from EPA, 1990)

Strategy	Assumptions	Potential Emission Reductions 2050	Potential Emission Reductions 2100	Comments
End Use Strategies Improved Transportation Efficiency	See Footnote a	6%	9%	Recent trends in US moving in opposite direction, many low mpg vans, light trucks replacing autos
Residential, Commercial Industrial Efficiency Gains	See Footnote b	9%	15%	Such reductions would require major marketing campaign, carbon taxes and other economic incentives
Production Strategies More Nuclear Power Use (Electricity Production)	See Footnote c	2%	4%	Such increased use would need to be accepted by public. Marketing incentives as well as assumed cost reduction needed
Solar Technologies (Electricity Production)	See Footnote d	2%	4%	Breakthrough in technology would be necessary for such penetration
Natural Gas Incentives (Electricity Production)	See Footnote e	<1%	<1%	Natural gas generates about half the CO_2 per output relative to coal. Availability of natural gas limits option.
Commercialized Biomass (Transportation & Stationary Source)	See Footnote f	8%	12%	Largest potential impact of renewable technologies; feasibility dependent on large areas dedicated to energy crops and available production technology and end use of infrastructure
Sequestration Strategies Reforestation	See Footnote g	7%	5%	Would require a massive turn around toward net forest gain relative to current rapid deforestation

a. The average efficiency of cars and light trucks in the U.S. reaches 30 mpg (7.8 liters/100 km) by 2000, new cars achieve 40 mpg (5.9 liters/100 km). Global fleet-average automobile efficiency reaches 43 mpg by 2025.
b. The rates of energy efficiency improvements in the residential, commercial, and industrial sectors are increased about 0.3-0.8 percentage points annually from 1985 to 2025 compared to the base case and about 0.2-0.3 percentage points annually from 2025 to 2100.
c. Assumes that technological improvements in the design of nuclear powerplants reduce costs by about 0.6 cents/kWh by 2050. In the base case nuclear costs in 1985 were assumed to be 6 to 10 cents/kWh (1988 $).
d. Assumes that low-cost solar technology is available by 2025 at costs as low as 6.0 cents/kWh. In the base case these costs approached 8.5 cents/kWh but these levels were not achieved until after 2050.
e. Assumes that economic incentives to use gas for electricity generation increase gas share by 5% in 2000 and 10% in 2025.
f. Assumes the cost of producing and converting biomass to modern fuels reaches $4.25/GJ (1988 $) for gas and $6.00/GJ (1988 $) for liquids. The maximum amount of liquid or gaseous fuel available from biomass (i.e., after conversion losses) is 205 EJ.
g. The terrestrial biosphere becomes a net sink for carbon by 2000 through a rapid reduction in deforestation and a linear increase in the area of reforested land and biomass plantation. Net CO_2 uptake by 2025 is 0.7 Pg C. In the base case, the rate of deforestation continues to increase very gradually, reaching 15 Mha/yr in 2097, and no reforestation occurs.

Table 11: Total Reported IEA Government R&DBudgets (Columns 1-7; US$ Billion (10^9) at 1994 Prices and Exchange Rates) and GDP (Column 8; U.S.$ Trillion (10^{12}) at 1993 Prices)

Year	(1) Fossil Energy	(2) Nuclear Fission	(3) Nuclear Fusion	(4) Energy Conservation	(5) Renewable Energy	(6) Other	(7) Total	(8) GDP	(9) % of GDP
1983	1.70	6.38	1.43	0.79	1.05	1.08	12.40	10.68	0.12
1984	1.60	6.12	1.44	0.70	1.02	0.99	11.88	11.20	0.11
1985	1.51	6.26	1.42	0.70	0.85	1.04	11.77	11.58	0.10
1986	1.51	5.72	1.31	0.59	0.66	0.94	10.74	11.90	0.09
1987	1.37	4.36	1.23	0.65	0.62	1.04	9.27	12.29	0.08
1988	1.46	3.64	1.13	0.53	0.62	1.19	8.58	12.82	0.07
1989	1.30	4.42	1.07	0.45	0.57	1.33	9.13	13.23	0.07
1990	1.75	4.48	1.09	0.55	0.61	1.15	9.62	13.52	0.07
1991	1.52	4.45	0.99	0.59	0.64	1.39	9.57	13.58	0.07
1992	1.07	3.90	0.96	0.56	0.70	1.28	8.48	13.82	0.06
1993	1.07	3.81	1.05	0.65	0.71	1.38	8.66		
1994	0.98	3.74	1.05	0.94	0.70	1.30	8.72		

12-May-97	GLOBAL TRACE GAS CONTRIBUTIONS TO WARMING, GLOWARM 3.0							
INPUT INFORMATION		CO2 Gwth	**CO2 Decay Option**		**Sulfate input**			**Tropo.O3**
1ST YR:	1980	1990-2030	IPCC-1992}	1	1980 Sulfate Impact			PPM-O3/KG:
; END YR:	2100	**1.85%**	Kasting Model}	2	**-1.65** watts/sq.m			CH4
;IMPACT YR:	**2100**	2030-2100	CO2 Option =	**1**	Average for North Hemi.			**3.50E-15**
CONTROL CASE NO:	**1**	**0.780%**	OUTPUT SUMMARY		**0.8** {SO4 effect.expone			NOx
1=BASE,6=Control, 7=Cap		**CH4 Gwth**	**Equil.Warming**		**For 1850 to 1980**			**3.80E-14**
START CONTROL	**2000**	1980-2030	**4.09** Deg.Celcius		**EQUIL.WARMING**			CO
;ANN.EMIS.CONTROL:	**1.0%**	**1.170%**			**0.54 Deg.Celcius**			**6.40E-15**
CFC PHASEOUT?	**1**	2030-2100	Transient Warming=					NMHC
(1=YES,2=NO,3=see B9)		**0.820%**	**2.07** Deg.Celcius		**Transient Warming=**			**3.60E-14**
Effect. of CFC Warming	0.5	**SO2 Gwth**			**0.48 Deg.Celcius**			Actual/Derwent=
% CFCs to H FC-134a	**0.35**	1990-2030	CH4 ppm N2Oppm CO2ppm		**1980**			**0.3**
METHANE LIFETIME	*11*	**1.20%**	4.55 0.388 812			**CH4 ppm**	**CO2ppm**	**Transient Response**
ATM.SENSITIV.2X,degree	**2.50**	2030-2100	**Rate of Eq.Warm.**	**0.034**	**pre-ind.**	**0.8**	**280**	**1**
		0.35%	(Degree C per Year)		**1980**	**1.65**	**338**	4=slowest,5=slow
								1=base,2=fast
								3=fastest

