PRELIMINARY
DRAFT

STUDY DESIGN

WP 12.2

January 1993

Energy Modeling Forum
Terman Engineering Center
Stanford University
Stanford, California

STUDY DESIGN FOR EMF 12 GLOBAL CLIMATE CHANGE: ENERGY SECTOR IMPACTS OF GREENHOUSE GAS EMISSION CONTROL STRATEGIES

INTRODUCTION

This document describes the initial design of Energy Modeling Forum study number 12 currently entitled "Global Climate Change: Energy Sector Impacts of Greenhouse Gas Emission Control Strategies." When the full working group meets again in the Spring of 1991 to review the results of the first phase of the project, this document will be revised based on the preferences of the working group at that time.

This document is composed of four main sections: (1) a description of the assumptions to be used by the modelers participating in the study in running the reference case scenario; (2) a set of scenario runs to be made around the reference case; (3) a description of the outputs requested from the modelers for all scenarios; and (4) a description of study groups being organized to interpret, expand upon and supplement the model runs. In past EMF studies the work of the study groups, although keyed to modeling work, has often been as significant as the model results themselves.

REFERENCE CASE INPUT ASSUMPTIONS

As in all EMF studies, the standardization of input assumptions is accomplished so that important inputs take on common values for each EMF scenario. This process facilitates the interpretation of the model comparison, allowing one to separate the dependence of key model results on model structure and on specific numerical inputs. However, in instances where a particular model includes an endogenous computation of an input selected for standardization, the modeler is urged to use the internal calculation in lieu of the EMF 12 input assumption. By design this situation arises infrequently, but it is important for the modelers to maintain this flexibility. This avoids producing only "least common denominator" level results from the model comparisons. Before discussing specific input values, the time periods and regional breakdown to be used in reporting model results are described. These dimensions of the study design condition the specification of the model inputs.

Time Periods

The global climate change problem is long run in nature. The time horizon for reporting model results needs to be much longer than that typically employed for other energy policy related issues. Thus, the time horizon adopted for this study extends out to the year 2100. On the other hand, the most difficult and costly transitions (especially with discounting of future cash flows) will come in the next 10-20 years. Thus, the time periods adopted for reporting results for this study are shorter (every five years) during the first twenty years of the study's time horizon than for the balance of the 21st century (every 10 years). Consequently, the reporting years for the study are 1990, 1995, 2000, 2005, 2010, 2020, 2030 2040, 2050, 2060, 2070, 2080, 2090, and 2100. Not every model will report all these years, nor will they report values for every output specified below.

Geographical Regions

The main reporting regions for the study take into consideration the present and likely future geographical distribution of greenhouse gas emissions. The main reporting region totals are: (1) U.S., (2) OECD total (including the US), (3) USSR, (4) China, and (5) World Total. For those who produce estimates for Canada, Japan, West and/or East Europe, results for these subregions may also be reported.

Economic Growth

The reference case includes assumptions about both population and economic growth. The assumptions chosen here are patterned after those made in the recently released report of the Intergovernmental Panel on Climate Change's (IPCC's) Response Strategy Working Group (RSWG) (September 1990). As in that report, we employ population growth projections contained in a World Bank report by Zachariah and Vu (1988). These population growth assumptions are shown in Table 1. The economic growth rate assumptions adopted here are the average of the higher and lower growth cases included in the IPCC/RSWG report. The growth rates for those two cases were patterned after the "low" GDP assumptions made for 1986-1995 in the World Bank's World Development Report for 1987 (World Bank, 1987). Since the IPCC/RSWG cases were symmetric variations about those World Bank projections, our 1990-2000 projections are patterned after the "low" GDP assumptions for 1986-1995 contained in the 1987 World Development Report. As shown in Table 2, the GDP growth rates are assumed to decline gradually after 2000 due to structural change and lower population growth.

