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STATEMENT OF GLOBAL CLIMATE CHANGE

J. A. Edmonds

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Pacific Northwest Laboratory
Richland, Washington 99352

Statement of
Jae Edmonds
on
GLOBAL CLIMATE CHANGE
before the
SUBCOMMITTEE ON ENERGY AND POWER
UNITED STATES HOUSE OF REPRESENTATIVES

SUMMARY

Greenhouse gases are gases which are effectively transparent to incoming sunlight but absorb infrared radiation escaping to space and thereby warm the surface of the Earth. Human activities result in the release of greenhouse and related gases in such quantities that they are changing the composition of the atmosphere. Greenhouse and related gases which human activities release include carbon dioxide (CO_2), methane (CH_4), carbon monoxide (CO), nitrous oxide (N_2O), nitrogen oxides (NO_x), chlorofluorocarbons (CFCs) and sulphur dioxide (SO_2).

Carbon dioxide is the most important of the greenhouse related gases. Approximately 7.4 PgC/yr are released globally by fossil fuel burning and land-use change. Fossil fuel burning is presently the dominant source of emissions. The United States is the largest single emitter of CO_2 from fossil fuel use, with annual carbon emissions exceeding 5 tonnes per person, as well as being a major contributor to the release of all other gases. However, the United States is actually a net absorber of CO_2 from land-use change.

Future projections of global emissions under business as usual conditions show stable or growing anthropogenic emissions to be highly likely for all greenhouse and related gases over the long term. United States emissions of fossil fuel carbon are anticipated to rise under business as usual assumptions, but the United States' relative role in future emissions is expected to decline over time as developing nations pursue economic growth objectives. There are no important natural constraints on the release of fossil fuel carbon. Carbon release from land-use change can be large, but cannot attain the scale of fossil fuel use. The Montreal Protocol and subsequent London Amendments are expected to reduce global emissions. The Clean Air Act Amendments of 1990 implement United States phase-out of CFCs. These emissions trends in conjunction with recent findings of a counterbalancing indirect (cooling) effect of CFC emissions through O_3 depletion result in a lessened concern about future greenhouse contributions by CFCs.

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GLOBAL CLIMATE CHANGE

INTRODUCTION

Thank you, Mr. Chairman and members of the subcommittee, for this opportunity to offer testimony on **Global Climate Change** with particular reference to present and potential future emissions. I would like to discuss two key issues:

1. *Current Emissions*--including the full array of greenhouse gases, and the relative contribution and intensity of United States emissions; and

2. *Emissions Forecasts*--including the range of forecasts, changing role of the United States contribution, and key assumptions which drive estimates.

I will begin by offering some general information on greenhouse gases and human activities and then move to the two topics enumerated above.

GREENHOUSE GASES AND HUMAN ACTIVITIES

Greenhouse gases are gases which are transparent to incoming solar radiation but which absorb and re-radiate energy returning to space in the infrared spectrum. This characteristic is responsible for the approximately 53°F average global surface temperature. Greenhouse gases include those which occur naturally: water vapor (H_2O), carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O), and ozone (O_3), as well as anthropogenic gases such as the chlorofluorocarbons (CFCs) like $CFCl_4$ and CF_2Cl_2. Other gases can affect the concentrations of greenhouse gases through atmospheric chemistry reactions. Such gases include carbon monoxide (CO) and nitrogen oxides (NO and NO_2, referred to as NO_x). Sulphur containing gases such as sulphur dioxide (SO_2) also affect surface temperature when transformed into sulphur aerosol particles which reflect incoming sunlight back to space, affect the concentration of O_3, and possibly increase cloudiness. To describe the set of all gases important to determining global warming we will use the term radiatively important gases (RIGs), regardless of whether the gas is itself a greenhouse gas or whether it simply affects the concentration of another gas that is a greenhouse gas.

Human activities affect the concentrations of many RIGs, including CO_2, CH_4, CO, N_2O, NO_x, SO_2, and all CFCs (whose only source is chemical manufacture). The release rates for human activities vary from gas to gas, Table 1.