Fig. 1: Glowarm Model Input and Output Screen

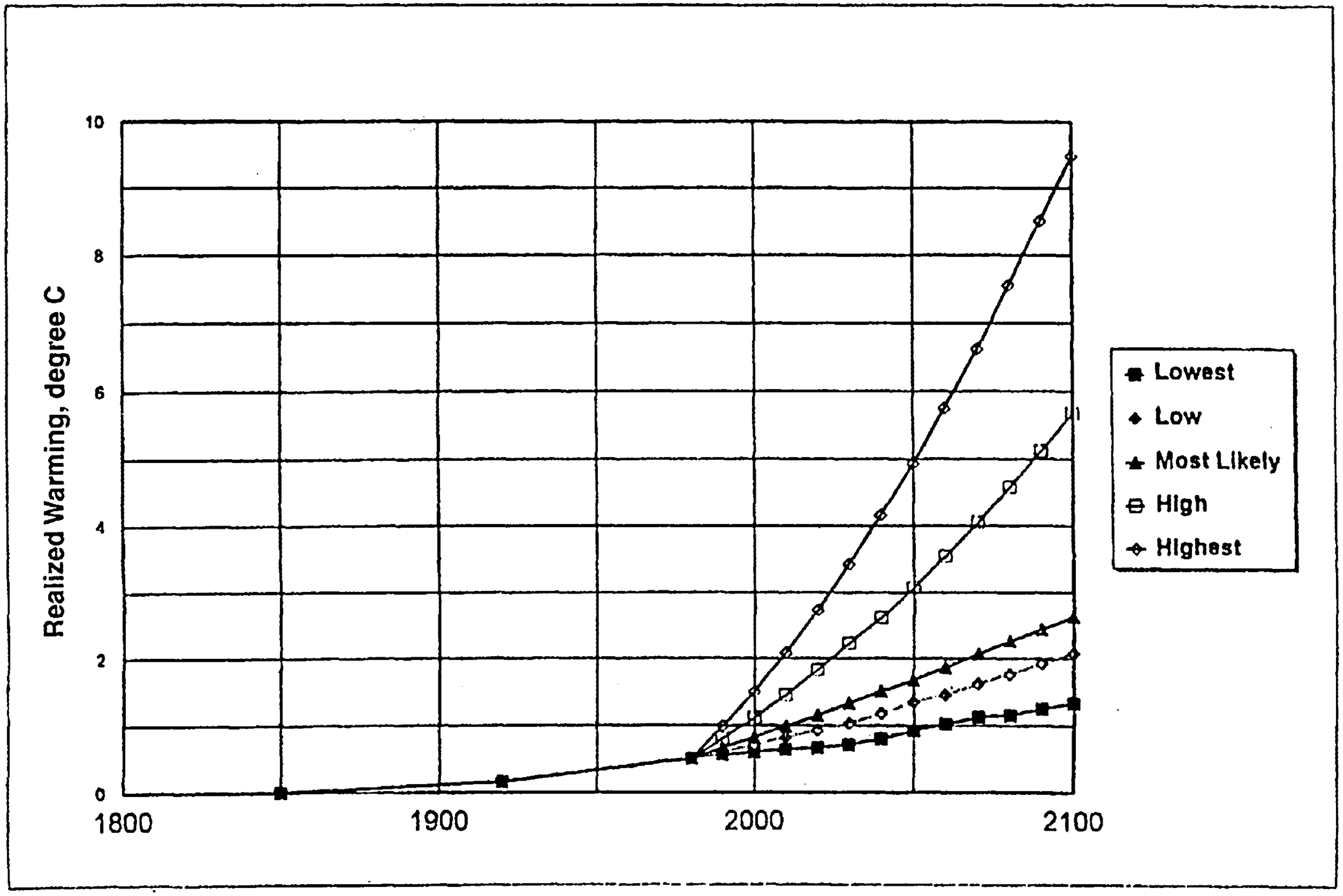


Fig. 2: Projected Realized Warming Vs. Time Since 1800 (actual warming 1800 to 1980)

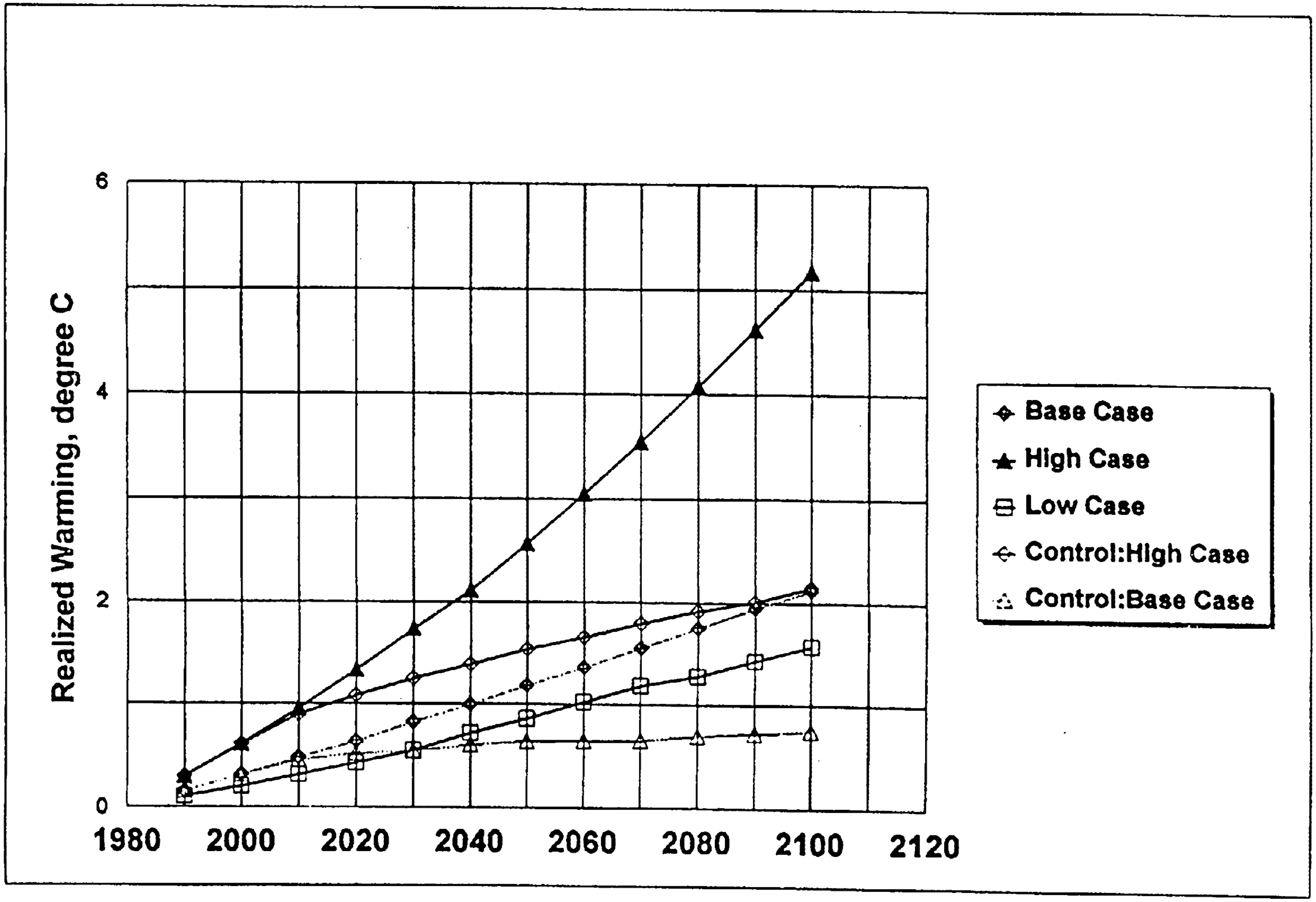


Fig. 3 : Projected Realized Global Warming for Three Business as Usual and Two Control Cases

