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Costs and benefits of a program to address Global Climate Change

Agenda

I. Costs:

How low can international trading bring costs down, under successively more ambitious assumptions?

II. Benefits:

- (1) reducing air pollution
- (2) reducing traffic congestion,
- (3) reducing traffic accidents

III. How sensitive are the above results to alternative

- (1) models?
- (2) assumptions about how sinks are accounted for?
- (3) a more optimistic assumption about technology (AEEI)?

Answer: very sensitive. Nevertheless, the general result is as follows: Optimistic assumptions about trading are sufficient to bring costs down a lot, but not enough to bring them below benefits.

IV. To close the gap between costs and benefits, one needs *either*:

- (1) to include the cost savings of a federal electricity restructuring bill, *or*
- (2) to assume that permits are auctioned to raise revenues used to cut taxes on capital, *or*
- (3) simply to argue that the future benefits of mitigating global climate change, while difficult to quantify in a single monetary number, should be large enough to merit the net costs that emerge from parts I and II above.

The Costs of Climate Change Policy: Assumptions

Modeling. For this analysis, we calculated the costs of abatement for all six categories of greenhouse gases by merging two modeling efforts:

- *SGM:* Outputs of carbon dioxide emissions reductions and costs from the Second Generation Model (SGM) were used. SGM is used in Energy Modeling Forum exercises, and in EMF-14 it yielded cost estimates that ranged from being second most expensive for no trading to least expensive under worldwide trading.
- *EPA Bottom-Up Analysis:* Estimates of emissions reductions and costs for the other greenhouse gases were derived through a bottom-up analysis by EPA.

Trading Assumptions. We assessed several different trading scenarios:

- *Full Annex I Trading:* All Annex I countries participate in international trading.
- *Umbrellas:* Two “umbrellas” were assessed. One excludes the EU from Annex I trading, while the other excludes the EU and Eastern European countries from Annex I trading.
- *Joint Implementation:* We also assessed joint implementation with all developing countries and trading with key developing countries (China, India, Mexico, and Korea).

Sinks Assumptions. Given the uncertainty about the impacts of the sinks definition in the Protocol on commitments, we assessed the trading regimes under 3 sinks assumptions:

- *No Sinks:* All countries are assumed to have no emissions reductions through sinks.
- *Reported Sinks:* All countries are assumed to have emissions reductions through sinks equal to their reported sinks estimates in their national communications. For the U.S., above ground sinks are 104 MMTCE in 2010.
- *Half of Reported Sinks:* These are half of the above (52 MMTCE for U.S.).

Technology Assumptions. Given the uncertainty in projecting rates of technological improvement, we analyzed the above scenarios under two assumptions:

- *1.0 AEEI:* Annual energy efficiency improvement is assumed to increase 1% (base case).
- *1.25 AEEI:* Annual energy efficiency improvement is assumed to increase 1.25% (optimist case).

Costs and Non-Climate Benefits without Sinks**Table 1. U.S. Costs and Non-Climate Benefits Summary (assuming 1.0 AEED)**

Scenario (no sinks)	2010 Permit Price	2010 Resource Cost	2010 Monetized Benefits¹
10/97 Administration Position (6 gases, net-net sinks, 1990 by 2010, updated baseline)	\$148/ton	\$41 billion	\$13 - 25 billion
Kyoto: No International Trading ²	\$171/ton	\$51 billion	\$15 - 29 billion
Full Annex I Trading	\$48/ton	\$22 billion	\$4 - 8 billion
Umbrella excluding EU and Eastern Europe	\$43/ton	\$20 billion	\$4 - 7 billion
Umbrella excluding EU	\$26/ton	\$13 billion	\$2 - 4 billion
Annex I Trading + JI (JI = 20% worldwide trading)	\$36/ton	\$17 billion	\$3 - 6 billion
Annex I Trading + Participation by Key Developing Countries	\$20/ton	\$10 billion	\$2 - 3 billion
Annex I Trading + Full Worldwide Trading	\$19/ton	\$10 billion	\$2 - 3 billion
Umbrella excluding EU + Full Worldwide Trading	\$10/ton	\$6 billion	\$1 - 2 billion

¹ Benefits include reductions in local air pollutants, traffic accidents, and congestion.² All subsequent cases evaluate the Kyoto Protocol.**Table 2. With accounting for sinks (assuming full Annex I trading)**

Sinks Assumption	2010 Permit Price	2010 Resource Cost	2010 Monetized Benefits
No Sinks (U.S.: 0 MMTCE)	\$48/ton	\$22 billion	\$4 - 8 billion
Half of Land Use Change and Forestry Sinks (U.S.: 52 MMTCE)	\$26/ton	\$12 billion	\$2 - 4 billion
All of Land Use Change and Forestry Sinks (U.S.: 104 MMTCE)	\$11/ton	\$5 billion	\$1 - 2 billion

Table 3. More Detailed Measures of Economic Effects of Various Trading Regimes¹

2010	No International Trading	Full Annex I Trading	Umbrella excluding EU	Umbrella excluding EU + Full Worldwide Trading
Permit Price	\$171/ton	\$48/ton	\$26/ton	\$10/ton
Resource Cost	\$51 billion	\$22 billion	\$13 billion	\$6 billion
Percentage of Reductions Occurring in U.S.	100%	47%	31%	14%
Value of Transfers	\$0	\$15 billion	\$11 billion	\$5 billion
Change in Household Energy Expenditures Relative to BAU	+30%	+9%	+5%	+2%
Change in Household Energy Expenditures net of Administration's Electricity Restructuring Proposal	+26%	+5%	+1%	-2%
Change in Gasoline Price (per gallon)	+ \$0.41	+ \$0.12	+ \$0.06	+ \$0.02

¹ This analysis assumes no sinks and a technology improvement based on 1.0 AEEL.

Non-Climate Benefits of U.S. Participation in the Kyoto Agreement

I. Percentage of total non-climate benefits expressible in dollars per year

Table 4. Distribution of Total Monetized Non-Climate Benefits

Category		Share of Total Non-Climate Benefits (Percentage)
Non-carbon Emissions reductions:	Utilities	27
	Vehicles	2
	Other	3
Highway fatalities		38
Highway accidents: injuries and other costs		22
Highway congestion		9
Increased fuel efficiency costs		-2
Total		100

II. Unquantifiable benefits

Inconvenience from highway congestion

Mercury emissions reductions

Sulfur dioxide emissions control cost savings

Energy independence

III. Caveat: The estimates are approximate and preliminary.

1) A key uncertainty is the effect of lighter cars on highway safety. The ranges provided in the costs and benefits tables reflect this uncertainty.

2) Estimates are generally proportional to fuel prices.

3) The estimated reductions in highway fatalities ignore effects of higher average speeds from reduced congestion.

4) The air emissions benefits estimates, while conservative, are uncertain and subjective, and based on control cost avoided.

Non-Monetized Benefits

Two very large categories of potential benefits have been left out of the foregoing list of costs and benefits: revenue recycling and climate change mitigation.

Revenue recycling If the emission permits to be issued in the budget period, 2008-2012, were to be auctioned off, rather than allocated for free, the resulting revenue for the government could provide major benefits. If the revenue were used to reduce taxes that fall on capital (i.e., to reduce the capital gains tax or corporate income tax, or to add an investment tax credit), then the result would be an increase in investment, and therefore an increase in growth. According to the Repetto-Austin meta-analysis of 16 leading models, the assumption of such revenue recycling together with several other assumptions (non-carbon backstop fuel, CGE model, increased energy and product substitution, and an idealized form of JI equivalent to global trading) is enough to turn what would otherwise be a negative effect of GDP into a positive one [2020]. Similarly, the IAT report estimated that under a policy of recycling revenues to business, the GDP effect would turn from negative to positive around 2010.¹ Using the revenue for deficit reduction is almost as good, because it lowers interest rates and again stimulates investment. Jorgenson, Shackleton, and other economists have similar findings.

However, returning the revenue to the general public through reductions in income taxes or payroll taxes, or through lump-sum redistribution, does not produce positive effects on GDP in these models. We suppose that cutting corporate taxes would be undesirable on political and income-distribution grounds, and that the government may want to use the revenue to ease the burden on those (e.g., displaced coal miners) who might be disadvantaged. For this reason, we have not as yet pursued the revenue recycling idea (also known as the double-dividend) any further.

Climate Change mitigation The goal of the entire exercise, of course, is to begin to move to an emissions path that implies lower levels of atmospheric concentrations of GHGs in future centuries, and thereby mitigate the likely extent of global climate change. Estimates of the economic damages from climate change (e.g., in the Integrated Assessment models of Nordhaus, Cline, and other economists) fall into the following areas: agriculture, sea-level rise, air conditioning and heating, water supply, human life and health, air pollution, and other costs (hurricanes, migration costs, human amenity, construction, leisure activities, urban infrastructure, and ecological damages such as forest loss and species loss). One must sympathize with those who critique the economists on the grounds that these costs are extremely difficult to quantify, particularly when it comes to possible catastrophe scenarios to which the scientists cannot assign

¹ (Figure 13 in IAT); this analysis assumes stabilization at 1990 levels by 2010, with 10-year phase-in; assuming a 1.25 % annual decrease in AEEI.

a reliable probability.

It turns out that the subject of perhaps the greatest uncertainty and sensitivity is the discount rate that is applied to the benefits of averting future climate change. Such a discount rate is needed, because the economic costs of the policies under discussion occur over the next few decades, whereas the prime benefits of averting climate change occur in coming centuries. Yet there is little agreement, even among economists, on the appropriate discount rate. Cline, for example, explicitly considers a low discount rate (and a high aversion to possible catastrophe) in getting his conclusion that the benefits of early and strong action outweigh the costs.

We take it as self-evident that the benefits of averting climate change are potentially enormous. But we have, so far, chosen not to try to quantify them in monetary terms, in light of the quantitative uncertainty, their timing (far outside the 2008-2012 window), and the need to make difficult decisions regarding the post 2012 path of emissions cuts in order to produce meaningful reductions in future concentrations. We are inclined to favor an attempt to add up the various possible costs and benefits of emissions policy excluding climate change. Thus a conclusion might be phrased along lines such as "the net benefits of our policies to reduce emissions [under the following conditions...] are likely to be positive, even before taking into account the benefits of averting climate change itself." Of course any testimony would also include an enumeration of the effects of climate change and the extent to which a mitigation program would help avert them; this would be partly *quantitative*, but would not include an estimate of *monetized* effects in the aggregate.

Technology Optimism Case**Table 5. U.S. Costs and Non-Climate Benefits (assuming 1.25 AEED)**

Scenario (no sinks)	2010 Permit Price	2010 Resource Cost	2010 Monetized Benefits¹
10/97 Administration Position (6 gases, net-net sinks, 1990 by 2010)	\$124/ton	\$34 billion	\$13 - \$27 billion
Kyoto: No International Trading ²	\$145/ton	\$44 billion	\$14 - \$30 billion
Full Annex I Trading	\$36/ton	\$16 billion	\$4 - \$8 billion
Umbrella excluding EU and Eastern Europe	\$31/ton	\$15 billion	\$4 - \$7 billion
Umbrella excluding EU	\$18/ton	\$9 billion	\$2 - \$4 billion
Annex I Trading + JI (JI = 20% worldwide trading)	\$27/ton	\$13 billion	\$3 - \$6 billion
Annex I Trading + Participation by Key Developing Countries	\$16/ton	\$8 billion	\$2 - \$4 billion
Annex I Trading + Full Worldwide Trading	\$15/ton	\$8 billion	\$2 - \$4 billion
Umbrella excluding EU + Full Worldwide Trading	\$8/ton	\$4 billion	\$1 - \$2 billion

¹ Benefits include reductions in local air pollutants, traffic accidents, and congestion.² All subsequent cases evaluate the Kyoto Protocol.**Table 6. With accounting for sinks (assuming full Annex I trading)**

Sinks Assumption	2010 Permit Price	2010 Resource Cost	2010 Monetized Benefits
No Sinks (U.S.: 0 MMTCE)	\$36/ton	\$16 billion	\$4 - \$8 billion
Half of Land Use Change and Forestry Sinks (U.S.: 52 MMTCE)	\$17/ton	\$8 billion	\$2 - \$4 billion
All of Land Use Change and Forestry Sinks (U.S.: 104 MMTCE)	\$7/ton	\$3 billion	\$1 - \$2 billion

Alternative Sinks Case

Table 7. U.S. Costs and Non-climate Benefits (assuming ½ of reported sinks, 1.0 AEE)

Scenario (accounting for half of reported sinks)	2010 Permit Price	2010 Resource Cost	2010 Monetized Benefits
10/97 Administration Position (6 gases, net-net sinks, 1990 by 2010, updated baseline)	\$148/ton	\$41 billion	\$14 - \$31 billion
Kyoto: No International Trading ²	\$146/ton	\$40 billion	\$14 - \$30 billion
Full Annex I Trading	\$26/ton	\$12 billion	\$3 - \$6 billion
Umbrella excluding EU and Eastern Europe	\$20/ton	\$9 billion	\$2 - \$4 billion
Umbrella excluding EU	\$11/ton	\$6 billion	\$1 - \$2 billion
Annex I Trading + JI (JI = 20% worldwide trading)	\$21/ton	\$10 billion	\$2 - \$5 billion
Annex I Trading + Participation by Key Developing Countries	\$12/ton	\$6 billion	\$1 - \$3 billion
Annex I Trading + Full Worldwide Trading	\$12/ton	\$6 billion	\$1 - \$3 billion
Umbrella excluding EU + Full Worldwide Trading	\$4/ton	\$2 billion	\$0.5 - \$1 billion

¹ Benefits include reductions in local air pollutants, traffic accidents, and congestion.

² All subsequent cases evaluate the Kyoto Protocol.

Table 8. With accounting for sinks (full Annex I trading)

Sinks Assumption	2010 Permit Price	2010 Resource Cost	2010 Monetized Benefits
No Sinks (U.S.: 0 MMTCE)	\$48/ton	\$22 billion	\$6 - \$11 billion
Half of Land Use Change and Forestry Sinks (U.S.: 52 MMTCE)	\$26/ton	\$12 billion	\$3 - \$6 billion
All of Land Use Change and Forestry Sinks (U.S.: 104 MMTCE)	\$11/ton	\$5 billion	\$1 - \$2 billion

Appendix 1 Non-carbon Emissions Reductions

The Kyoto agreement will lead to ancillary reductions in emissions that contribute to local air pollution, e.g., NO_x, and VOCs. NO_x, for example, is a combustion by-product that contributes to ground-level ozone and fine particulate formation. Thus to the extent that carbon emissions are reduced through reductions in fuel use, NO_x emissions will also fall. In addition, NO_x emissions per unit energy are also greater from coal, a carbon-intensive fuel, so that substitution of natural gas for coal, as well as reductions in fuel use, will also result in reductions in NO_x.

We here treat the ancillary reductions in emissions of these gases as reducing the costs of meeting the new national ambient air quality standards (NAAQS). EPA estimated the costs of meeting the new NAAQS in 2010 to be \$9.6 billion per year for ozone, and \$37 billion per year for particulate matter. (These cost estimates may not be additive.)

Although we treat these emission reductions as providing cost-savings, they may be better viewed as providing ancillary environmental and health benefits. An approach that uses ancillary benefits instead of ancillary cost-savings would be

- 1) more direct (and more easily understood),
- 2) potentially less arbitrary, as there is no clear analytic basis for any single cost/ton figure,
- 3) more valid to the extent that the avoided costs wouldn't be incurred anyway, as would be the case if nonattainment continues beyond 2010, as many observers expect.

However, the ancillary benefits approach would likely lead to lower estimates because EPA's incremental monetized benefits of full attainment relative to partial attainment are \$1.6 to \$10 billion annually, of which \$1 to \$6 billion is from the particulate matter standard. I will continue to pursue a benefits estimate, but this work will not be feasible to complete in the next few days.

A key question in estimating cost savings is whether carbon emissions reductions would avoid NAAQS related control measures. NAAQS related control costs would be avoided only if carbon-reduction strategies also reduced emissions that contribute to ozone and PM, *and* these ancillary emissions reductions were included in State Implementation Plans (SIPs) in lieu of reductions from specific new control measures. SIPs that "demonstrate attainment" with the new NAAQS will be due around 2002 for ozone and approximately 2005 for particulate matter. To date EPA has accepted in SIPs only those emission reductions that result from legally enforceable State actions. Thus EPA acceptance of emissions reductions from lower vehicle use resulting from higher fuel prices would be precedent setting, although it is apparently within the Agency's discretion. Since most of the control measures associated with attainment of the NAAQS entail

sunk costs, cost savings may be reduced if controls to reduce carbon emissions occurred after, say, 2005, as may well be the case.

This note addresses ancillary reductions resulting from both reductions in fuel use and fuel switching based on the (incomplete) existing literature. Using conservative assumptions, it concludes that these ancillary benefits would range into the billions of dollars per year, given a carbon price of about \$100/ton. In particular, fuel switching might reduce NOx emission control costs by \$1.1 to \$3.3 billion per year. Reduced vehicle use might reduce NOx and VOC emission control costs by \$.15 billion in the short run to \$.5 billion in the long run. Emissions cuts from other sectors may reduce control costs by between \$.38 and \$1.1 billion per year.

I. Utilities.

Electric utilities are expected to reduce carbon emissions through both reductions in fuel use and fuel switching. EIA has provided us with an estimate of NOx emissions reductions from electric utilities as a result of a \$100/ton carbon tax and a \$200/ton carbon tax. EIA estimate is 3 million tons of NOx emissions per year nation-wide from both fuel use and fuel switching. This estimate is an overstatement because it neglects both the recent PM/ozone standards and EPA's recently proposed OTAG SIP call to reduce NOx. EIA believes this overstatement is a "little" but not "substantial". In addition, the estimate includes emissions reductions in areas where NOx reductions would not otherwise be required, and where NOx does not contribute to significant pollution problems. EIA also estimates slight SO2 emissions reductions, and very large SO2 permit price reductions. In the case of a \$100/ton carbon price, the SO2 price would fall from \$189 to zero, presumably because utilities would switch to natural gas to such an extent that they would no longer operate existing scrubbers. In such a scenario, the cost savings from no longer having to control SO2 are likely to be in the range of several hundred million dollars per year. These estimates are summarized below.

Annual Ancillary Utilities Emission Reductions: Tons and Cost Avoided
Table 1

Carbon Permit Prices	SO ₂ Cost Savings (billions)	NOX		Total Savings (billions)
		Million Tons	Savings (billions)	
\$50/ton	<\$0.5	1.5 ²	\$1.5 to \$4.5	forthcoming

²Based on a linear interpolation that EIA suggests may be inaccurate. New data may be available in the next few days.

\$100/ton	"	3	\$3 to \$9	forthcoming
\$200/ton	"	3.5	\$3.5 to \$10	forthcoming

For nationwide NOx reductions, we use \$1000/ton, and \$3000/ton. The EPA's Regulatory Impact Assessment for the NAAQS, uses \$3,200/ton of NOx as an estimate of average control cost for specified measures in this full attainment scenario (see p. 9-15). The EPA also used a figure of \$10,000/ton that for the incremental cost of the emissions reductions needed to reach full attainment of the new NAAQS, from a baseline of partial attainment. As the values in the NAAQS RIA may be too high for NOx to the extent that ancillary NOx reductions occur in areas that do not significantly contribute to ozone and particulate matter nonattainment, we use lower estimates, which may be conservative. For SO2, which is subject to a national cap, this concern does not apply.

EIA will later provide estimates of reductions in emissions of mercury.

Thus NOx and SO2 emission reductions valued at billions of dollars per year are likely to result from the utilities emissions reductions under the Kyoto accord. In particular a \$100/ton carbon price might yield NOx cost savings of \$3 to \$9 billion per year.

II. Vehicles

NOx and VOC emission reductions from motor vehicles may come from more fuel efficient engines, reduced use, or changes in fleet composition. EPA estimates that 2010 Clean Air Act baseline NOx emissions from mobile sources (including motor vehicles and nonroad emissions sources) in ozone nonattainment areas will be 970 million tons; motor vehicle emissions nation-wide will be 7637 million tons.

Annual Ancillary Emission Reductions: Tons and Cost Avoided
Mobile Sources

Table 2

Area	Thousand tons/year					Cost Avoided per year (billions)	
	NOx	VOCs	Total Emissions	Emissions Reduced		Short Run	Long Run
				SR	LR		
Nation-wide ³	7,637	5,834	13,400	270	940	\$.3 ⁴ to \$.8	\$.9 to \$2.8
Nonattainment areas ⁵	1,433	841	2,300	50	160	\$.15 ⁶	\$.5

Note: Short run (SR) and long run (LR) emissions reductions reflect different price elasticities of demand; the long-run presumes vehicle fleet turn-over.

One recent study suggests that fuel price increases lead to reductions in carbon that are much larger than reductions in other emissions.⁷ Several estimates for four metropolitan areas in California indicate that fuel taxes of \$0.50 per gallon lead to NOx emissions reductions about 40 percent as large as carbon emission reductions. Reductions in VOCs are slightly larger, but for simplicity we ignore this difference. Given these relationships, we can posit a fuel price increase necessary to achieve a carbon emissions reduction, and then scale the NOx and VOC emissions reductions accordingly.

Our point of departure is the price hike needed to meet the Kyoto agreement. If the Kyoto agreement led to a cap and trade system for carbon it might raise gasoline prices by \$100/ton of carbon, or \$0.26 / gallon of refined petroleum products. This is approximately a 20 percent

³Reflects Clean Air Act Baseline, and so does not exclude emission reductions to meet the NAAQS. Sum of nonroad and motor vehicle emissions.

⁴ At \$1000/ton and \$3,000/ton.

⁵Reflects Partial Attainment Scenario baseline. Sum of mobile and non-road emissions.

⁶These reductions are valued at \$3,200/ ton because they are exclusively in nonattainment areas.

⁷See *Transportation Pricing Strategies for California: An Assessment of Congestion, Emissions, Energy and Equity Impacts*, California Environmental Protection Agency, November 1996

price increase. Given a demand elasticity (short-run estimates are around .25, long run estimates as high as .9) consumption should fall by 5 percent in the short run and 18 percent in the long-run. Using the scaling factor of .4 from the California study, NOx and VOC emissions reductions would be 2 percent in the short run and 7 percent in the long run. Applying these percentages to the baseline emissions reported in Table 2 above, the reductions in the short run are 270 and 50 thousand tons per year nationally and in nonattainment areas respectively. Reductions in the long-run are 940 and 160 thousand tons per year nationally and in nonattainment areas respectively.

For simplicity we do not distinguish between the control costs avoided for VOCs and NOx. VOC emissions in EPA's NAAQS RIA were assumed to be controllable at an average marginal cost of \$10,000/ton, but identified measures had an average incremental cost of \$4000/ton, i.e., above the comparable figure of \$3,200 for NOx. We ignore this difference and value both VOCs and NOx at \$3200/ton in nonattainment areas and \$1000 to \$3000 in attainment areas. This range of values is likely to be conservative for nonattainment areas; the extent of conservatism for nation-wide reductions is not clear. Thus the cost avoided from mobile source emissions reductions may be about a half billion dollars per year.

III. Other Sectors

Emissions from sectors other than utilities and mobile sources are summarized below.

Other Sector Emissions
Thousands of tons per year
Table 3

Pollutant	Industrial Point Sources	Area Sources
VOC	2164	7533
NOX	1958	2932
SO2	5990	1518
PM2.5	745	8931
Total	10857	20914
Grand Total	31771	

These emission estimates are not broken down by non-attainment area. However, EPA has argued in the development of its particulate matter NAAQS that fine particulates and their

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precursors move over large distances. In this case as a rough approximation, one might suppose, following the earlier discussion, a 12 percent reduction in all these emissions, i.e., a reduction of about 3800 thousand tons per year. Valuing these at \$1000/ton would give ancillary benefits from these sources nation-wide of \$380 million per year. At a higher value of \$3,000/ton these ancillary benefits would be \$1.1 billion per year.

Appendix 2

Congestion Related Benefits From Fuel Price Increases

The Kyoto agreement will reduce emissions from carbon by about 27 percent ($100/137=.73$). To the extent that these emissions reductions are achieved through fuel price increases, there will be a reduction in the use of motor vehicles, and there may be resulting increases in traffic congestion.

One recent study suggests that fuel price increases would lead to significant reductions in traffic delays.⁸ Several estimates for four metropolitan areas in California indicate that fuel taxes of \$0.50 per gallon in 1991 would have led to reductions in delay of about 7 percent.

A recent report funded by the Department of Transportation put the costs of congestion, relative to free-flowing traffic, at nearly \$60 billion in 1994, up from less than \$40 billion in 1986.⁹ These costs reflect both the dollar value of delays to motorists, and the additional fuel consumption from congestion, although only about a tenth of the total estimated costs are fuel-related.

Thus a \$100/ton carbon tax would lead to a \$0.25/gal fuel tax, and reductions in congestion related delays of about 3.5 percent in the four California cities. If extrapolated nationwide, reductions in congestion related delays, including the fuel savings, would be worth about \$2 billion per year.

These estimates exclude the reductions in inconvenience that travelers would experience as a result of being able to begin trips closer to their preferred travel time. Such reduced inconvenience may be as valuable as the reductions in delay.

⁸See *Transportation Pricing Strategies for California: An Assessment of Congestion, Emissions, Energy and Equity Impacts*, California Environmental Protection Agency, November 1996

⁹ *Urban Roadway Congestion --1982 to 1994* Texas Transportation Institute, Texas Department of Transportation, and the Federal Highway Administration, August 1997

Appendix 3

Improvements in Highway Safety From Fuel Price Increases

Higher fuel prices may improve highway safety. One effect on highway safety is through fewer vehicle miles traveled, although this may be offset somewhat by higher speeds associated with reduced congestion. Another effect is through lighter and potentially less safe vehicles. A third effect is through accelerated fleet turnover. The first effect is likely to be much larger than the other two effects, and forms the basis for our quantitative estimate. We consider each in turn and calculate illustrative magnitudes assuming a \$100/ton carbon price.

I. Vehicle miles traveled.

As higher fuel prices induce people to drive less, the reduction in driving reduces the losses from traffic accidents. To calculate the reduction in driving recall that total vehicle miles traveled (VMT) is identical to gasoline consumption times average miles per gallon (mpg). Thus the elasticity of VMT with respect to price equals the elasticity of gasoline consumption with respect to price *plus* the elasticity of miles per gallon with respect to price. Estimates of these elasticities are presented below:

Estimates of the Elasticity of Vehicle Miles Traveled With Respect to Fuel Price
Table 1

Run	price elasticity of gasoline consumption	price elasticity of miles per gallon	implied price elasticity of VMT
Short Run	-.26	⁰ ₁₀ to .1 to .12	~-.14 to ~-.26
Long Run	-.9	.08 to .21	~-.8 to ~-.7

Source: Dahl and Sterner, "Analysing Gasoline Demand Elasticities: A Survey", Energy Economics, July 1991 for fuel price elasticities. For fuel-efficiency elasticities, see Dahl "Demand for Transportation Fuels: A Survey of Demand Elasticities and Their Components", Division of Economics and Business, Colorado School of Mines, (September), as cited in Khazzoom.

We develop estimates using elasticities of .2 and .7 for the short-run and the long-run.

Thus fuel price increases of \$0.26 /gallon, given a base of \$1.30 / gallon imply VMT declines of nearly 4 percent in the short run. Assuming that fatal accidents are proportional to VMTs, we estimate that such a fuel price increase might prevent about 1700 highway fatalities per year in the short run, or 6000 in the long-run. If these were valued at \$5 million per statistical life, this would amount to savings of \$8.5 billion per year in the short-run or \$30 billion per year in the

¹⁰Price hikes should affect fleet efficiency only to the extent that people buy new cars. Thus in the very short run, the elasticity must be zero.

long-run, when the vehicle fleet has changed. Higher estimates result could result in different assumptions about the likelihood of two-car collisions. A physical model of vehicles as random particles would suggest that 2-vehicle accidents might fall in proportion to the square of the percentage reduction in VMT. In this case the number of fatalities avoided would more than double, to about 3800.

Total private passenger and commercial insurance claims equaled \$83.67 billion dollars in 1996. Of that, \$2.8 billion dollars equaled the liability insurance cost of auto fatalities. Thus the insurance cost of accidents apart from fatalities was \$80.9 billion. If these fell by an amount proportional to VMT, savings in the short run would be about \$3.1 billion per year; in the long run they could reach \$10 billion.

Another estimate of the savings in insurance costs can be derived. A paper by the California Energy Commission estimated that the marginal insurance cost per mile driven, including the fatality cost is \$0.04/mile, on the basis of a simple regression of five years of data for all California counties. The short-run declines in VMT of four percent that are expected to result from a fuel price increase of \$0.26/gallon, correspond to about 88 billion vehicle miles traveled, given the baseline of the 2.3 trillion vehicles miles traveled in 1993. If the marginal cost of 4¢/mile is applied to these miles, the result is about \$3.5 billion per year. This estimate corresponds fairly closely to the \$3.1 billion estimate that assumes that insurance costs are proportional to VMT. (This estimate may be too high because it assumes insurance costs in the rest of the country are as high as in California.)

These estimates should use a baseline of 2010, which will be different because vehicle miles traveled are projected to grow at an annual rate of nearly 2 percent over the next decade. If this growth rate is applied to 15 years, e.g., from 1993 through 2008, then the incremental insurance related cost is \$4.8 billion in the short-run.

One complication in the relationship between VMT and safety is that with less VMT, roads will be less congested and vehicle speeds greater. Higher speeds lead to more severe crashes, given that crashes occur, and since a large share of the economic losses from traffic accidents is fatalities, there may be an offset due to greater fatalities at higher speeds. A California study indicates that a \$.50 /gallon tax lowers travel times (and hence raises average speeds) by about 5 percent, an increase slightly larger than the estimated decrease in VMT from the same tax. To control for these effects requires information about average speed on fatality risk holding road conditions constant. For simplicity we ignore these offsetting effects. (We are pursuing these estimates.)

II. Vehicle weight.

The claim that more efficient vehicles, e.g., those adopted as a result of fuel efficiency

III. Fleet composition.

Higher fuel prices will accelerate the scrapping of older fuel-inefficient vehicles. Newer cars are generally safer than older cars, however, due to air-bags, automatic braking systems, etc. Khazzoom finds that "given these additional characteristics contribute to safety, the inducement to advance replacement brought about by [higher fuel prices] leads to higher levels of fleet safety. This will always be the case, so long as these other characteristics contribute more to safety than the increase fuel efficiency detracts from it, which is very unlikely to be the case in light of our findings above", (p.123). Even if fuel-efficiency gains did come at the expense of safety, these would be offset by the greater safety of a newer vehicle fleet.

IV. Social cost of greater fuel efficiency.

Increases in fuel efficiency are typically costly, holding performance constant. Crandall and Graham estimate that the cost of each mile per gallon improvement is \$1 billion. Given our price increase of \$0.26 and our elasticity of efficiency with respect to price of .1, the projected improvement in miles per gallon is about two percent in the short run. Thus if 23 mpg were taken as the baseline efficiency, and a two percent gain were projected, then the absolute gain in mpg would be about .4 mpg. This gain would cost about \$.4 billion, taking Crandall's estimate of \$1 billion/mpg as given.

standards, tend to be lighter, less crash-worthy, and therefore less safe, is contentious. We develop alternative estimates that reflect this effect and sketch arguments to justify ignoring it.

An article by Crandall and Graham has quantified the effect of weight on safety; they estimate elasticities of fatalities to vehicle weight of 1 to 2. We can not apply this estimate without knowing the effect of higher fuel prices on weight. We have no direct estimates of this relationship, so we use instead an indirect approach based on the relationship between fuel efficiency and prices, and fuel efficiency and vehicle weight. As mentioned above, Dahl reports average estimated elasticities of fuel efficiency with respect to fuel prices of .1 to .12. Crandall *et al.*, (Regulating the Automobile, 1986), report elasticities of miles per gallon with respect to weight of .7 to .8. We assume that the elasticity of weight with respect to fuel price is thus .13 [$.13 = .1/.75$]. Thus an increase in fuel price of \$0.26/gallon or 20 percent leads to a .026 percent reduction in weight, and an increase in fatalities of 2.6 percent to 5.2 percent. These amount to between 1100 and 2300 of the 44400 highway fatalities that occurred in 1993(?). Valuing these at \$5 million each provides for an offset to the ancillary benefits of \$5.5 billion to \$12 billion annually.

More recent research, however, has drawn a different conclusion, which is also pursued here. For example, Dan Khazzoom of RFF¹¹ is quite critical of claims that lighter vehicles are less safe. He argues

- The underlying econometric models of fatalities as a function of vehicle weight neglect vehicle size. This neglect introduces omitted variable bias so that weight appears to have a beneficial effect, although it is size that in fact matters. Models that have included size and weight gave no support for the claim that weight enhances safety, at least in single vehicle crashes.
- The National Research Council, in a study of two car crashes, concluded that the total number of injuries when both cars are made lighter could rise, fall or remain unchanged.
--Although the weight of loaded trucks would not decrease with higher energy prices, passenger cars and light trucks would generally become lighter as a result of higher fuel prices, so this result seems applicable.
- Down-weighting without down-sizing is a plausible response to higher fuel prices and according to Khazzoom, "the more recent evidence does not support the theory that reducing car weight is a detriment to safety." (p.115)

¹¹J. Daniel Khazzoom, "Impact of Pay at the Pump on Safety through Enhanced Vehicle Fuel Safety", *The Energy Journal*, Vol. 18, No.3, 1997, pp.115-133.

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Summary of Cost Analysis Methodology

Since no model exists to handle all of the key parameters of the Kyoto Protocol (sinks, 6 gases, international trading, clean development mechanism), CEA assessed the economic implications of the Protocol by drawing on several available tools. To develop cost estimates, CEA completed four actions:

- **Constructed cost curves:** CEA drew from results from 60+ model runs from the Second Generation Model to develop country- and region-specific cost curves for carbon dioxide abatement. Further, CEA employed an EPA-developed bottom-up analysis for non-CO₂ greenhouse gases for the United States. Integrating these two sets of data generated cost curves for all 6 gases under the Kyoto Protocol.
- **Constructed baselines:** While estimates of 1990 emissions and 2010 projected emissions for carbon dioxide are widely available for most Annex I countries, CEA had to draw from 25+ submitted National Communications to the Framework Convention, official reports of the Framework Convention, and EPA and DOE analyses to construct the appropriate 6 gas baselines. In some cases, extrapolations were made from one country to another based on common characteristics (e.g., GDP, size, etc.). These baseline estimates were used to identify the magnitude of necessary cuts (or paper tons) required of Annex I countries under the Protocol.
- **Identifying market clearing prices for trading blocs:** After developing the baselines and cost curves, CEA identified the market clearing prices for umbrella trading blocs. This required an analysis of different countries' and regions' cost curves to find where abatement costs would be minimized. The cost-effective price then serves as the estimated permit price.
- **Estimating effects on energy prices:** The permit prices were converted to estimated energy price effects based on an analysis available from Treasury.

METHODOLOGY

Trading

Abatement Cost Curves in Industrialized Countries: Marginal cost curves in countries derived from SGM for CO₂ hold for all six gases and sinks for all countries except for the United States (this likely overstates costs of abatement under international trading). The U.S. cost curves are derived from SGM outputs for CO₂ and from EPA/OAR for the other gases and sinks. The cost curve for the other gases and sinks ends at \$70/ton -- we assume that no other reductions are available beyond those achievable at that price.

Intergas Trading: Trading is assumed to occur across all gases and sinks based on 100-year global warming potential.

Trading Blocs: We assessed three different industrialized country trading blocs.

- Annex I implies trading between all Annex I countries (note that in model, some small countries, e.g., New Zealand, Norway, Iceland, are not included).
- Umbrella with Eastern Europe implies trading among all Annex I countries except for the EU.
- Umbrella without Eastern Europe implies trading among all Annex I countries except for the EU and Eastern Europe.

Abatement Cost Curves in Developing Countries: Marginal abatement cost curves for developing countries only include opportunities to reduce carbon dioxide released through energy consumption. Given that numerous options for sequestration projects in these countries exist, these curves overestimate the costs of developing country participation.

AEEI: All of the SGM derived marginal abatement cost curves are based on model outputs assuming an AEEI of 1.0.

Electricity Restructuring: Interagency staff analysis on the Administration's electricity restructuring proposal indicates that carbon reductions resulting from RPS, PBF, and green marketing could range between 13 and 33 MMTCE. For this analysis, we assume the upper end of this range.

Baseline Construction

Carbon Dioxide Emissions: For projections of carbon dioxide, we used the business as usual projections in SGM, with the exception of the U.S., where we employed the more recent AEO98 estimate of 2010 BAU for energy-based CO₂ and the Climate Action Report (U.S. National Communication) projection for non-energy-based CO₂. For the EU, an adjustment was made to the Western Europe value in SGM to reflect the non-participation of Iceland, Norway, Switzerland, and Turkey in the EU bubble. Based on CO₂ emissions estimates from Oak Ridge National Lab, 66.1 MMTCE were deducted from the Western Europe estimate to derive the EU 1990 baseline CO₂ emissions value. For 2010 BAU, 85 MMTCE were deducted (this increase assumes that the four non-participating countries increase their BAU emissions at the same rate as the EU).

Emissions of Other GHG: For projections of the other five categories of greenhouse gases, we used the information provided in the national communications to the Framework Convention on Climate Change.