Emissions of gases important to understanding global warming occur at greatly differing rates. Furthermore, gases have different effects on the Earth's energy balance and thereby the rate of global climate change. Scientists have struggled with the problem of creating a set of weights capable of comparing different RIGs. The basic idea of such numbers is to provide a measure of the damage that might be caused by the release of an additional kilogram of each gas. The global warming potential (GWP) coefficients were developed by the International Panel on Climate Change (IPCC) and reported in IPCC (1990). These coefficients measured cumulative change in

radiative forcing, over a specific period of time (20, 100, and 500 years), for one kilogram of each gas released, as compared to the effect of a one kilogram release of CO_2. IPCC (1990) published values for both direct and indirect effects.

Table 1: The Human Role in Emissions of Greenhouse and Related Gases

Gas	Human Emission	% Total annual flux
CO_2	7.4 PgC/yr	n.a.
CH_4	0.35 $PgCH_4$/yr	67%
CO	0.43 PgC/yr	50%
N_2O	4.3 TgN/yr	25%
NO_x	34 TgN/yr	55%
SO_2	76 TgS/yr	65%
$CFCl_4$	0.30 Gg/yr	100%
CF_2Cl_2	0.36 Gg/yr	100%

Sources: IPCC (1992) Table A3.11 for emissions; IPCC (1992) Table A1.3 for CH_4, Table A1.5 for N_2O, Table A1.10 for SO_2 though it should be noted that total flux contains DMS and H_2S as well as SO_2, Table A1.9 for NO_x; Wuebbles and Edmonds (1991) Table 6.1 for CO.

Further study of GWP calculations revealed that (i) errors were made in initial calculations, (ii) background emissions assumptions over the course of the integration period were important, especially for CO_2, and (iii) the problem of measuring the indirect effect of different gases was much more difficult than initially thought. As a consequence the IPCC prepared a major revision of GWP coefficients for IPCC (1992). In this volume IPCC reports only direct effects by greenhouse gases and only the sign of indirect effects. No calculation was made for sulphur emissions. Table 2 indicates the relative contribution to total GWP weighted emissions of three major greenhouse gases and the CFCs plus other ozone depleting substances (ODSs) as a group.

Since the most important anthropogenic emission is CO_2 and the single most important source of CO_2 emissions is fossil fuel combustion, this section discusses first fossil fuel carbon emissions, then the other major source of CO_2 emissions, land-use change. In the remainder of the section, we discuss emissions of other gases in turn.

Fossil Fuel Carbon: Global rates of fossil fuel carbon emissions plus CO_2 emissions from cement manufacture have been estimated to be 6.1 PgC/yr for the year 1990 (Marland and Boden, 1992). Of this total, approximately 1.3 PgC/yr were emitted by the United States, which is the largest single national emitter in the world, accounting for 21% of the global total. This fraction has declined from the post-World War II share of 40%. During the period 1945 through 1979 the rate of CO_2 emissions from fossil fuel use grew at 4.5%/yr. Emissions declined from 1979 until 1983, but have risen subsequently. The United States, former Soviet Union, and China account for half of the world's fossil fuel CO_2 emissions. Since the dissociation of the Soviet Union, China has become the second largest national emitter, slightly surpassing Russia in 1990.

The dominant source of emissions is fossil fuel use, with cement manufacture accounting for only 0.15 PgC/yr of the 1990 global total. Emissions from liquids and solids are of approximately equal increments, 40%. Natural gas accounts for 16% of the 1990 total, while gas flaring and cement make up the remaining 4%.