Also shown in Table 2 are estimates of GDP for 1990 for the study regions. Except for the USSR and China, these estimates are consistent with a number of published estimates. For the USSR and China, there exists considerable uncertainty regarding the purchasing power parity adjustments necessary to translate economic activity measured in non-convertible currencies into dollars. This conversion is complicated for these two major countries because of the absence of market-based pricing systems. Our approach here was to take the average of the GDP estimates produces by the CIA and those produced by a group at the RAND Corporation. The two sets of calculations (summarized in the Appendix) appear to span the range of current thinking in this area. Our averaging procedure does, however, result in somewhat lower GDP estimates for the USSR than those produced by the CIA and much higher estimates for China.

Table 1. Population Growth Assumptions

Region	1990 Level (10^6)	Projections (Millions)				
		2000	**2025**	**2050**	**2075**	**2100**
USA	250	267	289	285	283	284
Other OECD	582	617	649	643	640	643
USSR	289	306	337	351	361	367
China	1116	1285	1576	1703	1750	1817
Rest of World	3024	3701	5339	6546	7143	7310
World Total	5261	6176	8190	9528	10,177	10,421

Source: Zachariah, K.C., and M.T. Vu, World Population Projections, 1987-1988 Edition, World Bank, Johns Hopkins University Press, Baltimore, 1988, 440p.

These projections are slightly lower for developing countries (3% lower by 2025), and identical for developed countries to those contained in World Population Projections: 1989-90 Edition, World Bank, Johns Hopkins University Press, 1990.

Oil Prices and Resource Base

For modelers requiring exogenous oil price inputs the world price of oil should be assumed to be $24/barrel in 1990 in 1990 dollars and to increase $6.50 per barrel each decade until 2030 (reaching the backstop level of $50/barrel in that year). For modelers requiring oil and gas resource base estimates, the 95th percentile estimates from Masters and Root (1987) shown here as Table 3 are recommended. The oil and gas sector assumptions should be employed in all first round scenarios.

Table 2. Economic Growth Rate Assumptions

Region	1990 GDP Trillions (per capita)	GDP Growth Rates (per capita growth rates)				
		1990-2000	2000-2025	2025-2050	2050-2075	2075-2100
USA	5.60 (22,400)	2.50% (1.84)	2.00% (1.68)	1.50% (1.56)	1.25% (1.28)	1.00% (.99)
Other OECD	10.20 (17,526)	2.70% (2.11)	2.00% (1.80)	1.50% (1.54)	1.25% (1.27)	1.00% (.98)
USSR	2.68 (9,273)	2.50% (1.92)	2.00% (1.61)	1.50% (1.33)	1.25% (1.14)	1.00% (.93)
China	1.10 (986)	4.50% (3.08)	4.00% (3.18)	3.50% (3.19)	3.25% (3.15)	3.00% (2.85)
Rest of World	3.34 (1104)	3.75% (1.71)	3.30% (1.82)	2.80% (1.98)	2.55% (2.20)	2.30% (2.20)
World Total	22.92 (4357)	2.88% (1.24)	2.37% (1.22)	2.00% (1.37)	1.88% (1.61)	1.79% (1.69)

Technology Costs

New coal-fired power plants are assumed to be able to generate electricity for 50 mills/kwH, with an overall efficiency of 34%, and a carbon emission coefficient of .25 metric tons carbon per thousand kilo-watt hours. It is assumed that three types of advanced "backstop" technologies will become available by 2010:

(1). A liquid synthetic fuel derived from coal or shale at $50/barrel of crude oil equivalent, and a carbon emission coefficient of .04 metric tons carbon per billion joules (or 40 million tons per exajoule).

(2). A non-carbon based liquid fuel at $100/barrel of crude oil equivalent.

(3). A non-carbon based electric option at 75 mills/KwH.