- Australia: Non-CO₂ GHG comprise 33% of all GHG emissions in 1990. These are assumed to be 25% of all GHG emissions in 2010 based on the trends projected in the U.S. and the EU. The 1990/95 baseline excludes SF₆ and HFCs.
- Austria: For methane and nitrous oxide, 2010 emissions are based on a linear extrapolation from the projected 2000 level using the average annual growth rate over the 1990-2000 period. For the three minor gases, estimated emissions for 1995 and 2010 are based on multiplying 1995 GDP times the emissions/GDP(1995) average ratios derived from the Netherlands, Sweden, and the UK.
- Belgium: For the three minor gases, estimated emissions for 1995 and 2010 are based on multiplying 1995 GDP times the emissions/GDP(1995) average ratios derived from the Netherlands, Sweden, and the UK.
- Canada: For non-CO₂ gases, Canada is assumed to have the same non-CO₂ emissions/total GHG emissions ratio as the US (.17 in 1990/95 and .13 in 2010). Total GHG emissions are then calculated based on historical and projected CO₂ emissions.
- Denmark: For methane and nitrous oxide, 2010 emissions are based on a linear extrapolation from the projected 2005 level using the average annual growth rate over the 2000-2005 period.
- Eastern Europe: For non-CO₂ gases, Eastern European countries are assumed to have the same non-CO₂ emissions/total GHG emissions ratio as the Former Soviet Union (.25 in 1990/95 and .19 in 2010). Total GHG emissions are then calculated based on historical and projected CO₂ emissions.

- Finland: For the three minor gases, estimated emissions for 1995 and 2010 are based on multiplying 1995 GDP times the emissions/GDP(1995) average ratios derived from the Netherlands, Sweden, and the UK.
- Former Soviet Union: Non-CO2 GHG comprise 25% of all GHG emissions in 1990. These are assumed to be 19% of all GHG emissions in 2010 based on the trends projected in the U.S. and the EU. The 1990/95 baseline excludes SF6, PFCs and HFCs.
- France: For the three minor gases, estimated emissions for 1995 and 2010 are based on multiplying 1995 GDP times the emissions/GDP(1995) average ratios derived from the Netherlands, Sweden, and the UK.
- Germany: For methane and nitrous oxide, 2010 emissions are based on a linear extrapolation from the projected 2005 level using the average annual growth rate over the 1990-2005 period. For the three minor gases, estimated emissions for 1995 and 2010 are based on multiplying 1995 GDP times the emissions/GDP(1995) average ratios derived from the Netherlands, Sweden, and the UK.
- Greece: For the three minor gases, estimated emissions for 1995 and 2010 are based on multiplying 1995 GDP times the emissions/GDP(1995) average ratios derived from the Netherlands, Sweden, and the UK.
- Ireland: For the three minor gases, estimated emissions for 1995 and 2010 are based on multiplying 1995 GDP times the emissions/GDP(1995) average ratios derived from the Netherlands, Sweden, and the UK.
- Italy: For the three minor gases, estimated emissions for 1995 and 2010 are based on multiplying 1995 GDP times the emissions/GDP(1995) average ratios derived from the Netherlands, Sweden, and the UK.
- Japan: Non-CO2 GHG comprise 4% of all GHG emissions in 1990. These are assumed to be 3% of all GHG emissions in 2010 based on the trends projected in the U.S. and the EU. The 1990/95 baseline excludes SF6, PFCs, and HFCs.
- Luxembourg: For methane and nitrous oxide, 2010 emissions are based on a linear extrapolation from the projected 2000 level using the average annual growth rate over the 1990-2000 period.
- Portugal: For the three minor gases, estimated emissions for 1995 and 2010 are based on multiplying 1995 GDP times the emissions/GDP(1995) average ratios derived from the Netherlands, Sweden, and the UK.

- Spain: The United Nations has not posted a national communication for Spain on the FCCC webpage. Estimates of the methane and nitrous oxide emissions are based on the average methane/GDP(1995) and nitrous oxide/GDP(1995) ratios for the other 14 EU countries multiplied by Spain's 1995 GDP. Similar calculations were done for the three minor gases, but only based on the average of the Netherlands, Sweden, and the UK's emissions.

Converting to Carbon Equivalence: In all cases where data are provided in tons of gas, or tons of carbon dioxide equivalent, the data were converted to tons of carbon equivalence based on their 100 year time horizon global warming potential (IPCC 1996, p. 121). Some countries aggregated all HFCs into one value (and in some cases, all PFCs into one value). We constructed an HFC weight and a PFC weight based on specific HFC and PFC emissions in the U.S. in 1995. For HFCs, I used the following weight:

$$[2 * \text{GWP}(\text{HFC-134a}) + \text{GWP}(\text{HFC-23})]/3 = 1300$$

HFC-134a was 52% and HFC-23 was 21% of all U.S. HFC emissions in 1995. For PFCs, I used the following weight:

$$[2 * \text{GWP}(\text{CF}_4) + \text{GWP}(\text{C}_6\text{F}_{14})]/3 = 1854$$

CF_4 was about 60% and C_6F_{14} was about 25% of all U.S. PFC emissions in 1995.

Sinks: Sink estimates are subject to significant uncertainty due to ambiguities in the Protocol definition of carbon sinks. The UN webpage provides a data set on carbon sequestration due to land use change and forestry activities. In addition, the compilation and synthesis of national communications document includes projections for some countries. In cases where only 1990 or 2000 data are available, it is assumed that the sequestration will be the same in 2010 for that country. Carbon sink data were available for the following countries: Australia (2000), Austria (1990), Belgium (2010), Bulgaria (2000), Czech Republic (2010), Denmark (2000), Estonia (1990), Finland (2010), France (2000), Germany (2000), Hungary (1990), Ireland (2010), Italy (2000), Japan (2000), Latvia (2000), Liechtenstein (1990), the Netherlands (2010), New Zealand (2010), Norway (2010), Poland (1988), Romania (1989), Russian Federation (1990), Slovakia (2010), Spain (2000), Sweden (2010), Switzerland (2010), United Kingdom (2000), and the U.S. (2010 -- 1997 Climate Action Report).

Given the uncertainties regarding the definition of sinks in the protocol, we are using these estimates without modification. Upon receiving more guidance from State and Agriculture, we may undertake some revisions to appropriately account for the three designated sink categories of afforestation, reforestation, and deforestation.

- EU Bubble Countries: Twelve of the fifteen EU bubble countries provide estimates of carbon sinks for at least some year between 1990 and 2010. The total for these twelve countries was scaled up proportional to the land area under forest cover in the fifteen countries (forest area from FAO statistical webpage).
- Canada: Since Canada has not provided a sinks estimate, we used the sink estimate from Climate Change 1995, Volume II (p. 777). The value of 80 MMTCE is based on the carbon flux estimated during the 1990s for Canada, and reflects sequestration in forest vegetation and forest soils.
- Eastern Europe: All but two countries in Eastern Europe provided carbon sink estimates. Again, we used the scaling procedure employed with the EU to estimate a total for all of Eastern Europe.
- Japan: The national communication estimated removal of carbon through managed forests is approximately 25 MMTCE. The provided data point was not modified for soil sinks, since the communication appears to exclude soils in its sequestration estimate.
- Former Soviet Union: All but two countries of the Former Soviet Union in Annex I provided carbon sink estimates. Again, we used the scaling procedure employed with the EU to estimate a total for all of FSU.
- United States: Three estimates of U.S. sinks in 2010 are used. First, a very conservative estimate of 0 is used simply for the purposes of establishing an upper bound on control costs. Second, 52 MMTCE refers to half of the amount of above ground sequestration and wood in use and landfill sinks estimated in the 1997 Climate Action Report. Third, all of the sequestration in these sink categories is used.

Kyoto Targets: The targets for countries were from the Kyoto Protocol. For the Former Soviet Union, the Russian Federation and Ukraine target of 1990/95 levels was used. For the Eastern Europe region, a target of 1990/95 - 2% was used, because it is roughly the average target for Bulgaria, Croatia, the Czech Republic, Hungary, Poland, Romania, Slovakia, and Slovenia. While several of the Eastern European countries have selected a year or period or years other than 1990 as their base year/period, we continue to use the 1990 SGM estimate for carbon dioxide.

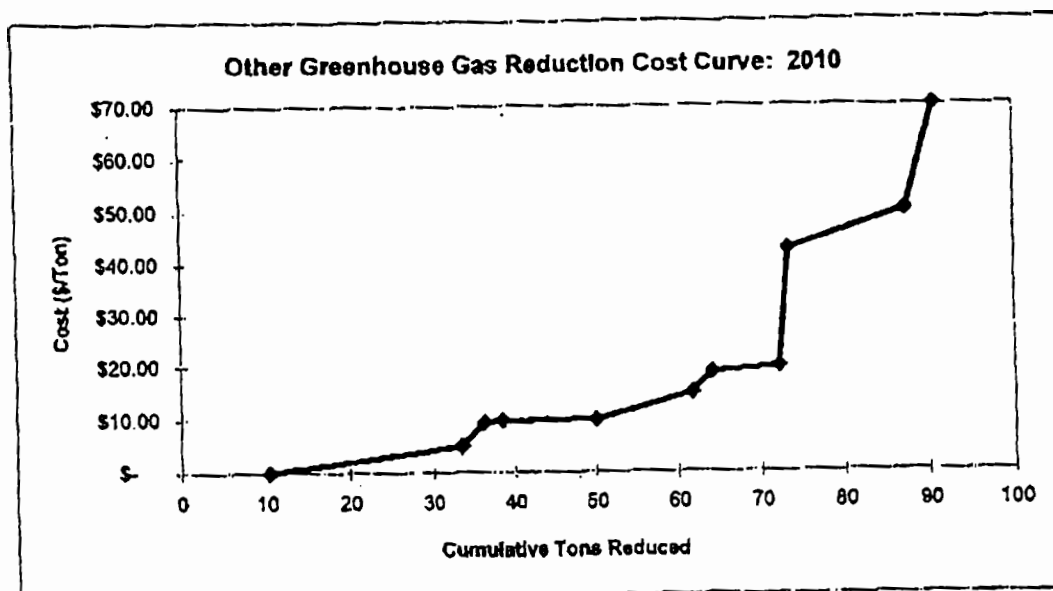
Sources:

IPCC. 1996. Climate Change 1995: The Science of Climate Change. Cambridge, UK: CUP.
First National Communication from Australia
First National Communication from Austria

Second National Communication from Belgium
First National Communication from Denmark
First National Communication from Finland
First National Communication from France
First National Communication from Germany
First National Communication from Greece
First National Communication from Ireland
First National Communication from Italy
First National Communication from Japan
First National Communication from Luxembourg
Second National Communication from the Netherlands
First National Communication from Portugal
First National Communication from the Russian Federation
Second National Communication from Sweden
First National Communication from the United Kingdom
Second National Communication from the United States (Climate Action Report 1997)
Communications from Parties Included in Annex I to the Convention, Addendum
Annual Energy Outlook 1998
Emissions of Greenhouse Gases in the United States 1996
Food and Agriculture Organization Statistical Webpage
Unpublished Cost Curve on Non-CO2 GHG from EPA

Costs of Reducing Non-energy Greenhouse Gas Emissions in 2010

Cumulative Tons Reduced	Cost (\$/ton)	MMTCE CH ₄	MMTCE HFC/PFC	MMTCE Sinks	MMTCE NO _x	Total Tons Reduced
10	\$ -	6.1			4.3	10.4
34	\$ 5.00	1.4	21.8			23.2
36	\$ 8.51			2.7		2.7
38	\$ 9.86			2.2		2.2
50	\$ 10.00	2.5	9.0			11.5
62	\$ 15.00	3.6	8.1			11.7
64	\$ 18.98			2.5		2.5
72	\$ 20.00	2.4	5.6			8.0
73	\$ 42.47			1.2		1.2
87	\$ 50.00	7.8	6.2			14.0
91	\$ 70.00	3.4				3.4
Total by Gas		27.1	50.6	8.7	4.3	
Average Cost = \$18 Per Ton		Total Reduction = 91 MMTCE				
Total Cost = \$1.650 Billion						



Note: \$70/ton was selected as the cutoff because it was the average value from EMF-12

OPTIONAL FORM 99 (7-93)

FAX TRANSMITTAL

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GENERAL SERVICES ADMINISTRATION

Summary of Trading Bloc Scenarios, U.S. Sinks = 50 MMTCE, AEEI = 1.0

Scenario	Permit Price	% Reduced at Home	Total Cost (Capital Transfer)
Annex I	\$44/ton	52%	\$18.4 b (\$12.7 b)
Umbrella (no EU)	\$23/ton	37%	\$10.7 b (\$8.7 b)
Umbrella (no EU, EE)	\$36/ton	47%	\$15.6 b (\$11.4 b)
Umbrella (no EU) + 20% JI	\$17/ton	31%	\$8.2 b (\$7.0 b)
Umbrella (no EU, EE) + 20% JI	\$25/ton	39%	\$11.4 b (\$9.1 b)

Summary of Trading Bloc Scenarios, U.S. Sinks = 50 MMTCE, AEEI = 1.25

Scenario	Permit Price	% Reduced at Home	Total Cost (Capital Transfer)
Annex I	\$31/ton	53%	\$12.9 b (\$8.7 b)
Umbrella (no EU)	\$15/ton	38%	\$6.9 b (\$5.6 b)
Umbrella (no EU, EE)	\$26/ton	49%	\$11.1 b (\$8.0 b)
Umbrella (no EU) + 20% JI	\$12/ton	34%	\$5.7 b (\$4.8 b)
Umbrella (no EU, EE) + 20% JI	\$19/ton	44%	\$8.4 b (\$6.4 b)

- All scenarios assume that the U.S. achieves 8.3% of its domestic reductions through sinks (50 MMTCE), while no other countries reduce through sinks.
- 20% JI scenarios assume that joint implementation is equal to 20% of the gains from ideal worldwide trade.
- The U.S. marginal abatement curve is such that the slope increases after a certain price (that price varies by AEEI) because there are very few inexpensive abatement opportunities among non-CO₂ gases above \$20 (actually, there is a step in the non-CO₂ supply curve, where the next large gain in emissions reductions is at \$50/ton). Thus, the percent abated per \$/ton is higher at lower permit prices than it is at higher permit prices.

Table 1. Summary of Trading Scenarios with Permit Prices around \$15/ton

Trading Scenario	Tech	Sinks	Permit Price	Resource Cost	Value of Transfers	% Reductions in U.S.	Change in Gas Price	Change in Electricity Price
Annex I	1.0	100% reported	\$11/ton	\$5 billion	\$4 billion	19%	+\$0.03/gal	+\$0.002/kWh
Umbrella - EU, EE + 100% JI	1.0	no sinks	\$14/ton	\$8 billion	\$7 billion	19%	+\$0.03/gal	+\$0.002/kWh
Umbrella - EU, EE + key LDCs	1.0	no sinks	\$16/ton	\$9 billion	\$7 billion	22%	+\$0.04/gal	+\$0.002/kWh
Umbrella - EU, EE + Key LDC + 20% JI	1.0	no sinks	\$15/ton	\$8 billion	\$7 billion	20%	+\$0.04/gal	+\$0.002/kWh
Annex I + 20% JI	1.25	50% reported	\$14/ton	\$7 billion	\$5 billion	31%	+\$0.03/gal	+\$0.002/kWh

Table 2. Summary of Trading Scenarios with Permit Prices around \$30/ton

Trading Scenario	Tech	Sinks	Permit Price	Resource Cost	Value of Transfers	% Reductions in U.S.	Change in Gas Price	Change in Electricity Price
Annex I	1.0	50% reported	\$26/ton	\$12 billion	\$9 billion	34%	+\$0.06/gal	+\$0.004/kWh
Umbrella - EU	1.0	no sinks	\$26/ton	\$13 billion	\$11 billion	31%	+\$0.06/gal	+\$0.004/kWh
Annex I + 20% JI	1.0	no sinks	\$36/ton	\$17 billion	\$13 billion	38%	+\$0.09/gal	+\$0.005/kWh
Umbrella - EU, EE + 20% JI	1.0	no sinks	\$30/ton	\$15 billion	\$12 billion	34%	+\$0.07/gal	+\$0.004/kWh
Umbrella - EU, EE	1.25	no sinks	\$31/ton	\$15 billion	\$10 billion	45%	+\$0.07/gal	+\$0.005/kWh

Required Cut Under Kyoto	Sinks	Elect Res	Scenario	Permit Price (92\$)	Domestic Reductions (MMTCE)	Permits Purchased Abroad	US Abatement Cost	US Capital Outflow	US TC (\$b)	TC/GDP
600	0	0	Umb - EU, EE w/ Key LDC	16	130	470	1.0	7.5	8.6	0.000932
600	52	0	Umb - EU, EE w/ Key LDC	9	72	476	0.3	4.3	4.6	0.000502
600	104	0	Umb - EU, EE w/ Key LDC	2	27	469	0.0	0.9	1.0	0.000105
600	0	0	A1 + 20% JI	36	229	371	4.1	13.4	17.5	0.001903
600	52	0	A1 + 20% JI	21	164	384	1.7	8.1	9.8	0.001065
600	104	0	A1 + 20% JI	9	72	424	0.3	3.8	4.1	0.000451
600	0	0	Umb - EU + 20% JI	20	157	443	1.6	8.9	10.4	0.001136
600	52	0	Umb - EU + 20% JI	9	72	476	0.3	4.3	4.6	0.000502
600	104	0	Umb - EU + 20% JI	0	0	496	0.0	0.0	0.0	0
600	0	0	Umb - EU, EE + 20% JI	30	204	396	3.1	11.9	14.9	0.001627
600	52	0	Umb - EU, EE + 20% JI	16	130	418	1.0	6.7	7.7	0.000841
600	104	0	Umb - EU, EE + 20% JI	4	45	451	0.1	1.8	1.9	0.000206
600	0	0	A1 w/ Key LDC + 20% JI	20	157	443	1.6	8.9	10.4	0.001136
600	52	0	A1 w/ Key LDC + 20% JI	12	102	446	0.6	5.4	6.0	0.000649
600	104	0	A1 w/ Key LDC + 20% JI	5	51	445	0.1	2.2	2.4	0.000256
600	0	0	Umb - EU w/ Key LDC + 20% JI	11	95	505	0.5	5.6	6.1	0.000662
600	52	0	Umb - EU w/ Key LDC + 20% JI	5	51	497	0.1	2.5	2.6	0.000284
600	104	0	Umb - EU w/ Key LDC + 20% JI	0	0	496	0.0	0.0	0.0	0
600	0	0	Umb - EU, EE w/ Key LDC + 20% JI	15	123	477	0.9	7.2	8.1	0.000879
600	52	0	Umb - EU, EE w/ Key LDC + 20% JI	9	72	476	0.3	4.3	4.6	0.000502
600	104	0	Umb - EU, EE w/ Key LDC + 20% JI	2	27	469	0.0	0.9	1.0	0.000105

US	Sinks	Elect Res	Scenario	Permit Price (92\$)	Domestic Reductions (MMTCE)	Permits Purchased Abroad	US Abatement Cost	US Capital Outflow	2010 GDP US TC (\$b)	9185 TC/GDP
Required Cut Under Kyoto										
600	0	0	Dom Only	171	600	0	51.3	0.0	51.3	0.005585
600	52	0	Dom Only	146	548	0	40.0	0.0	40.0	0.004355
600	52	33	Dom Only	130	515	0	33.5	0.0	33.5	0.003645
600	104	33	Dom Only	105	463	0	24.3	0.0	24.3	0.002646
600	0	33	Dom Only	155	567	0	43.9	0.0	43.9	0.004784
497	-55	0	10/97 position	148	552	0	40.8	0.0	40.8	0.004447
600	104	0	Dom Only	121	496	0	30.0	0.0	30.0	0.003267
600	0	0	Annex I	48	281	319	6.7	15.3	22.1	0.002401
600	52	0	Annex I	26	187	361	2.4	9.4	11.8	0.001287
600	104	0	Annex I	11	95	401	0.5	4.4	4.9	0.000537
600	0	0	Umb - EU	26	187	413	2.4	10.7	13.2	0.001434
600	52	0	Umb - EU	11	95	453	0.5	5.0	5.5	0.000599
600	104	0	Umb - EU	0	0	496	0.0	0.0	0.0	0
600	0	0	Umb - EU, EE	43	258	342	5.5	14.7	20.3	0.002205
600	52	0	Umb - EU, EE	20	157	391	1.6	7.8	9.4	0.001022
600	104	0	Umb - EU, EE	5	51	445	0.1	2.2	2.4	0.000256
600	0	0	A1 + JI	19	150	450	1.4	8.6	10.0	0.001086
600	52	0	A1 + JI	12	102	446	0.6	5.4	6.0	0.000649
600	104	0	A1 + JI	5	51	445	0.1	2.2	2.4	0.000256
600	0	0	Umb - EU + JI	10	84	516	0.4	5.2	5.6	0.000608
600	52	0	Umb - EU + JI	4	45	503	0.1	2.0	2.1	0.000229
600	104	0	Umb - EU + JI	0	0	496	0.0	0.0	0.0	0
600	0	0	Umb - EU, EE + JI	14	116	484	0.8	6.8	7.6	0.000826
600	52	0	Umb - EU, EE + JI	8	66	482	0.3	3.9	4.1	0.000449
600	104	0	Umb - EU, EE + JI	2	27	469	0.0	0.9	1.0	0.000105
600	0	0	A1 w/ Key LDC	20	150	450	1.5	9.0	10.5	0.001143
600	52	0	A1 w/ Key LDC	12	102	446	0.6	5.4	6.0	0.000649
600	104	0	A1 w/ Key LDC	5	51	445	0.1	2.2	2.4	0.000256
600	0	0	Umb - EU w/ Key LDC	12	102	498	0.6	6.0	6.6	0.000717
600	52	0	Umb - EU w/ Key LDC	5	51	497	0.1	2.5	2.6	0.000284
600	104	0	Umb - EU w/ Key LDC	0	0	496	0.0	0.0	0.0	0

US									2010 GDP (b92\$)	9185
AEI	Kyoto	Sinks (US)	Scenario	US Permit Price	Domestic Reductions	Permits Purchased Abroad	US Abatement Cost	US Capital Outflow	US TC (billions 92\$)	TC/GDP
1	600	50	A1	44	312	288	5.76	12.67	18.44	0.0020
1	600	50	U-EU	23	222	378	1.98	8.69	10.67	0.0012
1	600	50	U-EU,EE	36	282	318	4.18	11.45	15.62	0.0017
1	600	50	U-EU, 20%JI	17	186	414	1.16	7.04	8.19	0.0009
1	600	50	U-EU, EE 20%JI	25	234	366	2.30	9.15	11.45	0.0012
1	600	50	U-EU + Key LDC	10	134	466	0.42	4.66	5.08	0.0006
1	600	50	U-EU,EE + Key LDC	14	166	434	0.81	6.08	6.89	0.0007
1	600	50	A1 + 20%JI	33	267	333	3.58	10.99	14.57	0.0016
1.25	600	50	A1	31	318	282	4.15	8.74	12.90	0.0014
1.25	600	50	U-EU	15	228	372	1.34	5.58	6.92	0.0008
1.25	600	50	U-EU,EE	26	294	306	3.17	7.96	11.13	0.0012
1.25	600	50	U-EU, 20%JI	12	204	396	0.92	4.75	5.68	0.0006
1.25	600	50	U-EU, EE 20%JI	19	264	336	2.03	6.38	8.42	0.0009
1.25	600	50	U-EU + Key LDC	7	146	454	0.34	3.18	3.51	0.0004
1.25	600	50	U-EU,EE + Key LDC	10	185	415	0.68	4.15	4.83	0.0005
1.25	600	50	A1 + 20%JI	24	286	314	2.83	7.54	10.37	0.0011

No sinks assumed for other countries

Trading Bloc	LDC Part	sinks (MMTCE)	Required Emissions Cut (MMTCE)	Permit Price (92\$)	US Red (MMTCE)	domestic abatement TC (\$b)	permits from abroad (MMTCE)	capital transfer (\$b)	TC to US (\$b)	TC/GDP	2010 GDP (\$b)
Domestic	none	0	600	145	600	43.5	0	0.0	43.5	0.47%	9185
		52	600	122	548	33.5	0	0.0	33.5	0.36%	9185
		104	600	99	496	24.7	0	0.0	24.7	0.27%	9185
Annex I	none	0	600	36	285	5.1	315	11.3	16.3	0.18%	9185
		52	600	17	199	1.7	349	6.1	7.8	0.08%	9185
		104	600	7	91	0.3	405	2.7	3.0	0.03%	9185
Umb - EU	none	0	600	18	204	1.8	396	7.1	9.0	0.10%	9185
		52	600	7	95	0.3	453	3.1	3.5	0.04%	9185
		104	600	0	0	0.0	496	0.0	0.0	0.00%	9185
Umb - EU, EE	none	0	600	31	268	4.2	332	10.4	14.6	0.16%	9185
		52	600	14	166	1.1	382	5.2	6.3	0.07%	9185
		104	600	4	56	0.1	440	1.8	1.9	0.02%	9185
Annex I	Jl	0	600	15	175	1.3	425	6.2	7.5	0.08%	9185
		52	600	8	115	0.5	433	3.6	4.1	0.04%	9185
		104	600	4	54	0.1	442	1.8	1.9	0.02%	9185
Umb - EU	Jl	0	600	8	111	0.5	489	4.0	4.4	0.05%	9185
		52	600	4	53	0.1	495	1.9	2.0	0.02%	9185
		104	600	0	0	0.0	496	0.0	0.0	0.00%	9185
Annex I	20% Jl	0	600	27	249	3.4	351	9.5	12.8	0.14%	9185
		52	600	14	172	1.2	376	5.3	6.6	0.07%	9185
		104	600	6	80	0.2	416	2.4	2.7	0.03%	9185

Cuts include paper tons				Cuts include paper tons			
	Cut1	Cut2	Cut3		Cut1	Cut2	Cut3
US	600	548	496	US	600	548	496
EU	277	247	218	EU	277	247	218
FSU	-318	-421	-523	FSU	-318	-421	-523
EE	-108	-112	-116	EE	-108	-112	-116
Aus	21	38	54	Aus	21	38	54
Jap	113	100	88	Jap	113	100	88
Can	62	22	-18	Can	62	22	-18
Annex I	647	422	199	Annex I	647	422	199
Umb-EU	370	175	-19	Umb-EU	370	175	-19
Umb-EU,EE	478	287	97	Umb-EU,EE	478	287	97
Emissions Cuts Under Various Sinks and Scenarios							
	No Sink	Sink1	Sink2	Sink3			
US	600	0	52	104			
EU	277	0	30	59			
FSU	-318	0	103	205			
EE	-108	0	4	8			
Aus	21	0	-17	-33			
Jap	113	0	13	25			
Can	62	0	40	80			

US MAC includes non-CO2 gas curves, EEFSU include paper tons in non-CO2																	
US						Japan		Aus		Canada		FSU					Umb - EU, EE
emissio	price					emissio	price	emissio	price	emissio	price	emissio	price				emissio price
												215	0	318	0	318	0
												318	0	318	0	318	0
												318	0	318	0	318	0
												318	0	318	0	328	0
16	4	29	4	45	4	2	4	2	4	2	4	237	4	340	4	391	4
25	7	35	7	60	7	4	7	3	7	3	7	255	7	358	7	428	7
33	9	36	9	69	9	5	9	3	9	3	9	262	9	365	9	445	9
41	11	52	11	93	11	6	11	4	11	4	11	271	11	374	11	481	11
67	16	62	16	129	16	9	16	5	16	6	16	294	16	397	16	546	16
72	17	63	17	135	17	9	17	6	17	7	17	306	17	409	17	566	17
92	21	72	21	164	21	12	21	7	21	8	21	325	21	428	21	619	21
99	23	72	23	171	23	12	23	7	23	8	23	321	23	424	23	622	23
113	26	72	26	185	26	14	26	8	26	9	26	342	26	445	26	661	26
115	26	72	26	187	26	14	26	8	26	10	26	344	26	447	26	666	26
140	32	72	32	212	32	17	32	9	32	11	32	359	32	462	32	711	32
165	38	72	38	237	38	20	38	10	38	13	38	383	38	486	38	766	38
177	41	73	41	250	41	21	41	11	41	13	41	382	41	485	41	780	41
234	57	88	57	322	57	28	57	14	57	18	57	432	57	535	57	917	57
277	70	91	70	368	70	34	70	16	70	21	70	462	70	565	70	1004	70
282	72	91	72	373	72	34	72	16	72	22	72	465	72	568	72	1013	72
330	89	91	89	421	89	41	89	19	89	24	89	494	89	597	89	1102	89
380	109	91	109	471	109	47	109	22	109	29	109	529	109	632	109	1201	109
514	173	91	173	605	173												

	Umb - EU			WEur		EEur					EuropeOnly			ANnex I			China
	emissio	price		emissio	price	emissio	price				emissio	price		emissio	price		emissio
	426	0				78	0	108	0		108	0		426	0		
	426	0				108	0	108	0		108	0		426	0		
	426	0				108	0	108	0		108	0		426	0		
	436	0				108	0	108	0		108	0		436	0		
	502	4		9	4	81	4	111	4		120	4		511	4		64
	541	7		15	7	83	7	113	7		128	7		556	7		102
	559	9		19	9	84	9	114	9		133	9		578	9		129
	597	11		23	11	86	11	116	11		139	11		620	11		
	665	16		34	16	89	16	119	16		153	16		699	16		207
	686	17		39	17	90	17	120	17		159	17		725	17		
	742	21		48	21	93	21	123	21		171	21		790	21		
	745	23		48	23	93	23	123	23		171	23		793	23		
	787	26		58	26	96	26	126	26		184	26		845	26		
	792	26		58	26	96	26	126	26		184	26		850	26		304
	841	32		68	32	100	32	130	32		198	32		909	32		343
	900	38		82	38	104	38	134	38		216	38		982	38		386
	915	41		83	41	105	41	135	41		218	41		998	41		409
	1063	57		116	57	116	57	146	57		262	57		1179	57		516
	1159	70		138	70	125	70	155	70		293	70		1297	70		
	1169	72		140	72	126	72	156	72		296	72		1309	72		
	1268	89		160	89	136	89	166	89		326	89		1428	89		
	1381	109		190	109	150	109	180	109		370	109		1571	109		

[illegible]

Umb - EU + Key LDC		Umb - EU, EE + Key LDC		A1 + 20%JI		Umb - EU +20% JI		Umb - EU, EE +20% JI		A1, Key LDC +20% JI	
emissions price		emissions price		emissions price		emissions price		emissions price		emissions price	
426	0	318	0	426	0	426	0	318	0	426	0
426	0	318	0	426	0	426	0	318	0	426	0
426	0	318	0	426	0	426	0	318	0	426	0
436	0	328	0	436	0	436	0	328	0	436	0
579	4	468	4	529	4	520	4	409	4	590	4
664	7	551	7	584	7	569	7	456	7	683	7
714	9	600	9	613	9	594	9	480	9	737	9
917	16	798	16	757	16	723	16	604	16	959	16
1169	26	1043	26	938	26	880	26	754	26	1239	26
1267	32	1137	32	1009	32	941	32	811	32	1350	32
1382	38	1248	38	1096	38	1014	38	880	38	1481	38

[illegible]

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Year	Country	MMTCO2	MMTCE	
2000	Australia	121.9	33.24545	
1990	Austria	-13.3	-3.62727	
2010	Belgium	-2.1	-0.57273	
2000	Bulgaria	-5.8	-1.58182	
	Canada		0	
	Croatia		0	
2010	Czech Rep	-5	-1.36364	
2000	Denmark	-2.6	-0.70909	
1990	Estonia	1.8	0.490909	
2010	Finland	-15	-4.09091	
2000	France	-39	-10.6364	
2000	Germany	-20	-5.45455	
	Greece		0	
1990	Hungary	-4.5	-1.22727	
	Iceland		0	
2010	Ireland	-9.7	-2.64545	
2000	Italy	-46.7	-12.7364	
2000	Japan	-92	-25.0909	
2000	Latvia	-8.9	-2.42727	
1990	Lichtenstein	-0.022	-0.006	
	Lithuania		0	
	Luxembourg		0	
	Monaco		0	
2010	Netherland	-1.7	-0.46364	
2010	New Zealan	-21.2	-5.78182	
2010	Norway	-14.8	-4.03636	
1988	Poland	-1.4	-0.38182	
	Portugal		0	
1989	Romania	-2.9	-0.79091	
1990	Russian Fe	-734	-200.182	
2010	Slovakia	-8	-2.18182	
	Slovenia		0	
2000	Spain	-25.7	-7.00909	
2010	Sweden	-22	-6	
2010	Switzerland	-5.1	-1.39091	
	Ukraine		0	
2000	United King	-9.2	-2.50909	
	USA		0	
	EC15		-56.4545	-59.2773
	FSU		-202.118	-204.948
	EEur		-7.52727	-7.83664
	Australia			33.24545
	Japan			-25.0909
	Canada			-118.508

Country	1990						1995						2010					
	Energy MMT	Forest MMT	Methane	Nitrous Oxide	HFC/PFC /SF6	Total MMT	Energy MMT	Forest MMT	Methane	Nitrous Oxide	HFC/PF C/SF6	Total MMT	Energy MMT	Forest MMT	Methane	Nitrous Oxide	HFC/PFC /SF6	Total
AUSTRALIA	74	33	36	5	1	148	88	28	40	0	0.4	157	102	12	47	0	3	164
NEW ZEALAND	7	-6	11	4	0	17	7	-4	11	4	0	19	10	-6	11	4	0.2	19
JAPAN	307	-23	9	9	12	314	332	-25	9	9	22	348	369	-15	9	11	40	413
U.S.A.	1353	-282	170	36	24	1301	1422	-251	177	37	40	1425	1669	-227	152	34	91	1719
CANADA	127	0	21	8	2	158	136	0	25	9	2	173	150	0	25	7	5	187
BULGARIA	23	-2	8	0	0	28	17	-1	7	0	0	23	28	-1	7	0	1	34
ESTONIA	10.3	0.5	4			15	8		4	0	0	12	9		4			13
HUNGARY	19	-1	3	0	0	21	16	-1	3	0	0	18	19	-1	3	0	2	23
SLOVAKIA	16	-1	3	1	0	19	13	-1	2	1	0	15	15	-2	2	1	0	16
CZECH REPUBLIC	45	-1	6	2	0	52	35	-1	5	2	0	40	45	-1	6	2	2	55
POLAND	108	-0.4	32	6	0	146	102	0.0	30	6	0	139	116	0	34	6	2	158
ROMANIA	47	-1	11	0	0	57	34	0	8	0	0	42	47	0	0	0	1	48
RUSSIA	1029	-107	180	0	0	1102	773	-160	127	0	10	750	933	-150	130	0	53	966
UKRAINE	194	-14	68	4		251	116	-18	48	2	1	148	163	-19	50	4	4	201
ICELAND	1	0	0	0	0	1	1	0	0	0	0	1	1	0	0	0	0	1
MALTA	1	0	0	0	0	1	1	0	0	0	0	1	1	0	0	0	0	1
NORWAY	10	-3	3	1	1	12	10	-4	3	1	1	12	13	-4	2	1	1	14
SWITZERLAND	13	-1	2	1	0	14	12	-1	2	1	0	14	13	-1	1	1	1	15
Non-EU Countries	3382	-409	566	76	42	3657	3123	-439	501	72	77	3334	3703	-416	484	72	205	4047
AUSTRIA	16	-4	4	1	0	17	17	-4	4	1	0	18	20	-4	0	1	1	18
BELGIUM	33	-1	4	3	0.1	40	33	-1	4	3	0	40	35	-1	0	3	0	37
DENMARK	16	-1	2	0	0	17	17	0	2	0	0	19	14	-1	2	1	0	16
FINLAND	15	-7	2	2	0	11	15	-4	2	2	0	15	17	-6	1	2	1	15
FRANCE	104	-9	20	16	1	133	105	-13	19	15	0	127	113	-13	22	0	0	122
GERMANY	277	-8	38	20	2	328	243	-8	32	19	3	289	233	-5	18	14	1	261
GREECE	22	0	0	0	0	22	21	0	2	0	0	23	30	0	2	0	0	32
IRELAND	8	-1	5	3	0	15	9	-2	5	2	0	15	11	-2	6	2	0	17
ITALY	112	-10	22	0	0	124	116	-12	19	0	0	123	150	-13	13	0	0	150
LUXEMBOURG	3	0	0	0	0	3	3	0	0	0	0	3	1	0	0	0	0	1
NETHERLANDS	47	0	7	4	2	61	50	0	7	5	3	65	46	0	4	6	1	57
SWEDEN	16	-9	2	1	0.4	10	16	-8	2	1	0	11	17	-6	2	1	1	15
PORTUGAL	11	0	1	0	0	12	0	0	0	0	0	0	21	0	0	0	0	21
SPAIN	61	-1	12	0	0	72	0	0	0	0	0	0	94	-1	0	0	0	93
U.K.	158	5	30	10	1	205	148	3	26	8	1	186	162	2	19	4	1.7	190
European Union	883	-42	147	58	.7	1070	776	-44	120	55	8	933	944	-46	89	34	6	1044
Total	4264	-451	713	135	49	4726	7039	-926	1125	201	162	7601	8370	-881	1056	178	416	9138

Estimates in this table come from 1st and 2nd national communications, EIA and IEA data, US Country Studies, EPA forecasts, and unpublished draft sources.