Carbon content varies by fuel. Of fossil fuels, natural gas is lowest (13.7 TgC/EJ); coal is highest (23.8 TgC/EJ); and oil falls between the two (19.2 TgC/EJ). The mining of oil shales in carbonate rock formations would add an additional stream of CO_2 to the atmosphere; the magnitude of this stream depends on the grade of the resource and the technology employed to extract it. The transformation of primary fossil fuel energy, as for example from coal to electricity or from coal to

synoil or syngas, releases carbon in the conversion process. Energy technologies such as hydroelectric power, nuclear power, solar energy, and conservation (including energy efficiency improvements) emit no CO_2 to the atmosphere. Traditional biomass fuels, such as crop residues and dung, release CO_2 to the atmosphere, but are in a balanced cycle of absorption and respiration whose time frame is short. The use of other biomass fuels such as firewood may provide either a net annual source or sink for carbon depending upon whether the underlying biomass stock is growing or being exhausted. Improvements in the efficiency of energy conversion technologies reduce the rate of emission of greenhouse gases per unit energy service provided.

Land-Use Change: There are approximately 560 PgC in the form of terrestrial biomass, principally stored in forests. This is estimated to be about 15-20% (≈120 PgC) less than was present in the mid-nineteenth century. On a global basis, this is estimated to vary less than about 10 PgC through the seasons as leaves and grasses grow and die. Northern and Southern Hemispheric cycles are temporally reversed.

Knowledge of the net annual emissions of carbon from land-use changes is far less certain than emissions estimates for fossil fuel use. Emissions of net annual CO_2 release from land-use changes have been estimated for the year 1980 by various researchers. Net release is calculated as the difference between annual gross harvests of biomass, plus releases of carbon from soils, less biomass carbon whose oxidation is long delayed (e.g., stored in forest products such as telephone poles, furniture, and housing) and additions to the stock of standing biomass. The IPCC (1990) estimates 1980 carbon emissions from land-use change to be 0.6 to 2.6 PgC/yr. This range is only slightly narrower than that given by Trabalka (1985), 0.0 to 3 PgC/yr.

Conventional estimates of net CO_2 release from land-use change do not take the possibility of a CO_2 fertilization effect into account. That is, they do not make any allowance for the possibility that the terrestrial biosphere may be sequestering carbon at an increasing rate. While a matter of heated debate, it has been suggested that increases in the atmospheric concentration of CO_2, and or nitrogen, could act to accelerate the rate at which the terrestrial biosphere stores carbon.

Land-use change in the United States is estimated to be a net sink for carbon. While harvesting of trees is estimated to release 0.35 PgC/yr, this quantity is offset by an estimated 0.46 PgC/yr absorption leaving a net 0.1 PgC/yr net uptake (US, 1992). Emissions of carbon from land-use change are much greater for nations such as Brazil, Columbia, the Ivory Coast, Indonesia, Laos, and Thailand, though great uncertainty surrounds emissions estimates in all cases.

CFC Emissions: Most key nations have either signed or agreed to sign the Montreal Protocol and the subsequent London Amendments. Under the Clean Air Act Amendments of 1990, the United States is committed to phase out CFC production by 1996. Global emissions of halocarbons including CFCs amounted to 1.7 Tg/yr in 1990. United States emissions amounted to 0.7 Tg/yr in 1988. Recent findings reported in IPCC (1992) indicate that the indirect effect of CFC emissions through the destruction of O_3 may be equal in magnitude over the course of 100 years, but opposite in sign to the direct effects. If this were the case, the net contribution of CFCs to global warming would be zero over the course of 100 years.

Methane Emissions: Estimates of methane emissions have improved over time, although the uncertainty surrounding sources remains greater than with fossil fuel carbon. Manmade emissions are currently thought to derive from energy use (coal mining, and natural gas production,

transmission, and distribution), rice paddies, animal husbandry (ruminant livestock and animal waste), anthropogenic waste (domestic sewage treatment and landfills), and biomass burning (including biomass for energy as well as land-use change and crop field burning). Total global anthropogenic emissions were estimated to have been approximately 350 $PgCH_4$/yr. Uncertainty in this estimate is in the range of $\pm$50%. United States emissions are estimated to be within the range 0.015 to 0.051 $PgCH_4$/yr.