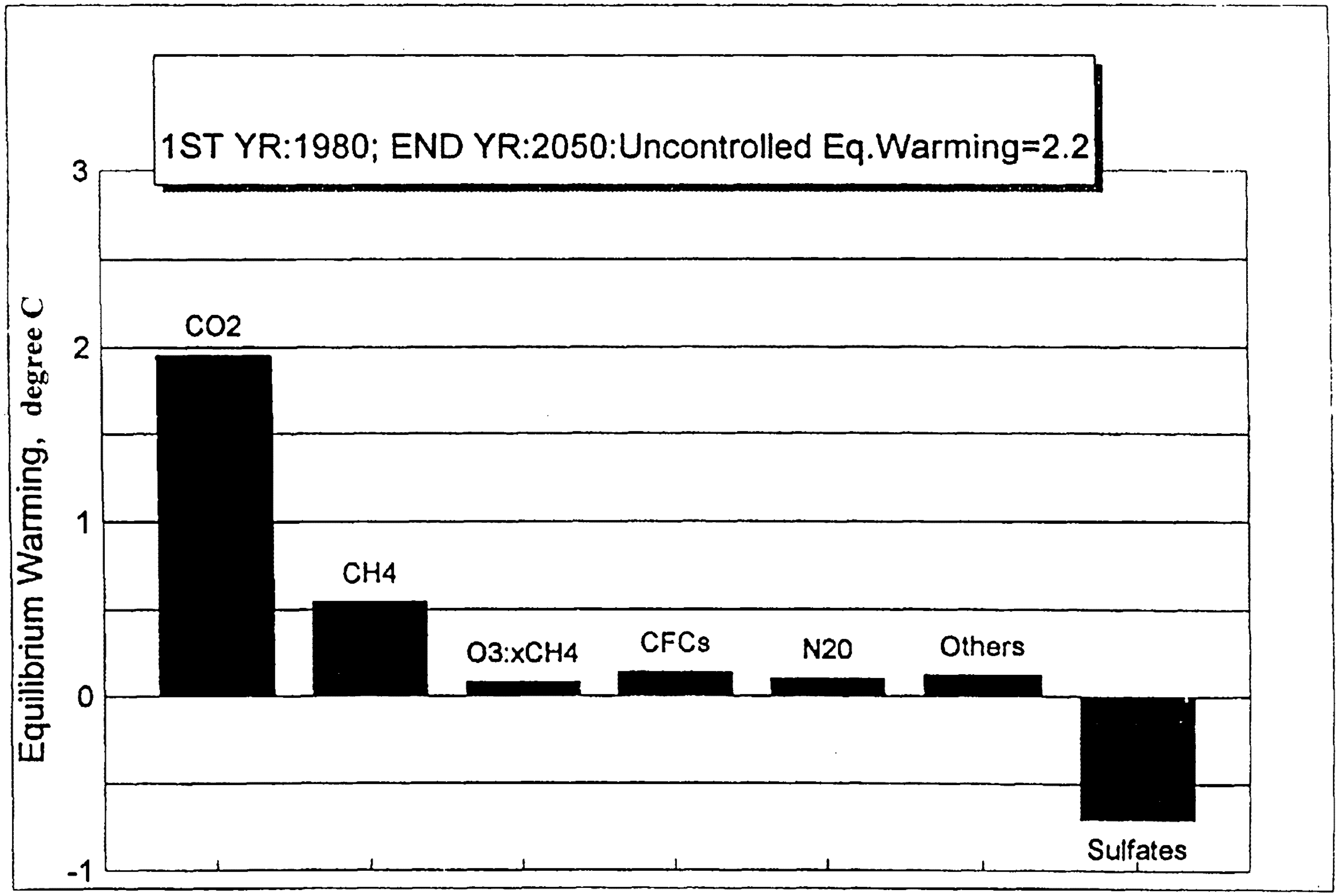


Fig. 4: Gas Contributions to Warming

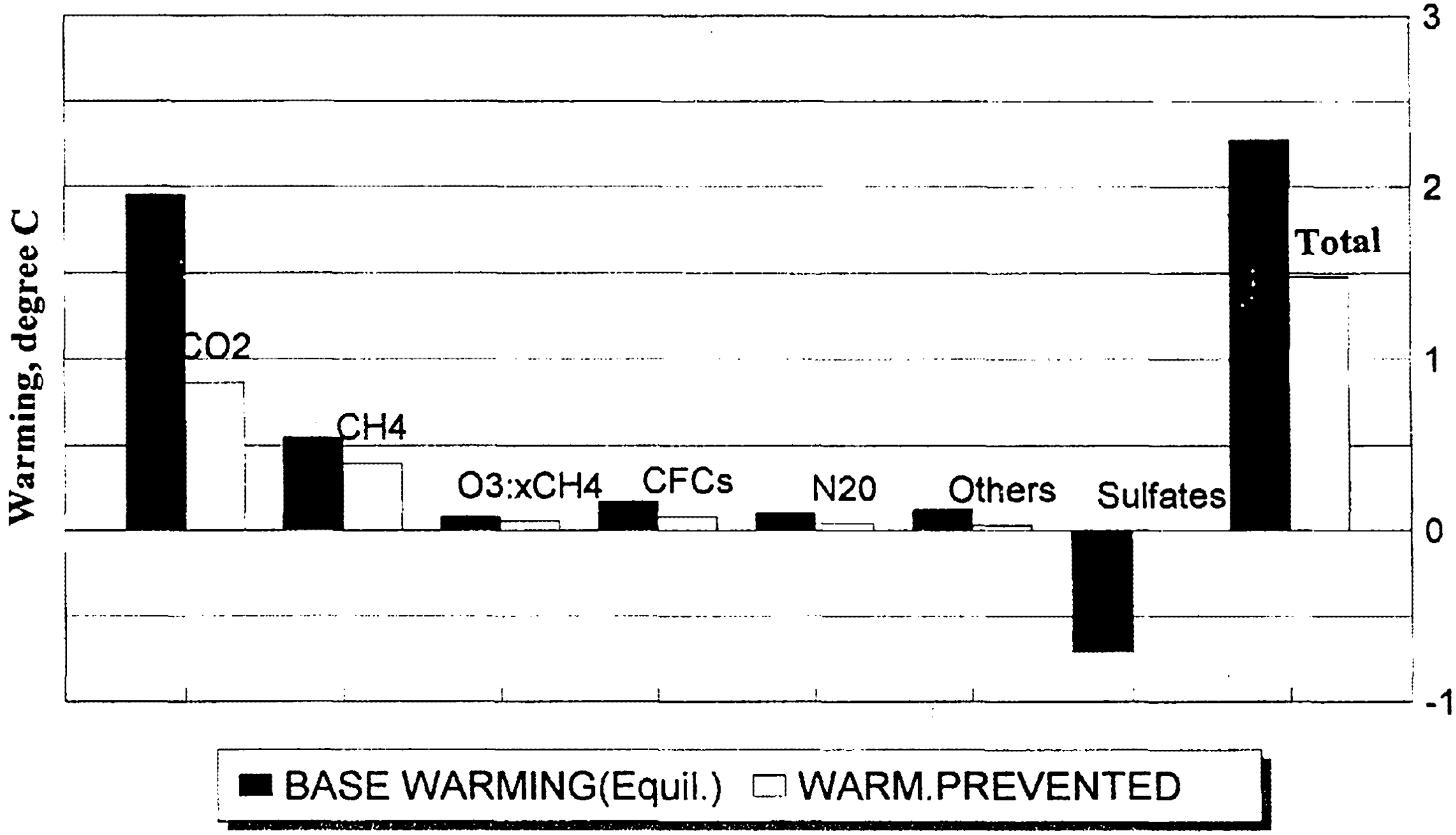


Fig. 5: Warming Prevented by 2000 Emission Control
(period 1980 - 2050, 1% per yr. control)