The HFC and PFC numbers in the table probably underestimate these emissions for some countries, particularly the EU countries, due to failure to report in national communications. The US EPA/DOE estimates aggregate Annex I emission estimates for the HFC/PFC/SF6 category are as follows:

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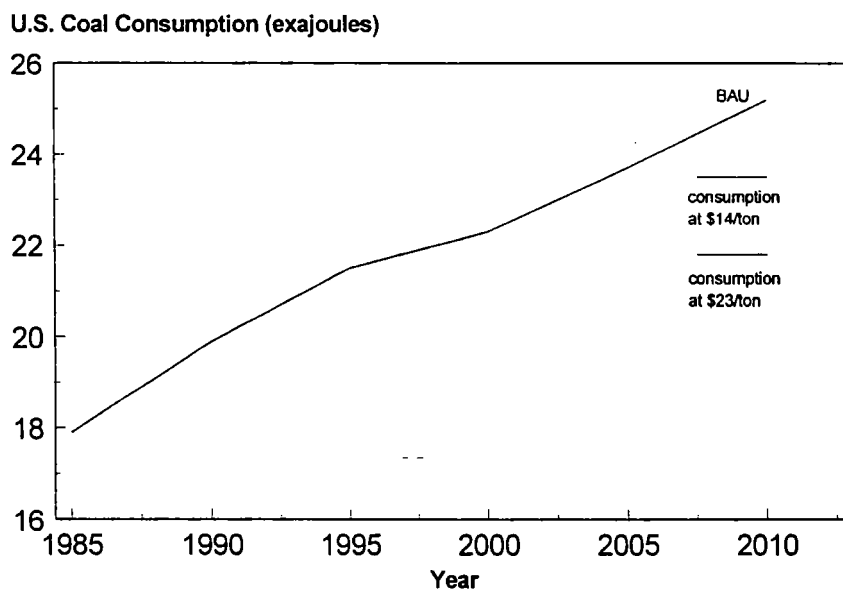
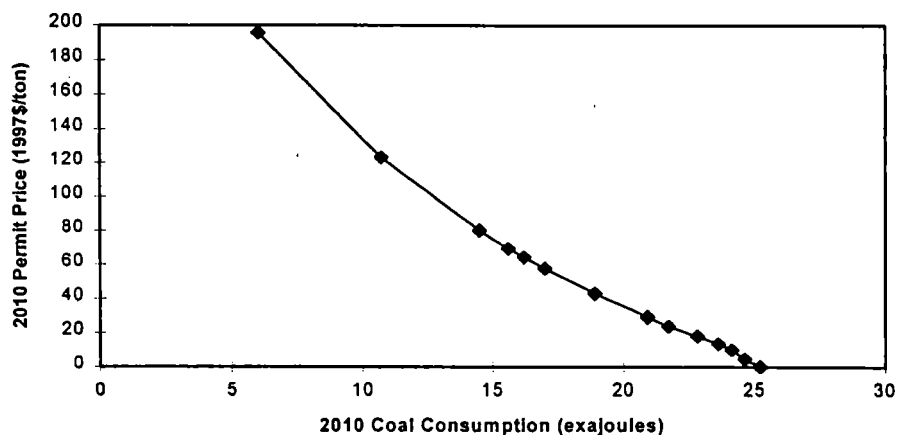
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EIA -- Carbon Emissions from Energy

Carbon Emissions by Region (Million Metric Tons)

	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012
USA	1,344	1,330	1,348	1,374	1,397	1,424	1,448	1,471	1,495	1,519	1,543	1,562	1,581	1,601	1,620	1,639	1,656	1,672	1,689	1,706	1,722	1,738	1,753
CANADA	137	131	135	137	140	143	146	150	153	156	160	162	165	167	170	172	174	176	178	180	182	184	186
JAPAN	308	321	324	335	354	361	369	377	385	393	401	407	413	419	425	432	438	445	452	459	466	471	477
Australia/NZ	100	99	98	97	95	112	112	113	113	114	114	115	117	118	120	121	122	123	125	126	127	128	129
UK	173	175	166	167	168	170	170	171	172	173	174	175	176	178	179	180	182	183	184	186	187	189	191
FRANCE	113	119	116	110	106	110	111	112	114	115	117	119	121	123	125	128	130	132	134	136	138	141	143
GERMANY	279	263	260	254	244	241	245	250	254	258	262	265	267	270	272	275	277	279	281	283	284	287	290
ITALY	118	120	120	114	114	124	125	125	126	126	126	128	129	131	132	134	135	136	138	139	141	142	143
NETHERLANDS	61	62	61	62	63	67	67	67	67	67	67	68	68	69	70	70	71	71	72	72	72	73	73
OTHER EU	272	285	285	284	292	303	309	316	322	329	335	340	345	350	355	360	365	370	375	380	385	391	397
EU Sub-total	1,016	1,025	1,009	992	987	1,014	1,028	1,041	1,054	1,068	1,081	1,094	1,107	1,120	1,134	1,147	1,159	1,171	1,184	1,196	1,208	1,222	1,236
FSU	1,029	946	905	814	711	653	669	685	701	717	733	747	761	774	788	802	816	830	844	858	872	884	897
EASTERN EUROPE	309	277	254	245	239	240	248	256	263	271	278	281	284	287	290	293	296	298	301	303	306	308	311
FSU/EE Subtotal	1,339	1,224	1,159	1,058	949	893	917	940	964	988	1,012	1,028	1,045	1,062	1,078	1,095	1,112	1,128	1,145	1,161	1,178	1,193	1,207
Baseline	1,339	1,339	1,339	1,339	1,339	1,339	1,339	1,339	1,339	1,339	1,339	1,339	1,339	1,339	1,339	1,339	1,339	1,339	1,339	1,339	1,339	1,339	1,339
Total Annex I	4,244	4,130	4,073	3,994	3,922	3,947	4,019	4,092	4,165	4,238	4,310	4,369	4,428	4,487	4,546	4,605	4,661	4,717	4,773	4,828	4,884	4,936	4,989

Coal Consumption and the Carbon Permit Price in SGM, 2010



Source: SGM

- SGM simulations project coal consumption to amount to approximately 25 exajoules in 2010 under business as usual. With a permit price of \$14/ton, coal consumption would decline about 7% below the BAU level. At \$23/ton of carbon, coal consumption would be about 13% below BAU. If all emissions reductions occurred at home, coal consumption would be about 75% below BAU.
- Under BAU, the average minemouth coal price is projected to be \$15.32 per short ton (1997\$, AEO98). At a \$14/ton permit, coal would cost \$22.89/short ton (~50% above BAU), and at a \$23/ton permit, coal would cost \$27.76/short ton (~80% above BAU).

The Costs of Kyoto

case	permit price	domestic reductions	domestic TC	permits purchased abroad	capital transfer	TC to US	TC/GDP
no trading	\$161	490	\$39.4b	0	0	\$39.4b	0.43%
Annex I	\$25	110	\$1.4b	380	\$9.5b	\$10.9b	0.12%
Umbrella w/ Ern Europe	\$12	48	\$0.3b	442	\$5.3b	\$5.6b	0.06%
Umbrella w/o Ern Europe	\$19	82	\$0.8b	408	\$7.8b	\$8.6b	0.09%

Trading Assumptions:

- Marginal cost curves in countries derived from SGM for CO2 hold for all six gases (this likely overstates costs of abatement).
- Trading is assumed to occur across gases based on GWP.
- EEFSU countries can sell a lot more than their differential in 1990/95 GHG emissions and their 2010 projected emissions because of substantial sequestration.
- Annex I implies trading between all Annex I countries (note that in model, some small countries, e.g., New Zealand, Norway, Iceland, are not included).
- Umbrella with Eastern Europe implies trading among all Annex I countries except for the EU.
- Umbrella without Eastern Europe implies trading among all Annex I countries except for the EU and Eastern Europe.

\$5 m m1 off vif deforestation
over budget penalty 2008-2012

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Oil Prices: 2010, 2025, 2050	Conc. (ppmv) in 2050 (Deviation from BAU)	Conc. (ppmv) in 2100 (Deviation from BAU)	Year Conc. (550 ppmv) Reaches 2x Pre-Ind. Level (Deviation from BAU)	Change in Temp. (deg. C) from 1990 in 2050 (Deviation from BAU)	Change in Temp. (deg. C) from 1990 in 2100 (Deviation from BAU)	Emission s Peak, mmtce (year)	Year Returns to 1990	Intl. Trade of Permits, 2010, 2050 (mmtce)	Date Received Run	File
	502	711	2065	1.06	2.36	no peak: 2245 (2050)	n/a	n/a	08/21/97	aldy/sgmrns/c ea90_~1.xls
	485 (-17)	658 (-53)	2072 (+7)	0.99 (-0.07)	2.16 (-0.20)	1637 (2005)	2010	n/a	08/21/97	aldy/sgmrns/c ea90_~2.xls
	485 (-17)	658 (-53)	2072 (+7)	0.99 (-0.07)	2.16 (-0.20)	no peak: 1714 (2050)	never returns	-202, -364	08/21/97	aldy/sgmrns/c ea90_~2.xls
	485 (-17)	658 (-53)	2072 (+7)	0.99 (-0.07)	2.16 (-0.20)	no peak: 2102 (2050)	never returns	-313, -752	08/21/97	aldy/sgmrns/c ea90_~2.xls
	481 (-21)	648 (-63)	2074 (+9)	0.98 (-0.08)	2.12 (-0.24)	1637 (2005)	never returns	n/a	08/21/97	aldy/sgmrns/c ea95_~1.xls
	481 (-21)	648 (-63)	2074 (+9)	0.98 (-0.08)	2.12 (-0.24)	1637(200	never returns	36, -122	08/21/97	aldy/sgmrns/c ea95_~1.xls
	481 (-21)	648 (-63)	2074 (+9)	0.98 (-0.08)	2.12 (-0.24)	no peak: 2073 (2050)	never returns	-131, -593	08/21/97	aldy/sgmrns/c ea95_~1.xls
	481 (-21)	653 (-58)	2074 (+9)	0.97 (-0.09)	2.11 (-0.25)	1637 (2005)	2010	n/a	08/21/97	aldy/sgmrns/c ea90m_~1.xls
	481 (-21)	653 (-58)	2074 (+9)	0.97 (-0.09)	2.11 (-0.25)	1637 (2005)	never returns	-180, -332	08/21/97	aldy/sgmrns/c ea90m_~1.xls
	481 (-21)	653 (-58)	2074 (+9)	0.97 (-0.09)	2.11 (-0.25)	no peak: 2060 (2050)	never returns	-332, -845	08/21/97	aldy/sgmrns/c ea90m_~1.xls
	489 (-13)	653 (-58)	2072 (+7)	1.01 (-0.05)	2.15 (-0.21)	1807 (2015)	2040	n/a	08/21/97	aldy/sgmrns/c ea90_~1.xls
	489 (-13)	653 (-58)	2072 (+7)	1.01 (-0.05)	2.15 (-0.21)	1807 (2015)	never returns	0, -367	08/21/97	aldy/sgmrns/c ea90_~1.xls
	489 (-13)	653 (-58)	2072 (+7)	1.01 (-0.05)	2.15 (-0.21)	no peak: 2102 (2050)	never returns	0, -752	08/21/97	aldy/sgmrns/c ea90_~1.xls
	n/a	n/a	n/a	n/a	n/a	no peak: 2066 (2050)	n/a	n/a	08/26/97	aldy/markal~1/ 8_26run1.wk4
	n/a	n/a	n/a	n/a	n/a	1586 (2005)	2010	n/a	08/26/97	aldy/markal~1/ 8_26run1.wk4
	n/a	n/a	n/a	n/a	n/a	1600 (2005)	n/a	n/a	08/26/97	aldy/markal~1/ 8_26run1.wk4
	n/a	n/a	n/a	n/a	n/a	1749 (2010)	2020	n/a	08/26/97	aldy/markal~1/ 8_26run1.wk4
	n/a	n/a	n/a	n/a	n/a	1767 (2015)	2040*			aldy/markal~1/ 8_26run1.wk4

ID	Scenario	Model	Modelers	Target	Timetable	Trading	Permit Allocation	Revenue Recycling	Burden Sharing	BAU Emissions Path Assumption	Paper Tons or Corresponding Reductions	AEEI	Ramp-up	Time Path	Outputs PDV (5%; 2000-2050) Foregone Consumption	GDP in 2010 (deviation from BAU)
SGM1	BAU	SGM, MAGICC	Battelle	n/a	n/a	n/a	n/a	n/a	n/a	IAT	n/a	1.0	n/a	-->2050, -->2100 (climate)	\$121,650 billion (BAU consumption)	\$9,185 billion (BAU GDP)
SGM9	-10% of 1990 in 2010	SGM, MAGICC	Battelle	-10% 1990 emissions level	stabilize in 2010	Annex I	auction	lump-sum	no LDC part.	IAT	PT	1.0	no	-->2050, -->2100 (climate)	\$485 billion	\$9,155 billion (-\$30 billion)
SGM8	-10% of 1990 in 2010	SGM, MAGICC	Battelle	-10% 1990 emissions level	stabilize in 2010	domestic only	auction	lump-sum	no LDC part.	IAT	PT	1.0	no	-->2050, -->2100 (climate)	\$980 billion	\$9,149 billion (-\$36 billion)
SGM10	-10% of 1990 in 2010	SGM, MAGICC	Battelle	-10% 1990 emissions level	stabilize in 2010	worldwide	auction	lump-sum	no LDC part.	IAT	PT	1.0	no	-->2050, -->2100 (climate)	\$50 billion	\$9,171 billion (-\$14 billion)
SGM18	1990 in 2010	SGM, MAGICC	Battelle	1990 emissions level	stabilize in 2010	Annex I	auction	lump-sum	LDC stabilizes at 2030 in 2030	IAT	PT	1.0	in 2005	-->2050, -->2100 (climate)	\$255 billion	\$9,172 billion (-\$13 billion)
SGM21	1990 in 2010	SGM, MAGICC	Battelle	1990 emissions level	stabilize in 2010	Annex I	auction	lump-sum	LDC BAU to 2030, equal per capita in 2050	IAT	PT	1.0	in 2005	-->2050, -->2100 (climate)	\$260 billion	\$9,172 billion (-\$13 billion)
SGM3	1990 in 2010	SGM, MAGICC	Battelle	1990 emissions level	stabilize in 2010	Annex I	auction	lump-sum	no LDC part.	IAT	PT	1.0	no	-->2050, -->2100 (climate)	\$225 billion	\$9,172 billion (-\$13 billion)
SGM20	1990 in 2010	SGM, MAGICC	Battelle	1990 emissions level	stabilize in 2010	domestic only	auction	lump-sum	LDC BAU to 2030, equal per capita in 2050	IAT	PT	1.0	in 2005	-->2050, -->2100 (climate)	\$740 billion	\$9,164 billion (-\$21 billion)
SGM17	1990 in 2010	SGM, MAGICC	Battelle	1990 emissions level	stabilize in 2010	domestic only	auction	lump-sum	LDC stabilizes at 2030 in 2030	IAT	PT	1.0	in 2005	-->2050, -->2100 (climate)	\$740 billion	\$9,164 billion (-\$21 billion)
SGM2	1990 in 2010	SGM, MAGICC	Battelle	1990 emissions level	stabilize in 2010	domestic only	auction	lump-sum	no LDC part.	IAT	PT	1.0	no	-->2050, -->2100 (climate)	\$665 billion	\$9,165 billion (-\$20 billion)
SGM22	1990 in 2010	SGM, MAGICC	Battelle	1990 emissions level	stabilize in 2010	worldwide	auction	lump-sum	LDC BAU to 2030, equal per capita in 2050	IAT	PT	1.0	in 2005	-->2050, -->2100 (climate)	\$25 billion	\$9,180 billion (-\$5 billion)
SGM19	1990 in 2010	SGM, MAGICC	Battelle	1990 emissions level	stabilize in 2010	worldwide	auction	lump-sum	LDC stabilizes at 2030 in 2030	IAT	PT	1.0	in 2005	-->2050, -->2100 (climate)	\$20 billion	\$9,180 billion (-\$5 billion)
SGM4	1990 in 2010	SGM, MAGICC	Battelle	1990 emissions level	stabilize in 2010	worldwide	auction	lump-sum	no LDC part.	IAT	PT	1.0	no	-->2050, -->2100 (climate)	\$5 billion	\$9,180 billion (-\$5 billion)

ID	Permit Prices: 2010	Permit Prices: 2025	Permit Prices: 2050	Conc. (ppmv) in 2050 (Deviation from BAU)	Conc. (ppmv) in 2100 (Deviation from BAU)	Year Conc. (550 ppmv) Reaches 2x Pre-Ind. Level (Deviation from BAU)	Change in Temp. (deg. C) from 1990 in 2050 (Deviation from BAU)	Change in Temp. (deg. C) from 1990 in 2100 (Deviation from BAU)	Emissions Peak, mmtce (year)	Year Returns to 1990	Intl. Trade of Permits, U.S., 2010 (MMTCE), (\$)	Intl. Trade of Permits, U.S., 2050 (MMTCE), (\$)	Date Received Run	File (h:\jaldy)
SGM1	\$0	\$0	\$0	502	711	2065	1.06	2.36	no peak: 2245 (2050)	n/a	n/a	n/a	08/21/97	cea90_~1.xls
SGM9	\$91	\$137	\$238	481 (-21)	645 (-66)	2074 (+9)	0.97 (-0.09)	2.11 (-0.25)	1637 (2005)	never returns	-180, (-\$16.4 billion)	-332, (-\$79.0 billion)	08/21/97	cea90m_~1.xls
SGM8	\$175	\$304	\$924	481 (-21)	645 (-66)	2074 (+9)	0.97 (-0.09)	2.11 (-0.25)	1637 (2005)	2010	n/a	n/a	08/21/97	cea90m_~1.xls
SGM10	\$33	\$37	\$45	481 (-21)	645 (-66)	2074 (+9)	0.97 (-0.09)	2.11 (-0.25)	no peak: 2060 (2050)	never returns	-332, (-\$11.0 billion)	-845, (-\$38.0 billion)	08/21/97	cea90m_~1.xls
SGM18	\$39	\$83	\$150	478 (-24)	565 (-146)	2091 (+26)	0.96 (-0.10)	1.82 (-0.54)	no peak: 1712 (2050)	never returns	-209, (-\$8.2 billion)	-362, (-\$54.3 billion)	08/27/97	case2.xls, 9/4/97 fax
SGM21	\$39	\$83	\$150	n/a	n/a	n/a	n/a	n/a	no peak: 1712 (2050)	never returns	-209, (-\$8.2 billion)	-362, (-\$54.3 billion)	08/27/97	case3.xls
SGM3	\$42	\$84	\$149	486 (-16)	655 (-56)	2072 (+7)	0.99 (-0.07)	2.15 (-0.21)	no peak: 1714 (2050)	never returns	-202, (-\$8.5 billion)	-364, (-\$54.2 billion)	08/21/97	cea90_~2.xls
SGM20	\$108	\$188	\$582	n/a	n/a	n/a	n/a	n/a	1550 (2000)	2010	n/a	n/a	08/27/97	case3.xls
SGM17	\$108	\$188	\$582	476 (-26)	564 (-147)	2092 (+27)	0.95 (-0.11)	1.82 (-0.54)	1550 (2000)	2010	n/a	n/a	08/27/97	case2.xls, 9/4/97 fax
SGM2	\$110	\$191	\$582	485 (-17)	658 (-53)	2072 (+7)	0.99 (-0.07)	2.16 (-0.20)	1637 (2005)	2010	n/a	n/a	08/21/97	cea90_~2.xls
SGM22	\$15	\$23	\$0	n/a	n/a	n/a	n/a	n/a	no peak: 2239 (2050)	never returns	n/a	n/a	08/27/97	case3.xls
SGM19	\$15	\$23	\$110	478 (-24)	565 (-146)	2091 (+26)	0.96 (-0.10)	1.82 (-0.54)	1883 (2040)	never returns	-316, (-\$4.7 billion)	-500, (-\$55.0 billion)	08/27/97	case2.xls, 9/4/97 fax
SGM4	\$16	\$23	\$32	486 (-16)	655 (-56)	2072 (+7)	0.99 (-0.07)	2.15 (-0.21)	no peak: 2102 (2050)	never returns	-313, (-\$5.0 billion)	-752, (-\$24.1 billion)	08/21/97	cea90_~2.xls

ID	Scenario	Model	Modelers	Target	Timetable	Trading	Permit Allocation	Revenue Recycling	Burden Sharing	BAU Emissions Path Assumption	Paper Tons or Corresponding Reductions	AEEI	Ramp-up	Time Path	PDV (5%; 2000-2050) Foregone Consumption	GDP in 2010 (deviation from BAU)
SGM36	1990 in 2020	SGM, MAGICC	Battelle	1990 emissions level	stabilize in 2020	Annex I	auction	lump-sum	no LDC part.	IAT	PT	1.0	yes	-->2050, -->2100 (climate)	\$195 billion	\$9,179 billion (-\$6 billion)
SGM35	1990 in 2020	SGM, MAGICC	Battelle	1990 emissions level	stabilize in 2020	domestic only	auction	lump-sum	no LDC part.	IAT	PT	1.0	yes	-->2050, -->2100 (climate)	\$660 billion	\$9,172 billion (-\$13 billion)
SGM37	1990 in 2020	SGM, MAGICC	Battelle	1990 emissions level	stabilize in 2020	worldwide	auction	lump-sum	no LDC part.	IAT	PT	1.0	yes	-->2050, -->2100 (climate)	-\$1 billion	\$9,183 billion (-\$2 billion)
SGM6	1995 in 2010	SGM, MAGICC	Battelle	1995 emissions level	stabilize in 2010	Annex I	auction	lump-sum	no LDC part.	IAT	CR	1.0	no	-->2050, -->2100 (climate)	\$380 billion	\$9,175 billion (-\$10 billion)
SGM5	1995 in 2010	SGM, MAGICC	Battelle	1995 emissions level	stabilize in 2010	domestic only	auction	lump-sum	no LDC part.	IAT	CR	1.0	no	-->2050, -->2100 (climate)	\$425 billion	\$9,174 billion (-\$11 billion)
SGM7	1995 in 2010	SGM, MAGICC	Battelle	1995 emissions level	stabilize in 2010	worldwide	auction	lump-sum	no LDC part.	IAT	CR	1.0	no	-->2050, -->2100 (climate)	\$30 billion	\$9,179 billion (-\$6 billion)
SGM33	1995 in 2020	SGM, MAGICC	Battelle	1995 emissions level	stabilize in 2020	Annex I	auction	lump-sum	no LDC part.	IAT	CR	1.0	yes	-->2050, -->2100 (climate)	\$410 billion	\$9,176 billion (-\$9 billion)
SGM32	1995 in 2020	SGM, MAGICC	Battelle	1995 emissions level	stabilize in 2020	domestic only	auction	lump-sum	no LDC part.	IAT	CR	1.0	yes	-->2050, -->2100 (climate)	\$445 billion	\$9,176 billion (-\$9 billion)
SGM34	1995 in 2020	SGM, MAGICC	Battelle	1995 emissions level	stabilize in 2020	worldwide	auction	lump-sum	no LDC part.	IAT	CR	1.0	yes	-->2050, -->2100 (climate)	-\$40 billion	\$9,180 billion (-\$5 billion)
SGM27	Peak in 2015	SGM, MAGICC	Battelle	2010 BAU emissions in 2015; 1990 level in 2040	stabilize in 2040	Annex I	auction	lump-sum	LDC BAU to 2030, equal per capita in 2050	IAT	PT	1.0	in 2005	-->2050, -->2100 (climate)	\$75 billion	\$9,185 billion (0 billion)
SGM24	Peak in 2015	SGM, MAGICC	Battelle	2010 BAU emissions in 2015; 1990 level in 2040	stabilize in 2040	Annex I	auction	lump-sum	LDC stabilizes at 2030 in 2030	IAT	PT	1.0	in 2005	-->2050, -->2100 (climate)	\$75 billion	\$9,185 billion (0 billion)
SGM12	Peak in 2015	SGM, MAGICC	Battelle	2010 BAU emissions in 2015; 1990 level in 2040	stabilize in 2040	Annex I	auction	lump-sum	no LDC part.	IAT	PT	1.0	no	-->2050, -->2100 (climate)	\$55 billion	\$9,185 billion (\$0 billion)
SGM30	Peak in 2015	SGM, MAGICC	Battelle	2010 BAU emissions in 2015; 1990 level in 2040	stabilize in 2040	Annex I	auction	lump-sum	no LDC part.	IAT	PT	1.0	in 2005	-->2050, -->2100 (climate)	\$75 billion	\$9,185 billion (0 billion)
SGM11	Peak in 2015	SGM, MAGICC	Battelle	2010 BAU emissions in 2015; 1990 level in 2040	stabilize in 2040	domestic only	auction	lump-sum	no LDC part.	IAT	PT	1.0	no	-->2050, -->2100 (climate)	\$235 billion	\$9,185 billion (\$0 billion)

ID	Permit Prices: 2010	Permit Prices: 2025	Permit Prices: 2050	Conc. (ppmv) in 2050 (Deviation from BAU)	Conc. (ppmv) in 2100 (Deviation from BAU)	Year Conc. (550 ppmv) Reaches 2x Pre-Ind. Level (Deviation from BAU)	Change in Temp. (deg. C) from 1990 in 2050 (Deviation from BAU)	Change in Temp. (deg. C) from 1990 in 2100 (Deviation from BAU)	Emissions Peak, mmtce (year)	Year Returns to 1990	Intl. Trade of Permits, U.S., 2010 (MMTCE), (\$)	Intl. Trade of Permits, U.S., 2050 (MMTCE), (\$)	Date Received Run	File (h:\jaldy\)
SGM36	\$23	\$86	\$150	486 (-16)	656 (-55)	2072 (+7)	0.99 (-0.07)	2.16 (-0.20)	no peak: 1714 (2050)	n/a	-180 (-\$4.14 billion)	-364 (-\$54.6 billion)	09/10/97	case20~1.xls
SGM35	\$71	\$192	\$582	484 (-18)	656 (-55)	2073 (+8)	0.98 (-0.08)	2.15 (-0.21)	1550 (2000)	2020	n/a	n/a	09/10/97	case20~1.xls
SGM37	\$9	\$24	\$33	486 (-16)	656 (-55)	2072 (+7)	0.99 (-0.07)	2.16 (-0.20)	no peak: 2101 (2050)	n/a	-246 (-\$2.21 billion)	-751 (-\$24.78 billion)	09/10/97	case20~1.xls
SGM6	\$74	\$119	\$202	483 (-19)	648 (-63)	2074 (+9)	0.98 (-0.08)	2.12 (-0.24)	1637 (2005)	never returns	36, (+\$2.7 billion)	-122, (-\$24.6 billion)	08/21/97	cea95_~1.xls
SGM5	\$62	\$131	\$317	483 (-19)	648 (-63)	2074 (+9)	0.98 (-0.08)	2.12 (-0.24)	1637 (2005)	never returns	n/a	n/a	08/21/97	cea95_~1.xls
SGM7	\$27	\$32	\$41	483 (-19)	648 (-63)	2074 (+9)	0.98 (-0.08)	2.12 (-0.24)	no peak: 2073 (2050)	never returns	-131, (-\$3.5 billion)	-593, (-\$24.3 billion)	08/21/97	cea95_~1.xls
SGM33	\$57	\$120	\$203	482 (-20)	648 (-63)	2074 (+9)	0.97 (-0.09)	2.12 (-0.24)	no peak: 1599 (2050)	n/a	20 (+\$1.14 billion)	-119, (-\$24.16 billion)	09/10/97	case20~2.xls
SGM32	\$51	\$131	\$318	482 (-20)	648 (-63)	2074 (+9)	0.97 (-0.09)	2.12 (-0.24)	1550 (2000)	n/a	n/a	n/a	09/10/97	case20~2.xls
SGM34	\$21	\$33	\$41	482 (-20)	648 (-63)	2074 (+9)	0.97 (-0.09)	2.12 (-0.24)	no peak: 2072 (2050)	n/a	-122 (-\$2.56 billion)	-592 (-\$24.27 billion)	09/10/97	case20~2.xls
SGM27	\$11	\$56	\$153	n/a	n/a	n/a	n/a	n/a	1755 (2015)	never returns	-5, (-\$0.06 billion)	-367, (-\$56.2 billion)	08/27/97	case5.xls
SGM24	\$11	\$56	\$153	481 (-21)	568 (-143)	2089 (+24)	0.98 (-0.08)	1.84 (-0.52)	1755 (2015)	never returns	-5, (-\$0.06 billion)	-367, (-\$56.2 billion)	08/27/97	case4.xls, 9/4/97 fax
SGM12	\$0	\$47	\$155	491 (-11)	n/a	n/a	1.02 (-0.04)	n/a	1807 (2015)	never returns	0, (n/a)	-367, (-\$56.9 billion)	08/21/97	cea90_~1.xls
SGM30	\$11	\$56	\$153	489 (-13)	658 (-53)	2071 (+6)	1.00 (-0.06)	2.17 (-0.19)	1755 (2015)	never returns	-5, (-\$0.06 billion)	-367, (-\$56.2 billion)	08/27/97	case6.xls, 9/4/97 fax
SGM11	\$0	\$84	\$559	489 (-13)	n/a	n/a	1.01 (-0.05)	n/a	1807 (2015)	2040	n/a	n/a	08/21/97	cea90_~1.xls

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ID	Scenario	Model	Modelers	Target	Timetable	Trading	Permit Allocation	Revenue Recycling	Burden Sharing	BAU Emissions Path Assumption	Paper Tons or Corresponding Reductions	AEEI	Ramp-up	Time Path	PDV (5%; 2000-2050) Foregone Consumption	GDP in 2010 (deviation from BAU)
MM1	BAU	Markal	DOE	n/a	n/a	n/a	n/a	n/a	n/a	IAT	n/a	~1.0	n/a	-->2025	n/a	\$9,205 billion (BAU GDP)
MM2	1990 in 2010	Markal	DOE	1990 emissions level	stabilize in 2010	domestic only	auction	lump-sum	no LDC part.	IAT	n/a	~1.0	n/a	-->2025	n/a	\$9,137 billion (-\$68 billion)
MM3	1995 in 2010	Markal	DOE	1995 emissions level	stabilize in 2010	domestic only	auction	lump-sum	no LDC part.	IAT	n/a	~1.0	n/a	-->2025	n/a	\$9,152 billion (-\$53 billion)
MM4	1990 in 2020	Markal	DOE	1990 emissions level	stabilize in 2020	domestic only	auction	lump-sum	no LDC part.	IAT	n/a	~1.0	n/a	-->2025	n/a	\$9,197 billion (-\$8 billion)
MM5	Peak in 2015	Markal	DOE	2010 BAU emissions in 2015; 1990 level in 2040	stabilize in 2040	domestic only	auction	lump-sum	no LDC part.	IAT	n/a	~1.0	n/a	-->2025	n/a	\$9,201 billion (-\$4 billion)

ID	Permit Prices: 2010	Permit Prices: 2025	Permit Prices: 2050	Conc. (ppmv) in 2050 (Deviation from BAU)	Conc. (ppmv) in 2100 (Deviation from BAU)	Year Conc. (550 ppmv) Reaches 2x Pre-Ind. Level (Deviation from BAU)	Change in Temp. (deg. C) from 1990 in 2050 (Deviation from BAU)	Change in Temp. (deg. C) from 1990 in 2100 (Deviation from BAU)	Emissions Peak, mmtce (year)	Year Returns to 1990	Intl. Trade of Permits, U.S., 2010 (MMTCE), (\$)	Intl. Trade of Permits, U.S., 2050 (MMTCE), (\$)	Date Received Run	File
MM1	\$0	\$0	n/a	n/a	n/a	n/a	n/a	n/a	no peak: 2066 (2025)	n/a	n/a	n/a	08/26/97	8_26run1.wk4
MM2	\$148	\$192	n/a	n/a	n/a	n/a	n/a	n/a	1586 (2005)	2010	n/a	n/a	08/26/97	8_26run1.wk4
MM3	\$136	\$146	n/a	n/a	n/a	n/a	n/a	n/a	1600 (2005)	n/a	n/a	n/a	08/26/97	8_26run1.wk4
MM4	\$0	\$198	n/a	n/a	n/a	n/a	n/a	n/a	1749 (2010)	2020	n/a	n/a	08/26/97	8_26run1.wk4
MM5	\$0	\$99	n/a	n/a	n/a	n/a	n/a	n/a	1767 (2015)	2040*	n/a	n/a	08/26/97	8_26run1.wk4



US ENVIRONMENTAL PROTECTION AGENCY
OFFICE OF AIR AND RADIATION
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*THAT
your copy*

TO: ① Gene Sperling ② Katie McGinnis ③ Jeff Frankel ④ Tom Gruber ⑤ Stu Eisenstat	FAX#: 456 7132, 456 2710, 355 6947 622 2633, 647 9763 PHONE#: 260 7400
FROM: David Doniger / David Gardiner	PHONE#:

COMMENTS:

We've already moved
just a bit in their direction;
in last night's version.
Joe. can we do a run
with AEE1 of 1.5 or 1.6,
just in case it is
required?

cc: JY
JA
RL
AM

GF

page 1 of 3 (including cover sheet)

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UNITED STATES ENVIRONMENTAL PROTECTION AGENCY
WASHINGTON, D.C. 20460

MEMORANDUM FOR TODD STERN

FROM: David Doniger, EPA *David Doniger*
David Gardiner, EPA *David Gardiner*

SUBJECT: The Role of the Climate Change Technology Initiative
in Evaluating the Costs of Kyoto

DATE: February 4, 1998

We are concerned that the economic analysis now being prepared underestimates the impact of the tax incentives and program investments contained in the President's Climate Change Technology Initiative (CCTI) and the broader technology transformation that these proposals are intended to trigger. While we are not directly involved in preparation of the economic analysis, it is our understanding that the current draft analysis uses a range of 1.0% to 1.25% to represent the annual rate of improvement in energy efficiency across the economy (e/gdp). EPA believes this range significantly understates the potential of the Administration's expanded climate proposals. As explained below, we recommend extending the range examined in the analysis upward, at a minimum, to 1.5%.

The Administration's climate policy follows two paths to reduce the costs of meeting the Kyoto targets. The first path, represented by the CCTI proposals, seeks to lower the cost of purely domestic action by accelerating deployment and R&D incentives for energy-efficient and low-polluting technologies. The second path seeks to obtain low cost reductions from abroad through international market mechanisms (emissions trading, JI, and the CDM). Following both paths simultaneously gives us better prospects of achieving a reasonable cost result than following one or the other path alone.

We are concerned that the 1.0%-1.25% range of rates of change currently being modeled does not reflect the impact of the CCTI and associated policies. Thus, while the analysis is strong on the cost-reducing potential of the international trading path, it appears to sell short the Administration's commitment to reducing costs through accelerated technology change. This will hamper our efforts to gain Congressional support for the CCTI proposals and for our overall post-Kyoto policy.

The draft IAT analysis released last summer concluded that "higher rates of technological progress can cut dramatically the implicit price of carbon and the associated transitional GDP losses." The IAT analysis took 1.25% as a central case, not an upper limit. In the 1997 U.S. National Communication submitted under the climate convention, the Administration projected levels of energy savings from the Climate Change Action Plan programs, at their current funding level of about \$1 billion over five years, that translate into a 1.25% annual improvement in e/gdp

(approximately 1.2% if measured against the higher baseline of AEO 98). The IAT analysis also reported that carbon emissions and control costs would be significantly reduced if the annual e/gdp improvement rate could be increased to 1.75%.

The proposed CCTI program, at \$6.3 billion in new funding over five years, significantly enlarges the CCAP effort. Funding for EPA and DOE programs to accelerate deployment of existing technologies is to be more than doubled. R&D funding is also substantially increased. These efforts are to be matched by \$3.5 billion in tax incentives for technology deployment. EPA conservatively estimates that the CCTI (including the base CCAP programs) can increase the annual improvement in e/gdp in the energy sector to at least 1.5%.

Expanding the range of efficiency improvement rates being modeled to 1.0%-1.5% would, at the upper end, roughly double the expected impact of the Administration's climate programs. Working from the AEO 98 baseline, a 1.5% e/gdp improvement rate is equivalent to a reduction of about 180 mmtce, or about 10% of the baseline emissions in the energy sector. This is also about 35% of the 2010 "gap" in the energy sector.

A range extending to 1.5% would also be a conservative way to incorporate the results of the DOE 5 Lab study. Last year EPA undertook an analysis that built technological assumptions consistent with the DOE 5 Lab study into the Markal-Macro model. These assumptions led to an annual e/gdp improvement rate of about 1.6%. That analysis suggested that the price of carbon in 2010 could be lowered by more than 40% with net *positive* gains in GDP.

In sum, EPA believes it is essential that new analysis of the costs of Kyoto include adequate consideration of the potential for the CCTI and our related policies to lower costs by accelerating technological change. The analysis needs to fairly represent the Administration's two-path approach — pursuing lower costs through domestic technology change as well as international market mechanisms — towards reasonable economic outcomes. To understate the value of one path would weaken our prospects for defending both the new budget proposals and the overall economics of the Kyoto agreement.