Nitrous Oxide Emissions: Nitrous oxide emissions are poorly documented, and all major sources and sinks may not have been identified. Anthropogenic emissions are estimated to be in the range 1 to 6 TgN/yr (IPCC, 1992). Nevertheless, anthropogenic emissions are a relatively small contribution to the overall methane budget. Principal sources of emissions include cultivated soils, biomass burning, stationary combustion, mobile sources, adipic acid production, and nitric acid production. United States emissions have been estimated to be 0.34 to 1.21 TgN/yr.

Sulphur Emissions: Sulphur emissions are a relatively recent addition to the list of RIGs. While the potential for sulphur to play a role in global warming has been known for some time, not until IPCC (1992) was it recognized that sulphur aerosols could be a major factor in explaining observed global temperature records. Unlike other RIGs, the addition of sulphur to the atmosphere tends to cool the surface of the Earth. Unfortunately, sulphur is also an acid precursor. Anthropogenic emissions are estimated by IPCC (1992) to range from 71 to 83 TgS/yr in contrast to the range of estimates for natural emissions, 7 to 14 TgS/yr. United States emissions were estimated to be 10 TgS/yr in 1989 (WRI, 1992). We note that sulphur compounds are not covered by the United States *National Action Plan for Global Climate Change* (1992).

ANTHROPOGENIC EMISSIONS FORECASTS

The range and variety of estimates of future greenhouse gas emissions vary greatly by gas. IPCC Working Group I (WG1) worked on this problem and presented its results in IPCC (1992).

Fossil Fuel Carbon: The fossil fuel resource base provides no constraint on future atmospheric CO_2 release. The present atmospheric stock of carbon is approximately 740 PgC (1988). The estimated resource of fossil fuels is huge by comparison. While the carbon content of conventional oil and natural gas resources is only slightly more than half as large as the current atmospheric stock of carbon, coal resources are an order of magnitude larger. The carbon content of unconventional oil resources is 55 times larger than the current atmospheric stock of carbon. The pool of carbon available for combustion might be constrained to 4000 PgC by considering only those resources recoverable under present technologies. Even this severely constrained resource definition provides no physical constraint on climate change from fossil fuel use. Approximately 80% of the coal resource base is thought to be in three countries: the United States, former Soviet Union, and China. There are approximately 800 PgC in the form of coal, recoverable with today's technologies, within the jurisdictional boundaries of the world's other countries.

A great deal of attention has been placed on the potential future fossil fuel carbon emissions. Edmonds et al. (1992) reviewed 30 selected reference case trajectories from 18 analyses of fossil fuel carbon emissions for comparison to the IPCC 1990 reference cases. These studies included analyses of uncertainty. It is highly likely that without intervention to reduce emissions, that emissions will rise over the course of the next century. The rate at which emissions rise is highly

uncertain. Relatively moderate emissions trajectories can place 1000 PgC into the atmosphere by the year 2100. Even if fossil fuel carbon emissions were stabilized at 1990 rates, 6.1 PgC/yr, cumulative emissions would reach approximately 650 PgC over the period to 2100. It is interesting to note that the stabilization of emissions at present levels implies that global average emissions must be roughly cut in half over the course of the next century.

The range of emissions scenarios is driven by the supply and demand for fossil fuels. These in turn reflect patterns of economic and population growth, changes in end-use energy intensity, the availability of inexpensive fossil fuels such as oil and natural gas, and the availability and cost of competing sources of energy services such as conservation, renewables, nuclear power, and fusion energy. In the uncertainty analysis conducted by Reilly et al. (1987) three factors were disproportionately important in shaping non-policy intervention future emissions scenarios: the rate of growth of labor productivity (directly related to GNP growth), the rate of exogenous end-use energy intensity improvement (i.e., the non-price induced change in energy productivity brought about by changes in technology and changing composition of product mix), and the income elasticity of demand for energy in developing nations (i.e., the relationship between economic growth and demand for market energy). Other factors, such as population growth were less influential in shaping the variation in future emissions trajectories.