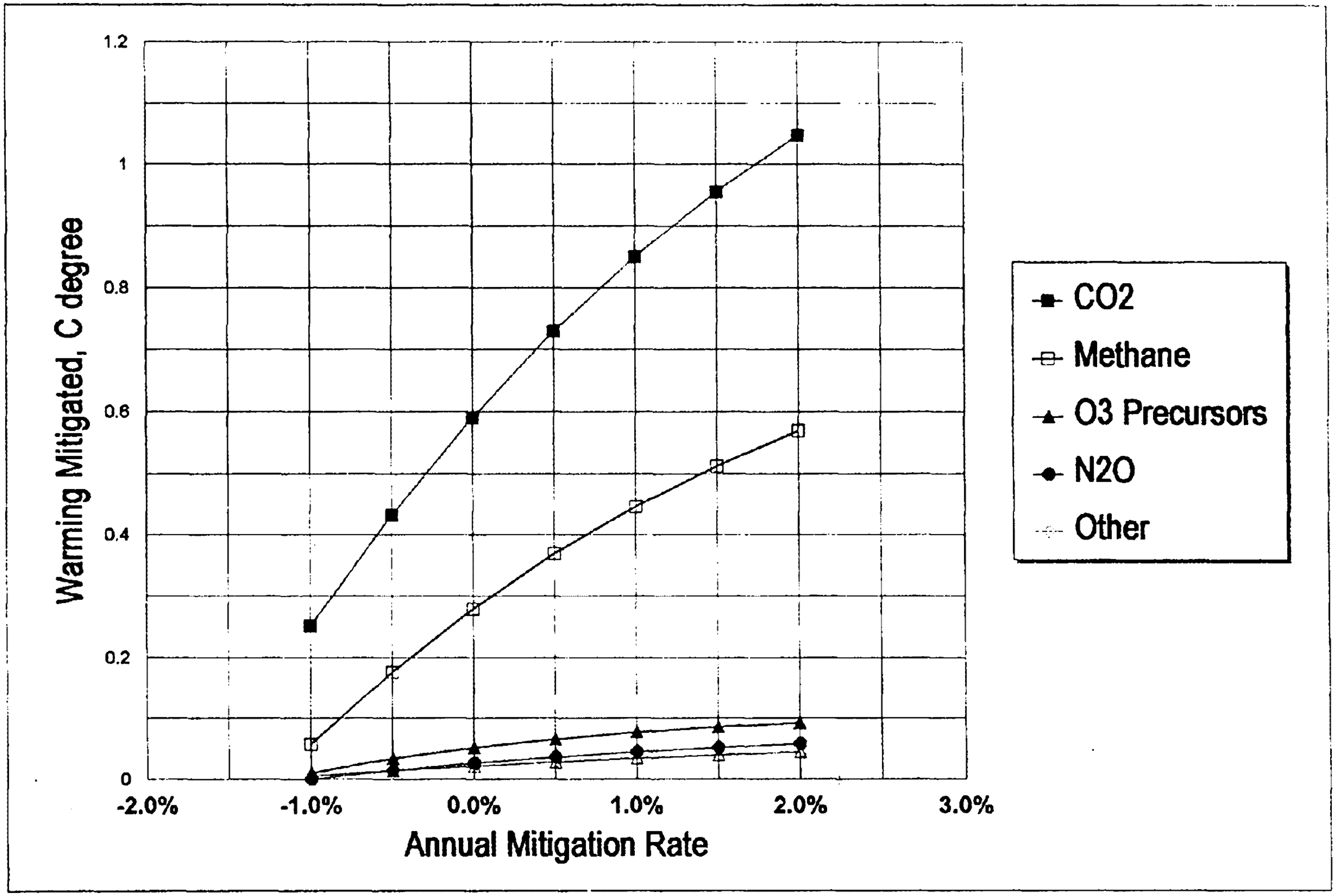


Fig. 6: Warming Abated by Gas vs. Mitigation Rate

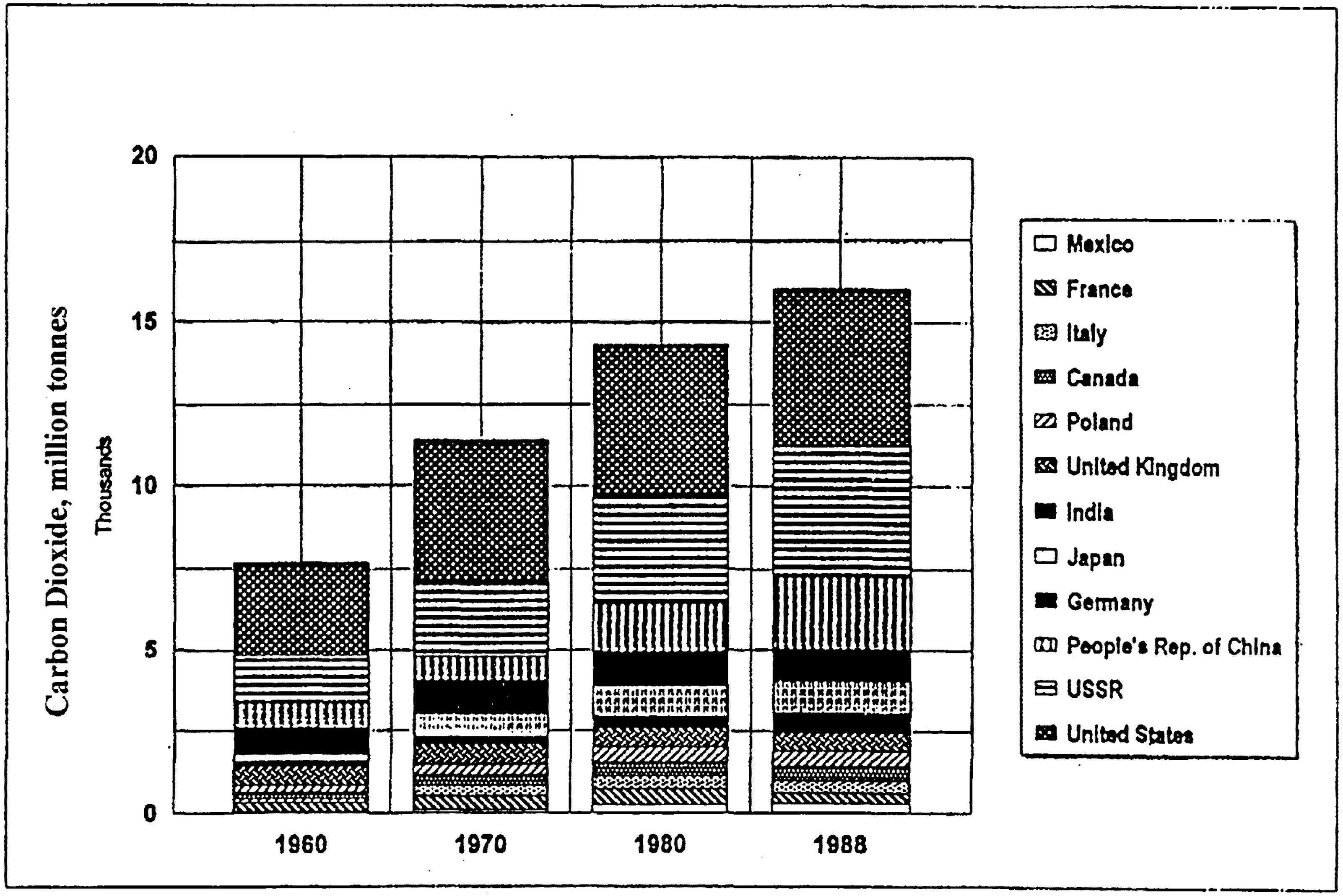


Fig. 7: Historical Emissions of CO_2 by Country (12 largest emitters in 1988)