We recognize that little time remains for preparation of next week's Congressional testimony. We will be happy to contribute in any way.

cc: Gene Sperling
Jeff Frankel
Katie McGinty
Jon Gruber
Stuart Eisenstat

DRAFT

Building the Kyoto Target

(source: EIA '96 GHG emissions report, Oct 97)

	1990	1995	Kyoto Target	(comment)
Carbon from Energy	1345.8	1411.4		
international bunkers	-21.9	-22.7		(subtract)
US territories	9.1	11.2		
cement	8.9	9.9		
industrial	8.0	8.5		
flaring	1.8	3.7		
Adjusted Carbon	1351.7	1422	1257.1	(93% of '90)
Methane (CH₄)	180.9	177.1	168.2	(93% of '90)
Nitrous oxide (N₂O)	38.0	38.4	35.3	(93% of '90)
HFCs	13.3	21.1	19.7	(93% of '95)
PFCs	5.2	6.4	6.0	(93% of '95)
SF₆	6.5	8.41	7.8	(93% of '95)
Total (MMTCe)	1595.6	1673.4	1494.1	

DRAFT

Baseline projection: without CCAP measures

	1990	1995	2000	2005	2010	2015	2020	(projection source)
Carbon from Energy	1345.8	1411.4	1577.3	1688.8	1803.2	1888.3	1956.2	(AEO98)
international bunkers	21.9	22.7	25.8	28.6	31.8	34.4	36.7	(from GDP trend)
US territories	9.1	11.2	12.5	13.4	14.3	15.0	15.5	(from national trend)
cement	8.9	9.9	11.2	12.5	13.8	15.0	16.0	(from GDP trend)
industrial	8.0	8.5	9.6	11.0	12.4	13.4	14.3	(from industry trend)
flaring	1.8	3.7	4.0	4.4	4.9	5.2	5.5	(from natural gas trend)
Adjusted Carbon	1351.7	1422.0	1588.9	1701.4	1817.0	1902.5	1970.8	(subtotal)
CCAP adjustments								
EIA estimates			0.0	15.0	30.0	37.8	45.7	(AEO 98)
USCAR estimates			33.0	64.0	95.0	119.9	144.7	(USCAR)
Adjusted C from Energy	1351.7	1422.0	1588.9	1716.4	1847.0	1940.3	2016.5	(add AEO est to C)
Methane (CH ₄)	180.9	177.1	166.0	170.7	176.0	177.5	179.0	(USCAR, EPA)
Nitrous oxide (N ₂ O)	38.0	38.4	36.0	37.6	39.2	39.2	39.2	(USCAR, EPA)
HFCs	13.3	21.1						
PFCs	5.2	6.4						
SF ₆	6.5	8.4	13.0	15.1	17.1	18.9	20.6	(USCAR, EPA)
HFC + PFC			49.4	88.5	114.4	138.2	161.9	(USCAR, EPA)
Total (MMTCe)	1595.6	1673.4	1853.3	2028.3	2193.7	2314.0	2417.2	(total)
Baseline GAP		179.4	359.3	534.3	699.7	820.0	923.2	(Kyoto Target)
percent reduction		10.7%	19.4%	26.3%	31.9%	35.4%	38.2%	(from Base)

*note: italicized numbers are interpolations

DRAFT

Projection with CCAP measures

	1990	1995	2000	2005	2010	2015	2020	(projection source)
Carbon from Energy	1345.8	1411.4	1577.3	1688.8	1803.2	1888.3	1956.2	(AEO98)
international bunkers	21.9	22.7	25.8	28.6	31.8	34.4	36.7	(from GDP trend)
US territories	9.1	11.2	12.5	13.4	14.3	15.0	15.5	(from national trend)
cement	8.9	9.9	11.2	12.5	13.8	15.0	16.0	(from GDP trend)
industrial	8.0	8.5	9.6	11.0	12.4	13.4	14.3	(from industry trend)
flaring	1.8	3.7	4.0	4.4	4.9	5.2	5.5	(from natural gas trend)
Adjusted Carbon	1351.7	1422.0	1588.9	1701.4	1817.0	1902.5	1970.8	(subtotal)
CCAP adjustments								
EIA estimates			0.0	15.0	30.0	37.8	45.7	(AEO98)
USCAR estimates			33.0	64.0	95.0	119.9	144.7	(USCAR, EPA)
Adjusted C from Energy	1351.7	1422.0	1555.9	1652.4	1752.0	1820.5	1871.8	(add EIA, sub CAR)
Methane (CH ₄)	180.9	177.1	150.0	151.7	152.0	153.0	154.0	(USCAR, EPA)
Nitrous oxide (N ₂ O)	38.0	38.4	30.7	32.3	33.9	33.9	33.9	(USCAR, EPA)
HFCs	13.3	21.1						
PFCs	5.2	6.4						
HFC + PFC			38.1	63.9	86.1	106.8	127.4	(USCAR, EPA)
SF ₆	6.5	8.4	4.2	4.6	4.9	5.4	5.9	(USCAR, EPA)
Total (MMTCe)	1595.6	1673.4	1778.9	1904.9	2028.9	2119.5	2193.0	(total)
with measures GAP		179.4	284.9	410.9	534.9	625.5	699.0	(Kyoto Target)
percent reduction		10.7%	16.0%	21.6%	26.4%	29.5%	31.9%	(from BASE)

*note: italicized numbers are interpolations

INTERPRETATION OF KYOTO PROTOCOL

U.S.

Kyoto mandates that the U.S. reduces its emissions (through domestic abatement, international trading, and joint implementation) to -7% of its 1990 levels for six categories of gases, net of the effects of certain sinks. Not accounting for carbon sinks, the U.S. may need to abate about 600 MMTCE relative to its 2010 BAU over the 2008-2012 commitment period. The following chart illustrates this target relative to business as usual.

Table 1. U.S. Greenhouse Gas Emissions, 1990/95 Baseline and 2010 BAU (MMTCE)

Gas/Sinks	1990/95 Emissions	-7% of 1990/95	2010 BAU Emissions
CO ₂	1374		1838
CH ₄	181		152
N ₂ O	38		34
HFCs, PFCs, SF ₆	36		91
Kyoto Sinks	n/a		?
Total	1629	1515	2115

Sources: AEO98, 1997 Climate Action Report

Annex I

Most Annex I countries must undertake substantial cuts from their BAU greenhouse gas emissions projection over the 2008-2012 period to comply with their Kyoto targets. Several countries undergoing economic transition will have paper tons available to sell to other countries.

Table 2. Required Greenhouse Gas Emissions Reductions Under Kyoto (MMTCE)

Country/ Region	Kyoto Target	2010 BAU Projection	Required Emissions Cut without Sinks
U.S.	1515	2115	600
EU	940	1217	277
FSU	1313	995	-318 (PT) ¹
EE	511	403	-108 (PT)
Australia	89	110	21
Japan	266	379	113
Canada	129	191	62

¹ PT refers to paper tons.

Source: CEA

Sinks

The Protocol states that the effects of carbon sinks, defined as "direct human-induced land-use change and forestry activities, limited to afforestation, reforestation, and deforestation since 1990, measured as verifiable changes in stocks", should be used by Annex I countries to meet their commitments. The State Department is working on a legal interpretation of the sinks provision, and the Department of Agriculture will make an estimate of the size of the U.S. sinks in 2010 in the near future. For this analysis, we employ an estimate of U.S. sinks from the 1997 Climate Action Report, and we assume that BAU sinks do not affect the target, but should be considered as "free" tons deducted from the projected BAU for estimating the control costs of meeting the U.S. target. We use estimates of carbon sinks for other countries based on data in National Communications, FAO statistical website, and the IPCC (see appendix for discussion of methodology).

Given the uncertainty in the sinks, we use three measures in our calculations. First, we consider the costs of complying with Kyoto by scoring sinks as 0 for all countries. This presumably makes the target more stringent for most Annex I countries (Australia is a significant exception because of their deforestation rate). Then we consider sinks based on the estimates for land use change and forestry provided in the national communications or in Climate Change 1995 (IPCC, WG-II). Given that the Protocol definition appears to be more constrained than this, we halve the sequestration in each country and assess those values as well. The no sinks and full sinks definitions serve as reasonable bounds, and the half of sinks could lie close to actual sink estimates.

Table 3. Annex I Sinks (MMTCE)

Country/Region	No Sinks	Half of Sinks	Full Sinks
U.S.	0	52	104
EU	0	30	60
Japan	0	13	25
Australia	0	-17	-33
Canada	0	40	80
Former Soviet Union	0	103	205
EE	0	4	8
Total	0	225	449

Sources: national communications, U.S. Climate Action Report 1997, CEA

Note that the sinks could significantly increase paper tons for FSU countries, and could possibly provide Canada with paper tons. Indeed, under the definition of full sinks, paper tons on an Annex I market could total nearly 700 MMTCE, which if sold to other Annex I countries, would account for nearly 80% of all required emissions reductions in the buying countries. Further, in the case where an umbrella trading bloc is formed without EU participation, the paper tons available would exceed the demand for emissions rights (which in the model would result in a \$0 permit price).

THE COSTS OF KYOTO

Domestic Only Abatement

If the U.S. had to meet its Kyoto target exclusively through domestic emissions abatement, the costs would likely be quite high. To provide some context of what Kyoto means, recall that domestic only abatement to get CO₂ to 1990 level in 2010 would cost \$108/ton (SGM: 380 MMTCE of abatement). By including the other gases and net-net sinks in the U.S. position and using the updated carbon dioxide projection in AEO98, our 1990 in 2010 proposal would likely cost about \$148/ton (SGM and EPA cost curves for other gases and expanding sinks: 552 MMTCE of abatement; total abatement cost: \$40.8 billion, 0.4% of GDP).¹ Note that the cost

¹ Dropping sinks entirely, the U.S. 6 gas position with AEO98 data would result in a permit price of \$121/ton.

curves for the other gases can significantly influence the permit price. If the sinks provision in Kyoto results in the U.S. having 48 MMTCE of carbon sequestration credits, then Kyoto will be comparable to the original U.S. position. Sinks that exceed this value would result in Kyoto being less stringent than the Administration's position.

The following chart provides estimates of permit prices and total costs to the U.S. with domestic abatement with several different assumptions about the size of the carbon sinks. Further, we consider the effects of the Administration's electricity restructuring proposal on carbon emissions. The last row provides an estimate of Annex I trading, but it assumes that the abatement cost curves in other countries for all six gases and sinks are the same as their cost curves for carbon dioxide (this assumption biases upward the permit price and the extent the U.S. purchases emissions rights from abroad).

Table 4. U.S. Domestic Only Abatement Costs in 2010 for U.S. to Meet Kyoto Target

sinks	elect. res.	permit price	domestic reductions	domestic abatement TC	permits from abroad	capital transfer	TC to US	TC/ GDP
0	0	\$171	600	\$51.3 b	0	0	\$51.3 b	0.6%
52	0	\$146	548	\$40.0 b	0	0	\$40.0 b	0.4%
52	33	\$130	515	\$33.5 b	0	0	\$33.5 b	0.4%
104	0	\$121	496	\$30.0 b	0	0	\$30.0 b	0.3%
104	33	\$105	463	\$24.3 b	0	0	\$24.3 b	0.3%
0	33	\$155	567	\$43.9 b	0	0	\$43.9 b	0.5%
0*	0	\$48	202	\$4.8 b	398	\$19.1 b	\$24.0 b	0.3%

* Annex I trading

Source: CEA

Annex I Trading

We assess a number of scenarios. In the first set we consider variations of Annex I trading regimes without joint implementation or trading with key developing countries.

Table 5. Annex I Trading, Abatement Costs in 2010 for U.S. to Meet Kyoto Target

case	sinks	permit price	domestic reductions	domestic abatement TC	permits from abroad	capital transfer	TC to US	TC/ GDP
Annex I	none	\$48	281	\$6.7 b	319	\$15.3 b	\$22.0 b	0.2%
Annex I	half	\$26	187	\$2.4 b	361	\$9.4 b	\$11.8 b	0.1 %
Annex I	full	\$11	95	\$0.5 b	401	\$4.4 b	\$4.9 b	0.1%
Umbrella w/o EU	none	\$26	187	\$2.4 b	413	\$10.7 b	\$13.1 b	0.1%
Umbrella w/o EU	half	\$11	95	\$0.5 b	453	\$5.0 b	\$5.5 b	0.1%
Umbrella w/o EU	full	\$0	0	0	496	0	0	0
Umbrella w/o EU, EE	none	\$43	258	\$5.5 b	342	\$14.7 b	\$20.2 b	0.2%
Umbrella w/o EU, EE	half	\$20	157	\$1.6 b	391	\$7.8 b	\$9.4 b	0.1%
Umbrella w/o EU, EE	full	\$5	51	\$0.1 b	445	\$2.2 b	\$2.3 b	0.03%

Source: CEA

International Trading (Annex I plus Developing Countries)**Table 6. Summary Table on U.S. Permit Prices (Total Cost) for Different Sinks and Trading Scenarios**

Scenario	No Sinks	Half of Sinks	Full Sinks
Domestic Only	\$171/ ton (\$51.3 b)	\$146/ton (\$40.0 b)	\$121/ton (\$30.0 b)
Annex I	\$48/ton (\$22.1 b)	\$26/ton (\$11.8 b)	\$11/ton (\$4.9 b)
Umbrella w/o EU	\$26/ton (\$13.2 b)	\$11/ton (\$5.5 b)	\$0/ton
Umbrella w/o EU, EE	\$43/ton (\$20.2 b)	\$20/ton (\$9.4 b)	\$5/ton (\$2.4 b)
Annex I + 100% JI (worldwide trading)	\$19/ton (\$10.0 b)	\$12/ton (\$6.0 b)	\$5/ton (\$2.4 b)
Umbrella w/o EU + 100% JI	\$10/ton (\$5.6 b)	\$4/ton (\$2.1 b)	\$0/ton
Umbrella w/o EU, EE + 100% JI	\$14/ton (\$7.6 b)	\$8/ton (\$4.1 b)	\$2/ton (\$1.0 b)
Annex I + Key LDC	\$20/ton (\$10.5 b)	\$12/ton (\$6.0 b)	\$5/ton (\$2.4 b)
Umbrella w/o EU + Key LDC	\$12/ton (\$6.6 b)	\$5/ton (\$2.6)	\$0/ton
Umbrella w/o EU, EE + Key LDC	\$16/ton (\$8.6 b)	\$9/ton (\$4.6 b)	\$2/ton (\$1.0 b)
Annex I + 20% JI	\$36/ton (\$17.5 b)	\$21/ton (\$9.8 b)	\$9/ton (\$4.1 b)
Umbrella w/o EU + 20% JI	\$20/ton (\$10.4 b)	\$9/ton (\$4.6 b)	\$0/ton
Umbrella w/o EU, EE + 20% JI	\$30/ton (\$14.9 b)	\$16/ton (\$7.7 b)	\$4/ton (\$1.9 b)
Annex I + Key LDC + 20% JI in ROW	\$20/ton (\$10.4 b)	\$12/ton (\$6.0 b)	\$5/ton (\$2.4 b)
Umbrella w/o EU + Key LDC + 20% JI in ROW	\$11/ton (\$6.1 b)	\$5/ton (\$2.6)	\$0/ton
Umbrella w/o EU, EE + Key LDC + 20% JI in ROW	\$15/ton (\$8.1 b)	\$9/ton (\$4.6 b)	\$2/ton (\$1.0 b)

Source: CEA

METHODOLOGY

Trading

Abatement Cost Curves in Industrialized Countries: Marginal cost curves in countries derived from SGM for CO₂ hold for all six gases and sinks for all countries except for the United States (this likely overstates costs of abatement under international trading). The U.S. cost curves are derived from SGM outputs for CO₂ and from EPA/OAR for the other gases and sinks. The cost curve for the other gases and sinks ends at \$70/ton -- we assume that no other reductions are available beyond those achievable at that price.

Intergas Trading: Trading is assumed to occur across all gases and sinks based on 100-year global warming potential.

Trading Blocs: We assessed three different industrialized country trading blocs.

- Annex I implies trading between all Annex I countries (note that in model, some small countries, e.g., New Zealand, Norway, Iceland, are not included).
- Umbrella with Eastern Europe implies trading among all Annex I countries except for the EU.
- Umbrella without Eastern Europe implies trading among all Annex I countries except for the EU and Eastern Europe.

Abatement Cost Curves in Developing Countries: Marginal abatement cost curves for developing countries only include opportunities to reduce carbon dioxide released through energy consumption. Given that numerous options for sequestration projects in these countries exist, these curves overestimate the costs of developing country participation.

AEEI: All of the SGM derived marginal abatement cost curves are based on model outputs assuming an AEEI of 1.0.

Electricity Restructuring: Interagency staff analysis on the Administration's electricity restructuring proposal indicates that carbon reductions resulting from RPS, PBF, and green marketing could range between 13 and 33 MMTCE. For this analysis, we assume the upper end of this range.

Baseline Construction

Carbon Dioxide Emissions: For projections of carbon dioxide, we used the business as usual projections in SGM, with the exception of the U.S., where we employed the more recent AEO98

estimate of 2010 BAU for energy-based CO₂ and the Climate Action Report (U.S. National Communication) projection for non-energy-based CO₂. For the EU, an adjustment was made to the Western Europe value in SGM to reflect the non-participation of Iceland, Norway, Switzerland, and Turkey in the EU bubble. Based on CO₂ emissions estimates from Oak Ridge National Lab, 66.1 MMTCE were deducted from the Western Europe estimate to derive the EU 1990 baseline CO₂ emissions value. For 2010 BAU, 85 MMTCE were deducted (this increase assumes that the four non-participating countries increase their BAU emissions at the same rate as the EU).

Emissions of Other GHG: For projections of the other five categories of greenhouse gases, we used the information provided in the national communications to the Framework Convention on Climate Change.

- **Australia:** Non-CO₂ GHG comprise 33% of all GHG emissions in 1990. These are assumed to be 25% of all GHG emissions in 2010 based on the trends projected in the U.S. and the EU. The 1990/95 baseline excludes SF₆ and HFCs.
- **Austria:** For methane and nitrous oxide, 2010 emissions are based on a linear extrapolation from the projected 2000 level using the average annual growth rate over the 1990-2000 period. For the three minor gases, estimated emissions for 1995 and 2010 are based on multiplying 1995 GDP times the emissions/GDP(1995) average ratios derived from the Netherlands, Sweden, and the UK.
- **Belgium:** For the three minor gases, estimated emissions for 1995 and 2010 are based on multiplying 1995 GDP times the emissions/GDP(1995) average ratios derived from the Netherlands, Sweden, and the UK.
- **Canada:** For non-CO₂ gases, Canada is assumed to have the same non-CO₂ emissions/total GHG emissions ratio as the US (.17 in 1990/95 and .13 in 2010). Total GHG emissions are then calculated based on historical and projected CO₂ emissions.
- **Denmark:** For methane and nitrous oxide, 2010 emissions are based on a linear extrapolation from the projected 2005 level using the average annual growth rate over the 2000-2005 period.
- **Eastern Europe:** For non-CO₂ gases, Eastern European countries are assumed to have the same non-CO₂ emissions/total GHG emissions ratio as the Former Soviet Union (.25 in 1990/95 and .19 in 2010). Total GHG emissions are then calculated based on historical and projected CO₂ emissions.

- Finland: For the three minor gases, estimated emissions for 1995 and 2010 are based on multiplying 1995 GDP times the emissions/GDP(1995) average ratios derived from the Netherlands, Sweden, and the UK.
- Former Soviet Union: Non-CO2 GHG comprise 25% of all GHG emissions in 1990. These are assumed to be 19% of all GHG emissions in 2010 based on the trends projected in the U.S. and the EU. The 1990/95 baseline excludes SF6, PFCs and HFCs.
- France: For the three minor gases, estimated emissions for 1995 and 2010 are based on multiplying 1995 GDP times the emissions/GDP(1995) average ratios derived from the Netherlands, Sweden, and the UK.
- Germany: For methane and nitrous oxide, 2010 emissions are based on a linear extrapolation from the projected 2005 level using the average annual growth rate over the 1990-2005 period. For the three minor gases, estimated emissions for 1995 and 2010 are based on multiplying 1995 GDP times the emissions/GDP(1995) average ratios derived from the Netherlands, Sweden, and the UK.
- Greece: For the three minor gases, estimated emissions for 1995 and 2010 are based on multiplying 1995 GDP times the emissions/GDP(1995) average ratios derived from the Netherlands, Sweden, and the UK.
- Ireland: For the three minor gases, estimated emissions for 1995 and 2010 are based on multiplying 1995 GDP times the emissions/GDP(1995) average ratios derived from the Netherlands, Sweden, and the UK.
- Italy: For the three minor gases, estimated emissions for 1995 and 2010 are based on multiplying 1995 GDP times the emissions/GDP(1995) average ratios derived from the Netherlands, Sweden, and the UK.
- Japan: Non-CO2 GHG comprise 4% of all GHG emissions in 1990. These are assumed to be 3% of all GHG emissions in 2010 based on the trends projected in the U.S. and the EU. The 1990/95 baseline excludes SF6, PFCs, and HFCs.
- Luxembourg: For methane and nitrous oxide, 2010 emissions are based on a linear extrapolation from the projected 2000 level using the average annual growth rate over the 1990-2000 period.
- Portugal: For the three minor gases, estimated emissions for 1995 and 2010 are based on multiplying 1995 GDP times the emissions/GDP(1995) average ratios derived from the Netherlands, Sweden, and the UK.

- Spain: The United Nations has not posted a national communication for Spain on the FCCC webpage. Estimates of the methane and nitrous oxide emissions are based on the average methane/GDP(1995) and nitrous oxide/GDP(1995) ratios for the other 14 EU countries multiplied by Spain's 1995 GDP. Similar calculations were done for the three minor gases, but only based on the average of the Netherlands, Sweden, and the UK's emissions.

Converting to Carbon Equivalence: In all cases where data are provided in tons of gas, or tons of carbon dioxide equivalent, the data were converted to tons of carbon equivalence based on their 100 year time horizon global warming potential (IPCC 1996, p. 121). Some countries aggregated all HFCs into one value (and in some cases, all PFCs into one value). We constructed an HFC weight and a PFC weight based on specific HFC and PFC emissions in the U.S. in 1995. For HFCs, I used the following weight:

$$[2 * \text{GWP}(\text{HFC-134a}) + \text{GWP}(\text{HFC-23})] / 3 = 1300$$

HFC-134a was 52% and HFC-23 was 21% of all U.S. HFC emissions in 1995. For PFCs, I used the following weight:

$$[2 * \text{GWP}(\text{CF}_4) + \text{GWP}(\text{C}_6\text{F}_{14})] / 3 = 1854$$

CF_4 was about 60% and C_6F_{14} was about 25% of all U.S. PFC emissions in 1995.

Sinks: Sink estimates are subject to significant uncertainty due to ambiguities in the Protocol definition of carbon sinks. The UN webpage provides a data set on carbon sequestration due to land use change and forestry activities. In addition, the compilation and synthesis of national communications document includes projections for some countries. In cases where only 1990 or 2000 data are available, it is assumed that the sequestration will be the same in 2010 for that country. Carbon sink data were available for the following countries: Australia (2000), Austria (1990), Belgium (2010), Bulgaria (2000), Czech Republic (2010), Denmark (2000), Estonia (1990), Finland (2010), France (2000), Germany (2000), Hungary (1990), Ireland (2010), Italy (2000), Japan (2000), Latvia (2000), Liechtenstein (1990), the Netherlands (2010), New Zealand (2010), Norway (2010), Poland (1988), Romania (1989), Russian Federation (1990), Slovakia (2010), Spain (2000), Sweden (2010), Switzerland (2010), United Kingdom (2000), and the U.S. (2010 -- 1997 Climate Action Report).

Given the uncertainties regarding the definition of sinks in the protocol, we are using these estimates without modification. Upon receiving more guidance from State and Agriculture, we may undertake some revisions to appropriately account for the three designated sink categories of afforestation, reforestation, and deforestation.

- **EU Bubble Countries:** Twelve of the fifteen EU bubble countries provide estimates of carbon sinks for at least some year between 1990 and 2010. The total for these twelve countries was scaled up proportional to the land area under forest cover in the fifteen countries (forest area from FAO statistical webpage).
- **Canada:** Since Canada has not provided a sinks estimate, we used the sink estimate from *Climate Change 1995, Volume II* (p. 777). The value of 80 MMTCE is based on the carbon flux estimated during the 1990s for Canada, and reflects sequestration in forest vegetation and forest soils.
- **Eastern Europe:** All but two countries in Eastern Europe provided carbon sink estimates. Again, we used the scaling procedure employed with the EU to estimate a total for all of Eastern Europe.
- **Japan:** The national communication estimated removal of carbon through managed forests is approximately 25 MMTCE. The provided data point was not modified for soil sinks, since the communication appears to exclude soils in its sequestration estimate.
- **Former Soviet Union:** All but two countries of the Former Soviet Union in Annex I provided carbon sink estimates. Again, we used the scaling procedure employed with the EU to estimate a total for all of FSU.
- **United States:** Three estimates of U.S. sinks in 2010 are used. First, a very conservative estimate of 0 is used simply for the purposes of establishing an upper bound on control costs. Second, 52 MMTCE refers to half of the amount of above ground sequestration and wood in use and landfill sinks estimated in the 1997 Climate Action Report. Third, all of the sequestration in these sink categories is used.

Kyoto Targets: The targets for countries were from the Kyoto Protocol. For the Former Soviet Union, the Russian Federation and Ukraine target of 1990/95 levels was used. For the Eastern Europe region, a target of 1990/95 - 2% was used, because it is roughly the average target for Bulgaria, Croatia, the Czech Republic, Hungary, Poland, Romania, Slovakia, and Slovenia. While several of the Eastern European countries have selected a year or period or years other than 1990 as their base year/period, we continue to use the 1990 SGM estimate for carbon dioxide.

Sources:

IPCC. 1996. *Climate Change 1995: The Science of Climate Change*. Cambridge, UK: CUP.
First National Communication from Australia
First National Communication from Austria
Second National Communication from Belgium

First National Communication from Denmark
First National Communication from Finland
First National Communication from France
First National Communication from Germany
First National Communication from Greece
First National Communication from Ireland
First National Communication from Italy
First National Communication from Japan
First National Communication from Luxembourg
Second National Communication from the Netherlands
First National Communication from Portugal
First National Communication from the Russian Federation
Second National Communication from Sweden
First National Communication from the United Kingdom
Second National Communication from the United States (Climate Action Report 1997)
Communications from Parties Included in Annex I to the Convention, Addendum
Annual Energy Outlook 1998
Emissions of Greenhouse Gases in the United States 1996
Food and Agriculture Organization Statistical Webpage
Unpublished Cost Curve on Non-CO2 GHG from EPA

Aldy scenario #	permit price	----- household level -----					-----end-user level-----				
		ch, en exp household	ch, en exp d(elast)	index	adj for elec restruct	net of elec restruct			index	adj for elec restruct	net of elec restruct
1	148	0.299	0.263	126	4.5	122	0.414	0.365	136	5.5	131
2	171	0.345	0.304	130	4.7	126	0.479	0.421	142	5.8	138
3	48	0.097	0.085	109	3.9	105	0.134	0.118	112	4.5	108
4	43	0.087	0.076	108	3.9	104	0.120	0.106	111	4.5	107
5	26	0.053	0.046	105	3.8	101	0.073	0.064	106	4.3	102
6	36	0.073	0.064	106	3.8	103	0.101	0.089	109	4.4	105
7	20	0.040	0.036	104	3.7	100	0.056	0.049	105	4.3	101
8	19	0.038	0.034	103	3.7	100	0.053	0.047	105	4.2	101
9	10	0.020	0.018	102	3.7	98	0.028	0.025	102	4.2	98
1990 expen				100					100		
ch, expend @\$100/ton		0.202					0.280				

Notes:

1. energy expenditure calculations based on an exercise of 10/97, which calculated that \$100/ton carbon tax implies 76% increase in energy expenditure at primary fuel level, 28% at end-use level, 20.2% at hhld level.

2. Change in energy expenditure calculated by multiplying (residential expenditure on elec, nat gas, fuel oil, and LPG = \$124b in 1993 + expenditure on gasoline = \$100.7b in 1993) by the % change in energy sector expenditure, calculated above for each scenario.

3. Index number reflects per capita energy expenditure. EIA projects primary energy consumption to grow at 1.0%/yr. Census Bureau middle series population projection rises at 1.0%/yr until 2010, so per capita energy consumption is flat. EIA projects energy prices, aggregated over all fuels, to be flat, as calculated in attached spreadsheet.

4. ch en exp d(elast) means change in energy expenditure taking account of price elasticity. Offline calculation indicates for a given expenditure calculated as "ch en exp" price elasticity effect offsets about 12% of the calculated total, averaged across household fuels. Thus, "ch en exp" multiplied by 88% to get "ch en exp d(elast)"

5. elec restructuring savings: 1993 exp, residential sector: \$81 b. 2010 exp = \$81 b x (index of hhld en exp for 2010). Demoninator is 1993 exp on all energy, hhld sector = \$124b + \$100b gasoline = \$224b, which is the basis of the base year index = 100. At end-use level, we assume \$20 b/yr savings, growing with index of energy exp growth, out of \$493 b total for all fuels (Stat Abstract Table 919)

To: Randy Luttles
 Phone: 395 - 3142
 FAX: " 6870

From: Phillip Tseug
 586 - 3892

Converting carbon value to energy price increases						
Carbon "Value"	Natural Gas (mcf)	Gasoline (gallon)	Coal (ton)	Coal-fired* electricity (\$/kwh)	Total* electricity (\$/kwh)	Total** electricity (\$/kwh)
\$0.00	\$0.00	\$0.00	\$0.00	\$0.0000	\$0.0000	\$0.0000
\$10.00	\$0.15	\$0.02	\$5.46	\$0.0026	\$0.0016	\$0.0017
\$20.00	\$0.30	\$0.05	\$10.92	\$0.0053	\$0.0033	\$0.0034
\$30.00	\$0.45	\$0.07	\$16.38	\$0.0079	\$0.0049	\$0.0050
\$40.00	\$0.60	\$0.10	\$21.84	\$0.0106	\$0.0066	\$0.0067
\$50.00	\$0.75	\$0.12	\$27.30	\$0.0132	\$0.0082	\$0.0084
\$60.00	\$0.89	\$0.15	\$32.76	\$0.0158	\$0.0099	\$0.0101
\$70.00	\$1.04	\$0.17	\$38.22	\$0.0185	\$0.0115	\$0.0118
\$80.00	\$1.19	\$0.19	\$43.68	\$0.0211	\$0.0131	\$0.0135
\$90.00	\$1.34	\$0.22	\$49.14	\$0.0238	\$0.0148	\$0.0151
\$100.00	\$1.49	\$0.24	\$54.60	\$0.0264	\$0.0164	\$0.0168
\$110.00	\$1.64	\$0.27	\$60.06	\$0.0290	\$0.0181	\$0.0185
\$120.00	\$1.79	\$0.29	\$65.52	\$0.0317	\$0.0197	\$0.0202

* Calculation based on 1995 electricity generation, excluding Cogen.
 ** Calculation based on 1995 electricity Sales.

1995 Price and Consumption of Natural gas, Gasoline, Coal, and Electricity			
	Price	Quantity	P*Q (\$billion)
Natural Gas (\$/mcf at wellhead, tcf)	\$1.61	22.2	\$35.71
Gasoline (\$/gallon, mmbd/day)	\$1.15	7.8	\$137.45
Coal(\$/ton at electric utilities, mil short ton)	\$27.01	847.0	\$22.88
Electricity(\$/kwh end-use, bkwh)	\$0.07	3,008.0	\$213.57

October 9, 1997

 Randall W. Lutter
02/23/98 05:52:27 PM

Record Type: Record

To: Janet L. Yellen/CEA/EOP

cc:

Subject: Here is Ray Squitieri's e-mail on prices and expenditures.

I am forwarding this as I promised. I think that it needs work and that you should give me til tomorrow morning to make it presentable before you spend time on it.

-RL

----- Forwarded by Randall W. Lutter/CEA/EOP on 02/23/98 05:48 PM -----



Ray.R.S.Squitieri @ MS01.DO.treas.sprint.com
02/23/98 03:04:00 PM

Record Type: Record

To: Randall W. Lutter

cc:

Subject: fact check

Date: 02/23/1998 03:50 pm (Monday)

From: Ray Squitieri

To: randy

Subject: fact check

Janet Yellin testimony on climate change
Notes on effect on average family

Treasury 10/97 calculation (spreadsheet attached) found that \$100/ton carbon tax implies 20.2% increase in direct energy expenditure at hhld level. Thus \$14 to \$23/ton carbon tax implies 3.8% increase before adjusting for price elasticity effect, or 3.4% increase after adjusting for price elasticity effect (which is about 12%).

Approximate agreement with earlier Treasury calculation done differently:

In 9/97 calculations, Treasury calculated the effect of \$100/ton carbon at \$514/hhld (\$1992) for direct energy expenditures. Yellen testimony cites permit price of \$14 to \$23/ton. So $18.5/100 \times 514 = \$95$ per hhld. In 1993, the average hhld had \$1282 in direct expenditures for energy (Stat Abstract, table 920) not including gasoline, and bought about 1000 gallons of gasoline at an average price of \$1.16 per gallon. Total direct energy expenditures were thus \$2442. Then $95/2442 = 3.9\%$.

Why 7% below Kyoto's "1990 levels" is no more than 3% below the President's proposal: a calculation

This paper compares the carbon numbers associated with the United States emissions commitment under the Kyoto Protocol with the commitment the President made in his October speech. The Kyoto Protocol and the President's speech differ both in the emissions budget and in the emissions accounting system that will determine the emissions that must be below the budget for compliance with the treaty, *so the targets cannot be compared directly*. The most significant differences between the two commitments are1:

- (1) Under the Kyoto Protocol, each party has its choice of 1990 or 1995 as a base year for emissions of three greenhouse gases: HFC, PFC, and SF6. The U.S. had 13 MMTCE more emissions of these gases in 1995 than in 1990, making the option of a 1995 base year less restrictive.
- (2) Under the Kyoto Protocol, the emissions budget is based only on gross emissions, not counting the carbon sequestered by forests in the base year (1990), the "sinks." The effect of this difference is to make the Kyoto budget less strict than it would have been using the President's assumption that the budget would be based on net emissions.
- (3) Under the Kyoto Protocol, the emissions accounting system includes only certain land use changes and forestry activities in its calculation of sinks, rather than the carbon activity in all U.S. forests. The effect of this provision relative to the President's plan depends on the methodology developed to account for sinks under the Kyoto agreement. 2

The Kyoto Protocol

(A) The Kyoto Target

Emissions budget = 5 years $\times$ (1990 Emissions of CO₂, CH₄, N₂O + 1995 Emissions of HFC, PFC, and SF₆) $\times$ 93%

1990 Emissions of CO₂, CH₄, N₂O = 1559 MMTCE
 1995 Emissions of HFC, PFC, and SF₆ = 37 MMTCE
 Total baseline emissions = 1596 MMTCE

Kyoto Emissions Budget, total for first budget period = 5 years × (1596) × 93%
 = 7421 MMTCE

Annual Average Budget in 2008-2012 = 1484 MMTCE
--

(B) The Kyoto Accounting System

2008-2012 emissions = [Total emissions of CO₂, CH₄, N₂O, HFC, PFC, SF₆]
 - [net changes of carbon stocks "from direct human-induced
 land-use change and forestry activities, limited to afforestation,
 reforestation, and deforestation since 1990, measured as
 verifiable changes in stocks in each commitment period"]

The President's Announcement

(A) The President's October Target

Under the President's October plan, the emissions target for the United States would be written:

Emissions Budget = 5 years × [(1990 Emissions of CO₂, CH₄, N₂O and HFC,
 PFC, and SF₆) - (net changes carbon stocks from all forests, including forest
 soils)]

Note that the budget equation includes sinks, which all else equal makes the budget tighter for the United States, which experienced positive sequestration in forests in 1990.

1990 Emissions of CO₂, CH₄, N₂O = 1559 MMTCE
 1990 Emissions of HFC, PFC, and SF₆ = 24 MMTCE
 Carbon activity in forests (sequestration) = -282 MMTCE
 Net emissions = 1301 MMTCE

President's Plan Emissions Budget = 5 years × (1301) = 6505 MMTCE

Annual Average Budget in 2008-2012 = 1301 MMTCE
--

(B) The President's October Accounting System

2008-2012 Emissions Calculation = [Total emissions of CO₂, CH₄, N₂O, HFC, PFC, SF₆ 2] - [net changes of carbon stocks from all U.S. forests]

Comparison: How much lower is the Kyoto target than the President's plan?

Recall that the two plans entail different accounting systems for the emissions that must be within budget, *so the budgets of the two commitments (1484 and 1301) are not directly comparable.*

The Kyoto commitment:

[Total emissions of all six gases] - [net changes of carbon stocks from certain activities] < 1484

Since the sink accounting system under the Kyoto Protocol is not yet determined, we must make an assumption about the net changes of carbon stocks from the activities specified in the treaty. The U.S. has said that the accounting system for carbon sinks will not increase the emissions calculation under the Protocol, and may in fact offset our emissions. If we assume that sinks are zero, that is they neither offset U.S. emissions nor contribute to them, then the Kyoto commitment is:

[Total emissions of all six gases] - 0 < **1484**

President's plan:

[Total emissions of all six gases] - [net changes of carbon stocks from all U.S. forests] < 1301

The change in carbon stocks from all U.S. forests in 2010 is estimated by USDA and EPA to be about 227 MMTCE. If that figure is about average for the budget period, the President's commitment would be equivalent to:

[Total emissions of all six gases] - 227 < 1301, or equivalently,

[Total emissions of all six gases] < **1528** (the total of the budget plus offsets by sinks)

Then the comparison question is: **how much lower is 1484 than 1538?**

Algebraically, the percentage difference, x , can be expressed: $1484 = (1-x)1538$

=> $x = 1 - 1484/1538 = .03$

=> **1484 is 3% below 1538.**

What if accounting for sinks under the Protocol offsets our emissions, as we expect

they may do? Then the total emissions of all six gases can be *higher* than 1484 by the amount of carbon sequestered in the eligible land use activities. That makes the Kyoto Protocol even less than 3% more stringent than the President's plan.

Conclusion: The Kyoto agreement is no more than 3% more stringent than the Presidents plan.