Table 3. Resource Base Assumptions
(Exajoules of Economically Recoverable Resources)

Resource	Category	USA	Other OECD	USSR	China	ROW	World
Crude Oil + Nat. Gas Liquids	Reserves	361	294	612	147	3812	5226
	Undiscovered resources, 95th percentile	495	728	1254	587	2992	6056
Natural Gas	Reserves	352	476	1372	27	1979	4206
	Undiscovered resources, 95th percentile	510	1255	3079	503	3899	9246

SCENARIOS

The EMF 12 scenarios are generic policy/technology excursions rather than detailed model structure investigations or policy implementation excursions. The scenario design consists of 12 alternative standardized scenarios (Table 4):

(I) a 20% reduction in CO_2 emissions from 1990 levels by 2010, (II) a 20% reduction from 1990 CO_2 emissions levels by 2010, with a 50% reduction from 1990 levels by 2050; (III) stabilize CO_2 emssions at 1990 levels from 2000 onward, (IV) scenario I with a 50% reduction in the non-electric carbon free backstop cost, and a 33% reduction in the electric carbon-free backstop cost; (V) scenario I with international trading of carbon emissions; (VI) a phased in carbon tax beginning at $15 per metric ton of carbon, escalating by 5% per year in real terms until a maximum tax of $1000 per ton (in 1990 dollars) is reached;

Table 4. Standardized EMF 12 Scenarios

First round scenarios retained for round #2

0. Base Case (Unconstrained)

I. 20% Reduction* by 2010 from 1990 Levels

II. 20% Reduction* by 2010/50% Reduction by 2050

III. Stabilize* by 2000 at 1990 levels

New Second Round Scenarios

IV. Accelerated Technology/20% Reduction* by 2010
$50/BBl Non-electric backstop
50 mills/KwHr electric backstop

V. International Emissions Trading
(Same as I. with international trading of carbon emissions)

VI. Phased in Worldwide Carbon Tax
($15/tonne in 1990 escalating at 5% real per year to a maximum of $1000 per tonne in about 2076, constant thereafter)

VII. Integrated Greenhouse Gas Reduction - 1
(20% reduction in "carbon equivalents" by 2010)
(see Table A for Carbon Equivalents)

VIII. Integrated Greenhouse Gas Reduction - 2
(CO_2 taxes from scenario I applied to "carbon equivalents")
(report "carbon equivalents" in the carbon emissions slot)

IX. Two Percentage Point Per Year Worldwide Reduction in Carbon Emissions With Respect to Base Projection

X. Same as I, But Quadruple World Undiscovered Natural Gas Resources#

XI. Same as I, But Lower Economic Growth+#
(DGEM projections - see Table B - report results through 2020 only)

XII. Base Case with Flat Oil Price+

*Industrialized countries (i.e., OECD and USSR) only: China and ROW emissions should be limited to no more than 50% over their 1990 levels by the dates specified. That is, emissions from those regions may not exceed 1.5 times 1990 levels in any year after the first control target date specified for the industrialized countries.

+To be implemented for the U.S. only.

#Report carbon tax and GNP loss relative to a new Base Case which includes specified alternative input assumption.

(VII) an integrated greenhouse gas emission scenario in which a tax on the carbon equivalents of all greenhouse gases is used to reduce total greenhouse gase emssions by 20% from their 1990 total by 2010; (VIII) an integrated greenhouse gas scenario in which the carbon taxes computed in scenario I are applied to the carbon eqivalents of all greenhouse gases (please report total "carbon equivalents" from greenhouse gas emissions for this case); (IX) a 2 percentage point per year reduction in carbon emissions with repect to the base case projection; (X) same as scenario I with a quadrupling of the undiscovered gas resource assumption for each region; (XI) same as scenario I with lower economic growth for the U.S. only; and (XII) base case with a flat oil price to be run for the U.S. only. The base case and policy scenarios I, II, and III have been carried over from the first-round study design.

In the technology cost reduction scenario (IV), the carbon free liquid and electric advanced technology costs are reduced to $50 per barrel of crude oil equivalent and 50 mills per KwH, respectively. Depending on the model, the policy scenarios may cover: (A) the U.S. alone; (B) the OECD/USSR; or (C) the whole world. In the world-wide cooperation cases, the reductions specified are to be used as targets for the OECD countries and USSR. China and ROW emissions should be constrained to increase to no more than 50% over their 1990 levels beginning with the first control target date specified for the industrialized countries and extending through 2100. Except for scenario V, individuals with world-wide models should run a "no-emissions trading" case in which the regional constraints are imposed independently for each region. This will facilitate the initial model comparisons and limit the number of implementations for each model to one per scenario. Emissions trading cases can be run by individual modelers as special experiments. Results from such experiments could prove extremely useful in designing more elaborate second round scenarios.