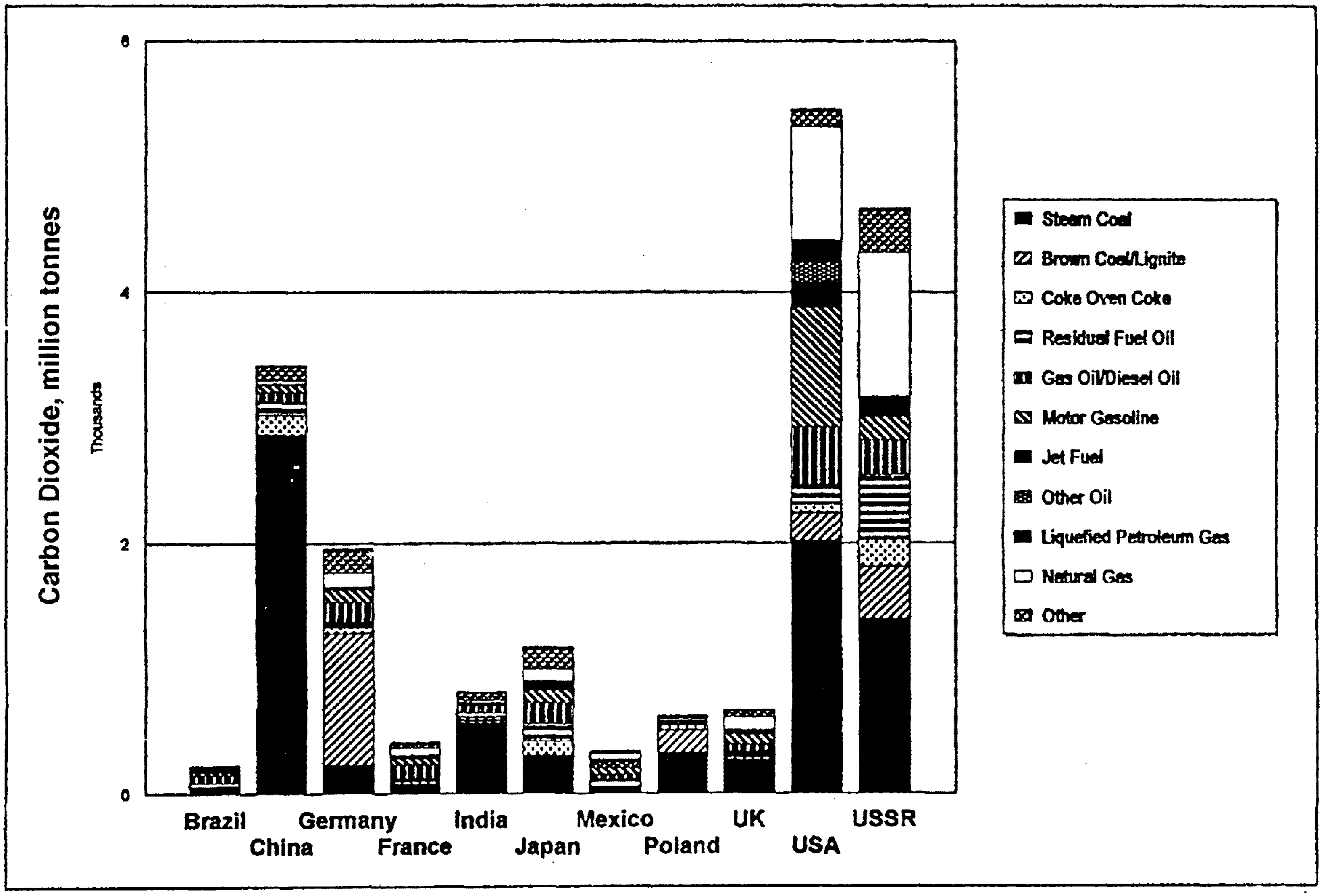


Fig. 8: Recent CO_2 Emissions by Country by Fuel

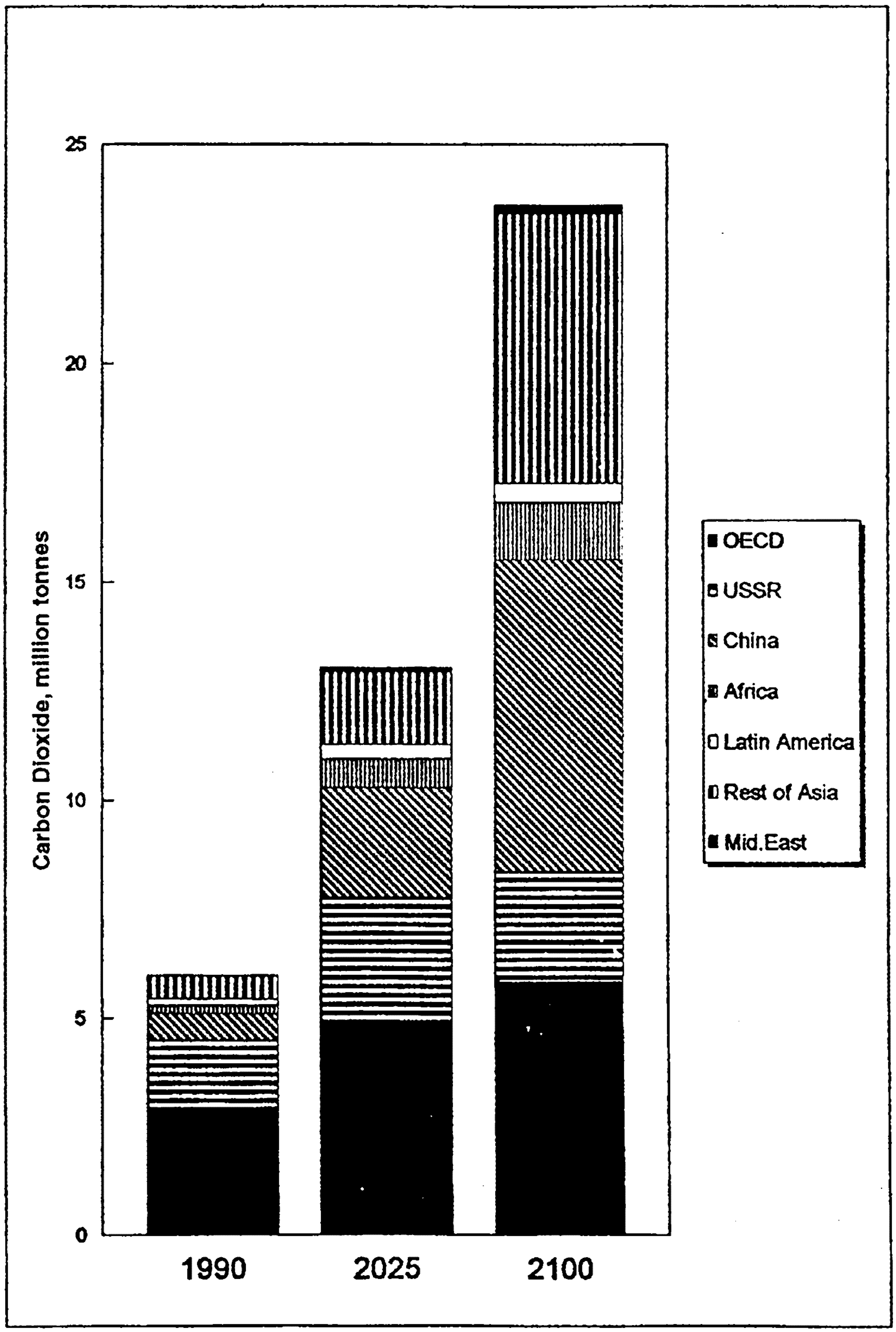


Fig. 9: Projected CO_2 Emissions for Selected Countries
(Cumulative bar chart; actual values 1960-1988)