CO₂ only
energy-related CO₂

ANNEX 1 CARBON EMISSIONS (million metric tons)

	1990 emissions	2010 emissions
United States	1,337	1,721 → AEO98: 1803
Former Soviet Union	1,029	872
Western Europe	1,016	1,208
Eastern Europe	309	306
Japan	308	466
Canada	137	182
Australia/ New Zealand	100	127
	<u>4236</u>	<u>4882</u>

Target 2010
4024 AI
7942.0244

DEVELOPING COUNTRIES (million metric tons)

	1990 emissions	2010 emissions
All other	904	1,811
China	625	1,523
India	159	421
Mexico	87	163
	<u>17</u>	<u>3918</u>
	6011	8800

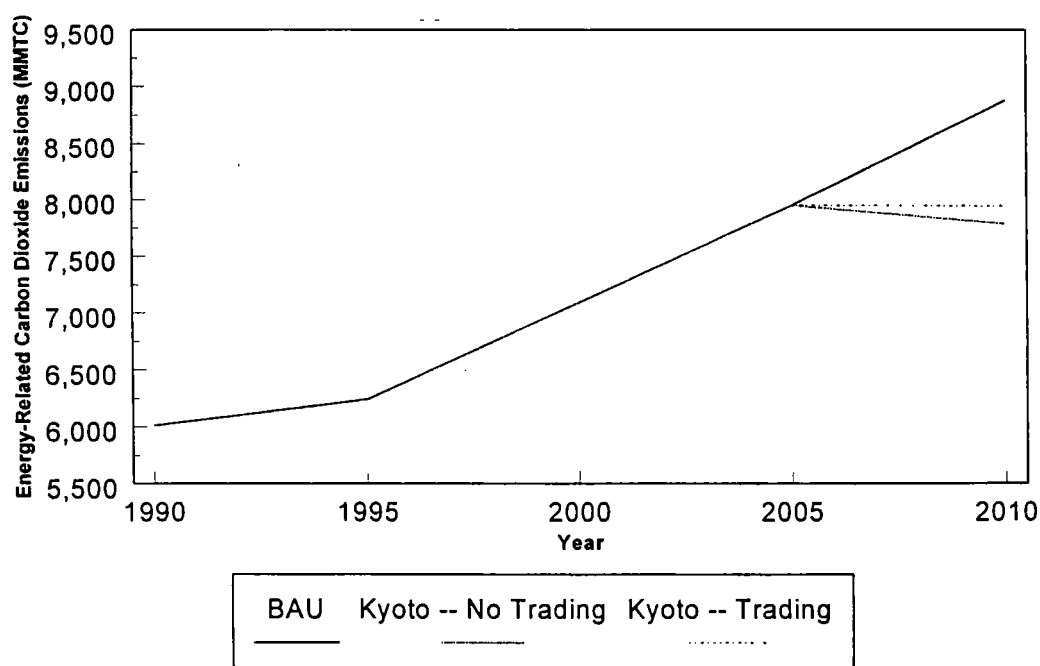
1997 Internal Energy Outlook

EIA

Trends in Energy-Related Carbon Dioxide Emissions

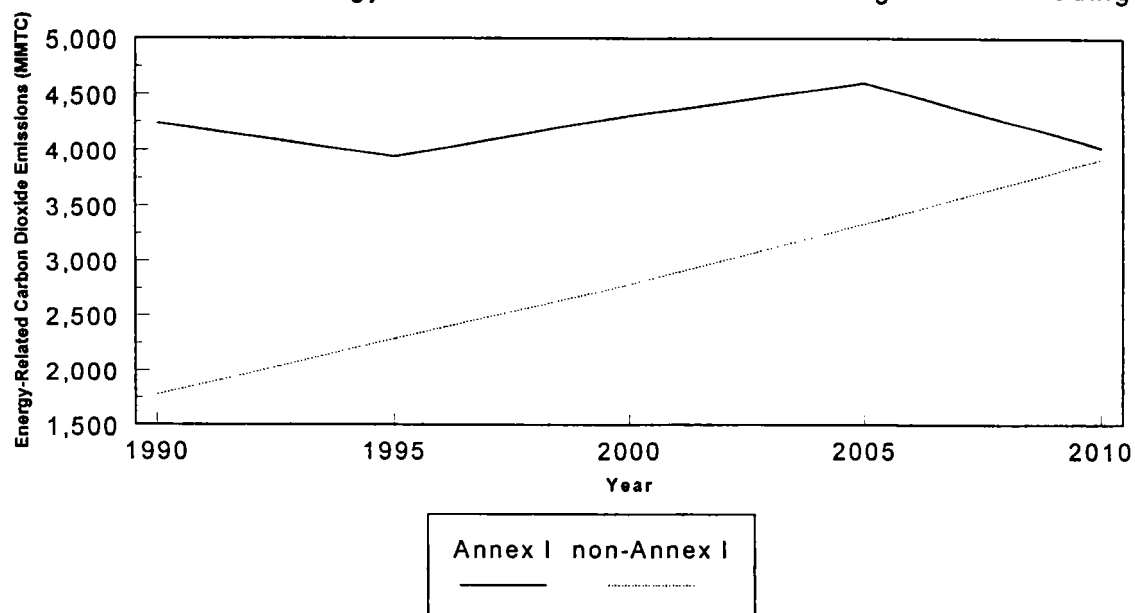
- To assess the implications of Kyoto on global greenhouse gas emissions, we had to make two simplifying assumptions because of data limitations. First, we assumed that energy-related carbon dioxide emissions could serve as an adequate proxy for greenhouse gas emissions (in the U.S., energy-related carbon dioxide emissions are more than 97% of all carbon dioxide emissions). Second, we assumed that Annex I countries will reduce their energy-related carbon dioxide emissions by the percentage cuts stipulated in Annex B of the Kyoto Protocol (in effect, we ignore any opportunities for what flexibility).
- Chart 1 illustrates the trend in world emissions under BAU and under two scenarios of Annex I emissions reductions. One scenario assumes no trading of emissions rights, which has lower total Annex I emissions because countries with paper tons would not be able to sell their excess rights. The other scenario assumes trading of emissions rights, so total Annex I emissions are higher.
- In 2010, both Kyoto scenarios have emissions slightly below 2005 BAU and a little more than 10% below global 2010 BAU. Because of the substantial growth in non-Annex I emissions, global emissions in 2010 under both Kyoto scenarios are approximately 30% above the global 1990 level.
- Charts 2 and 3 illustrate the breakdown of emissions between Annex I and non-Annex I. Without international trading, non-Annex I emissions will surpass Annex I emissions in 2010. With international trading, non-Annex I emissions are slightly lower than Annex I emissions, but would likely pass Annex I emissions by the end of the first commitment period.

Chart 1: Trend in Global Energy-Related CO₂ Emissions



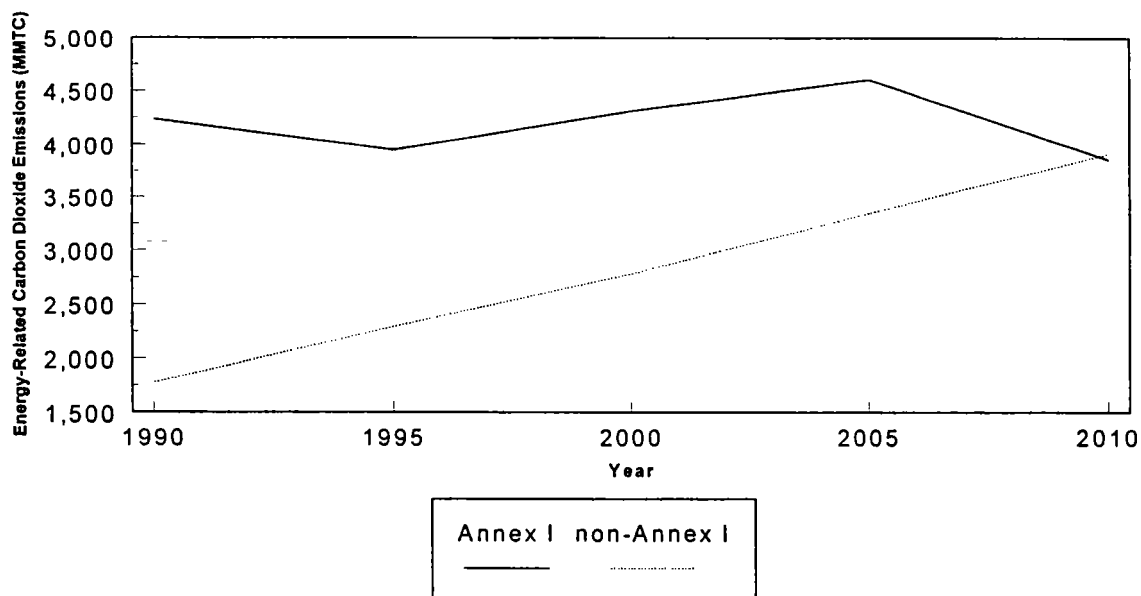
Sources: EIA IEO97 and AEO98

Chart 2: Trend in Energy-Related CO2 Emissions Assuming Annex I Trading



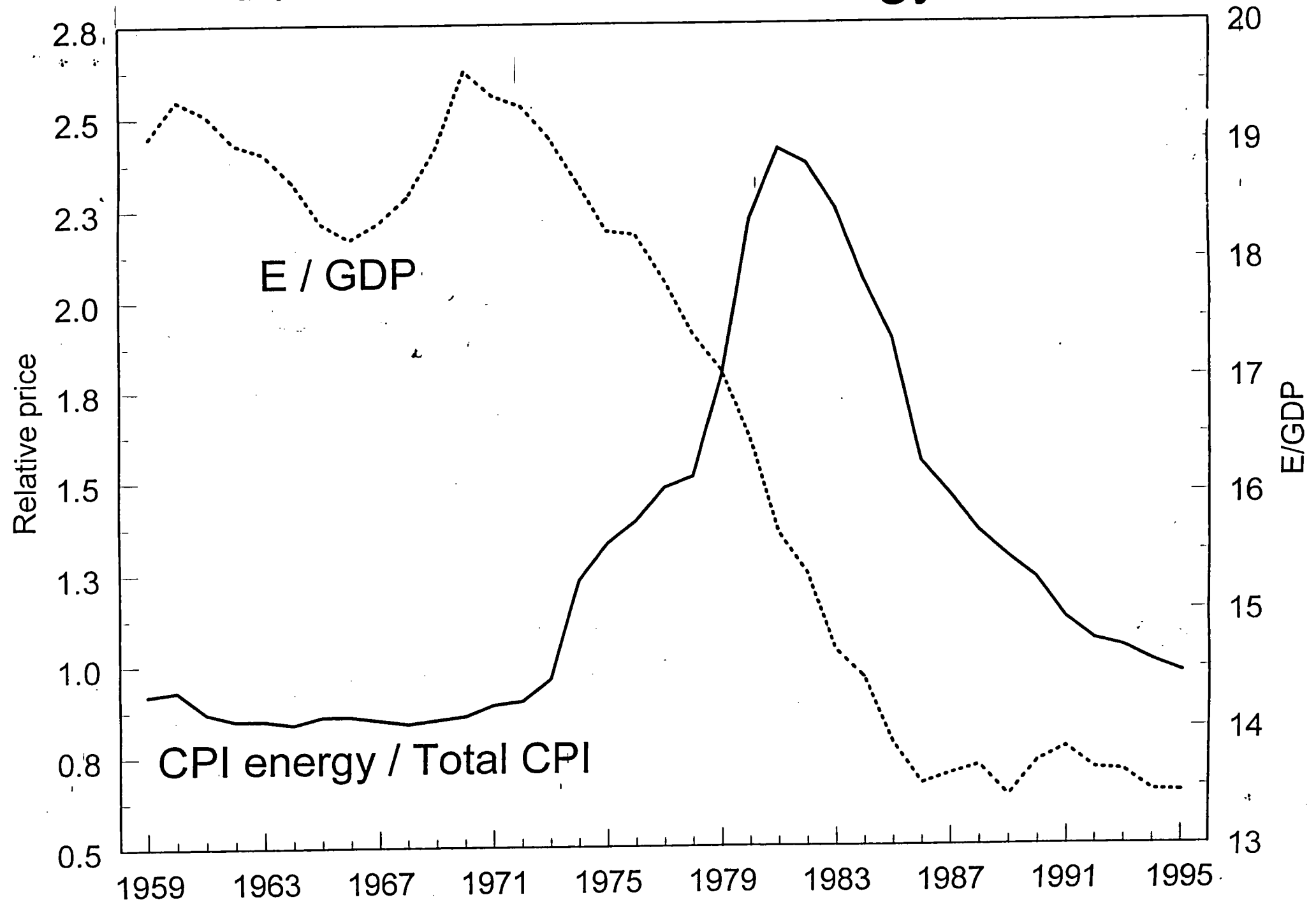
Sources: EIA IEO97 and AEO98

Chart 3: Trend in Energy-Related CO2 Emissions Assuming No Annex I Trading



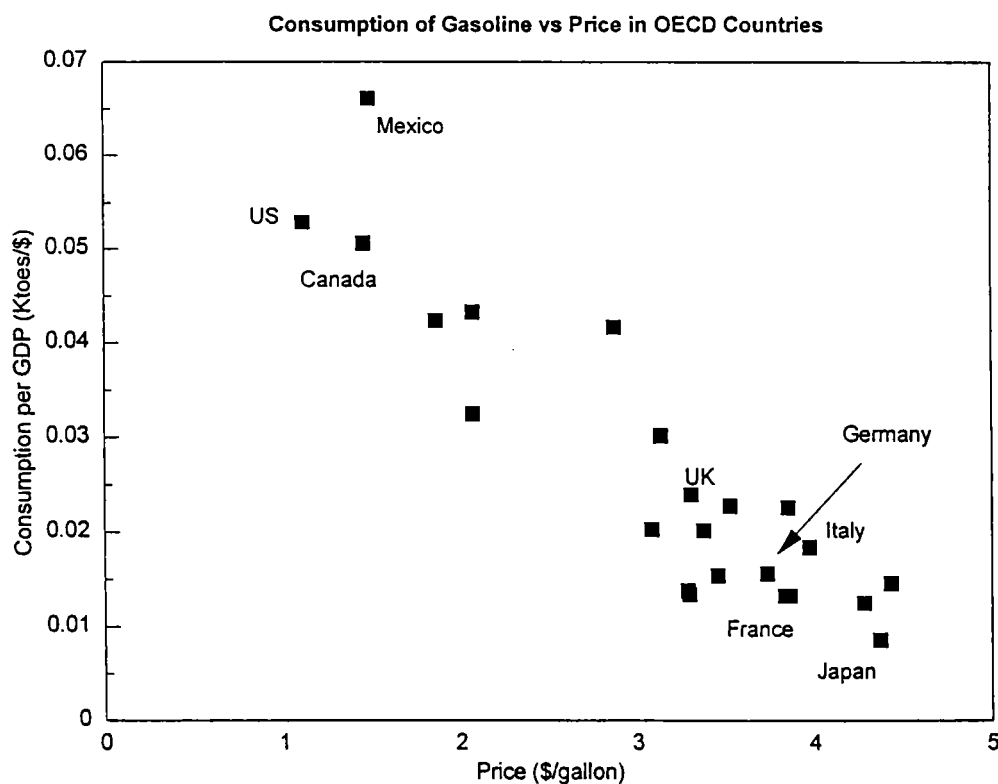
Sources: EIA IEO97 and AEO98

E/GDP & Relative Energy Price (Levels)



Price and Consumption of Energy in The Ten Largest OECD Countries (1994)

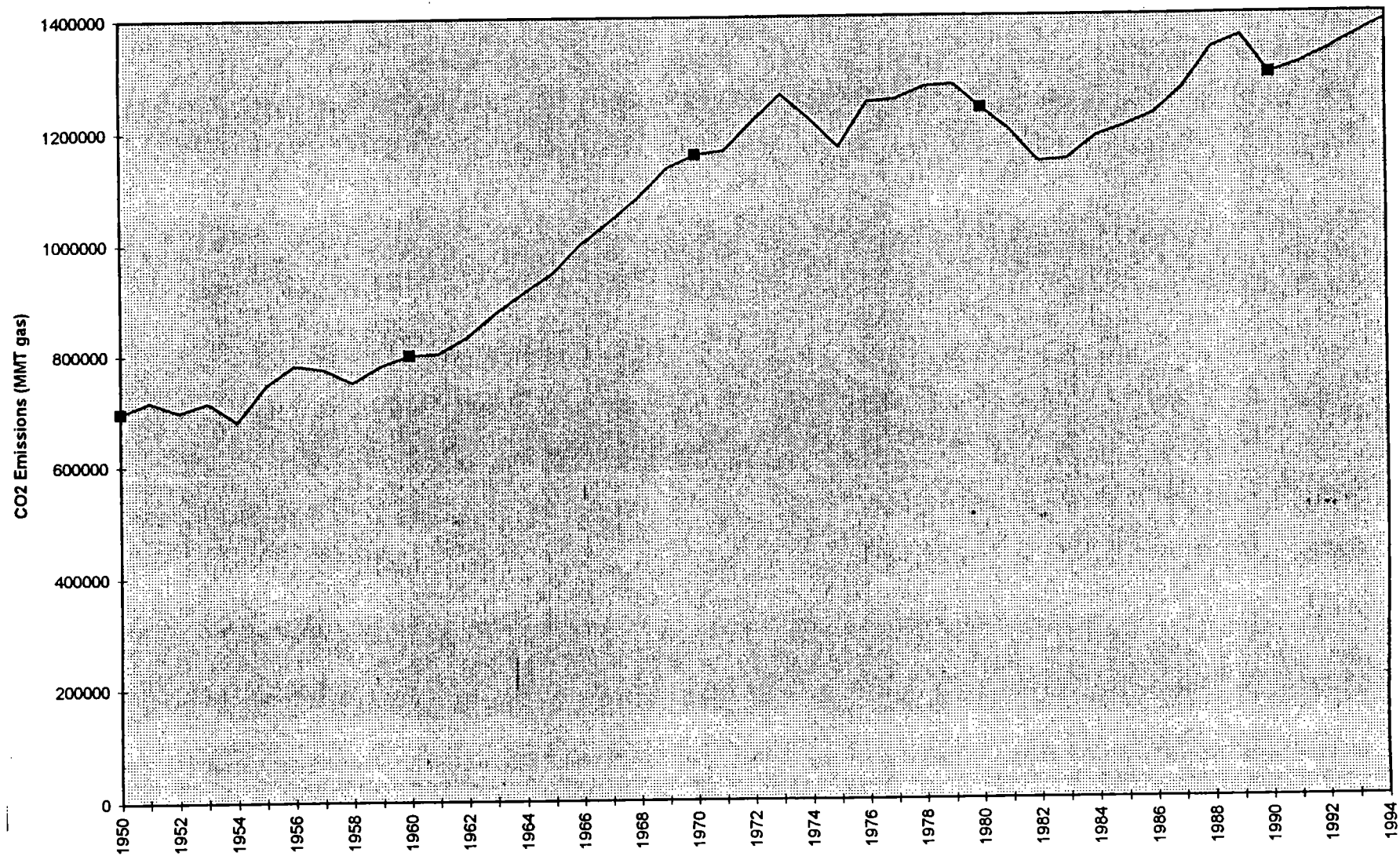
	Gasoline			Other Energy	
	Tax (per gallon)	Price (per gallon)	Consumption/GDP (Ktoe per \$)	Price of Electricity: Households (per toe)	Total Energy Consumption/GDP (Ktoe per \$)
Netherlands	\$3.25	\$4.28	0.0529	\$1,744	0.1193
France	\$3.09	\$3.83	0.0156	\$2,072	0.1184
Italy	\$3.02	\$3.97	0.0184	\$1,907	0.1180
Germany	\$2.89	\$3.73	0.0240	\$1,428	0.1547
UK	\$2.50	\$3.30	0.0086	\$2,901	0.0733
Japan	\$2.11	\$4.37	0.0125	\$1,343	0.1645
Spain	\$2.11	\$3.08	0.0203	\$2,023	0.1394
Canada	\$0.73	\$1.45	0.0529	\$977	0.2068
U.S.	\$0.38	\$1.11	0.0661	\$788	0.2690
Mexico	\$0.14	\$1.48	0.0506	\$692	0.3175



Sources: Energy Prices and Taxes: Second Quarter 1996; International Energy Agency (IEA); OECD
 Energy Statistics of OECD Countries: 1993-1994; IEA; OECD
 OECD in Figures: Statistics of the Member Countries (1996 Edition)

Graph CO2 Emissions Over Time Chart 2

CO2 Emissions, 1950-1994



Energy Consumption and CO2 Emissions, 1950-1994

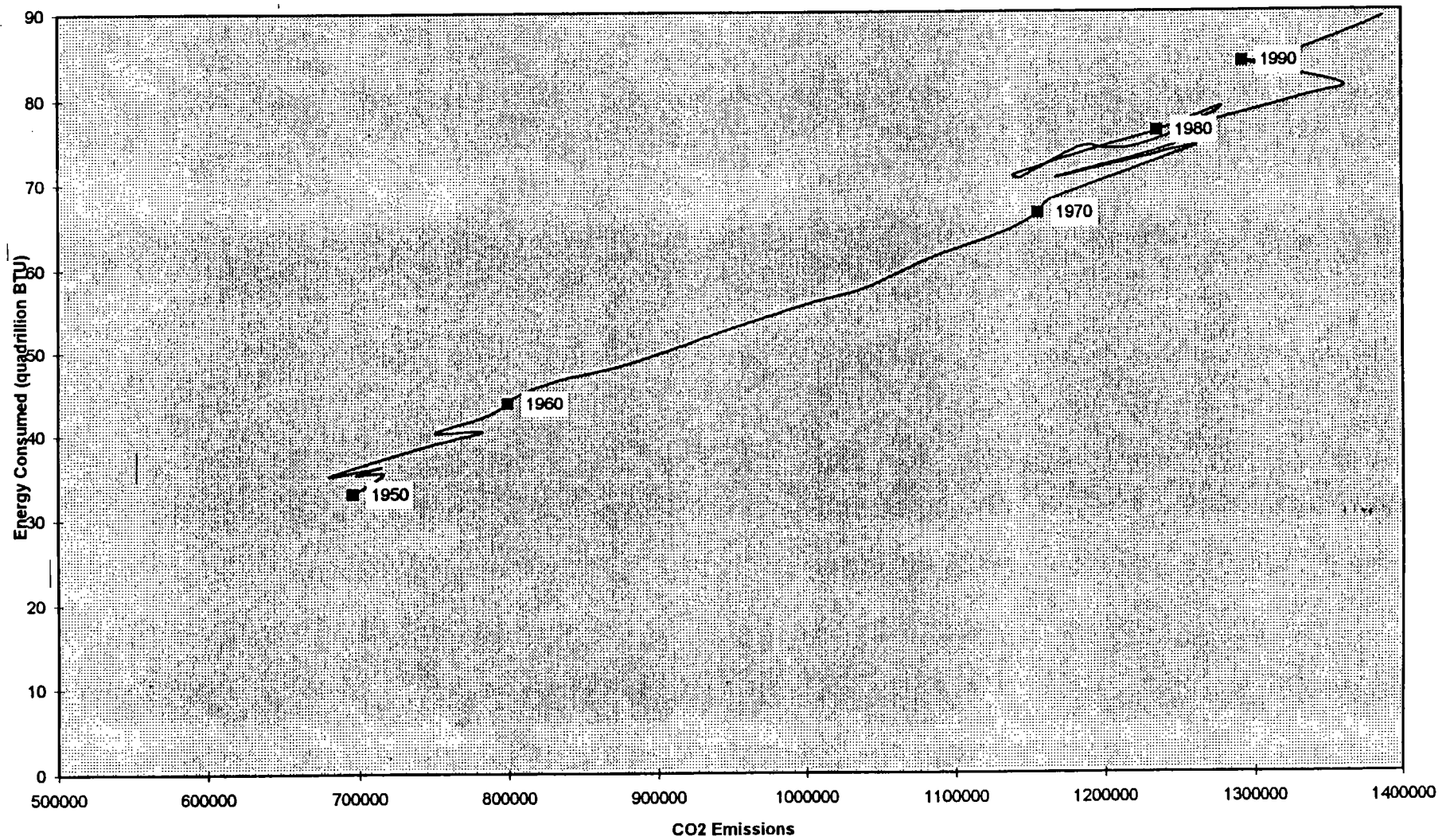
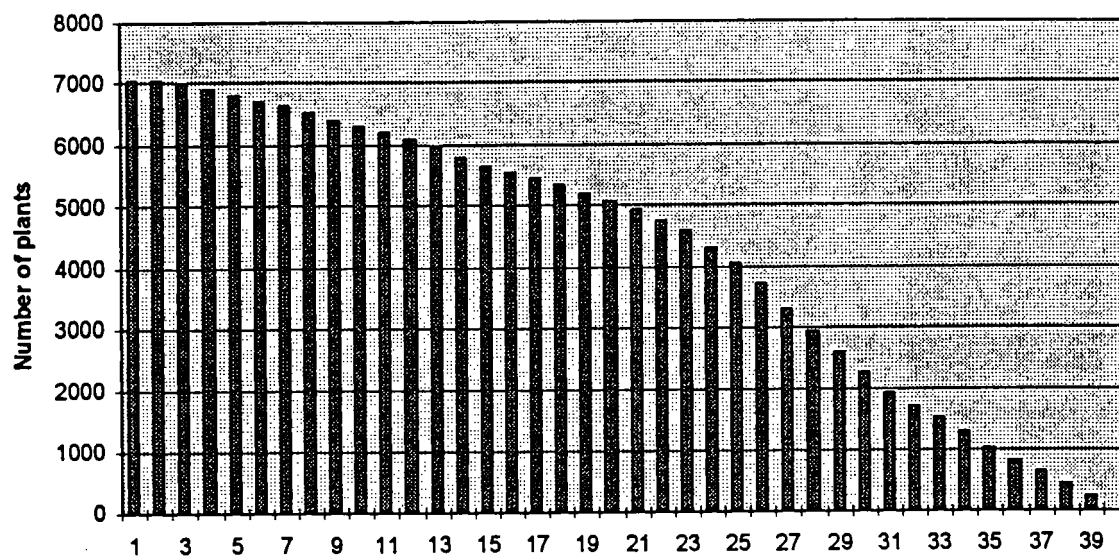


Figure 1. Accelerated Replacement of Electric Power Plants



Bar height shows number of plants to replace (beyond normal replacement schedule) if complete change-over occurs within number of years shown on axis

The Structure of the Kyoto Protocol: US Efforts Needed to Meet Commitments

In October 1997, President Clinton proposed to return greenhouse gas net emissions to 1990 levels in 2008-2012. This target was premised on the long-standing US position of comprehensive coverage of all greenhouse gases (CO₂, CH₄, N₂O, PFCs, HFCs, and SF₆) and all sectors (including land use and forestry systems). Although comprehensiveness increased the tonnes of US reductions required to meet a given numerical target, we have pushed for it because it provides greater cost-effectiveness and increases the industrial support for the agreement. The EU or Japanese wanted to exclude the synthetic gases and land use and forestry, making their targets several percentage points "easier" to achieve than if their proposals had been comprehensive.

The Kyoto Protocol assigns the US a 7% reduction below base period emissions. The U.S. accepted changes in calculation of the obligation for synthetic gases, forests and land use change that allowed the US to deepen its numerical target for the same level of effort. These changes simultaneously increased the level of effort required by the EU and Japan.

The U.S. also agreed to increase the strength of its obligation. The total of the accounting changes and increased strength result in the change of target to 7% below base period levels. Despite the accounting changes, the U.S. gained virtually comprehensive coverage during the commitment period of 2008 to 2012.

Synthetic Gases (HFC/PFC/SF₆) *→ Fastest growing gases*

The President's proposal included the rapidly growing synthetic gases, using a base year of 1990. The US won inclusion of these gases, and accepted a 1995 base year for calculation of the commitment. The recalculation of base period emissions allowed the U.S. to adjust downward its numerical target by roughly 13 MMTCE, the amount by which the synthetic greenhouse gases grew between 1990 and 1995 (about 1% of the U.S. commitment). For the EU and Japan, which had not counted synthetic gases in their proposals, the broader coverage made their targets more difficult.

Exclusion of Forest and Land Use Change Category.

Forest carbon sequestration is a large, but declining offset to US emissions. U.S. estimates, using 1996 IPCC guidelines adopted by the Parties, indicate that US forest carbon sequestration is expected to decline by 55 MMTCE between 1990 and 2010.¹ Unlike emissions from energy use, emissions or removals in the base period cannot be continued indefinitely; emissions decline as available land is exhausted and removals decline as forest systems mature. Therefore,

¹ The US Climate Action Report estimated that US forest sinks would decline by 16 MMTCE. This estimate was updated to include soil carbon, to conform with the 1996 IPCC guidelines and the U.S. goal of comprehensive coverage.

including this sector in calculation of the GHG obligation penalizes those Parties with net removals in the base period and rewards Parties with net emissions. The Kyoto Protocol therefore, as standard practice, excludes LUCF from the base period emissions on which the GHG obligation is based, eliminating the "penalty" in the President's proposed target of 55 MMTCE of carbon (slightly more than 3% of our overall commitment). It had no effect on the EU or Japan, which had excluded the category from their target proposals.

In addition, the U.S. gained crediting of specific forest activities, limited to: afforestation, reforestation, and deforestation since 1990. While the U.S. was initially opposed to this approach due to its inherent accounting uncertainty, we believe that these credits may further reduce the level of effort needed for a given target by a significant but as yet unquantified amount.

Additional Reductions

The US accepted an additional -3 percentage points of real effort in order to get agreement with the European Union, Japan, and the G-77. The U.S. reached a target 7% below the base period emissions by combining the two changes in calculation of base period emissions, which made the President's proposal equivalent to -1 percentage points for synthetic gases plus -3 percentage points for forests and land use change, with the -3 percentage points of additional reductions.

FAO PRODUCTION YEARBOOK

LAND USE	Land Use Country Notes
IRRIGATION	Specific Country Notes
General Country Notes	

Land use (land cover)

It should be borne in mind that definitions used by reporting countries vary considerably and items classified under the same category often relate to greatly differing kinds of land.

Definitions of land use (land cover) categories are as follows:

11 Total Area 1000ha:

the total area of the country, including area under inland water bodies. Data in this category are obtained mainly from the United Nations Statistical Division, New York. Possible variations in the data may be due to updating and revisions of the country data and not necessarily to any change of area.

31 Land Area 1000ha:

total area excluding area under inland water bodies. The definition of inland water bodies generally includes major rivers and lakes. Data in this category are obtained mainly from the United Nations Statistical Division, New York. Possible variations in the data may be due to updating and revisions of the country data and not necessarily to any change of area.

51 Agricultural Area 1000ha:

up to 1994, this element shows total of data under Elements 061 (Arable land and Permanent crops) and 131 (Permanent pastures).

61 Arable and Permanent Crops 1000ha:

Arable land and land under permanent crops shows the total of data in Elements 071 (Arable land) and 121 (Permanent crops).

71 Arable Land 1000ha:

land under temporary crops (double-cropped areas are counted only once), temporary meadows for mowing or pasture, land under market and kitchen gardens and land temporarily fallow (less than five years). The abandoned land resulting from shifting cultivation is not included in this category. Data for "Arable land" are not meant to indicate the amount of land that is potentially cultivable.

121 Permanent Crops 1000ha:

land cultivated with crops that occupy the land for long periods and need not be replanted after each harvest, such as cocoa, coffee and rubber; this category includes land under flowering shrubs, fruit trees, nut trees and vines, but excludes land under trees grown for wood or timber.

131 Permanent Pasture 1000ha:

land used permanently (five years or more) for herbaceous forage crops, either cultivated or growing wild (wild prairie or grazing land). The dividing line between this category and the category "Forests and woodland"; is rather indefinite, especially in the case of shrubs, savannah, etc., which may have been reported under either of these two categories. In the year 1995 and onward there will be no data for this element.

141 Forests and Woodland 1000ha:

land under natural or planted stands of trees, whether productive or not. This category includes land from which forests have been cleared but that will be reforested in the foreseeable future, but it excludes woodland or forest used only for recreation purposes. The question of shrub land, savannah, etc. raises the same problem as in the category "Permanent meadows and pastures". In the year 1995 and onward there will be no data for this element.

181 All Other Land 1000ha:

up to 1994, this category includes any other land not specifically listed under elements 051

(Agricultural land) and 141 (Forests and Woodland). This element includes: built-on areas, roads, barren land, etc. for which no specific data are available.

191 Non arable and permanent crops 1000ha:
from 1995 this element includes any other land not specifically listed under elements 061 (Arable land and Permanent crops) i.e.: permanent pastures, forests and woodland, built on areas, roads, barren lands, etc.

LAND USE COUNTRY NOTES

The following are specific country notes pertaining to land-use (land-cover) categories:

Australia: Data on arable land include about 27 million hectares of cultivated grassland.

Greenland: "Total area" refers to area free from ice.

Mauritius: Data on total area exclude dependencies.

Russian Federation: Data on total area exclude the portion of land under the White Sea and the Azov Sea.

Switzerland: Data from 1992, with the exception of "Total area" are not comparable with those of the previous years because of a new statistical method recently applied by the country.

Ukraine: Data on total area exclude the portion of land under the Azov Sea.

USSR: Data on total area include the White Sea (9 million hectares) and the Azov Sea (3.73 million hectares). Data on arable land and land under permanent crops and on permanent meadows and pastures refer to the land being used by agricultural undertakings and farms, i.e. excluding State land reserves and areas belonging to nonagricultural undertakings.

Irrigation

051 Irrigated Area 1000ha:

Data on irrigation relate to areas equipped to provide water to the crops. These include areas equipped for full and partial control irrigation, spate irrigation areas, and equipped wetland or inland valley bottoms.

The following are specific country notes:

Cuba: Data refer to State sector only.

Hungary: Data exclude complementary farm plots and individual farms.

Japan; Korea, Republic of; Sri Lanka: Data refer to irrigated rice only.

GENERAL COUNTRY NOTES

Anguilla

Data for Anguilla are included with those of Saint Kitts and Nevis.

China

Data for China generally include those for Taiwan (Province of China).

Cyprus

As a result of the present situation in Cyprus, data refer to the government-controlled area only, except for total area and Population where data refer to all Cyprus.

Czech Republic, Slovakia

Starting in 1993, these independent republics, formerly Czecho slovakia, are shown separately.

East Timor

Most data for recent years are included in those of Indonesia.

Eritrea, Ethiopia

Starting in 1993, Eritrea and Ethiopia, formerly Ethiopia PDR, are shown separately.

Independent republics of the USSR

Starting in 1992, the independent republics Armenia, Azerbaijan, Georgia, Kazakhstan, Kyrgyzstan, Tajikistan, Turkmenistan and Uzbekistan are shown separately in Asia, while Belarus, Estonia, Latvia, Lithuania, Moldova, the Russian Federation and Ukraine are shown separately in Europe. However, they are not included in the continental totals. Data before 1992 are shown under USSR.

Independent republics of Yugoslavia SFR

Starting in 1992, the independent republics Bosnia and Herzegovina, Croatia, the former Yugoslav Republic of Macedonia, Slovenia, and the Federal Republic of Yugoslavia (Serbia and Montenegro) are shown separately. Data for the years prior to 1992 are shown under Yugoslavia SFR.

India and Pakistan

Data relating to KashmirJammu, whose final status has not yet been determined, are generally included under India and excluded from figures for Pakistan. Data for Sikkim are included under India.

Pacific Islands

This heading includes data for the Republic of the Marshall Islands, the Commonwealth of the Northern Mariana Islands, the Federated States of Micronesia and the Republic of Palau.

Saint Helena

Data for Saint Helena include those for Ascension and Tristan da Cunha.

Yemen

Data for the former Yemen Arab Republic and the former Yemen, Democratic, have been combined.

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LAND USE	Year					
LAND AREA (1000HA)	1990	1991	1992	1993	1994	1995
ALBANIA	2,740	2,740	2,740	2,740	2,740	2,740
AUSTRALIA	768,230	768,230	768,230	768,230	768,230	768,230
AUSTRIA	8,273	8,273	8,273	8,273	8,273	8,273
BEL-LUX	3,282	3,282	3,282	3,282	3,282	3,282
BULGARIA	11,055	11,055	11,055	11,055	11,055	11,055
CANADA	922,097	922,097	922,097	922,097	922,097	922,097
CZECHOSLOVAK	12,536	12,536	12,536			
DENMARK	4,239	4,239	4,243	4,243	4,243	4,243
ESTONIA			4,227	4,227	4,227	4,227
FINLAND	30,459	30,459	30,459	30,459	30,459	30,459
FRANCE	55,010	55,010	55,010	55,010	55,010	55,010
GERMANY	34,927	34,927	34,927	34,927	34,927	34,927
BOSNIA HERZG			5,100	5,100	5,100	5,100
GREECE	12,890	12,890	12,890	12,890	12,890	12,890
HUNGARY	9,234	9,234	9,234	9,234	9,234	9,234
CROATIA			5,592	5,592	5,592	5,592
ICELAND	10,025	10,025	10,025	10,025	10,025	10,025
IRELAND	6,889	6,889	6,889	6,889	6,889	6,889
ITALY	29,406	29,406	29,406	29,406	29,406	29,406
JAPAN	37,652	37,652	37,652	37,652	37,652	37,652
LATVIA			6,205	6,205	6,205	6,205
LIECHTENSTEN	16	16	16	16	16	16
LITHUANIA			6,480	6,480	6,480	6,480
NETHERLANDS	3,392	3,392	3,392	3,392	3,392	3,392
MACEDONIA			2,543	2,543	2,543	2,543
NEW ZEALAND	26,799	26,799	26,799	26,799	26,799	26,799
NORWAY	30,683	30,683	30,683	30,683	30,683	30,683
CZECH REP				7,728	7,728	7,728
POLAND	30,442	30,442	30,442	30,442	30,442	30,442
PORTUGAL	9,150	9,150	9,150	9,150	9,150	9,150
ROMANIA	23,034	23,034	23,034	23,034	23,034	23,034
RUSSIAN FED			1,688,850	1,688,850	1,688,850	1,688,850
YUGOSLAVIA			10,200	10,200	10,200	10,200
SLOVENIA			2,012	2,012	2,012	2,012
SLOVAKIA				4,808	4,808	4,808
SPAIN	49,944	49,944	49,944	49,944	49,944	49,944
SWEDEN	41,162	41,162	41,162	41,162	41,162	41,162
SWITZERLAND	3,955	3,955	3,955	3,955	3,955	3,955
UK	24,160	24,160	24,160	24,160	24,160	24,160

UKRAINE			57,935	57,935	57,935	57,935
USA	915,912	915,912	915,912	915,912	915,912	915,912
YUGOSLAV SFR	25,540	25,540				
EC (15)	313,183	313,183	313,187	313,187	313,187	313,187
E EUROPE	114,581	114,581	114,488	114,488	114,488	114,488

LAND USE	Year					
FOREST&WOOD (1000HA)	1990	1991	1992	1993	1994	1995
ALBANIA	1,045	1,050	1,051	1,048	1,048	0
AUSTRALIA	145,613	145,000	145,000	145,000	145,000	0
AUSTRIA	3,227	3,227	3,218	3,240	3,240	0
BEL-LUX	709	709	709	709	709	0
BULGARIA	3,345	3,348	3,348	3,348	3,348	0
CANADA	453,300	453,300	453,300	453,300	453,300	0
CZECHOSLOVAK	4,618	4,619	4,618			
DENMARK	417	417	417	417	417	0
ESTONIA			2,016	2,022	2,017	0
FINLAND	23,373	23,222	23,186	23,186	23,186	0
FRANCE	14,811	14,850	14,872	14,931	15,012	0
GERMANY	10,735	10,700	10,700	10,700	10,700	0
BOSNIA HERZG			2,100	2,000	2,000	0
GREECE	2,620	2,620	2,620	2,620	2,620	0
HUNGARY	1,675	1,701	1,712	1,719	1,719	0
CROATIA			2,074	2,076	2,076	0
ICELAND	123	120	120	120	120	0
IRELAND	500	570	570	570	570	0
ITALY	6,760	6,764	6,772	6,800	6,809	0
JAPAN	25,105	25,230	25,230	25,100	25,000	0
LATVIA			2,815	2,839	2,870	0
LIECHTENSTEN	3	3	3	3	3	0
LITHUANIA			1,983	1,983	1,983	0
NETHERLANDS	334	334	334	334	334	0
MACEDONIA			1,066	1,020	1,020	0
NEW ZEALAND	7,667	7,667	7,667	7,667	7,667	0
NORWAY	8,330	8,330	8,330	8,330	8,330	0
CZECH REP				2,629	2,629	0
POLAND	8,672	8,732	8,732	8,732	8,732	0
PORTUGAL	3,102	3,102	3,102	3,102	3,102	0
ROMANIA	6,685	6,680	6,682	6,682	6,680	0
RUSSIAN FED			767,693	768,436	765,912	0
YUGOSLAVIA			1,769	1,769	1,769	0
SLOVENIA			1,077	1,077	1,077	0

SLOVAKIA				1,989	1,989	0
SPAIN	15,807	15,858	15,915	16,137	16,137	0
SWEDEN	28,025	28,025	28,025	28,025	28,025	0
SWITZERLAND	1,186	1,186	1,186	1,186	1,186	0
UK	2,326	2,390	2,390	2,390	2,390	0
UKRAINE			9,239	9,239	9,239	0
USA	295,990	295,990	295,990	295,990	295,990	0
YUGOSLAV SFR	9,118	9,120				
EC (15)	112,746	112,788	112,830	113,161	113,251	0
E EUROPE	35,158	35,250	34,229	34,089	34,087	0

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Number of Database Accesses=388457

The Second Generation Model (SGM)

Summary and Comments

Structure

Sectors:

7 energy sectors

(crude oil extraction, natural gas extraction, coal mining, uranium mining and processing, electricity, oil refining, and gas transmission and distribution)

Agriculture,

Other products

Subsectors for the energy sectors:

3 different grades of oil and gas, differing by extraction cost.