Table 5. Global Warming Potentials

Gas	Lifetime (years)	Instantaneous Radiative Forcing (relative to CO_2)	Potency Over 100 Years (relative to CO_2)
CO_2	120	1	1
Methane	10	58	21
CFCs	7-200	1640-5800	430-7300
Nitrous Oxides	150	206	290
Ozone	1	1600	57

Source: IPCC Science Report.

The policies to be used to achieve the emission reductions is left up to the discretion of the modeling teams. It was argued that this type of scenario design would be most useful to policy makers and would reveal a great deal about the policies under consideration, the representation of these policies in the models, and model behavior. We will, however, ask each modeling team to specify the policies they have employed to achieve the specified emission reductions.

Table 6. DGEM Projected GDP Growth Rates

Period	Annual Growth Rate
1990-1992	2.8%
1996-2000	1.5%
2001-2005	1.4%
2006-2010	1.3%
2011-2020*	.6%

*Since results for DGEM are not reported beyond 2020, do not report results beyond that date. For models with look ahead features it is suggested that the growth rate be slowly reduced from .6% in 2020 to .3% in 2060 to 0 in 2100.

In addition to the standardized study scenarios, several "non-standardized scenarios" may be run by ech model represented in the study (Table 7): (A) a scenario in which each modeler can reduce CO_2 emissions by 20% by 2010 relative to 1990 levels bywhatever combination of policies minimizing the cost of attainment among the policy alternative the model can represent; (B) revenue recycling scenarios being designed by the policy group; (C) a scenario where emissions trading is permitted within the United States; and (D) as many AEEI\Elastiticty of substitution sensitivities as seem appropriate to the models.

Table 7. Non-Standardized EMF 12 Scenarios

A. "Your Choice" 20% CO_2 Reduction Scenario
Achieve 20% Co_2 emissions reduction relative to 1990 using whatever combination of policies yield approximately the least cost of all policies your model can represent.

B. Revenue Recycling Scenarios
Different ways of recycling carbon tax revenues to the economy.
To be co-ordinated by the policy group. To be run by DGEM, and several other models that did not participate in round #1.

C. Within U.S. Emissions Trading

D. AEEI/Elasticity of Substitution Sensitivities

OUTPUTS REQUESTED

Table 8 shows the output variables being requested from each model for each reporting year and region for each scenario. For the energy variables, the format is patterned after that used by the IEA/OECD in reporting energy balances for OECD countries and 85 non-OECD countries. Historical data are available through 1988. Also shown in Table 5 are our best estimates for values for the reporting variables for 1990. Actual reporting of data will be implemented in Lotus format via floppy disks to be provided by EMF headquarters. There will be alphanumeric labels for each data series, but blank data fields to be filled in by participating modelers.

Table 8. Output Reporting Form
(1990 values in Exajoules unless otherwise indicated)

Variable	USA	Other OECD	USSR	China	ROW	World
Primary Energy Consumption						
Non-Electric:						
Oil	35.10	40.16	18.37	5.18	35.37	134.18
Gas	18.44	13.59	26.29	.53	14.04	72.89
Coal/Shale	19.78	16.05	13.56	21.99	25.05	96.43
Biomass	-	-	-	-	-	-
Other Carbon Free	-	-	-	-	-	-
Electric:						
Hydro, Geothermal	2.21	9.85	2.45	1.14	6.55	22.20
Other Carbon Free	6.46	10.00	2.40	-	-	18.86
(e.g., nuclear,solar)	------	------	------	------	------	-------
Total	81.99	89.65	63.07	28.84	81.01	344.56
Conventional Oil Production	17.39	13.59	24.87	5.74	72.59	134.18
Secondary Energy Consumption						
Liquids	31.81	34.49	14.44	4.03	27.46	112.23
Solids	2.74	5.25	7.16	17.59	9.54	42.28
Gas	13.27	10.05	12.64	.43	7.59	43.98
Electricity	9.59	11.84	5.06	1.95	7.60	36.04
Heat	-	.40	4.28	.60	2.69	7.97
Final Consumption						
Industry	15.84	22.42	25.16	13.28	23.16	102.78
Transport	21.47	17.72	6.57	1.25	14.60	61.61
Residential/Comm.	16.83	17.15	6.71	6.40	9.44	58.42
Other	.97	2.57	3.55	1.65	6.31	15.05
Others (1990$s)						
Total Carbon Emissions (million metric tons)*	1431	1375	1056	641	1503	6003
Carbon Tax ($/metric ton Carbon)						
GDP Loss ($billions)**						