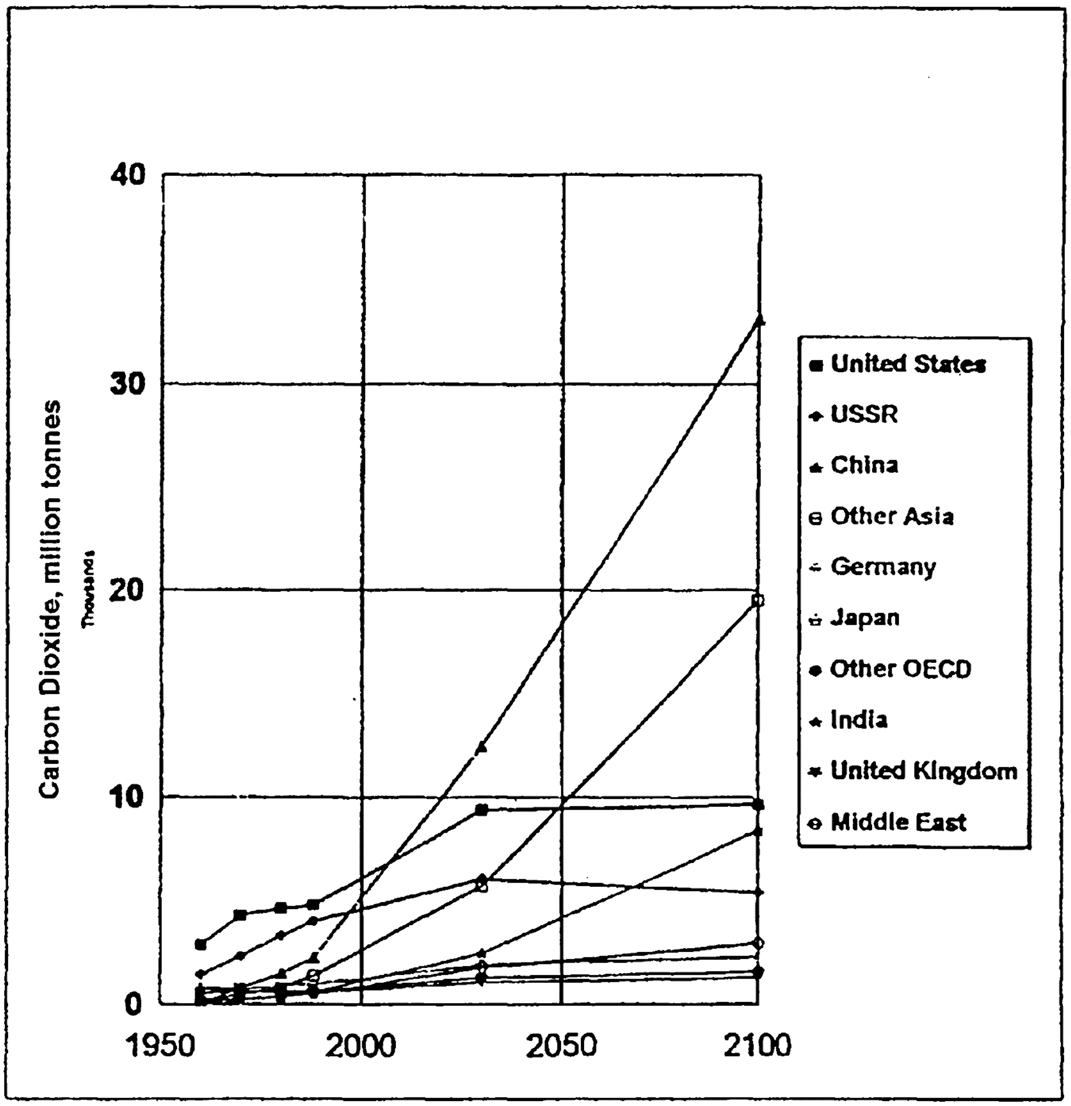


Fig. 10: Projected CO_2 Emissions for Selected Countries
(line chart; actual values 1960 - 1988)