6 different electricity generation subsectors, differing by energy source,

Inputs: land, labor and capital of a various vintages, (e.g., 4 for capital lasting 20 years)

Capital is fixed factor, specific to sector or subsector, and of constant productivity until average lifetime is reached.

Accounting for reserves of depletable resources by resource by vintage

Technology:

Separate CES production functions for each vintage capital

Hick's neutral technological change by sector

Historical values range from 0 in agriculture to 2 percent in coal.

Other products is 0.5 percent.

Demand: 3 sectors:

--government (education, national defense and general government) the government maximizes utility defined over the 3 government services, and finances deficits net of domestic borrowing through foreign borrowing.

--households, savings assumed to vary directly with the real interest rate, interest elasticity of savings of .4, households can demand land and labor as well as final products, price and income elasticities taken from existing literature.

--trade: SGM assumes zero trade for all goods except crude oil

Firm behavior:

Profit maximization under adaptive expectations,

Accelerator-based investment, a sector's share of total investment depends on its

relative expected future profitability, given macro investment demand function.

Implementation

--Calibration chooses model parameters to exactly reproduce observations in a given base year.

--Assumes base-year data reflect equilibrium, and “normal” growth path.

Issues:

Ability to replicate historical data is uncertain.

Behavior ignores uncertainty / risk.

Modelling global change

Note to the reader from the UNU

Future Global Change and Modelling is an ongoing programme that aims to have the United Nations University serve as a forum on the megatrend of global change and structural transformation. This programme is a response to the need to evaluate recent changes in the perception and structure of the world's politics, economics, demography, technology, ecology, and ethics. Practitioners of futures research have, over the past few decades, developed an array of systematic and powerful methodologies in an effort to understand the range and probabilities of future global scenarios. The UNU brings together this international community of scholars to undertake futures studies of global change and incorporate a wide range of variables and methodologies to increase both the early warning and longer-term planning capacities of the UN system and policy makers in general.

This book is based on the first of a series of UNU conferences on Future Global Change and Modelling held in Tokyo in October 1991. Scholars and representatives from various UN agencies and leading research institutions from 17 countries discussed immediate and long-term world problems with simulation analysis by various model systems. Subsequent UNU conferences held under this programme include Arms Reduction: Economic Implications in the Post-Cold War Era, and Global Environment, Energy, and Economic Development.

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sterile and did not go further to exploit the potential of the simple, but differentiated enough model. Thus, for example, it might be interesting to analyse the effects of various asymmetric policies, in which various countries would face different target levels, or the potential use of compensation schemes to induce less developed countries to introduce abatement measures. For it is highly probable that concerted international measures will be hindered by the pressing needs for development and economic restructuring of the less or medium developed countries, who on the other hand are emitting a significant amount of greenhouse gases leading to global consequences.

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9

Modelling future greenhouse gas emissions: The second generation model description

J.A. Edmonds, H.M. Pitcher, D. Barns, R. Baron, and M.A. Wise

Introduction

The analysis of greenhouse gas emissions has made enormous progress during the course of the past decade.¹ Analysis has progressed from the use of simple time-trend extrapolations to the analysis of emissions of several greenhouse gases with parallel but independent behavioural and optimization models of energy, manufacturing, agriculture, and land-use systems. But our ability to examine potential future scenarios of greenhouse gas emissions is limited because modelling tools adequate to the task of integrating analyses of technologies and human activities on a global scale with regional detail, including energy production and consumption, agriculture, manufacturing, capital formation, and land-use, along with the interdependencies between these categories, do not yet exist.

The first generation of models were specially models which focused on a particular aspect of the emissions problem without regard to how that activity interacted with other human and natural activities. The Edmonds-Reilly model (ERM) (Edmonds and Reilly 1985), for example, is a global energy model in which the production of commercial biomass has no interaction with the agriculture sector or land-use in general. The Global 2100, Manne and Richels (1990a,b,c,d,

1991) is a computable general equilibrium model, but is limited in its applicability beyond energy-related issues. Other computable general equilibrium models such as Jorgenson and Wilcoxon (1990a,b) focus exclusively on national issues. Other modelling systems such as the Atmospheric Stabilization Framework (ASF) (Lashof and Tirpak 1989), utilize a system of models that provide global coverage of all emissions generating human activities, but do not provide a consistent analysis system in which the interaction between human activities can be analysed. The number of models in use to analyse greenhouse gas emissions reductions is large and growing, including for example: Nordhaus and Yohe (1983); Fossil2, AES (1986, 1991); GREEN, Burniaux et al. (1991), OECD (1991); CETA, Peck and Teisberg (1991); GEMINI, Scheraga et al. (1991); and IMAGE, Rotman et al. (1989).

The current state of understanding of the natural science of the global environmental change issue indicates that a variety of gases are associated with potential changes in the radiative composition of the atmosphere. These gases include: CO₂, CH₄, CO, N₂O, NO_x, SO₂, VOCs, chlorofluorocarbons (CFCs) and CFC substitutes. These gases are released in the process of a wide variety of human activities including: fossil fuel production, transfer and oxidation, land-use change, silviculture, the application of some fertilizers to crops, the husbandry of ruminant livestock, the cultivation of wetland rice, and specific manufacturing processes such as cement manufacture, nylon manufacture, and chemical manufacture. Moreover, though local air chemistry plays an important role with regard to very short-lived¹ gases, it is the sum of all releases and absorptions of all gases by all human activities that governs the short-term³ rate of change of the atmospheric composition of radiatively important gases, and the earth's atmospheric radiation profile. In addition, the human activities that govern emissions are interdependent. That is actions that are taken in one segment of the economy affect other segments of the economy. These interactions are likely to become extremely important if policies are undertaken to reduce potential future emissions. For example, carbon taxes raise great quantities of revenue. While the disposition of tax revenue can generally be assumed to be unimportant to the scale of macroeconomic activity, this is certainly not the case with carbon taxes (Bradley et al. 1991; Brinner et al. 1991; and Scheraga et al. 1991). Other potential policy actions such as tree planting to enhance the carbon sink and/or the extensive development of potential biomass resources to replace fossil fuel energy

stock
problem

sources, can have substantial impacts on land-use, Marland (1988), Kinsman and Marland (1989), Sedjo and Solomon (1989), Moulton and Richards (1990), Adams et al. (1991), Bradley et al. (1991), and Barfield et al. (1991). Finally, it is essential that the relationship between technology, institutions, economics, and human activity be explicitly represented.

No currently existing model is capable of assessing the global emissions from all human activities and the major direct and indirect consequences of potential policies to reduce emissions. Future analysis requires a more sophisticated suite of models. The new suite of models must include both a global integrating model and compatible regional/national models. These new models must be capable of analysing the emissions of all greenhouse gases from all sources, including both those of natural and human origin, and provide an analysis of the interplay between the variety of human and natural activities responsible for greenhouse gas emissions.

The purpose of this paper is to describe the design of a model, currently under development, which is capable of addressing greenhouse gas emissions and the potential consequences of alternative policy options. We refer to this model as the *second generation model* (SGM).

Paradigms for the SGM

The development of SGMs will benefit greatly from the application of three simple principles: problem orientation, minimum modelling, and parametric modelling. The overriding design principle is that the model should be problem oriented. That is, the design of the model should be derived from an analysis of the underlying problem. Model design cannot begin with the set of available models and then try to make the problem fit existing model characteristics. For greenhouse gases, the issues to be addressed are: What are global emissions of greenhouse gases likely to be over the course of the next five to 100 years by region and human activity? What effect will the exercise of policy instruments to control emissions have and what will they cost? What effect will new technologies have on emissions?

Beginning with the problem and working to the design of the model allows the implementation of the second design principle, minimum modelling. Minimum modelling means that the model contains all of the information pertinent to answer the research question, but no extraneous information. If chemical manufacture of CFCs is an important activity in determining the rate and timing of climate

change it should be included. Moreover, the model should be parametric. That is, the model should utilize a database in which all parameters are open to examination and change by the user. In addition, the model should be an open model. The purpose of the model is not to provide a one-pass forecast of the future. Where complex human activities subject to public policy action are involved, the future is fundamentally unpredictable. The purpose of a formal model is to provide a consistent, reproducible framework in which to examine possible scenarios. It is important that model results be reproducible and that the model be open to public scrutiny, and criticism, and that all of the parameters be available for inspection and alteration by model users. Finally, given the complexity of the model, it is important to use a sequential model development process, beginning with a simple model and adding additional important behaviours in a sequential fashion.

In applying the above cited principles, it is necessary to begin by outlining the pertinent dimensions of the greenhouse gas emissions phenomenon. The critical features associated with the emissions of radiatively important gases are as follows:

1. The issue is global, emissions from all sources in all regions of the world determine total atmospheric change;
2. the greenhouse results from the emission of multiple gases including: CO₂, CH₄, CO, N₂O, NO_x, SO₂, VOCs, CFCs, and CFC substitutes;
3. emissions result from multiple human activities including: agriculture (including forestry), energy production and consumption, transportation, manufacture, services, and land-use;
4. emissions depend upon multiple resources and technologies including: managed and unmanaged ecosystems, capital stocks, and labour;
5. emissions depend on international trade patterns, and possibly, migration patterns;
6. factors 3, 4, and 5 depend upon institutional arrangements;
7. policy analysis requires both mid-term (five-year) and long-term (100-year) time horizons.

The second generation model

In light of the above discussion we have undertaken the design of the SGM incorporating the above-listed criteria into the model archi-

ture. The model is global in scope, with five-year time steps and a horizon of 2100. All the major sources of greenhouse gases, as well as SO₂ will be modelled. The economic model is a member of the class referred to as computable general equilibrium models. It contains sectoral detail on households, government, agriculture, energy, and other products activities. Capital stocks are kept by vintage, with economic retirement and retrofit options available. Depletable and renewable resources are tracked in addition to land-use. Economic decision makers include households, government, and producers. The model is regionally disaggregated, with key countries represented individually. Trade between the regions occurs in energy, agriculture, and other products.

Model overview

At base the SGM is a very simple model. Figure 1 depicts the basic structure and flows of goods and services within the SGM version 0.0. At the core of the model are three productive sectors: agriculture, energy, and other products. These, as we will discuss, are disaggregated into 10 sectors in SGM version 0.0. The greatest disaggregation, eight sectors, is found in the energy sector. The central focus on energy reflects the central role energy issues play in determining the future release of radiatively important gases into the atmosphere. Agriculture is similarly handled separately due to the importance of agriculture and land-use issues in determining emissions. All other production is aggregated into a single sector, other products, in SGM version 0.0.

The three productive sectors use three primary factors of production: land, labour, and capital, in combination with produced factors: energy, agriculture, and other products, to produce final output. Note that two aspects of land-use are considered: surface land resources, and sub-surface resources, for example, energy resources.

The household sector is assumed to own land, labour, and private capital. The demographic character of the society is determined within this sector. Household supplies of land and labour are determined on the basis of the price of these factors, which in turn determine, with distributed corporate profits, taxes, and subsidies, the income of the household sector. Household savings are also determined in this sector and vary with the interest rate. This sector also determines the mix of final products to consume.

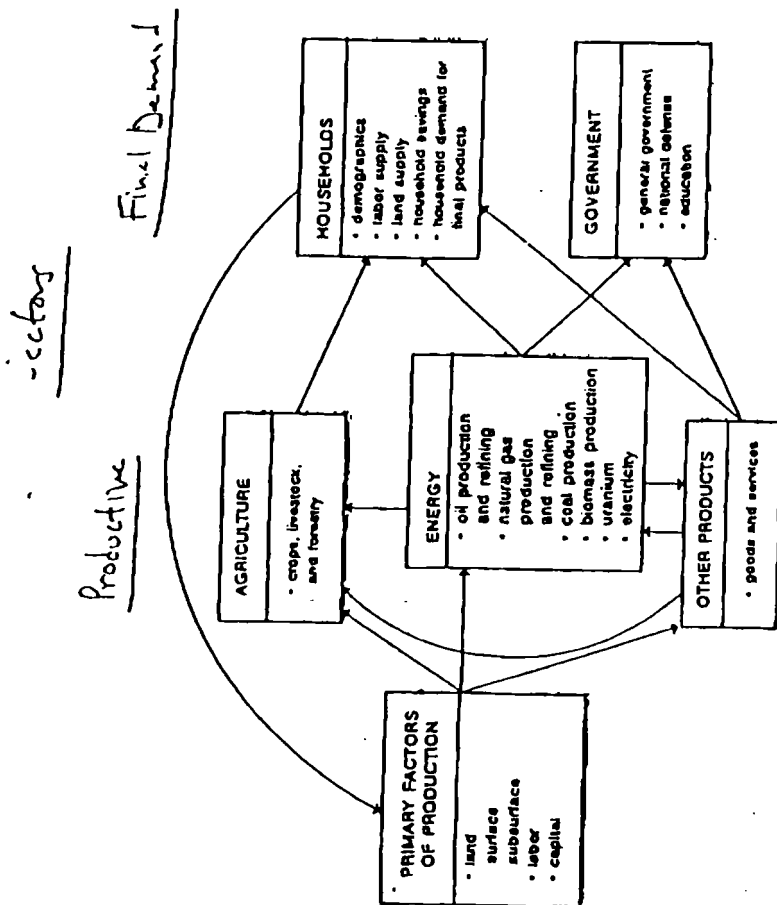


Fig. 1 The flow of goods and services in SGM version 0.0

Greenhouse gas emissions

Finally, the government sector obtains tax revenues from other parts of the economy which are either augmented by borrowing (or reduced by government savings). These revenues go to produce three government services: general government, national defence, and education.

The SGM version 0.0 is a self-consistent dynamic model of the relationship between these six general human activities.

Emissions coefficients are applied to each sector's associated sub-sector and technology activity rates to derive sectoral, regional, and global emissions of radiatively important gases.

Model development strategy

To reflect the current understanding of anthropogenic sources and sinks for radiatively important gases, and to anticipate the potential for new sources, the model has been designed with a generic structure. This structure allows for a flexible number of production activities, consumption activities, and markets. The implementation of this model utilizes the sequential model development principle. That is, the initial model version will be much simpler than the intended final version. Two model versions are currently identified; SGM version 0.0 and SGM version 1.0. SGM version 0.0 is intended to provide a proof in principle for the modelling system. SGM version 1.0 is intended to provide the first full implementation of the SGM system. SGM version 1.0 will be distributed to the public and have a complete documentation set including: theoretical model description, database description, software description, and user's guide.

For both SGM version 0.0 and SGM version 1.0, the energy production, transformation, and consumption activities will utilize databases developed in support of the ERM, Edmonds and Reilly (1985), Edmonds et al. (1986), Edmonds and Barns (1990; 1991). In addition to the energy structure of the ERM, two producing sectors, agriculture and other products have been added for SGM version 0.0. For SGM version 1.0, the number of sectors will be increased to include expanded government, transportation, other products, and agricultural activities. Final demand sectors for investment, government, and households have been developed. Model development is anticipated to proceed beyond SGM version 1.0, but such model designs lie beyond the present planning horizon.

Overview of the SGM structure

Any dynamic model has two problems that it must address. It must describe where the system is at any moment in time and it must describe the process by which it evolves. The SGM is a behavioural model. That is, it attempts to describe how economic systems behave. It is not an optimizing model. The differences between these two approaches are not as great empirically as one might expect.⁴ Nevertheless, we have taken the behavioural approach to developing the SGM for two reasons. First, several extremely interesting questions can be addressed in a non-optimizing, imperfect foresight analysis framework. For example, the importance of alternative expectation formation hypotheses can be tested. That is, there is no reason to believe that energy sector decision makers have perfect foresight. In fact, the immediately preceding quarter century of energy history would support the alternative hypothesis, that is that energy decision makers have very imperfect foresight about key future energy parameters such as price. In addition, the behavioural models are computationally simpler in that present behaviour is assumed to be independent of actual future events and decisions. This is of course the domain in which actual decision makers operate. However, the model and its assumed behaviour does depend on anticipated future events and decisions.⁵

Sectors, subsectors, technologies, markets, and accounting

At any moment in time a set of relationships between economic actors can be summarized in a set of accounts that are referred to as an input-output framework. It is important to emphasize that the SGM is not a traditional static input-output model. The use of input-output accounting identities to describe economic interrelationships at a point in time does not mean that the SGM simply uses a set of static input-output coefficients that are assumed to remain fixed for an indefinite period in the future to determine production levels and demands. Rather, the simultaneous determination of these input-output coefficients in conjunction with a consistent set of prices is the principal problem facing a computable general equilibrium model like the SGM.

An input-output table shows the relationship between the production, distribution, and use of goods and services in an economy. A row-column entry shows the quantity of a good or service associated

	E	A	O	L	...
E					
A					
Gov					
Inv					
Ext					

Greenhouse gas emissions

with a row by the sector designated by the column. If a good or service is produced in the economy, it will have both a row and column associated with it. Some sectors, for example, households, investment, and government, may be assumed to consume new final goods and services, but to provide no net output for the rest of the economy. Some factors of production, for example, land, labour, and capital, may be utilized for production in a given period, but are not produced using current flows of goods and services.

GNP accounting: The accounting framework for the SGM relies on simple economic relationships. For example, we can define GNP for any region (note we drop the regional subscript to simplify the notation) as the price-weighted sum of net production of all products,

$$GNP = \sum_{i=1}^N P_i \left(X_i - \sum_{j=1}^N A_{i,j} \right) = \sum_{i=1}^N P_i (C_i + G_i + I_i + EX_i - IM_i), \quad (1)$$

where GNP is the Gross National Product; X_i is the gross domestic production of product i ; A_{ij} is the domestic use of product i in the production of product j ; P_i is the price of product i ; N is the number of product; C_i is the domestic consumption by households of product i ; G_i is the domestic consumption by government of product i ; I_i is the domestic investment uses of product i ; EX_i is the gross exports of product i ; and IM_i is the gross imports of product i , which in turn is equal to the disposition of net output among final demand sectors. Alternatively, the GNP can be expressed as the sum of payments to the factors of production,

$$GNP = \sum_{i=1}^N \left(P_i X_i - \sum_{j=1}^N P_j A_{j,i} \right) = \sum_{i=1}^N \left(TX_i b_i + \pi_i + \sum_{l=1}^{N+M} P_l A_{l,i} \right), \quad (2)$$

where $TX_i b_i$ is the indirect business taxes; π_i is the profits including net interest and capital consumption allowances; and M is the number of primary factors of production (e.g. labour and land).

The fundamental problem that the model must address is finding a set of prices that are consistent with demands by producers and consumers for goods, services, and primary factors of production. The major behavioural components of the model describe the rela-

relationship between prices, production, and consumption of goods and services.

Defining sectors, subsectors, technologies, and markets: For the purposes of SGM documentation we have chosen to use several terms in a specific manner.

Sectors

Sectors represent human activities that produce or consume goods and services. There are two types of sectors, producing sectors and final demand sectors;

Producing sectors

Producing sectors combine factors of production, including the products of other producing sectors and primary factors of production, to produce net output. For example, agriculture, energy, and other products are sectors in SGM version 0.0;

Final demand sectors

Final demand sectors provide final demands for final goods and services, and include households, government, investment, and net exports in SGM version 0.0;

Markets/factor inputs

Markets and factor inputs are intimately related in the SGM. A market exists in the SGM whenever production and consumption decisions are determined separately in the model. Each traded good is also potentially a factor of production, although a product may or may not be used in the production process in the implemented model. For example there may be no net demand for agricultural products by any producing sectors. Nevertheless, there will always exist a row entry in the SGM input-output accounting structure even if the element entered there is zero. Markets define the primary level of aggregation in the model. That is, all subsectors and technologies (see descriptions below) in a sector/market produce a single homogeneous commodity. Markets are defined for each producing sector plus for each primary factor of production, for example, agriculture, energy, and other products plus labour and land in SGM version 0.0;

Subsectors

A subsector exists in the SGM whenever two human activities produce the same output. All subsectors within a sector face the same

price for outputs, but would be expected to have different production functions, for example the production of electricity using oil, gas, coal, hydroelectric power, nuclear power, or solar power. Subsectors may be defined for both producing sectors and final-demand sectors;

Technologies

For some human activities an additional level of disaggregation is useful. Whereas, the number of subsectors for an individual sector in a specific region would not be expected to change from analysis to analysis, there will be times in which multiple, non-mutually exclusive, technology options should be considered. These options have the same output price as the subsectors and sector, but would have individual production functions.

SGM sectors, subsectors, technologies, and markets

For SGM version 0.0 sectors, subsectors, and markets have been identified and are listed in table 1. The technology level of the model has not been separately identified here as there is only one technology for each subsector in version 0.0.

Economic sectors

There are eight energy sectors and two non-energy production sectors in SGM version 0.0. Data for the energy sectors is largely drawn from the ERM model, Edmonds and Reilly (1985) and Edmonds et al. (1986) as updated for Edmonds and Barns (1991). The non-energy sector of the economy will be the primary focus of efforts between SGM version 0.0 and SGM version 1.0. Table 2 shows the additional sectors to be added to SGM version 0.0 to create SGM version 1.0. Producing sectors can be roughly categorized as being either agricultural, energy, or other-products related. The level of disaggregation in each area is driven by the need to understand factors affecting potential future emissions of greenhouse gases and the potential consequences of policy actions to reduce potential future greenhouse gas emissions.

Agriculture

The agriculture sector produces food, fibre, and forest products. In version 0.0, there will be only a single aggregate agricultural commodity. In version 1.0 there will be nine outputs, disaggregated primarily on the basis of greenhouse gas emissions. The three sectors

Table 1 SGM sectors, subsectors, and markets model version 0.0

Sector No.	Market No.	Sector	Subsector No.	Subsector name
1	1	Agriculture	1	Agriculture
2	2	Crude oil production	1-10	Crude oil production by grade. Each resource grade is modelled as a subsector.
3	3	Oil refining	1	Conventional oil refining
			2	Coal liquefaction
			3	Biomass liquefaction
4	4	Natural gas production	1-10	Natural gas production by grade. Each resource grade is modelled as a subsector.
5	5	Natural gas transformation	1	Conventional gas
			2	Coal gasification
			3	Biomass gasification
6	6	Coal production	1-10	Coal production by grade. Each resource grade is modelled as a subsector.
7	7	Biomass production	1	Traditional biomass
			2	Biomass waste
			3	Biomass farms
8	8	Uranium production and refinement	1-10	Uranium production and processing by grade. Each resource grade is modelled as a subsector.
9	9	Electric power generation	1	Oil
			2	Gas
			3	Coal
			4	Biomass
			5	Nuclear
			6	Solar/fusion
			7	Hydro
10	10	Other production	1	Other production
11	n.a.	Households ^a	1	Consumer demand
			2	Demographics
			3	Land supply
			4	Labour supply
			5	Savings
12	n.a.	Government	1	General government
			2	Education
			3	National defence
n.a.	11	Labour	n.a.	n.a.
n.a.	12	Land	n.a.	n.a.
n.a.	13	Savings/investment	n.a.	n.a.

a. Listed household subsectors represent major decisions made within the household sector rather than subsector as used in the other sectors. See section 'Households' below for further details.

Table 2 Sectors and subsectors added to SGM version 0.0 to create SGM version 1.0

Sector SGM version 0.0	Sectors SGM version 1.0	Subsectors
Agriculture	Other grains Ruminant livestock Other livestock Other food Fibre Forests Pulp and paper Wood and wood products Processed foods	Rice Other grains Ruminant livestock Other livestock Other food Fibre Forests Pulp and paper Wood and wood products Processed foods
Other production	Manufacturing Passenger transport Freight transport Services	Materials intensive Other manufacturing Rail Air Bus Other ^a Rail Air Truck Other Health and other services

a. Passenger automobile in household sector.

closely associated with greenhouse gas emissions are rice (principally CH₄), ruminant livestock (principally CH₄), and forestry (principally CO₂). All sectors are associated with N₂O emissions through the application of fertilizer. Significant quantities of greenhouse gases are also associated with traditional agricultural technology, in particular the practice of slash and burn. The principal inputs in version 0.0 will be land, labour, and energy. In version 1.0 these will be expanded to include fertilizer and materials and land will potentially be disaggregated into multiple categories in accordance with soil types and climate.

Energy

There will be eight energy sectors in the model. Each of these will have subsectors as detailed in table 1 to allow the competing methods for producing the product in question to be accurately modelled.

Two types of energy technologies will be identified, those associated with depletable resources and those associated with renewable resources. All energy technologies will be associated with a resource constraint. A distinction will be made between reserves and resources. Reserves are those resources where two types of energy have been identified and whose location is known and which are known to be producible under present and anticipated economic conditions. Reserves are depleted over time as they are produced. Total reserves are augmented by additions from the resource base. The additions to reserves are determined by grade structure of resources and technologies available to extract them. Renewable resources are handled in a manner similar to depletable resources except that the capacity to produce persists beyond the point of production. Solar energy is an example of a renewable energy resource. A renewable resource may be degraded by production, however. Agriculture, for example, may deplete soils unless investments are made to maintain soil quality.

Other products

In version 0.0, the other products sector will include everything which is neither agriculture nor energy. In version 1.0, the other products sector will be broken down into manufacturing, passenger and freight transportation, and health and other services. There is the possibility of further splitting manufacturing into materials and other manufacturing. Inputs will be capital, labour, and energy in version 0.0 with materials being added in SGM version 1.0. The principal sectors are further disaggregated into subsectors on the basis of their importance to the greenhouse issue, either because they are major energy users, or because they are direct emitters or sinks for a greenhouse gas.

Regions

SGM version 0.0 has 11 regions while SGM version 1.0 will have 20 regions as shown in table 3.

Policy options

Because of the pervasive nature of activities that generate greenhouse gases, a wide variety of policy options needs to be included in the model. Making provision to model these options has had a sig-

Table 3 Regions in SGM model versions 0.0 and 1.0

SGM version 0.0	SGM version 1.0
1. USA	1. USA
2. Canada	2. Canada
3. Western Europe	3. European Community
4. Japan	4. Other Western Europe
5. Australia/New Zealand	5. Japan
6. Eastern Europe and Russia	6. Australia/New Zealand
7. China and other planned Asia	7. Eastern Europe
8. Mid East	8. Russia
9. Africa	9. China
10. S. & E. Asia	10. Centrally planned Asia
11. Latin America	11. Mexico
	12. Brazil
	13. Other Latin America
	14. Indonesia
	15. India
	16. Philippines
	17. South Korea
	18. Other S. & E. Asia
	19. Middle East
	20. Africa

nificant impact on the structure of the model. In addition to the usual tax and regulatory options, provisions have been made in the SGM structure to model such strategies as carbon sequestration by reforestation and afforestation, and biomass energy production, and mandated technologies and practices. The SGM is also designed to explore the consequences of changes in real government expenditure patterns/or complementary reductions in non-greenhouse taxes.

Theoretical structure of the model

The SGM employs a generic production-cost structure to facilitate the continued development of the model with a minimum of code changes and a flexible modelling response to the wide variety of potential analyses that may be required. The core of the model is the description of production activities. These activities are described by a generic production-cost relationship. This relationship utilizes the theory of duality to describe production functions alternately in physical or financial terms.

The generic production/cost relationship

The generic production/cost (GPC) relationship uses information about prices, technology, and previous investments to compute levels of production and consumption of commodities as well as demands for investment in new capital stock. Productive activities are described by functional relationships in the SGM which are referred to hereafter as technologies. The term technology is used here to cover a broad array of activities including everything from the production of iron and steel to the production of rice. Technologies, as described earlier, are the fundamental unit of disaggregation in the model. Each sector contains at least one subsector and each subsector contains at least one technology. For SGM version 0.0, there is only one sector, market, subsector, and technology for the production of agricultural output. For the production of electricity, there are seven subsectors each of which can potentially utilize multiple technology options. The SGM keeps all of its information on productive capacity at the technology level of detail.

The SGM uses a vintaged description of technologies. This has a number of important implications. First, it means that history matters. When a technology is installed it remains in existence and can be operated until its retirement. New technologies affect productivity primarily at the margin. They can only affect historical decisions if they are so attractive (unattractive) that they force prices down to the point where existing technologies are retired early (undergo life extension). Another important implication is that once installed, capital stock is not malleable. It cannot be shifted around from one sector of the economy to another. In fact, once installed, capital costs no longer matter. In other words, once the technology is installed the decision to operate or idle a technology depends solely on the ability of the technology to recover its current operating expenses plus taxes and less subsidies.

A technology is described by an array of characteristics including:

1. production function parameters;
2. emissions coefficients;
3. capital investment parameters;
4. installation parameters (e.g. date of first availability, date of removal from the list of options, nominal lifetime, length of installation period); and
5. vintage.

A technology option can be described by the information contained

in parameter sets 1, 2, 3, and 4. Once installed, the operating characteristics of a technology can be described by parameter sets 1, 2, and 6.

Within the GPC relationship, the producing sectors all follow the same general structure. There are, of course, some characteristics that are specific to a sector or apply only to a subset of sectors. However, the basic model structure is sufficiently general to accommodate the production/cost and operating characteristics of the various producing sectors in its parameter set.

The sectors represent the highest level of aggregation of production characteristics in the GPC. Within the GPC framework, these production sectors are disaggregated into one or more production/cost subsectors. All sectors, subsectors, and technologies produce a common output and face a common external market price for produced output. The GPC structure allocates investment to technologies based on prior investment history and relative profitability, using a logit market-share allocation scheme.

As an example of this sector-subsector hierarchy, consider an electricity production sector with subsectors for coal, oil, natural gas, biomass, nuclear, and hydroelectric power. These subsectors all produce electricity, and they all receive the same price for the electricity they generate. These subsectors do, however, have quite different operating and input requirements for producing electricity, which will in turn affect their relative profitabilities. The allocation of investment among these subsectors in the GPC will reflect these differences in profitability.

Each technology is represented by a vintage-dated, constant elasticity of substitution (CES) production/cost function (one for each vintage of capital stock in operation). For each technology, technological change through time can be captured in the model through the CES production function parameter set. In SGM version 0.0 both an initial set and a terminal set of CES coefficients or parameters is specified for each producing subsector. For any future vintage, the CES coefficients used are a time-dependent interpolation between the initial and terminal values. Different technological change scenarios can thus be modelled in each subsector by varying the terminal coefficient values and the time required to reach these terminal values.

The general execution path for the GPC is to (1) determine desired levels of investment in new capacity, (2) operate the new capacity, (3) retrofit existing capital stocks, and (4) operate or retire existing capital stocks.

sector
↓
subsector
↓
technology

The CES production/cost-function

The CES production function can be written,

$$X_s = \alpha_0 \left(\sum_{i=1}^N \alpha_i X_i^\rho \right)^{1/\rho}, \quad (3)$$

where X_s is the gross output of the process; X_i is the use of input factor i ; α_0 is the scale coefficient; α_i is the individual factor coefficients; and ρ is the elasticity of substitution parameter.

Profit maximization implies that,

$$P_i = P_0 \frac{\partial X_s}{\partial X_i}, \quad i = 1, \dots, N - M, \quad (4)$$

where P_i is the price of i th input; P_0 is the price of output; $N - M$ is the number of variable factors; and M is the number of fixed factors.⁷

Profits can be written as,

$$\pi = P_0 X_s - \sum_{i=1}^{N-M} P_i X_i. \quad (5)$$

By judicious application of algebra, and equation (4), profits can be expressed as a function of price and the quantities of M non-variable factors of production via,

$$\pi = \alpha_0 P_0 \left[1 - (P_0 \alpha_0)^\mu \left(\sum_{i=1}^{N-M} \alpha_i^{\mu/\rho} P_i^{-\mu} \right) \right]^{-1/\rho} \left(\sum_{i=N-M+1}^N \alpha_i X_i^\rho \right)^{1/\rho}, \quad (6)$$

where

$$\mu = \frac{\rho}{1 - \rho}. \quad (7)$$

It is well known that the partial derivative of this expression with respect to the price of the i th input is the negative of the total factor demand, that is

$$\frac{\partial \pi}{\partial P_i} = -X_i. \quad (8)$$

The demand for the i th factor input to the production process can therefore be calculated directly as,

$$X_i = \left(\alpha_0 P_0 \frac{\alpha_i}{P_i} \right)^{\rho/\rho} \left(\frac{Y}{Z} \right)^{1-\rho}, \quad i = 1, \dots, N - M, \quad (9)$$

where

$$Y = \sum_{i=N-M+1}^N \alpha_i X_i^\rho, \quad (10)$$

and

$$Z = 1 - (\alpha_0 P_0)^\mu \left(\sum_{i=1}^{N-M} \alpha_i^{\rho/\rho} P_i^{-\mu} \right). \quad (11)$$

The above equations can be used to model both operational decision making and investment determination.

Expected future profits from the operation of a technology which employs

$$x_k = (X_{N-M+1}, \dots, X_N)$$

fixed factors over the course of T years of operation is simply,

$$\pi_k(t_0) = \sum_{t=1}^T \left(\frac{\pi(x_k, t)}{1 + \text{dis}} \right)^t, \quad (12)$$

where $\pi(x_k, t)$ is the profit rate consistent with expected future prices in future period t and dis is the discount rate.

Investment and operating decisions

Once a technology has been installed, operation is determined by the set of factor prices for variable factors of production, and the quantity of the fixed factor employed. The determination of factor demands is therefore a relatively simple matter. Investment decisions however are not so simple. These are determined both by the present set of

factor prices and the set of expected future factor prices extending out over the expected lifetime of the investment. In the SGM, there are two types of investments, investments in new capacity and investments in existing capacity, in the form of retrofit and renovation (life extension) investments. The existence of retrofit and renovation (life extension) investment alternatives means that present operations are never simple, and that the technology chosen for an addition to new capacity may be substantially altered before its ultimate retirement. The analysis of investment alternatives requires a mechanism for the determination of expectations regarding future prices and taxes.

Future price and tax rate expectations

In each sector, investments are allocated among subsectors on the basis of their relative *expected* profitabilities. Therefore, investment decisions for each subsector require expected profit rate calculations, which require expected prices and taxes for all inputs. For an open economy the purchase price of the good produced by the i th sector in region "1" is given by:

$$P_{i,t} = \alpha_{i,t} [P_i (1 + \delta_{i,t} Tr_i) (txa_{i,t} + txb_{i,t})], \quad (13)$$

where $\alpha_{i,t}$ is an adjustment factor to reflect markups and intra-regional transport costs; Tr_i is the import transportation costs for the i th good; $\delta_{i,t}$ is a logic driven parameter whose value is 0 if the region is a net exporter, and 1 otherwise; $txa_{i,t}$ is the proportional tax on the i th product in region 1; and $txb_{i,t}$ is the additive tax on the i th product in region 1.

Obviously, the price received by the producer of the j th good is simply,

$$P_{i,j} = P_i (1 + \delta_{i,j} Tr_i). \quad (14)$$

The direct computation of $n_i(t_0)$ is cumbersome. An approximation of this value can be obtained by substituting a set of present discounted prices directly into the profit function. This yields an exact solution when $\mu = 1$ (see equation [7]). The present discounted price for product j (either an input or an output), $Pe_{j,t}$, is calculated by,

$$Pe_{j,t}(T) = \sum_{t=1}^{T_{exp}} P_{j,t}(t_0) \cdot \left(\frac{1+r_j}{1+dis} \right)^t, \quad (15)$$

where T_{exp} is the nominal life of the investment; r_j is the rate of expected price change; and dis_j is the discount rate for that subsector.