The lower ranking of population growth in determining overall emissions growth stems from two factors. First, changes in adult population are much more important in determining overall emissions than changes in total population. Only when population reaches adult age does it begin to have a major impact on national output and therefore on national energy consumption. Changes in fossil fuel emissions lag behind any change in population growth rate. Furthermore, the variation in possible population growth scenarios is not as great as the variation in factors such as economic growth.

Land-Use Change: Estimates of net carbon emissions from land-use change under "business-as-usual" conditions begin with the handicap that present emissions rates are highly uncertain. Unlike fossil fuel carbon emissions, cumulative emissions from land-use change are bounded by the total stock of carbon stored in above ground living matter, approximately 560 PgC. None of the IPCC scenarios released as much as half that amount. The maximum rate of net carbon emissions from land-use change in the set of IPCC scenarios was approximately 3 PgC/yr, and in the later years of some scenarios, net emissions were negative. Land use is determined by a somewhat different set of factors than energy use. The demand for land depends on the productivity of land under alternative uses, technological options for producing land services, the availability of capital to implement technological alternatives, the value of goods produced by the land, and policy options.

CFCs: The least complicated of the emissions are those of the chlorofluorocarbons (CFCs). These gases are being phased out under the Montreal Protocol and subsequent agreements. Emissions in both the near- and long-term will not likely be substantially below 1990 levels. Furthermore, as we discussed earlier, the indirect effect on global warming of CFCs, through the pattern of ozone destruction, may lead to a cooling over the course of a century which is equal in magnitude to the direct warming by the CFCs themselves.

Substantial uncertainty surrounds the pattern of future production, use and character of CFC substitutes. At present hydrogenated chlorofluorocarbons (HCFCs) and hydrogenated fluorocarbons

(HFCs) are most likely replacements of CFCs. While these gases have much shorter lifetimes than the CFCs, they are nonetheless radiatively active and can affect global warming.

Methane: Because the sources of CH_4 are uncertain, forecasts of emissions are also uncertain. Most forecasts simply project the rate of accumulation in the atmosphere to continue. More recently attempts have been made to estimate future emissions based on estimates of energy (coal mining, gas production, and landfills) and agricultural activities (rice cultivation and ruminant livestock production), which in turn are determined by assumptions about population, economic growth, tastes, and the assumed natural gas resource base. Studies that have attempted to develop emissions forecasts from forecasts of underlying human activities, assuming business as usual conditions, yield growing CH_4 emissions (for the period to 2050) ranging from 0.5%/yr (EPA, 1989) to 1.25%/yr (Rotman et al., 1989). IPCC (1992) developed a series of methane emissions trajectories which range from a scenario with only 15% emissions growth by the year 2100 to a case in which total emissions more than approximately double by 2100.

Nitrous Oxide Emissions: Forecasts of future N_2O emissions vary greatly. Those which were constructed prior to the discovery of the sampling artifact link future emissions of N_2O primarily to the use of coal. Emissions growth rates for such studies as Rotman et al. (1989) and Mintzer (1987) for the period to 2050 produce rates of growth of emissions that range between 0.50 and 1.75 %/year. The U.S. EPA (1989) uses a much lower emission coefficient for fossil fuel N_2O with a consequent lower rate of emission growth, 0.3%/year. IPCC (1992) developed a series of N_2O emissions trajectories which range from a scenario with almost no growth in emissions through the next century to a case in which total emissions approximately double (reach 19 TgN/yr in 2100). Forecasts show a relatively small role for N_2O in determining future radiative forcing, generally contributing 5% and almost always less than 10% of total radiative forcing. This result is in spite of the fact that an individual molecule of N_2O is estimated to be approximately 250 times more efficient in absorbing infrared radiation than a molecule of CO_2 and has an extremely long average residence time in the atmosphere, 100 to 175 years. These factors are generally counterbalanced by low emissions, which grow at rates similar to those forecast for other greenhouse gases.