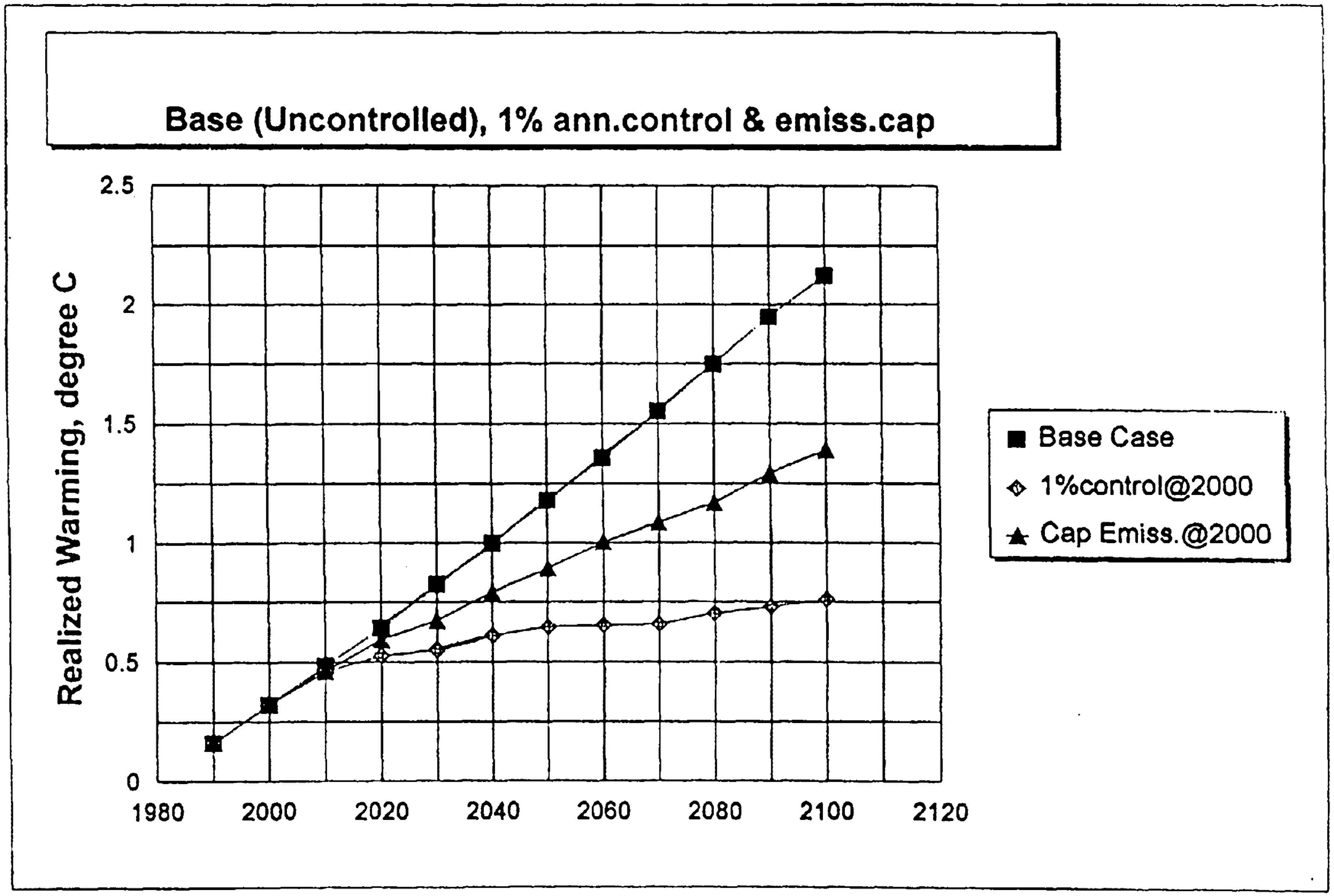


Fig. 11: Projected Global Warming for the Base Case and Two Mitigation Scenarios

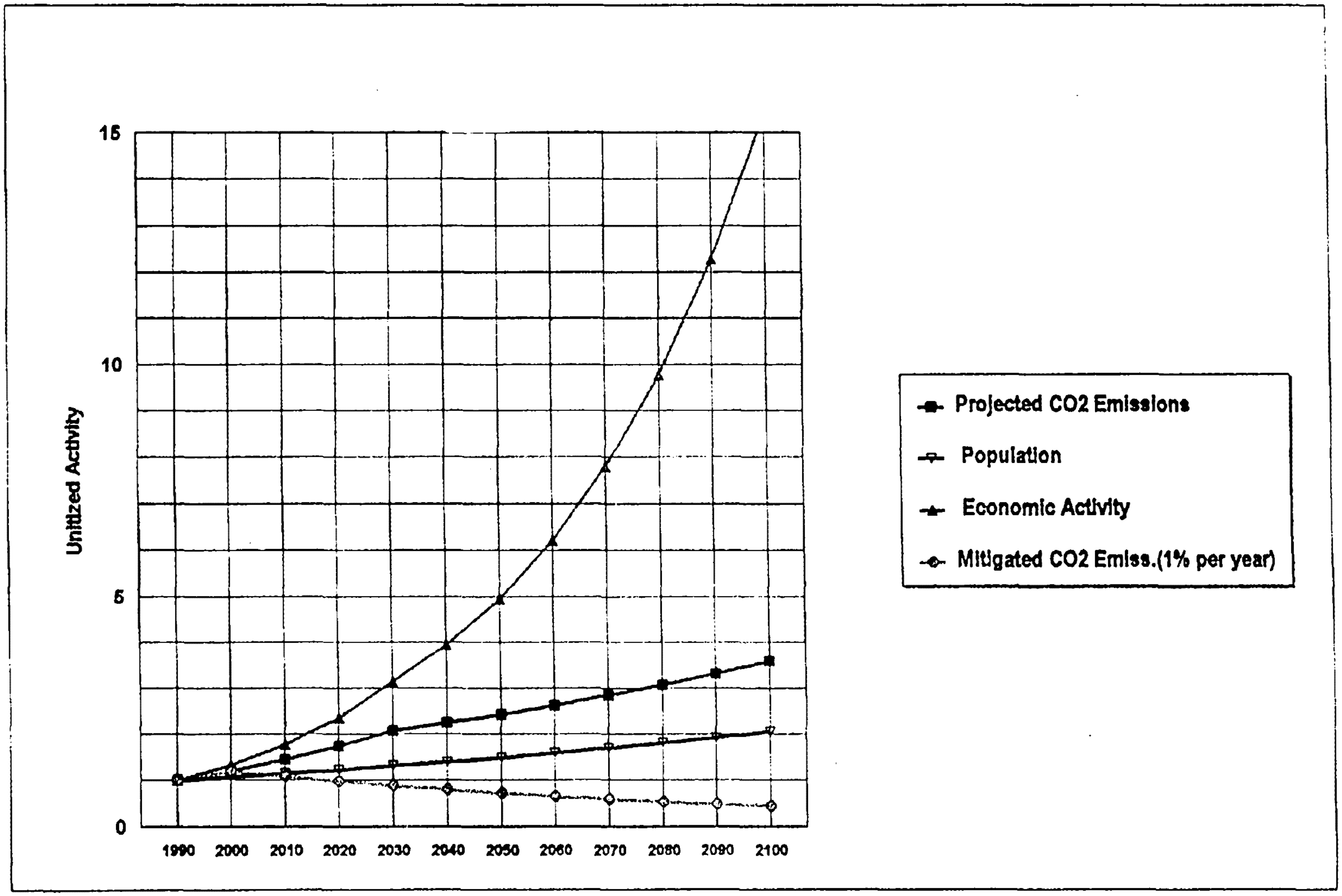


Fig. 12: Projected Growth of Economic Activity, Population, and CO_2 Emissions (unitized at 1990 levels)