As noted above, the nominal life of the investment is a parameter of the technology. This parameter value may be different from the maximum potential life of the technology. The tax rate tx is an exogenous variable. Both the rate of expected price change r_j and the discount rate dis are behavioural variables. Expectations of future price and tax rate expectations are assumed to be formed in one of two ways. Either they are given exogenously, and assumed known, or they are formed on the basis of prior experience. This yields four alternative formation assumptions for future prices and taxes of inputs and outputs which can be created by combining assumptions 1, 2, 3, and 4 from the following matrix:

	Formed on the assumption that previous B periods rate of change will continue indefinitely	Given exogenously
Prices	1	3
Taxes	2	4

Note that whenever price or tax expectations are formed on the basis of prior experience, the period of prior experience, B , must also be specified. For $B = 0$, present prices or taxes are assumed to remain constant indefinitely. Furthermore, it is possible to run the model in an iterative sequence to develop a perfect foresight set of exogenously specified set of prices. This would be accomplished by specifying prior solution prices as the set of expected future prices and iterating until stability is reached.

We feel that the ability to model behaviour in which price expectations are formed on the basis of imperfect foresight is important. The period of time between 1970 and the present is marked by decision-making on the basis of flawed foresight in energy markets.

Furthermore, the effectiveness of tax and regulatory policies may in fact depend on the expectations formed with regard to long-term commitment.

The relationship between the discount and interest rates

The discount rate and the real interest rate need not be the same. A great deal of behavioural literature suggests that these rates may in fact be significantly different from each other, Lind (1983), Meier and Whittier (1983), Hausman (1979), and Gately (1980). To reflect this phenomenon, the discount rate, dis , will be linked to the interest rate calculated in the model, $interest$, by a constant factor of addition, fac_r . The sector-specific discount rate for retrofit investments, will therefore be given by,

$$dis_r = interest + fac_r \quad (16)$$

The add-on factor for retrofit investments need not be the same as the add-on factor for new investments.

The expected future profit rate for a capacity increasing technology

The expected profit rate relative to the capital cost, K , denoted as π_r , is given by,

$$\pi_r = \frac{NR_r}{K} \quad (17)$$

and

$$\frac{NR_r}{K} = \alpha_0 P e_0 \left[1 - (P e_0 \alpha_0)^{\rho/(1-\rho)} \left(\sum_{i=1}^{N-M} \alpha_i^{1/(1-\rho)} P e_i^{-(\rho/(1-\rho))} \right) \right]^{(1-\rho)/\rho} \times \left(\sum_{i=N-M+1}^N \alpha_i x_i^{\rho} \right)^{1/\rho} (1 - tx) \quad (18)$$

where NR_r is the expected net revenue, tx is the profits tax rate, there are M fixed factors, and the other $N - M$ factors are variable factors.

In version 0.0, there is only one fixed factor and the fixed factor term reduces to $\alpha_0^{(1/\rho)}$.

When investments in new capacity occur over more than one period

For most investments the decision to invest and the initiation of operation can be assumed to occur within a single five-year time step. This is not always the case. For example, the construction of nuclear electric power plants may require more than five years from start of construction to first production. Forestry similarly requires more than five years between the time of initial investment and the time of harvest. Each of these circumstances requires a somewhat different approach.

Extended construction time

When the construction time for an addition to capacity extends over $T_{\text{construct}}$ periods then there is an evaluation of the investment in each of these periods under the assumption that the fraction of total investment required in each period is equal. That is, if the total investment in the new capacity is taken to be K , and the construction time is $T_{\text{construct}}$, then in each period an investment of

$$K_t = K/T_{\text{construct}}$$

is assumed to be made. If the investment is expected to be profitable in the first period, then construction begins. The present discounted value of the investment requirement is then,

$$K_{t,t} = \left(\frac{K}{T_{\text{construct}}} \right) \sum_{t=1}^{(T_{\text{construct}}-1)} \left(\frac{1}{1 + dis} \right)^{tc} \quad t = 1, \dots, T_{\text{construct}} \quad (19)$$

where, t is the investment period in which the investment decision is being made, $t = 1, \dots, T_{\text{construct}}$; and tc is an index of periods of investment remaining, $t = 1, \dots, T_{\text{construct}}$. Note that as each period of construction passes, the expected profit rate will rise, other things being equal, because previous period investments become sunk costs.

Expected net revenues from operation of the investment must also be discounted by a factor,

$$\sum_{t=1}^{(T_{\text{construct}}-1)} \left(\frac{1}{1+\text{dis}} \right)^t c \quad t = 1, \dots, T_{\text{construct}} \quad (20)$$

The growth-harvest decision

The growth-harvest decision problem does not occur in SGM version 0.0, as all agricultural activities are aggregate. In SGM version 1.0, a forestry sector will be disaggregated and this problem will occur. In this case an investment occurs in period t_0 , but no revenue is received until T_{harvest} . But T_{harvest} is not predetermined. For growth-harvest production functions the production function given by equation (3) and

$$u_t = \alpha(C_t, C_{t-1}, \text{Atmos}_t, \text{Atmos}_{t-1}, t - t_0), \quad (21)$$

where α is now a function of a vector of climate and atmospheric state variables, and the amount of time that has elapsed between the initial investment, t_0 , and the present period t , C_t is a vector of climate variables such as for example, temperature, precipitation, soil moisture, and evapotranspiration, for $t = t, t - 1$; and Atmos_t is a vector of atmospheric state variables such as for example the concentration of atmospheric CO_2 , for $t = t, t - 1$.

The expected profit rate for an investment in a growth-harvest activity is determined by equations (18) and (21) using the expected price vector for the potential harvest T_{harvest} periods in the future⁸ and discounted by the value,

$$\text{discount factor} = \sum_{t=1}^{T_{\text{harvest}}} \left(\frac{1}{1+\text{dis}} \right)^t \quad (22)$$

The value of π_r can be computed for any two potential harvest periods, $T_{\text{harvest}0}$ and $T_{\text{harvest}0} + 1$, denoted respectively $\pi_r(T_{\text{harvest}0})$ and $\pi_r(T_{\text{harvest}0} + 1)$. The maximum potential value for π_r can be estimated by beginning with $T_{\text{harvest}} = 1$, and increasing the value of T_{harvest} whenever,

$$\pi_r(T_{\text{harvest}} + 1) \geq \pi_r(T_{\text{harvest}}).$$

Investments with a maximum value for $\pi_r > 0$ are included in the pool of sector specific competing investments.

Resource constrained technologies

Many economic activities take place against a background of resource constraints. This is of particular interest in the field of energy economics, but is in no way limited to the energy sector. For example, the resource base for conventional oil is ultimately finite, and cumulative production from that resource base may potentially approximate the total resource over the period of analysis. Fossil fuels are an example of a depletable resource. Renewable resources, such as solar, wind, tidal, and ocean thermal energy conversion also exist. For renewable resources the resource is available in each period independent of consumption during the previous period. We will define depletable and renewable resources as follows:

- **Depletable resources:** A depletable resource is one in which the consumption of the resource in one period affects potential consumption in the next period.
- **Renewable resources:** A renewable resource is one in which the consumption of the resource in one period does not affect potential consumption of the resource in the next period.

Describing the relationship between resources and production is important for such activities.

Depletable resources

For depletable resources the total resource available for consumption over all periods is the sum of the resource available in each grade of NG grades,

$$R_i = \sum_{g=1}^{NG} R_{i,g}, \quad (23)$$

where R_i is the total amount of resource of type i which could be potentially recovered under any possible conditions; and $R_{i,g}$ is the total amount resource of type i , found in concentration c_g or higher up to c_{g-1} under any possible conditions. The resource base can be partitioned into discovered and undiscovered resources. Discovered resources are made up of extracted resources, RE , and reserves, RV . Undiscovered resources are denoted as RU . Thus,

$$R_i = RE_i + RU_i + RV_i, \quad (24)$$

$$R_{i,g} = RE_{i,g} + RU_{i,g} + RV_{i,g}. \quad (25)$$

In the model each sector that produces a depletable resource has a different subsector for each grade of the resource. For a given technology, the grade of the resource is reflected in the value of $\alpha_{it} = \alpha_{i,t,x}$ in the production function. Desired extraction from each resource grade is determined by the expected rate of profitability. The production function implicitly includes the cost of converting undiscovered resources into reserves. Production occurs out of reserves as determined by profit maximization subject to the constraint imposed by total investment in each vintage's productive capacity. The production activity occurs only from reserves, and shifts resources from the reserve category to the extracted category.

Because of the multiplicity of resource grades and the existence of substitutes, there is no guarantee that the price of a depletable resource will rise at a rate equal to the rate of interest, the 'hotelling' result.

Competition among capacity increasing investments within a sector

As discussed earlier, the sector is the highest level of aggregation in the model. Subsectors are assumed to produce an essentially homogeneous product within the sector. For example, in SGM version 1.0 it is expected that there will be four different types of freight transport: rail, air, truck, and other. Each will produce a common unit of output, tonne kilometres of freight transport. Obviously, this assumption violates physical reality. Nevertheless, it is intended to capture the essence of the system. For each subsector, there also exists an additional level of disaggregation, which we refer to as the technology level. Technologies compete within the confines of an individual subsector, and in turn determine the overall profitability of the subsector. A logit function is used to determine the share of total sectoral investment each technology obtains. That share is given by:

$$S_{i,tech} = \frac{(n_{i,tech}^{\sigma} / N_{i,tech} N_{st})}{\sum_{j=1}^{NO} (n_{j,tech}^{\sigma} / N_{i,tech} N_{st})}, \quad (26)$$

where $n_{i,tech}$ is a metric of the characteristic upon which competition is based for technology, tech, in subsector i , N_{st} is the number of

subsectors, $N_{i,tech}$ is the number of technologies competing in subsector i , σ is a sensitivity parameter, and

$$NO = \sum_{i=1}^{N_{st}} N_{i,tech}. \quad (27)$$

The logit function is homogeneous of degree zero. That is, any scalar change in the values of all $n_{i,tech}$ leaves the values of all $S_{i,tech}$ unchanged. For values of σ equal to zero, $S_i = 1/(N_{st} N_{i,tech})$. If greater values of $n_{i,tech}$ enhance market share, then the value of σ is taken to be non-negative. (If greater values of $n_{i,tech}$ diminish market share, then the value of σ is taken to be negative.) As the value of σ approaches ∞ , $S_{i,tech}$ approaches one for the largest value of $n_{i,tech}$.

In this model, we will use the logit function to determine the share of a sector's total investment spending that is allocated to each subsector, that is to say each competing technology option. The independent variables then are the profit rate values of π obtained earlier. In general the value of σ will be set to reflect existing market sensitivity.

Aggregate sector investment in new capacity

Aggregate regional sector investment levels are determined by using an accelerator from the previous periods total investment. Specifically,

$$K_{tot,t+1} = K_{tot,t} \cdot \text{baserate}_{t+1} \cdot f(\exp(\pi_{t+1})), \quad (28)$$

where K_{tot} is the total new investment in sector i , in period $t+1$; baserate is the base rate of growth of investment; and $f(\exp(\pi))$ is a function of the expected profit rate, $\exp(\pi)$.

We do not prejudice the determination of either baserate or the function $f(\exp(\pi))$. For present model development we use,

$$\text{baserate}_{t+1} = \frac{K_{tot,t}}{K_{tot,t-1}}. \quad (29)$$

The expected rate of profit is taken to be the average expected profit rate which is given by,

$$\exp(\pi_{t+1}) = \bar{\pi}_{t+1} = \left(\sum_{i=1}^{NO} \pi_{i,t+1}^{\sigma} \right)^{1/\sigma}, \quad (30)$$

where π_{it} is the profit rate for the i th technology (taken over all subsectors), in period t . This derivation is given in Clarke (1991). For SGM version 0.0 we use,

$$f[\exp(\pi_{it})] = \left(\frac{\exp(\pi_{it})}{\bar{\pi}_t} \right)^\alpha \quad (31)$$

where α is a sensitivity parameter.

Retrofit and renovation investment decisions and the operation of existing technology vintages

For existing technologies, or technologies with capacity already in place, there are four possible outcomes in any period:

1. *Operate* without change,
2. *Retrofit* and operate,
3. *Idle* the capacity, but do not retire,
4. *Retire* the technology.

The determination of operating mode depends upon the behavioural assumptions. Given the five-year time step in the model, it has been decided to eliminate option 3. In other words, producers will either operate a vintage in the current period or retire that vintage.

For market economies profit maximization is the behavioural paradigm. For investment decisions this means that NR is maximized. That is, existing technologies will continue to be operated as long as current operating costs can be covered, unless otherwise prevented from doing so. They will add retrofit technologies either if they are required or if they add to profitability. The behaviour of command economies is similar, except that (1) substantial subsidies, in both the cost of input factors and direct subsidies to total operating costs; and (2) allocation schemes where administered prices do not clear markets are an important determinant of economic behaviour.

Retrofit technologies

Retrofit technologies are the principal complicating factor in the analysis of existing technology operations. The level of operation of the technology is assumed to be identical to the parent technology. The additional capital cost, relative to the original capital cost, is a technology parameter. The presence or lack of presence of retrofit options does not affect the base production or cost functions.

New retrofit options can be incorporated into the operating structure of the technology if they either are required or are determined to be profitable. If retrofit technologies are not required, then it must be determined if the base technology will continue to be operated. If the base technology can cover current costs, it will continue to be operated, even if its present discounted expected future revenues are negative. If it cannot cover present operating costs, then the technology will be retired unless some retrofit package can produce a present discounted expected future profit.

Under some circumstances the present technology may cease to be an option because a retrofit technology must be applied. In such cases the technology will be retired unless some retrofit package can produce a present discounted expected future profit just as if the base technology had been unprofitable in the current period.

To evaluate retrofit technologies we make the following calculations. Consider an existing technology of vintage V , installed in period V , with nominal lifetime T , in existence in period t . To determine the profitability of retrofit options for that technology, we begin by computing,

$$Pe_j = P_j(t) \cdot \sum_{i=1}^{T-t} \left(\frac{1+r_j}{1+\text{dis}} \right)^i \cdot [1 + \alpha(r)], \quad j = 1, \dots, N. \quad (32)$$

Note that a set of expected future prices for retrofit technologies may be different from the set of expected future prices for the base technology due to different discount rates for the two activities. That is, some firms may have a higher discount rate for retrofit technologies than for new base load investments.

Because each retrofit technology can affect the original technology in a wide variety of ways, the total technology, that is including both the base technology and a package of retrofit options, is given by a separate CES production function whose net additional capital cost is some fraction of the original capital investment, and whose lifetime is the expected lifetime remaining on the original technology.

The general formulation for profit with a fixed factor CES production function, as given by equation (6), is used to compute a value of π_{retrofit} for each technology with a retrofit option. Note that for $\text{retrofit} = 0$, the expected future profit for the base technology is given. If any retrofit technology has a positive present discounted

expected profit higher than the base technology, then the retrofit technology package with the highest expected future profit rate is selected. If expected profits are negative no retrofit technology is adopted, and if either the base technology is unable to cover present operating costs, or is no longer available due to mandated retrofit actions, then the technology is retired.

Renovation

Renovation is a special case of the general investment/retrofit problem. At the end of T_{exp} years of service the technology must either be retired or renovated. Renovation takes the form of a one-time capital investment, that occurs in the T_{exp} th year of service. In effect, however, the retrofit option can be thought of as competing with other new investment opportunities with the production function coefficients of the original technology, a capital cost of K_{extend} , and T_{extend} years of expected life. The profit rate is computed using equation (15) and expected future prices based on an expected technology life of T_{extend} years. Of course, more than one life-extension technology option is possible. In the case where multiple options are available, the technology with the highest expected profit rate is chosen.

The present operating profitability, NR , is still computed from equation (6). The operation, retirement and retrofit logic diagram is given below:

	$NR > 0$	$NR < 0$
$\pi > 0$	Operate and Retrofit	Retire
$\pi < 0$	Retire	Retire

That is, the technology will be retired unless it both can make money in the immediate period and is expected to add to the wealth of the sector over its expected lifetime.

Greenhouse gas emissions

As discussed earlier, the greenhouse issue is complicated by the fact that a wide array of gases are associated with the effect. We make no attempt to discuss either the nature or the extent of the effect various

gases have on the radiative balance of the earth/atmosphere energy balance, but simply note that the following suite of gases will be considered.

- CO₂ emissions from fossil fuel and biomass combustion processes.
- VOC emissions resulting from energy production processes, selected manufacturing processes, some combustion processes (mainly of petroleum based fuel in internal combustion engines), and from selected natural processes.
- CFC emissions from losses from refrigeration and air-conditioning equipment, foam blowing, aerosol propellants, cleaning solvents, and fire extinguishers.
- CH₄ emissions which emanate from the production and distribution of natural gas, mining of coal, from the raising of ruminant animals, the growing of rice, from sanitary landfills, and from combustion processes (principally biomass burning).
- CO emissions, most of which emanate from incomplete combustion of carbon-based fuels, principally in the transportation sector.
- N₂O emissions from combustion processes, fertilizer use, and selected natural sources.
- NO_x emissions from combustion processes - especially from electrical power generation and in internal combustion engines.
- SO₂ emissions and consequent sulphate transformations so that albedo changes can be monitored.

Greenhouse gas emissions coefficients will be included with each technology description. Emissions will be assumed to be proportional to either the scale of input utilization or output of the technology.

Emissions can be calculated simply as,

$$E_{m,l} = \sum_{i=1}^{NS} \sum_{ss=1}^{NSS(i,l)} \sum_{tech=1}^{N_{tech}(i,ss,l)} \sum_{v=V_0}^V \sum_{j=1}^{NI} (e_{m,l,ss,tech,j} X_{i,ss,tech,j,1,v} + f_{m,l,ss,tech,j} X_{S,i,ss}) \quad (33)$$

where, $e_{m,l,ss,tech,j}$ is the technology specific emission coefficient for emission m , in sector l , subsector ss , using technology $tech$, with input j ; $X_{i,ss,tech,j,1,v}$ is the input demand for factor j by sector i , subsector ss , using technology $tech$, of vintage v , in region 1; $f_{m,l,ss,tech,j}$ is the technology specific emission coefficient for emission m , in sector l , subsector ss , using technology $tech$, producing output j ; and

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$X_{i,ss,tech,j,l,v}$ is the output of good j by sector i , subsector ss , using technology $tech$, of vintage v , in region 1.

When emissions are released costlessly into the atmosphere they have no effect on either the cost of production or the optimum demand for investment goods. Releases need not be costless. Like other inputs and outputs from the technology, emissions may be priced. Emissions coefficients have been related to individual technologies. This is because the determinants of emissions can be relatively complex. This is even the case for emissions as simple as fossil fuel combustion carbon emissions. In general the release of carbon to the atmosphere is considered to be proportional to the energy content of the specific fuel by a fixed ratio and therefore largely independent of the technology in which the fossil fuel form is combusted. This need not be the case. Emissions capture technologies exist, and the rate of release of carbon to be atmosphere per unit of fossil fuel energy combusted may therefore vary by technology.

On the presumption that emissions can be measured and therefore costs can be associated with them, emissions fees would affect the cost of production. The effect of fees will be reflected in a modification to equations (13) and (14). For consumers of the j th product in the i th sector the cost would become,

$$P_{i,ss,tech,j,l} = a_{i,l} P_i (1 + \delta_{i,l} Tr_i) (x a_{i,l} + x b_{i,l} + \sum_{m=1}^{EM} e_{m,i,ss,tech,j} X_{m,i,ss,tech,j}) \quad (34)$$

where $P_{i,ss,tech,j,l}$ is the price of good j consumed in sector i , subsector ss , using technology $tech$, in region 1. For producers, the income from the sale of the j th product produced in sector i is,

$$P_{i,ss,tech,j,l} = P_i (1 + \delta_{i,l} Tr_i) - \sum_{m=1}^{EM} f_{m,i,ss,tech,j} X_{m,i,ss,tech,j,l} \quad (35)$$

Final demand sectors

In addition to the sectors that produce goods and services, there are three final demand sectors, households, government, and foreign. As is the case with the directly productive sectors, final demand sectors

Greenhouse gas emissions

have demands for goods and services and can produce goods and services. We begin with the government sector, not because the analysis of the behaviour of the government sector is simpler than that of the household, but rather because our modelling approach to this sector is simpler than that of the household sector.

Government

Expenditures by the budget of the government sector must satisfy the following identity:

$$TX_{tot} - S_{gov} = TR_{gov} + \sum_{i=1}^N P_i X_{i,gov} \quad (36)$$

where TX_{tot} is the total of all net tax revenues, where subsidies are measured S_{gov} is the net government savings, or for negative values equals net government borrowing, and TR_{gov} is its transfer payments by the government.

In SGM version 0.0, S_{gov} is assumed to be zero. In SGM Version 1.0 this assumption will be relaxed.

In SGM version 0.0 transfer payments are assumed to be a function of demographics,

$$TR_{gov} = \beta_0 POP_{tot}^{\beta_1} \left(\frac{POP_{15+} + POP_{65+}}{POP_{tot}} \right)^{\beta_2} \left(\frac{POP_{25\%Y}}{POP_{tot}} \right)^{\beta_3} \left(\frac{Y_{personal}}{POP_{tot}} \right)^{\beta_4} \quad (37)$$

where POP_{tot} is the total population; POP_{15+} is the population under age 15; POP_{65+} is the population over age 65; $POP_{25\%Y}$ is the population whose personal income is 25% or less than the mean; $Y_{personal}$ is the personal income; and β_i is the appropriate empirically determined coefficients.

The government is modelled as producing services. In SGM version 0.0 there are three services produced. In SGM version 1.0 this will be expanded to five. These are given in table 4.

The demand for goods and services by the government sector is modelled as a constrained optimization problem. Government max-

Table 4 SGM government subsectors version 0.0 and version 1.0

SGM version 0.0	SGM version 1.0
General, National Defence, Education	General, National Defence, Education, Infrastructure, R&D

inizes a utility function, presumed to be CES in SGM version 0.0, defined over the three subsectors (general government, national defence, and education), and subject to the net income given by equation (36). This can be represented as,

$$G = \left(\sum_{s=1}^{NGS} \delta_s G_s^\mu \right)^{1/\mu} \quad (38)$$

where G is the government utility, an unobservable variable; G_s is the production of government service s ; δ_s is a scale parameter; μ is an elasticity parameter; and NGS is the number of services produced by the government.

Government services are assumed to be produced with fixed input-output coefficients. Thus the cost of an additional unit of government service, type s , can be computed as simply,

$$P_{s,s} = \sum_{l=1}^N a_{l,s} P_l \quad (39)$$

where $P_{s,s}$ is the cost of the next unit of government service s , that is P_l is the price of input l in the production process; and $a_{l,s}$ is the amount of input l required to produce government service from government subsector s .

Because the cost of producing the next unit of government service is constant for any set P_l ,⁹ the determination of government demands for goods and services is greatly simplified. This problem can be stated as one of maximizing utility subject to a budget constraint, equation (36), maximize $G(G_1, \dots, G_{NGS})$, subject to

$$TX_{tot} - S_{gov} - \sum_{s=1}^{NGS} P_{s,s} G_s = 0. \quad (40)$$

This problem has a simple solution,

$$G_s = (TX_{tot} - S_{gov} - TR_{gov}) \beta_s P_{s,s}^{\mu-1} \left(\sum_{s=1}^{NGS} \beta_s P_{s,s}^\mu \right)^{-1} \quad (41)$$

where $\beta_s = \delta_s^{-1/(\mu-1)}$ and $\gamma = \mu/(\mu-1)$.¹⁰

Households

A great number of decisions are carried out in the household sector. These include the following:

1. Demographics
2. Labour supply
3. Land supply
4. Household savings
5. Household demand for final products

In SGM version 0.0 the determination of the demographic characteristics of each region's population, and its supplies of labour, land, and savings are handled sequentially. Only the composition of demand for final goods and services is handled in a holistic utility maximization framework. Because the demographic characteristics of a region's population are an important determinant of other household behaviour we discuss this element of the model first. We then consider labour, land, and savings supplies. These factors determine disposable personal income allocated to consumption. Finally, we describe the determination of final demand for goods and services.

Demographics

The demographic component of the household sector determines population in a region by employing assumptions with regard to three characteristics: survival rates, fertility rates, and migration rates. For any period, t , total population is given by,

$$POP_{tot,t} = \sum_{age=1}^{NAGE} POP_{age,male,t} + POP_{age,female,t} \quad (42)$$

where $POP_{age,male,t}$ is the males in age group age ; $POP_{age,female,t}$ is the females in age group age ; and $NAGE$ is the number of age groups defined.

For the youngest age group, age = 1,

$$POP_{age=1,gender,t} = \sum_{age=2}^{NAGE} g_{age,gender} f_{age,t} POP_{age,gender,t-1} \quad \text{gender = male, female,} \quad (43)$$

where $POP_{age=1,gender,t}$ is the population in the youngest age group, age = 1, by gender, in period t ; $f_{age,t}$ is the fertility rate for females in age group, age, in period t ; and $g_{age,gender}$ is the fraction of births by gender, with $g_{age,1} + g_{age,2} = 1$, and for other age groups, population is determined by survival via,

$$POP_{age,gender,t} = SV_{age,gender,t} POP_{age-1,gender,t-1} + POPmig_{age,gender,t} \quad c = 2, \dots, NAGE. \quad (44)$$

where $SV_{age,gender,t}$ is the survival rate by gender from age group age to age + 1; $POPmig_{age=1,gender,t}$ is the net immigration of population into the region in age group, age = 1.

At this point, fertility rates, survival rates, and migration rates are determined exogenously, with the exception that net migration summed over all regions is always zero for each age and gender.

Labour supply

The supply of labour is determined by the working age population, rate of labour force participation, and the wage rate.

$$X_{labour} = \sum_{male} \sum_{age=1}^{NAGE} \alpha_{age,gender} POP_{age,gender} [P_{labour}(1 - tx_{labour}) - tx_{b_{labour}}] \beta_{age,gender} \quad (45)$$

where P_{labour} is the wage rate for labour; $\alpha_{age,gender}$ is a scale coefficient for the supply of labour, by age and gender; $\beta_{age,gender}$ is the price elasticity of supply of labour by age and gender, and tx_a, tx_b are proportional and additive tax rates, respectively.

Land supply

In version 0.0, land supply is total land area in the region. All land services are sold on the domestic market. Households supply land on the basis of the rental rate via

$$X_{land} = LAND_{tot} \alpha_{land} [1 - \exp(-\beta_{land} P_{land})], \quad (46)$$

where $LAND_{tot}$ is the total surface area potentially available for allocation; α_{land} is the maximum potential share of land supplied to the market; β_{land} is a land supply price responsiveness coefficient; and P_{land} is the rental rate on a unit of land.

In SGM version 1.0, the land supply sector will become much richer. One of the potentially most important determinations is the representation of the character of land, and its potential supply and use, and the potential changes to land character as it is affected by human activity. To be most useful, the model of land must be capable of explaining both the present allocation and use of land, how that allocation and use changes with time, and the consequences of land-use for greenhouse gas emissions. Furthermore, the characterization must also be capable of providing a framework for assessing the consequences of potential changes in atmosphere and climate, and of changes in sea level. Several alternative specifications are being considered. A description of land use in SGM version 1.0 will be the subject of future model development reports.

Personal income

Personal income can be computed from the information already developed via the equation,

$$Y = X_{labour} supply [P_{labour}(1 - tx_{labour}) - tx_{b_{labour}}] + X_{land} supply [P_{land}(1 - tx_{land}) - tx_{b_{land}}] + \pi_{tot}(1 - tx_{\pi} - s_{\pi}) + TR_{gov} \quad (47)$$

where Y is the disposable personal income; π_{tot} is the total net profits from the operation of all enterprises; tx_{π} is the profits tax rate; s_{π} is the rate of retained corporate earnings; and tx_y = income tax rate.

Savings supply

SGM version 0.0 represents savings as a function of present income and the interest rate,

$$S_{hh} = \alpha_{hh,save} Y [1 - \exp(-\beta_{hh,save}(\text{interest} + fac_{hh}))] \quad (48)$$

where S_{hh} is the total supply of savings by households; $\alpha_{hh,save}$ is the maximum potential household savings rate; $\beta_{hh,save}$ is the price sensi-

tivity of households to the available interest rate; and fac_{hh} is an adjustment factor linking the market interest rate to the interest rate available to households.

While it is usual for a general equilibrium model to maximize a utility function to determine household behaviour, version 0.0 does not do this. The development of a more sophisticated description of aggregate household behaviour is a development task.

Household demand for final products

Own demands for factor inputs labour and land are computed separately from demands for other goods and services.

The own demand for land is a function of the number of households,

$$\text{NIH} = \left(\sum_{\text{age}=1}^{\text{NAGE}} \text{POP}_{\text{age}} \right) / \alpha_{hh}, \quad (49)$$

where NIH is the number of households; and α_{hh} is the average number of people per household.

Therefore,

$$X_{\text{land},hh} = \text{NIH} \alpha_{\text{land},hh} P_{\text{land}}^{\beta_{\text{land},hh}}, \quad (50)$$

where $\alpha_{\text{land},hh}$ is the household land intensity factor; and $\beta_{\text{land},hh}$ is the price elasticity of demand by households for land.

The household demand for labour is a function of the price of labour,

$$X_{\text{labour},hh} = X_{\text{labour}} \alpha_{\text{labour},hh} P_{\text{labour}}^{\beta_{\text{labour},hh}}, \quad (51)$$

where $\alpha_{\text{labour},hh}$ is the household labour demand intensity factor; and $\beta_{\text{labour},hh}$ is the price elasticity of demand by households for labour.

The total value of consumption can then be calculated by difference

$$Y_c = Y - S_{hh} - X_{\text{land},hh} P_{\text{land}} - X_{\text{labour},hh} P_{\text{labour}}. \quad (52)$$

Consumption of any final product can then be computed using price and income elasticities and an income expenditure normalization via,

$$x_{i,hh} = \alpha_{i,hh} P_{i,hh}^{\beta_{i,hh}} Y_c^{\gamma_{i,hh}} \left(\frac{1}{\lambda} \right), \quad (53)$$

where $X_{i,hh}$ is the demand for good i by the household sector; $\alpha_{i,hh}$ is the household demand intensity factor for good i ; $\beta_{i,hh}$ is the price elasticity of demand by households for good i ; and $\gamma_{i,hh}$ is the income elasticity of demand by households for good i , and

$$\lambda = \sum_{i=1}^{NS} \alpha_{i,hh} P_{i,hh}^{\beta_{i,hh}+1} Y_c^{\gamma_{i,hh}-1}. \quad (54)$$

Each consumption good, which in version 0.0 is identical to a produced commodity in the GPC, is assumed to have an income and a price elasticity of demand.

In version 1.0, the plan is to embed the household decision making process in a cohesive intertemporal decision-making process which includes consumption, savings, and education. Education is important because, at least in the United States, it is the most important determinant of life-cycle labour-force participation. In addition, the sub-sector structure in the model will be used to expand the number of demographic groups. The number of such groups has not yet been determined but will reflect significant differences with respect to savings and education decisions. In version 1.0 consumption categories will probably be different from production categories, implying the need for a translation matrix from consumption to production commodities. Computationally more versatile forms for the labour and land supplies will also be explored.

General equilibrium

As noted earlier, markets are defined for each of the 10 producing sectors in SGM version 0.0 plus one for each of the three primary factors of production: land, labour, and capital.¹¹ There are at least 13 markets for the model to clear even when only a single region is being considered. When multiple regions are being considered simultaneously, the number of markets will expand. Land and labour markets are considered to be closed. This increases the number of markets from 13 to $11 + 2NL$, where NL is the number of regions. If capital markets are closed this number increases to $10 + 3NL$.¹² In addition, the model user can open or close any market in any

Table 5 An example of trading relationship table

Commodity	Region										
	1	2	3	4	5	6	7	8	9	10	11
1. Agri.	1	1	1	1	1	1	1	1	1	1	1
2. Crude oil	1	1	1	1	1	1	1	1	1	1	1
3. Oil ref.	1	1	1	1	1	1	1	1	1	1	1
4. Nat. gas	1	1	2	1	2	1	1	1	1	1	1
5. Nat. gas tr	1	1	1	1	1	1	1	1	1	1	1
6. Coal prod.	1	1	1	1	1	1	1	1	1	1	1
7. Biomass	1	1	1	1	1	1	1	1	1	1	1
8. Uranium	1	1	1	1	1	1	1	1	1	1	1
9. Elec.	1	1	2	3	0	2	3	0	0	0	0
10. Other	1	1	1	1	1	1	1	1	1	1	1
11. Labour	0	0	0	0	0	0	0	0	0	0	0
12. Land	0	0	0	0	0	0	0	0	0	0	0
13. Sav/inv	0	0	0	0	0	0	0	0	0	0	0

region relative to the rest of the world, and thus create trading groups. This is indicated through a variable, Mktlink defined over regions and commodities, where if for one of the 13 commodities and 11 regions,

Mktlink = 0 indicates that region L is permanently closed to trade in commodity IN . For example, all regions are closed to trade in land in the above matrix;

Mktlink > 0 indicates that the region trades with all other regions with similar Mktlink values for that commodity.¹³

An example of a trading relationship table is given in table 5.

The number of markets will also vary during the execution of the model. This occurs because transportation costs involved in international trade are non-trivial. It is easily possible to encounter a case in which a region would desire to export a good if the region is treated as an importing region and domestic producers are assumed to be able to obtain the world price of the commodity plus the cost of transportation. On the other hand, if the region is treated as an exporting region, in which domestic producers can obtain only the world price of the commodity, the quantity of the product demanded by the region increases and the quantity supplied decreases to the point where the region would desire to import the good. Under such

circumstances, the model will treat that region/commodity combination as if it were temporarily closed.¹⁴

For each region/commodity combination, an excess demand can be calculated by

$$e_{i,j} = \sum_{n=1}^{N_s} \sum_{m=1}^{N_{s1,n}} \sum_{tech=1}^{N_{tech,i,n}} (x d_{i,j,s1,tech,j} - x s_{i,j,n,tech,j}), \quad i = 1, \dots, N. \quad (55)$$

where $e_{i,j}$ = excess demand for commodity i in region j .

Consider for a moment the simplest case in which all commodities are traded internationally. For any period, equilibrium exists when a set of prices, $P = (P_1, \dots, P_N)$ can be found for which

$$\sum_{j=1}^{N_L} e_{i,j} = 0, \quad i = 1, \dots, N. \quad (56)$$

This set of prices is not unique. Walras's law,

$$\sum_{i=1}^N \sum_{j=1}^{N_L} e_{i,j} P_i = 0, \quad (57)$$

which holds as an identity, and guarantees that if an equilibrium set of prices exists, that any positive scalar multiple of those prices is also an equilibrium set of prices. Any commodity can be chosen as a numeraire and its price determined arbitrarily, set for example to one. The number of independent market prices is always one less than the number of markets.

Similarly, since the unit of measure chosen for commodities is also arbitrary, units can be chosen such that all equilibrium prices are unity in one period.

Solving the SGM

The BRM first generation model, used a Newton search procedure in an elasticity metric. Elasticities were computed numerically by perturbing each market price slightly and re-evaluating the model. This required $N_{mkt}+1$ evaluations for each search step. It also created a N_{mkt}^2 matrix of partial derivatives, which needed to be inverted. With 42 independent markets, this procedure requires a matrix of

1,764 elements to be inverted. The ERM also incorporated a variety of procedures to be invoked in the event that no change in a disequilibrium set of prices could be identified, through the Newton search approach, which reduced the metric of disequilibrium, the sum of squared excess demands.

Increasing the number of markets to 42 in SGM version 0.0 increases the complexity of the problem of finding numerical solutions to the model. The SGM will employ an even more diverse set of solution algorithm alternatives than the ERM. The most important addition to the set of search techniques is the Gauss-Seidel procedure. This solution algorithm begins with an initial price vector, and then updates each element of the price vector individually.¹³

Concluding remarks

This paper describes a new model under development, a second generation model of global energy and other human activities and greenhouse gas emissions. The model addresses the problem of the relationship between human activities in a wide array of domains, and their effect on the emissions of radiatively important gases, and the potential consequences of changes in the atmospheric composition and climate on those human activities. To address the extremely broad scope implied by these objectives, we have begun the development of a global, computable general equilibrium model, which provides insights not possible with linked independent market equilibrium models. It is also designed to address a specific problem. Its level of complexity and disaggregation reflects the character of that problem. Energy is the single most important human activity affecting greenhouse gas emission. It therefore receives the greatest attention in the model. Agriculture and land-use are the next most important issues and receive greater attention than, for example, their value-added contribution to GNP would indicate they warrant. Other sectors of the economy are modelled in relatively aggregate detail.

The model will be exercised for both regional/national economies independently of the world economy, and as a world model. Projects to model the United States, Chinese, and former Soviet Union are underway in partnership with sister institutions in China and Russia. These projects are anticipated to produce results during 1992. This work in turn will help inform the development of the SGM global model. Progress on these endeavours will be the subject of future reports.

Notes

1. The authors would like to express appreciation to the United States Department of Energy, Office of Energy Research and the Office of Policy, Planning, and Analysis, and to the United States Environmental Protection Agency, for support in the conduct of this research. The authors would also like to express appreciation to Yoichi Kaya, Nehajin Nikicénović, Kliti Parikh, Yuangzheng Fan, Rest Hickman, and Ken Ruffing for their thoughtful comments on an earlier draft of this paper.
2. Cases with characteristic α -folding or average molecular lifetime values of less than 10 years.
3. Century time scales.
4. For example, control runs using the ERM and GLOBA1. 2100 models yield remarkably similar results when standard assumptions are employed in both models. This is despite the fact that the ERM is a behavioural model and GLOBA1. 2100 is a dynamic optimising model.
5. It is always possible to recast a model such as the SGM within the dynamic optimization with perfect foresight paradigm.
6. Compared to competing technologies.
7. Note that the price received by the producers, P_u , is equal to the f.o.b. price. The prices paid by producers are equal to the f.o.b. price plus taxes and markups.
8. Note that in this case the period-specific expected price vector replaces the present discounted price vector given by equation (14).
9. Note that this property is characteristic of any production function which is homogeneous of degree one, such as for example the CES, and not simply the Leontief specification.
10. To see this note that first-order conditions require that

$$G_{i,t} = \lambda^{1/(1-\alpha)} G_{i,t}^{\alpha} P_{i,t}^{1-\alpha}$$

where λ is a Lagrangian multiplier. For convenience define,

$$Y = TX_{wt} - S_{i,t} - TR_{i,t}$$

and note that

$$Y = \sum_{i=1}^{NG} G_{i,t} P_{i,t}$$

Substitute (1) into (2) to yield,

$$\lambda^{1/(1-\alpha)} G = Y \left(\sum_{i=1}^{NG} P_{i,t} P_{i,t} \right)^{-1}$$

Re substituting (3) into (1) gives the final result.