Sulphur Emissions: The first major study of global sulphur emissions developed using an integrated model was performed by the IPCC. The range of future emissions depends greatly on policies to reduce acid rain throughout the world. In the IPCC (1992) low case, emissions actually decline globally by approximately 20% by the year 2100. In the highest emissions case, emissions grow by more than 150% in that same period. Unlike the other RIGs, sulphur has a cooling effect on global temperature, leading to the irony that improving local and regional air quality may in fact "unmask" some global warming hidden by sulphur aerosols.

Thank you, Mr. Chairman. I would be pleased to answer questions.

REFERENCES

Edmonds, J., I. Mintzer, W. Pepper, K. Major, V. Schater, M. Wise, R. Baron. 1992. ***A Comparison of Reference Case Global Fossil Fuel Carbon Emissions***, background paper prepared for Working Group I of the Intergovernmental Panel on Climate Change, Pacific Northwest Laboratory, Washington, DC.

EPA 1989. ***Policy Options for Stabilizing Global Climate***, Draft Report to Congress, U.S. Environmental Protection Agency, Office of Policy, Planning and Evaluation, Washington D.C.

IPCC (Intergovernmental Panel on Climate Change), 1992. ***Climate Change 1992: The Supplementary Report to the IPCC Scientific Assessment.*** J.T. Houghton, B.A. Callander and S.K. Varney (eds.), Cambridge University Press, Cambridge, United Kingdom.

IPCC (Intergovernmental Panel on Climate Change), 1990. ***Scientific Assessment of Climate Change.*** World Meteorological Organization/United Nations Environmental Program. Cambridge University Press, New York.

Marland, G., and T.A. Boden. 1992. ***Gloal, Regional, and National CO_2 Emissions Estimates from Fossil Fuel Burning, Cement Production, and Gas Flaring: 1950-1990***, NDP030/R4, Carbon Dioxide Information Analysis Center, Oak Ridge National Laboratory.

Mintzer, I. 1987. ***A Matter of Degrees: The Potential for Controlling the Greenhouse Effect.*** Research Report #5, World Resources Institute, Washington, D.C.

Reilly, J.M., J.A. Edmonds, R.H. Gardner, and A.L. Brenkert. 1987. "Uncertainty Analysis of the MIT/ORAU CO_2 Emissions Model," ***The Energy Journal*** *8*(3):1-29.

Rotman, J., H. de Boois, and J. Swart. 1989. ***An Integrated Model for the Assessment of the Greenhouse Effect: The Dutch Approach.*** National Institute of Public Health and Environmental Protection, Rijksinstituut voor Volksgezondheid en Milieuhygiaene, Postbus 1, 3720 BA, Bilthoven, The Netherlands.

Trabalka, J. (ed.) 1985. ***Atmospheric Carbon Dioxide and the Global Carbon Cycle.*** DOE/ER-0239. National Technical Information Service, U.S. Department of Commerce, Springfield Virginia 22161.

United States of America. 1992. ***National Action Plan for Global Climate Change***, U.S. Government Printing Office, Washington, D.C.

World Resources Institute. 1992. ***World Resources: 1992-93.*** Oxford University Press, New York.

Wuebbles, D.J. and James A. Edmonds. 1991. ***Primer on Greenhouse Gases***, Lewis Publishers, Chelsea, Michigan.

UNITS OF MEASURE

1 gC = 1 gram of carbon

1 PgC = 1 petagram of carbon
= 10^{15}gC = 1 gigatonne C
= 1 billion metric tonnes of carbon

1 TgC = 1 teragram of carbon
= 10^{12}gC = 1 megatonne C
= 1 million metric tonnes of carbon

1 Gg = 1 gigagram
= 10^{9}gC = 1 kilotonne
= 1 thousand metric tonnes

1 EJ = exajoule = x10^{18}J = 0.948 Quads

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