* Not corrected for non-energy uses of fossil fuel. Following Marland and Boden, Statement before the Senate Committee on Energy and Natural Resources, July 26, 1989, computed by assuming emissions' coefficients of 19.94 million metric tons of carbon per exajoule of primary oil consumption, 13.74 for natural gas and 24.12 for coal.

** Relative to unconstrained base case.

Sources:
Energy Balances of OECD Countries: 1987-1988, OECD/IEA, 1990.
World Energy Statistics and Balances: 1985-1988, OECD/IEA, 1990.
1990 energy consumption estimates obtained by starting with actual data for 1988 and assuming 1985-88 average growth rates continue for 1989 and 1990.

Following the BP Statistical Review of World Energy, (British Petroleum, p.l.c, June 1990), primary energy includes commercially traded fuels only. Excluded therefore are fuels such as wood, peat and animal waste which, though important in many countries, are unreliably documented in terms of consumption statistics.

Energy quantities should be expressed in terms of "net"calorific value. The difference between the "net" and the "gross" calorific value for each fuel is the latent heat in condensation of the water vapor produced during combustion of the fuel. For coal and oil, net calorific value is about 5 percent less than gross. For most forms of natural and manufactured gas, the difference is 9-10 per cent, while for electricity there is no difference. The use of net calorific value is consistent with the practice of the Statistical Offices of the European Communities and the United Nations.

STUDY GROUPS

At the first working group meeting it was suggested that four study groups (see Figure 1) be established to help facilitate the achievement of the goals of the EMF 12 study. The "Model/Scenarios group would oversee the implementation, interpretation and modification of the study scenarios as the project progresses. The "Technology" study group would study all available information and analyses regarding the appropriate characterization of new and existing technologies in the models. Peter Blair and Bob Friedman of the Office of Technology Assessment have agreed to coordinate the work of this study group. The "Decision Framework/Methods" group would serve as an interface between the modeling results produced during this study and the needs and interests of policy makers. This group would look at available information regarding the importance of all greenhouse gases and look at a broader range of policy initiatives (e.g., reforestation options) than those included in the study models. This group would also be charged with recommending methods for decision making under the considerable uncertainties inherent in the global climate change issue. The final group would be on "Impacts" of greenhouse gas emissions increases, and would cover both global climate models and the various impacts of the induced climate changes. Our intent here would not be to do any of our own work in this area, but rather to have selected working group members (e.g., Gary Yohe, Bill Nordhaus, and John Reilly) summarize what has been learned to provide a useful perspective for the other groups, especially the "Decision Framework/Methods" group.

Technology Study Group

In Dave Wood's report on the deliberations of the "Technology" group, he described five main areas of interest to that group: (1) understanding the existing technology data bases, containing information on the cost, performance, and dates of availability of new and existing supply- and demand-side energy equipment, (2) identifying, understanding, and quantifying "institutional" impediments to greater use of demand-side (a.k.a. energy efficiency) technologies, (3) understanding the way technology development and technology trends are represented in aggregate models (e.g., through AEEI, Autonomous Energy Efficiency Improvement, parameters), and whatever guidance more micro analysis can provide on appropriate values for such parameters, (4) the relationship between policy implementation and technology development, focuses specially on how greenhouse gas emission control regulations might affect private sector R&D over the long time horizon over which global climate change much be addressed; and (5) how to communicate the results of (1)-(4) to policy makers in a useful and unbiased manner.