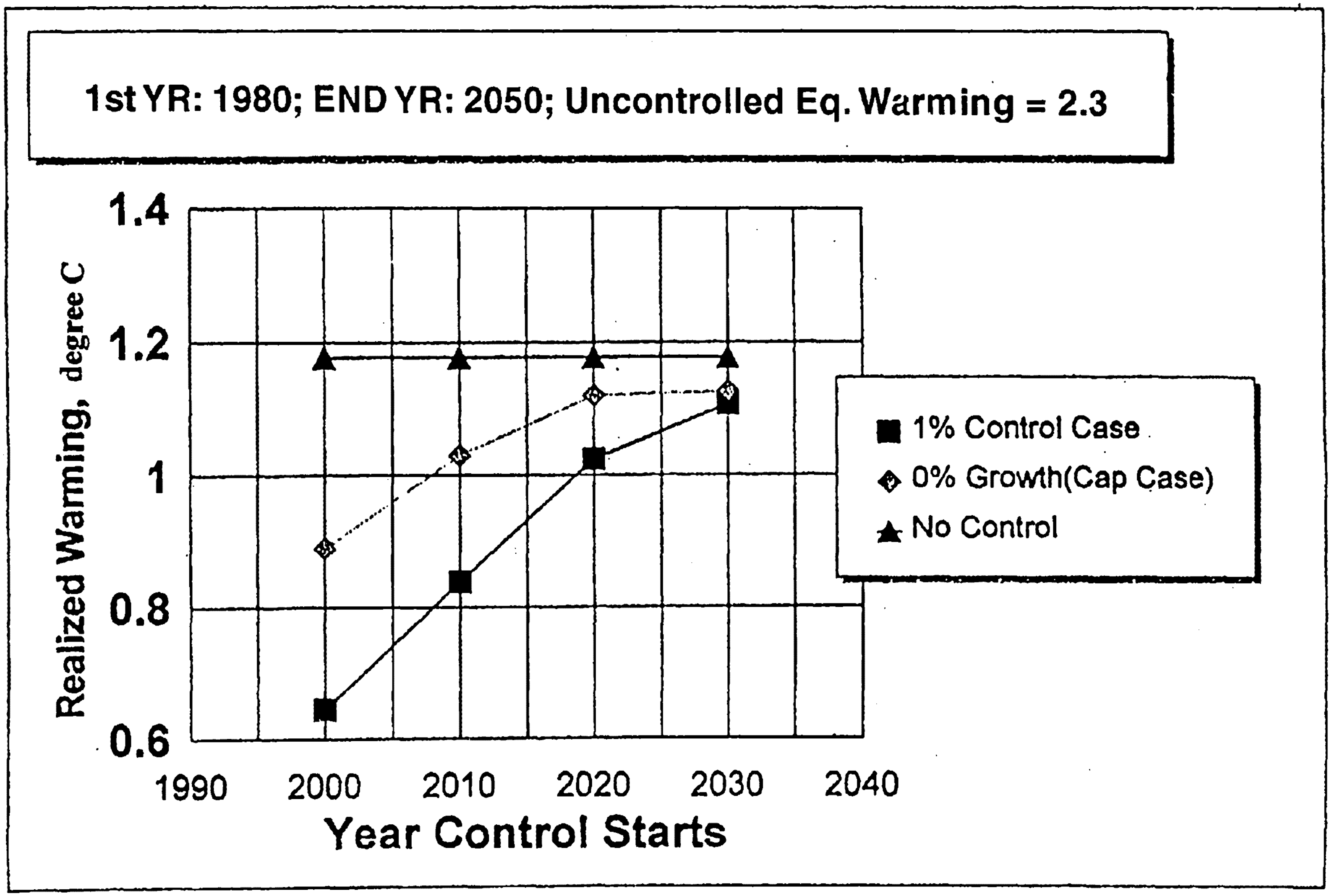


Fig. 13: Projected Realized Warming Vs. First Year Control

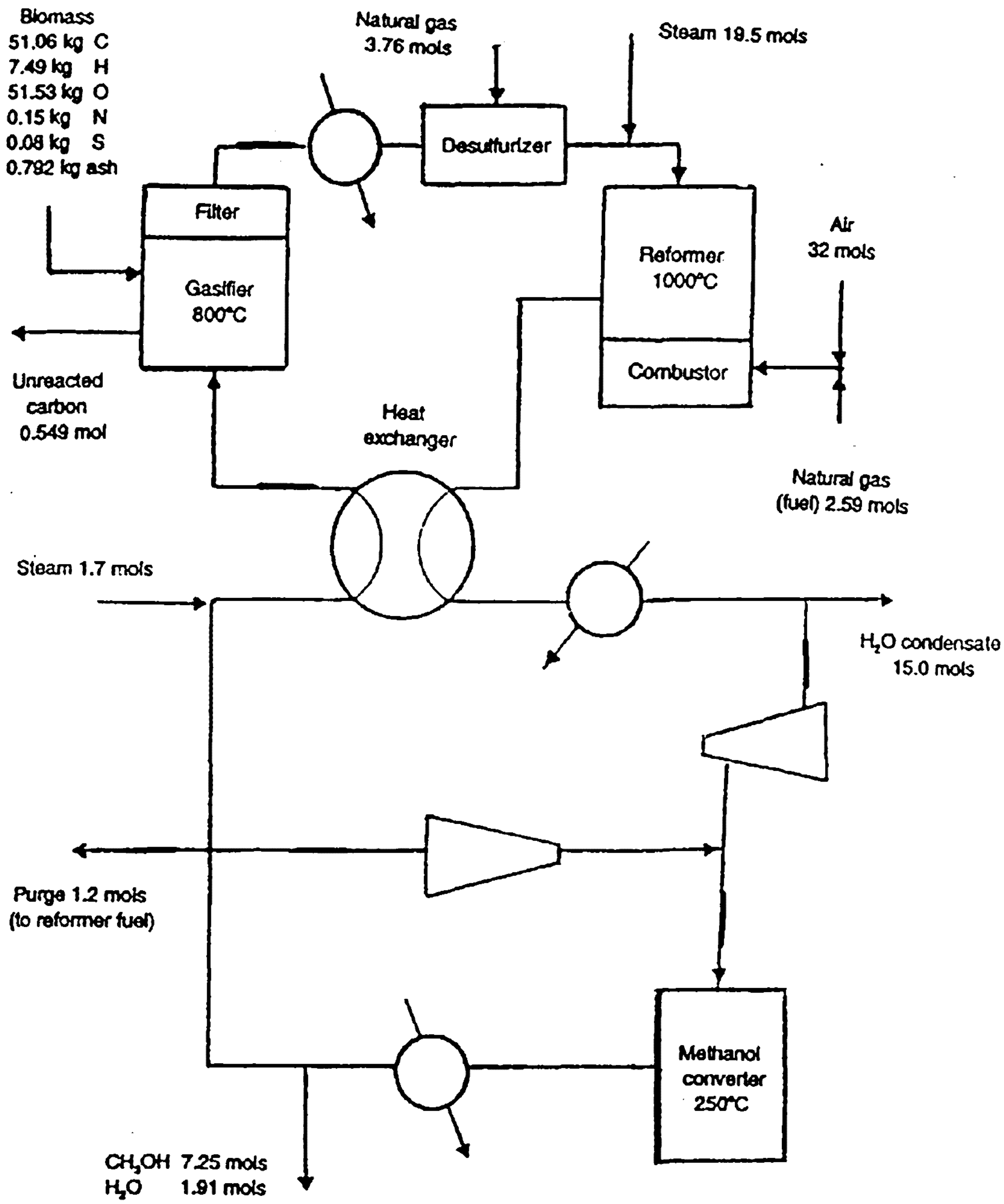
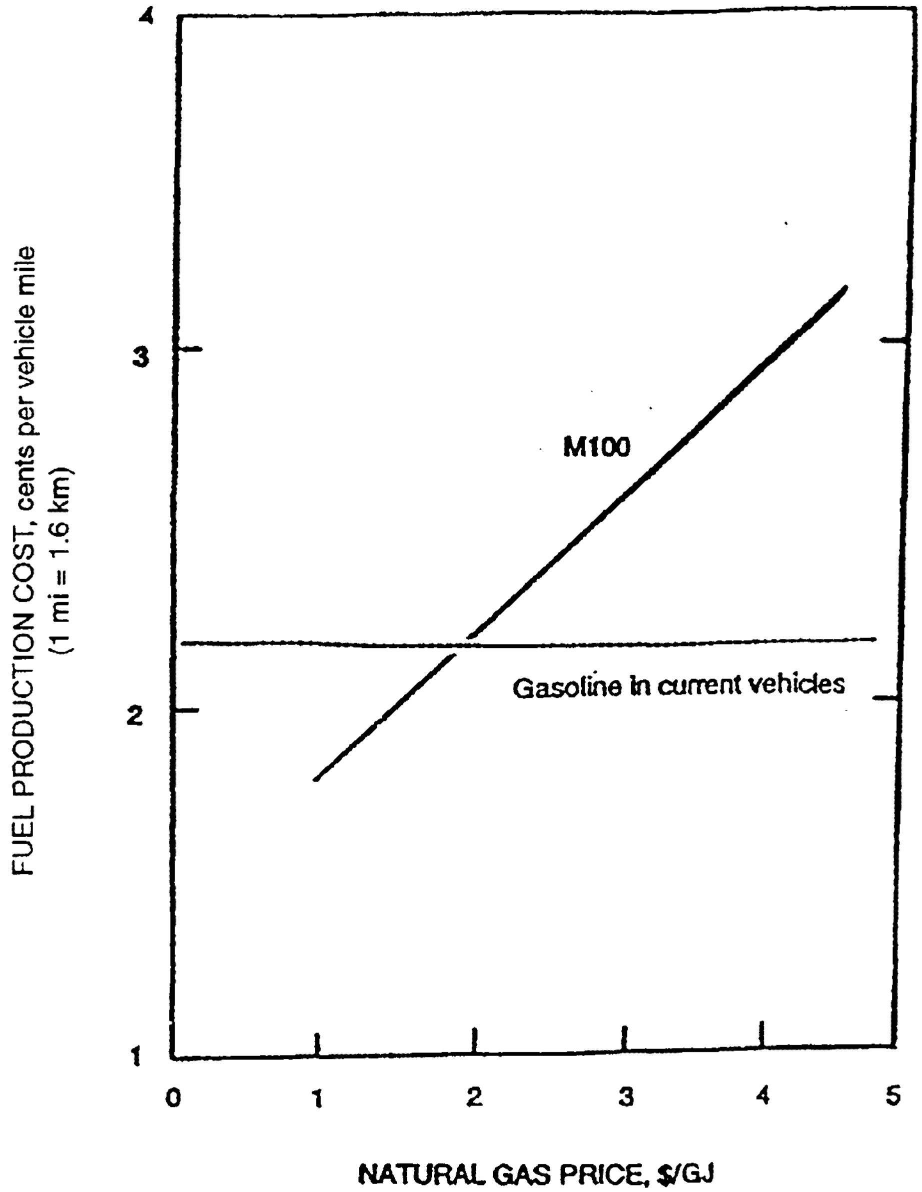


Fig. 14: The Hynol Process



ASSUMPTIONS

1. **Production cost of gasoline is assumed constant at \$ 0.60/gal (\$ 0.16/liter)**
2. **Fuel economy of conventional gasoline vehicles is assumed to be 27 miles/gal (11.3 km/liter)**
3. **Optimized methanol vehicles using M100 are 27% more fuel efficient than gasoline vehicles**
4. **Hynol plant size is 7900 tonnes/day**
5. **Biomass is delivered at \$61/tonne**
6. **Optimized Hynol process produces methanol at \$ 0.42/gal (\$ 0.11/liter)**

Fig. 15: Hynol Methanol Vs. Gasoline Used in Vehicles
with Internal Combustion Engines

NRMRL-RTP-P-199

TECHNICAL REPORT DATA
(Please read Instructions on the reverse before compl

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16. ABSTRACT The paper discusses the role that renewable and other mitigation approaches could play in ameliorating projected greenhouse gas (GHG) warming. (NOTE: Human activity has led to an increased atmospheric concentration of carbon dioxide (CO2), methane (CH4), and other gases which resist the outward flow of infrared radiation more effectively than they impede incoming solar radiation. This imbalance yields the potential for global warming as the atmospheric concentrations of these gases increase.) The paper discusses: the range of projected warming; the relative importance of the various GHGs; the major and projected sources of CO2; the emission controls that achieve various levels of GHG warming mitigation; candidate mitigation technologies, both on the end-use side and the production side; and some of the economic, institutional, and other barriers that hinder commercialization of one particular renewable technology, the Hynol process.

17. KEY WORDS AND DOCUMENT ANALYSIS

a. DESCRIPTORS	b. IDENTIFIERS/OPEN ENDED TERMS	c. COSATI Field/Group
Pollution	Pollution Control	13B
Greenhouse Effect	Stationary Sources	04A
Carbon Dioxide	Greenhouse Gases	07B
Methane	Renewable Technologies	07C
	Global Warming	
	Hynol Process	

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