11. Recall that the capital market is a market for savings and investment. It does not allocate existing capital stocks. Those are quasi fixed as a vintage capital stock.
12. The relaxation of the assumption that capital markets are closed requires the creation of an investment vehicle. This could be accomplished by the creation of an international bond. This bond would imply a future return flow of resources in exchange for savings. Net interest payments would be added to GNP and household disposable income, assuming households hold the bonds.
13. Note that while model logic will not be affected, there should always be at least two regions involved in a trading group for each commodity. The value of the Markov variable gives a reference region whose f.o.b. price of commodity IN determines the f.o.b. price for that commodity in all other regions in the trading group. For example, in the matrix above, all

regions, except China, use the f.o.b. price of agricultural products in the United States (region 1) as a common reference f.o.b. price.

The value used in Mktlink should always use the lowest region index number of any member of the trading group. For example when regions 3 and 6 form an electricity trading group, both members use the number 3 for their Mktlink values.

We note that a region cannot be open to trade in only one commodity.

14. When a region is temporarily treated as if it were closed to trade in a particular commodity, the value of Mktlink is set to the negative of the reference group number.
15. This procedure has an expected solution rate of between 50mkt and 100mkt model evaluations. It is thus computationally very efficient. The order in which the Gauss-Seidel algorithm operates may be important. For example, we may wish to solve the world market, then iterate to the regional labour and land markets, and then return to the world market. Some thought needs to be given to getting appropriate output and tracking the solution process with an eye to improving its efficiency.

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Comments on chapter 9

1. Nebojša Nakićenović

The design and implementation of the "second generation" model for analysis of future greenhouse gas emissions is indeed a formidable task. Edmonds et al. (1992) set the goals of such a model well beyond the state of the art by specifying that it should be "capable of analysing the emissions of all greenhouse gases from all sources, including both those of natural and human origin, to provide an analysis of the interplay between the variety of human and natural activities responsible for greenhouse gas emission." Clearly, such models currently do not exist that are capable of "assessing emissions from all human activities and major direct and indirect consequences of potential policies to reduce emission." There are many models that already address some specific parts of the problem, e.g., carbon dioxide emissions associated with energy use or models that cover all anthropogenic sources of emissions and resulting atmospheric concentrations (e.g. EPA's Atmospheric Stabilization Framework, Lashof and Tirpak 1989). They are, of course, still very far from the comprehensive approach suggested by Edmonds et al. Hence, the development of the second generation model of the type proposed by

Edmonds et al. is certainly a most welcome effort, although a very ambitious one.

Undeniably, much could be learned by the modelling community from the exercise proposed by Edmonds et al. In particular, the efforts suggested to endogenize demographic and technological changes merit particular praise and attention. However, within a policy context there is also the issue of how such a model can help reduce the uncertainties inherent in modelling global change.

Alternatively how can the modelling exercise make more transparent and explicit the uncertainties stemming either from our insufficient understanding of natural and social phenomena or their inadequate abstraction (modelling)? Therefore, a word of caution may be in order. The policy dimension of global warming must confront simultaneously the problems of extreme uncertainty, both in the causes and consequences of global warming, and in the future contexts within which policies related to global warming will operate. Thus, there is a need for great flexibility in policy measures since the socio-economic and technological contexts within which any global change policy is situated will clearly vary and alter. We are confronting policy choices related to a global environmental issue whose effects will be measured in decades and centuries. To illustrate the difficulty of this task, imagine confronting similar issues a century before, say in 1892. At that time, electricity did not have a significant role, the motor car had just been invented, the aeroplane was unknown except as a concept, and nuclear weapons were unthinkable due to the lack of basic physics, while major urban problems were particulates from coal and dung from horses. Thus, it should be clear that it is unlikely we will forecast the future evolution of energy systems, technologies, or its social contexts over the next 100 years any more accurately today than if we had performed the same exercise a century ago. Yet, modelling and assessment of strategies for mitigation of climate change require a very long-term view, one which extends far beyond normal planning horizons.

In view of the large and still unresolved scientific uncertainty surrounding greenhouse gas emissions, their sources and sinks, the consequences such as adverse and irreversible climate change and possible response strategies, the development of the second generation model of the parametric type proposed by Edmonds et al. is a very useful effort since it will allow the testing of different hypotheses concerning future energy and greenhouse gas emissions.

In this short commentary we will discuss a few of the salient char-

acteristics of such a model that appear to be required if it is to fulfil the expectations of its authors, but we will not raise the specific technical questions that would need to be resolved before the model can actually be built. The technical questions include, for example, the problem of integrating the global warming potential of emission and concentration of multiple greenhouse gases, or how to account for historical and current N_2O emissions from human activities and natural sources, or how to reconstruct the capital vintage structure for economies in transition and developing countries. These questions are far from being resolved but are the subject of a number of research activities and international efforts from which the proposed modelling exercise could benefit. Let us assume that these uncertainties and unknowns can be resolved by a parametric modelling approach.

We now return to the discussion of important model characteristics which (in order to be brief) we will limit to four issues: (1) population dynamics, (2) endogenization of technology, (3) socio-cultural aspects and (4) provision of energy services. They are important because they are all linked to the requirement of adopting a very long time horizon for model applications, which extends to the end of the next century. The authors are to be complimented for taking the long-term and global view. Models that focus on time-scales of two to three decades can be based on many static assumptions due to the relative stability of demographic trends, social and cultural relations, and the technology base over such periods. Conversely, extension of the time horizon well into the next century means that many of these long-term processes will become fluid and can no longer be treated as constants or "slow variables."

1. Population dynamics

In a century global population could stabilize but during the next few decades it will certainly continue to grow at rates fairly close to the current 1.7 per cent per year. In fact, the momentum behind global population growth is indeed very large. Even if we assume an abrupt change in fertility throughout the world down to or even below the replacement levels of about 2.2 children per woman, as it now prevails in most of the West European countries (and will thus result in a significant population decline), the global population would continue to grow for a few decades as illustrated in figure 1. Thus, the demographic transition is an important issue if a long time horizon is

World: Total Population in Millions

	1950	1955	1960	1965	1970	1975	1980	1985	1990	1995	2000	2005	2010	2015	2020	2025
Low Variant	2546	2713	2830	2924	3008	3079	3146	3201	3242	3270	3288	3296	3294	3282	3259	3224
High Variant	2546	2713	2830	2924	3008	3079	3146	3201	3242	3270	3288	3296	3294	3282	3259	3224
Medium Variant	2546	2713	2830	2924	3008	3079	3146	3201	3242	3270	3288	3296	3294	3282	3259	3224

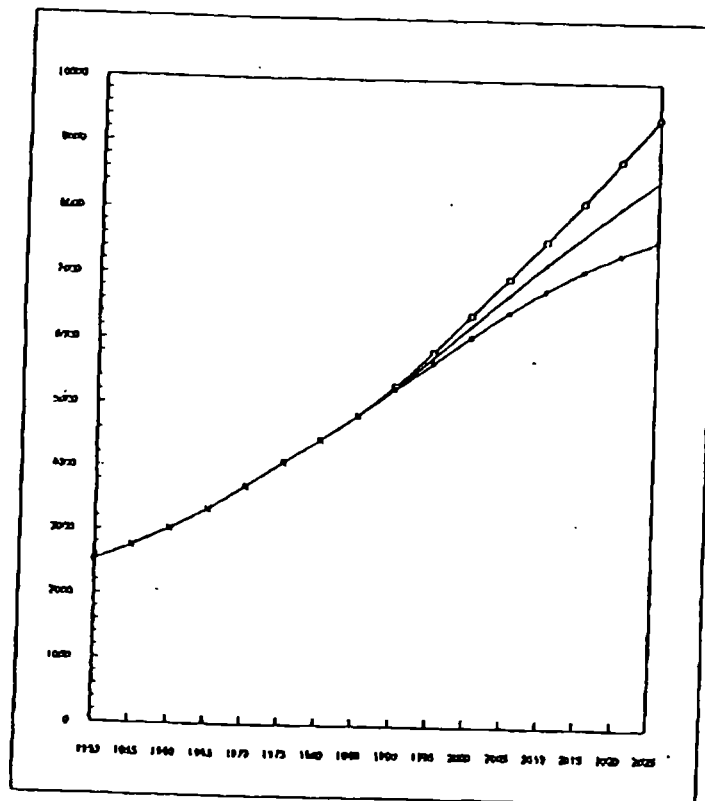


Fig. 1 World population growth, 1950 to the present and three alternative projections to the year 2025 (UN World Population Prospects 1990). In the case of the high variant the population is expected almost to double during the next 35 years. Despite the declining growth rates from now on, the high variant still leads to an increasing absolute population increase. By the year 2020 population increase is still about 40, 80, and 130 million per year in low, medium, and high variant respectively compared to about 100 million increase per year today (Source: Heilig 1992).

adopted. It is of paramount importance whether the global population will reach 10 billion or grow beyond. What is almost certain is that it can be expected to double during the next 100 years.

The objective to "endogenize" population growth in the next model version is to be welcomed. The actual problem is how to implement the link between development and population: is the demographic transition a prerequisite for rapid development or the other way around? How to account for the diverse experiences among countries and regions with respect to the demographic transition? A critical impasse is how to model these theoretically poorly understood linkages at the global and regional level. For the time being Edmonds et al. plan to include assumptions concerning survival, fertility, and migration rates for individual regions over the time horizon. However, increasing the number of exogenously assumed driving variables does not necessarily lead towards a better understanding of the complex issues between development and demographics. It might, therefore, be simpler and also more transparent to assume different population-growth scenarios exogenously as done by the United Nations population forecasts that are the standard reference in this field (UN 1990). Personally I see little merit in making numerous assumptions in a model without explicitly describing the linkages between the variables. The approach leaves a false impression of certainty and accuracy that does not actually exist. This critically affects particularly the treatment of migration in the proposed model. Clearly, emissions will depend on trade and migration patterns but the problem is that there is no obvious way to model international migration, especially the large movements of people that might be caused by the adverse effects of climate change. Low population growth rates and high levels of affluence in some parts of the world can also be expected to attract additional migration and, this again is a possible linkage between development and population issues.

II. Endogenization of technology

One of the important shortcomings of many energy models is that resource scarcity is one of the central driving forces of future energy development. Once the cheap and clean sources of energy are exhausted, the models "dig deeper" into dirtier and costlier options. This is close to the Malthusian concept of limited resources and has by and large been historically falsified for most factor inputs including

energy, minerals, or land. It turns out that in the long run technological change leads to production of more with less rather than of less with more. And yet technological change is still a static concept entirely absent in most models. Fossil energy resources remain static, potentials for technological improvements are ignored, etc. Yet alone since the energy crises of the 1970s the discoveries of additional fossil energy reserves have outpaced their consumption. The resource base continues to increase. Table 1 shows that the known global fossil energy resources are equivalent to about 3,000 gigatons of carbon! The carbon content of the atmosphere is in comparison small with about 760 gigatons of carbon. If the current concerns regarding prospects of global warming are confirmed in the future, it is probable that most of this carbon will remain in the ground. The point here is that technological progress and development are exogenous parameters: as soon as some of these externalities are endogenized, decarbonization strategies will be economically more attractive and less costly than "dirtier" options. In retrospect, we no longer consider technologies that are hazardous to human health as "cheaper" options, but rather as non-options. Therefore, the model needs a "dynamic base" rather than the planned static concept of depletable and degradable resources.

The adoption of a capital vintage approach to endogenizing technological change by Edmonds et al. represents a significant improvement and will undoubtedly produce most valuable insights, as dem-

Table 1 Fossil energy consumption, reserves and resources (Gt C)

	Coal	Oil	Gas	Total
1860-1987	114.9	58.2	24.5	197.6
1987	2.5	2.4	1.0	5.9
Reserves	391.6	92.1	58.5	542.2
Resources	2289	622	>115	3026
Additional occurrences	>3500	>1000	>700	>5200

Note: Accounting for historical, present, and potential future carbon emissions from fossil fuel use in gigatons carbon. Historical (1860-1987) and present (1987) carbon emissions from fossil fuel use by source and carbon content in identified, economically recoverable fossil fuel reserves, resources (identified quantities with uncertain prospects of economic recoverability), and additional occurrences (additional quantities inferred from geological information but with speculative technical and economic potential). Compared to historical fossil fuel use, the remaining resources in the ground represent a (perhaps even far too large) "carbon endowment" which is more than a factor 10 as large as the total carbon pool in the atmosphere of around 760 Gt C (corresponding to a present CO₂ concentration rate of about 350 ppm) (Drüßler and Nakićenović 1991).

onstrated by similar models for analysing economic structural change. The capital vintage approach can help to model technological change by the introduction of learning and economies-of-scale effects into new additions to the capital stock and the resource base. Nevertheless, the assumption of static resources (even if total potentially recoverable resources are subdivided into reserves and undiscovered resources) over a period of 100 years is indeed a very restrictive constraint that will, no doubt, almost "automatically" lead to high carbon emissions (since cheap and low carbon options are exhausted and renewables and nuclear limited by other "constraints"). For instance, only 10 years ago the existence of methane clathrates was largely unknown. Will they be included as a potential resource base in the model and how is the resource base going to change with the availability of new technologies?

During the next century many new energy systems can also be expected to be introduced that may help avoid the astronomical levels of greenhouse emissions envisaged in many business-as-usual scenarios (e.g., see IPCC 1990). Figure 2 illustrates that even at historical diffusion rates new energy systems can be expected to reach high market shares during the next century. Such systems may include completely new technologies such as carbon removal and deposition (e.g. into the deep ocean) but they will most certainly be also based on improvements and refinements of current technologies such as the electric or hydrogen car (Nakićenović 1992; Nakićenović and John 1991). But even these more evolutionary options will need enabling systems and technologies such as new batteries and fuel cells. The diffusion of whole families of new technologies needs to be modelled both within the energy system and other sectors of the economy. It is not clear how this will be handled in the second generation model, although it is clearly crucial for the understanding of the mitigation and adoption potential offered by new, less carbon-intensive and carbon-free technologies.

III. Socio-cultural aspects

Socio-cultural determinants of future greenhouse gas emissions are also important at all scales but become especially difficult to model when the time horizon is extended to 100 years in the future. Is there cultural convergence over such long periods, especially if the world actually becomes "smaller" through more interaction, global com-

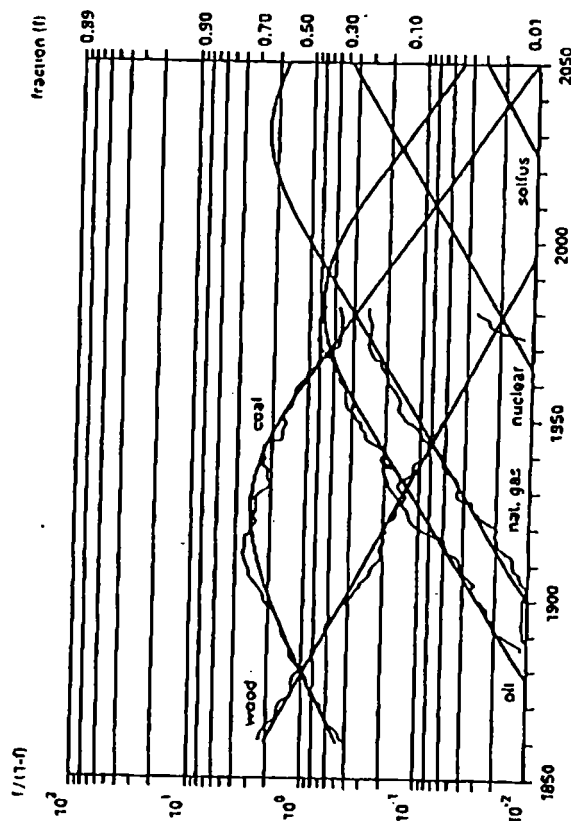


Fig. 2 World primary energy substituted. Shares of primary energy sources in global consumption. Smooth lines represent model calculations, and jagged lines are historical data. "Nat. gas" is natural gas; "solus" is a term employed to describe a major new energy technology, for example solar or fusion (Marchetti and Nakicenovic, 1979; Nakicenovic, 1990). It shows that the diffusion of new sources of energy is a very long process lasting many decades. Replacement of other infrastructures such as that of transport systems is also a long process.

munication, and mobility? At the other extreme, a divergence could be assumed with more heterogeneity and diversity in the world. In fact, this was the historical experience during the last century as illustrated in figure 3 for carbon intensity of value added. In contrast, many of the development strategies and scenario trajectories imply a common global path, e.g., universal adoption of technologies and their transfer despite diverse institutional and regional characteristics, and irrespective of the actual appropriateness of these systems in a given case. The second generation model can be expected to help identify some of the linkages among these issues, but the real problem occurs with the treatment of these social and cultural determinants. For the time being, socio-cultural variables have defined quantifications in most global models and at best have been included as residual values (e.g., derived from general production function approaches). Even if these variables cannot be modelled in the sense of formal abstractions from causality relations, it will be important to make explicit assumptions and scenarios in the model concerning socio-cultural development. This is a potential advantage of a parametric approach.

As another example, is it really reasonable to assume a general equilibrium approach and market-clearing mechanism for analysing the long-term future, when market-clearing mechanism imperfections and regulatory mechanisms are a prevailing characteristic of the world economy rather than an exception? Transfer of "sensitive" technologies is explicitly blocked, diffusion and adoption of technologies can be blocked by local cultures or regulations, and so on. The examples are so plentiful that it is difficult to construct a list of competitive international markets. There are, of course, many methodological reasons for adopting a general equilibrium approach, but the question is whether too much is assumed away by that approach in a model that otherwise includes so much detail. In more aggregate models this might indeed be a very viable and appropriate simplification but in a complex model such as the one proposed it is not clear how to balance detail in some areas against simplistic assumptions in others. In any case, this approach makes the analysis of major and revolutionary changes impossible. Adjustment paths to a low-emissions future is by design at best gradual and excludes socio-cultural diversity. All regions are assumed to have market-based economics and rational, utility maximizing agents (envisaged for version 1.0).

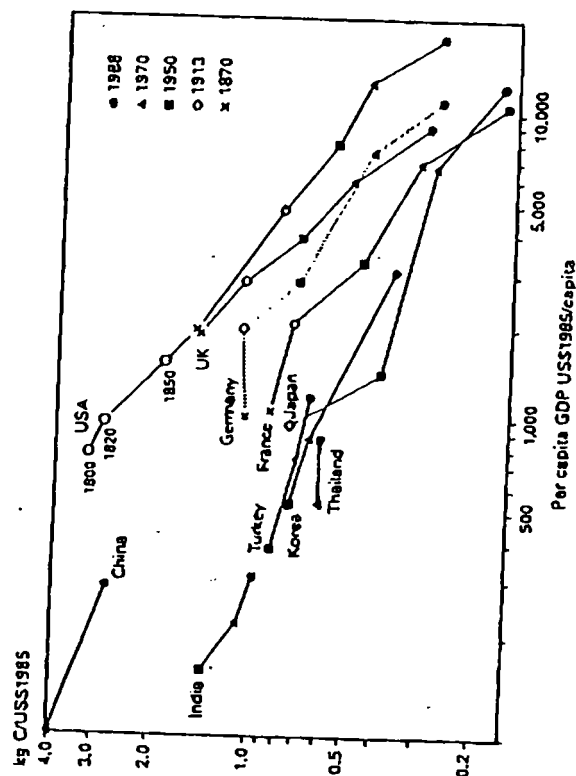


Fig. 3 Energy CO₂ emissions intensity per constant GDP in kg per constant 1985 US\$ versus per capita GDP in constant 1985 US\$. Energy data include also non-commercial sources such as fuelwood. In general, carbon intensity of economic activities improves as a function of differences between countries for similar per capita GDP levels. It shows that developed countries had higher specific emissions per unit GDP during early development phases that are comparable to current emission intensities of GDP in developing countries (Source: Grubler and Fujii 1991).

IV. Provision of energy services

Rationality of agents is in general a very sticky subject when it comes to describing actual energy consumption and end-use behaviours. Conservation and efficiency lag behind what appears to be rational. Often efficiency improvements are offset by increased energy services. For example, new cars are on average more efficient than the old ones in Germany, but they consume more fuel because they are larger, faster, more powerful, comfortable, and safer. Demand for more comfort at home has also increased due to older age structure, smaller family size, and larger dwellings per household, leading again to higher energy services. Figure 4 shows that longer life expectancy and shorter working time have over the last 100 years reversed the share of life spent at work compared to leisure activities from about 80 per cent to about 20 per cent today. This results in more travel, leisure activities, and time spent at home. All of these phenomena are also linked to economic structural changes, productivity increases, and evolving socio-cultural patterns. The problem arises when changes in the end use are observed at the macro-level and explained only by price mechanisms (e.g., elasticities) rather than by changes in human behaviour and social patterns. In those cases fallacies can occur. For example, the price of motor fuel increases but consumers purchase cars that consume more fuel even though they may be more efficient. Perhaps many of these considerations are marginal on a 100-year time-scale. The salient question for personal mobility in the world is rather whether car ownership will diffuse throughout the world to the degree it has in the industrialized countries. Today there are over 400 million cars in the world. Whether this number doubles or increases tenfold during the next decades will have a larger effect than any model variations in the price elasticity of motor fuels. Another example given in figure 5 shows that most of the cars are owned by the male population in Germany, while only a few, mostly young, women own automobiles. Should the ownership rates converge in the future this could almost double the fleet size.

These examples illustrate that the long-time horizon almost inherently demands an interdisciplinary approach in evaluating greenhouse-gas emission mitigation and response strategies. Economic mechanisms alone will not do nor will engineering perspectives. The complex fabric of many dimensions has to be integrated into more holistic approaches for analysing alternative development paths, those that lead to high emissions and those that are responsive to

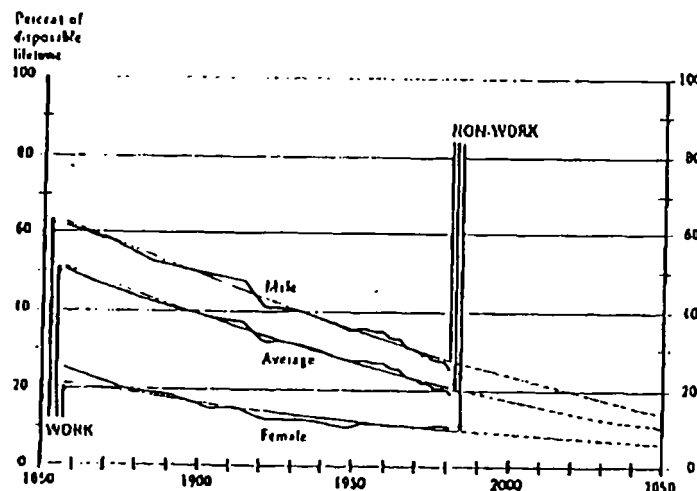


Fig. 4 Fraction of disposable lifetime spent at work and non-work of female, male, and average working population, UK 1856–1981. Figures are derived by comparing life hours of work to total disposable, active non-work hours for adults. Disposable hours are calculated by subtracting 10 years for childhood and first elementary education and also required "physiological" time, e.g., time required for sleep, eating, and personal hygiene, assumed an average to amount to 10 hours per day. For the average working population in the United Kingdom, working hours decreased from about 124,000 to 69,000 hours between 1856 and 1981, while at the same time disposable lifetime hours increased from 292,000 to 378,000 hours. Thus, non-working hours increased from about 118,000 to 287,000 hours over a lifetime. On average over 60 per cent of the disposable lifetime of male adults was spent working in 1856, this percentage has fallen to less than 20 per cent at present (Source: Ansuel and Grüber 1990).

climate change. Perhaps creative scenario writing would even further enhance the value of models such as the one proposed by Edmonds et al.

The ultimate question is what is the appropriate model scale (e.g., number of sectors, equations, variables) that is required to capture some of these characteristics? It is clearly undesirable to have a high degree of complexity in treating problems that are poorly understood such as the effect of global warming on international migration patterns. It is better instead to treat with higher accuracy those things that are well known such as the effect of urbanization, mobility, or

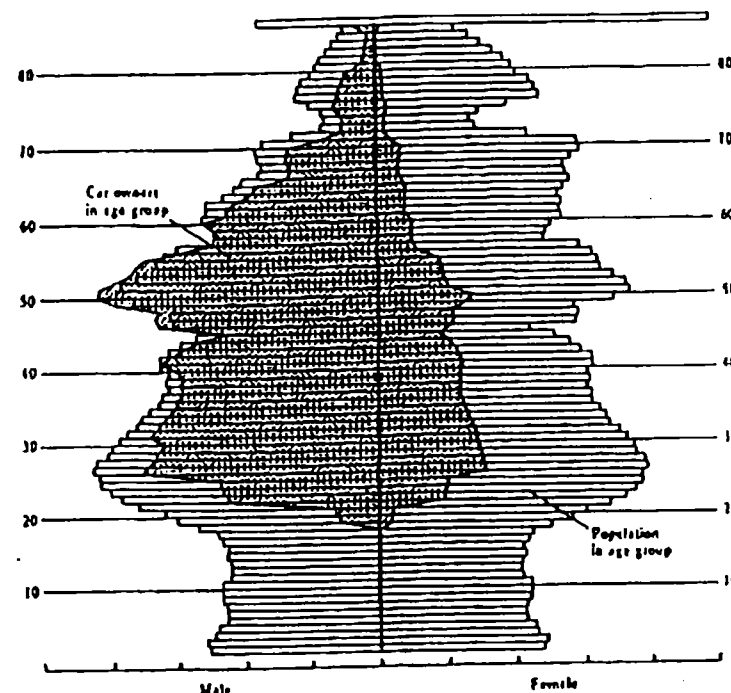


Fig. 5 Demographics of car ownership in Germany (only former FRG territory) in 1989 revealing significant intergenerational and gender differences in car ownership. Combined with demographic projections scenarios of future car ownership are developed at IASA based on different scenarios of lifestyle changes of successive cohorts entering driving age. Conversely the ownership (or non-ownership) patterns of older generations are assumed to remain relatively stable, consistent with historical experience (Source: Böttner and Grüber 1991).

geography and climate on energy end-use patterns. It is a disbenefit to know the magnitude of the global warming potential of multiple gases if carbon dioxide effects and emissions are known with great accuracy while direct and indirect effects of methane and its emissions are very uncertain. In this case, it would be better to know the atmospheric concentrations of these two gases individually. The second generation model can help and improve the analysis of many of these issues provided it is "scaled" appropriately to answer the posed

questions – to use the words of Edmonds et al., it should be problem-oriented and involve minimum modelling. I hope that they will succeed. The proof of the pudding will come in eating it – in this case we will have to be patient and wait for the first model implementation and results. In any case, the authors must be complimented on their ambitious and courageous undertaking.

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2. Kiril S. Parikh

At the outset, let me say that this is an extremely ambitious effort. It is even more ambitious than the one upon which we embarked at the International Institute for Applied Systems Analysis (IIASA) in 1976

in its Food and Agriculture Programme (FAP). We built what we called a Basic Linked System (BLS) of National Food and Agricultural Policy Models.¹ The national models are applied general equilibrium models with a general equilibrium linkage. The system has some 34 models, 20 referring to specific countries or groups of countries having a common agricultural policy and 14 models representing countries of the rest of the world from different regions, grouped according to the similarity of their likely behaviour on the international market. The models distinguish 10 different commodities at the international level (more domestically), of which nine were agricultural commodities and the tenth was a non-agricultural sector to close the system. The parameters of the models were empirically estimated from time-series data. Empirical estimation as opposed to benchmarking was considered essential if the model system were to describe the world with some measure of confidence. It took some 200 person years of effort. The first demonstration version of the model was ready in 1980. A usable one became available in 1984.

However, that was in 1976. Today, it is 1991 and the progress that has been made over these years in computers, algorithms, communication networks, data availability, and the experience obtained with general equilibrium modelling, should make the proposed effort of Edmonds et al. succeed within a reasonable length of time. Without the *Kitty Hawk* of the Wright brothers, 707s would not have come about when they did. With our and similar efforts on building applied general equilibrium-based linked systems, such an ambitious effort could now be conceived and launched.

My comments on the paper are grouped under different headings. First, I would comment on its approach, then on its scope, limitations, and problem-orientation. These will be followed by some suggestions.

The approach

The approach is a bottom-up approach and the model provides enormous details. With any model that you use, the users always demand more details than what is incorporated into the model. I can confirm that from my personal experience. The model of India that we developed as a part of the IIASA Basic Linked System was one of the more detailed models of the system. I have been using this model for policy analysis and I often find that questions are asked that the model cannot answer without incorporating more details or greater

articulation. All the time we keep on updating and modifying the model to address new policy issues as they come up. I am, therefore, sympathetic to the level of detail that is being sought to be incorporated into this model.

There is yet another reason for having a detailed model. A model provides scenarios and these scenarios provide consistent descriptions of a set of variables. These variables can be divided into endogenous and exogenous variables. While a model's solution provides consistency among the endogenous variables, it is not always recognized that consistency among the exogenous variables in specifying a scenario is a difficult and critical task. It does therefore help in specifying for a scenario a set of consistent values for exogenous variables, if their number is minimized. On the other hand this means that the number of parameters to be estimated becomes large. One may also note that when one is exploring long-term strategic alternatives, even empirically estimated parameters cannot be taken to be stable. Even then, the question of descriptiveness of the model cannot be dispensed with: a model scenario is an "if ... then" proposition and the "if" ought to describe the world that we live in if the "then" is to have any relevance.

A simpler CGE model, say of the Manne and Richels, or the Edmonds and Reilly type, provides a starting point for broadly defining some strategic alternatives. However, these models are already available. One should really try to build on them. Moreover, a more detailed model is indeed needed to provide guidance for policy formulations, for international agreements, or to facilitate international negotiations. For these purposes, a model is needed that tells us who gains and who pays under alternative policies and this is where I find some problems with the model.

Problem-orientation, scope, and limitations

I find the model to be what I call a "growth and greenhouse" model and not a "development and environment" model. Its emphasis is largely on loss in economic growth and on the trade-off between economic growth and greenhouse gas emissions. What is required however, is a model that treats both development and environment in a broader perspective. Questions of income distribution, questions of local versus global effects of environmental policy, questions of lifestyles of different groups of people, and questions of consumption patterns and development are very critical and not addressed by the model.

For example, the developing countries do not feel responsible for the current greenhouse problem. Their emissions of CO₂ are less than 30 per cent of the total greenhouse gas emissions in the world, even though they constitute nearly 80 per cent of the world's population. Many of these countries face severe environmental stress in their urban areas due to air pollution, poor sanitation, congestion in slums, use of dirty fuels in poorly ventilated kitchens, and crowded settlements. These environmental issues affect the welfare of their populations in a much more direct way than the consequences of the greenhouse effect. These countries, therefore, rightly feel that they should tackle these local environmental problems before they spend any resources for global environmental problems that in any case they themselves have not created. But, to explore such trade-offs, one needs to incorporate into the model the details of income distribution across different groups in rural and urban areas as mentioned earlier.

To do policy analysis with a model means to compare alternative situations. Some form of comparison of welfare in alternative situations is inescapable. The Edmonds et al. model does not stipulate an integrable demand system without which welfare comparisons would be extremely difficult to make. A consistent integrable demand system is quite essential for such a model. Here, I may also point out that to estimate a consistent demand system that remains meaningful over long periods and large changes in income levels is difficult. Recently, I had occasion to project food demand for the year 2050. When I used elasticities, or a simple linear expenditure system to project these, I got absurd results. The calorie intake implied in these projections was sometimes as high as 10,000 Kcal per day. This is clearly not a feasible intake level. One needs to find an alternative demand system. Here, what we did in the IIASA model is worth noting. We had estimated a separate demand function for each commodity as a function of income and own price. We had also estimated a separate relationship between per capita calorie intake and per capita income. This relationship was asymptotic of what one might consider the physiological limit. For a given target price vector and income level, we estimate an initial vector of demand using each of these individual demand functions. Then we find a vector point that is close to this vector and is such that it satisfies the adding up properly as well as meets the aggregate calorie intake constraint. Around the new vector point we then construct a linear expenditure system. Such a procedure was repeated at each time period in IIASA's BLS models. The resulting system can be considered as a local approximation for

an underlying utility function and can be shown to be consistent. Such a procedure gave sensible projections for 2050, which were also much more robust to changes in income levels. While the calorie constraint was a logical constraint to impose when dealing with food demand as we were doing in the DLS, it is not adequate for the proposed model, which has many other non-agricultural commodities. It may be necessary to impose some other natural constraint. Perhaps one could impose a constraint on the time required for alternative consumption activities and on the total time available to consume the various commodities. Such a constraint might make the demand system behave sensibly.

It is important that a model does provide insights into trade-offs between alternative development paths, between consumption patterns, between production structures, and across time. Even a long-term model must address some short-term policy issues and the issues of resulting transition costs. If a model does not provide any guidance on what we do now, the model is in some sense useless.

Some points of detail

There are some points of detail which need to be mentioned. First, it is vital to maintain common units for trade of commodities among countries. This is a critical problem and requires much care and data-gubbing work. From the description of the model, I am not sure how these problems are to be handled and how units are going to be kept consistent across different countries.

Secondly, an observation is made in the paper that capital stock data can be "relatively easy to observe." This is not so, as capital stock data are notoriously difficult to obtain. Estimates of total factor productivity growth in Indian industries based on the same data source by two different researchers arrive at two completely contrary results; one saying that factor productivity in India has grown, the other saying that it has not. The difference can be largely ascribed to the way capital stock data are put together from information on the time-series of investment at current prices by assuming certain rates of real depreciation. Unfortunately, the depreciation rates are not observed and a seemingly small change in the rate of depreciation whether it is .3 or 4 per cent per year can make a difference as to whether total factor productivity grew or not.

Thirdly, the model seems to assume that governments do not own land. However, governments can and do own land and substantial

amounts of it in many countries. Thus, questions of deforestation and land markets cannot be adequately dealt with without bringing in government behaviour in the land market. Neither do I see fishery mentioned anywhere, and consequences for oceans seem to be left out of the model, hopefully only for the moment.

Some suggestions

I would like to make a couple of suggestions. It seems to me that the agricultural sector model of IIASA's BLS would provide a very good starting point for this modelling work and the authors might explore the possibility of using this model for the agricultural sector. In addition, the algorithm development for IIASA's system has proved over the years to be robust and efficient even when dealing with policy regimes with quotas. They might also explore the possibility of using the algorithm that was developed by Michiel Keyzer¹ using the Kantorovich lemma.

Finally, I would like to emphasize that in using the model, one should keep in mind that no model can address the important question of welfare distribution and responsibilities. We have to keep this earth functioning and we must think in terms of a mechanism, a system that is fair and feasible. I suggest that we think in terms of using market-friendly approaches towards maintaining the global commons at the desired level by giving tradable emission quotas to different countries. Initial allocation of these should be consistent with the carrying capacity of the earth and should be done fairly. I suggest that the allocation based on population would be a fair way. In order not to encourage people to increase their populations, we may keep the allocations to the populations of a past year, say 1990. I hope this model would give us insights into alternative ways of preserving the global commons, of enhancing local environment, and of improving the quality of life for all persons on earth. I congratulate the modellers on their ambitious project and wish them luck.

Notes

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3. Yuangzheng Luo

Many of the points taken up in the paper are of interest to me and I have yet to digest them. I cannot agree more with the view expressed in that paper that in the process of designing, a new model should be problem-oriented. We should not lapse into the practice of making the problem fit the model. That would be repeating the mistake of the fool in the Chinese fable who chopped off part of his feet so that they could fit the shoes.

In their reconstruction and economic development after World War II, Europe and Japan did not pay due attention to the issue of environmental pollution. Thus it went unheeded until the 1960s when it became an explosive issue. How to control environmental pollution and maintain the ecological balance became a great concern of the United Nations and governments around the world. To this end the United Nations set up the Environmental Council under the Economic and Social Council (ECOSOC). China began to take part in the Council's work in the 1970s. The developed countries have designed a number of models on environmental pollution in addition to formulating relevant policies and legislation. These have proven through practice to be effective in bringing environmental pollution under control step by step. However, from the global perspective, the problem of environmental pollution has not been solved. The global environmental issue has been aggravated as a result of the accelerated transfer by the industrialized countries since the 1980s of highly polluting and energy-guzzling labour-intensive industries to the developing countries and also as a result of the industrial development of the developing countries themselves. Moreover, the emission of greenhouse gases and the depletion of the ozone layer led to global environmental warming. People are becoming increasingly concerned about such global environmental issues. The developing countries have come to see that prevention is better than "cure." But it must be pointed out that the industrialized countries should bear the main responsibility for global environmental pollution and the degradation of the environment. While they seek to protect the environment in their own countries, the industrialized countries must transfer environmentally sound technologies to the developing countries, increase aid to them for environmental protection, and put an end to the transfer to developing countries of industries that pollute the environment.

Great strides have been made in environmental protection since

the 1960s when the problem of pollution began to catch the attention of industrialists, policy makers, and the general public. In many countries, effective measures have been taken and laws passed to keep the air and the rivers and lakes clean. Today, more and more attention is focused on the greenhouse effect. I am confident that with a common understanding of the gravity of the problem and through concerted efforts, better technologies will be developed to reduce emissions of greenhouse gases from industrial plants, vehicles, and home appliances and wiser policies adopted to control such emissions.

As a developing country, China is equally concerned about the greenhouse effect and about environmental protection. In its pursuit of a reformist policy and its opening up to the outside world, China has, in the past decade or so, made notable progress in controlling environmental pollution and preserving the ecological balance. China is fully aware of the importance of striking a proper balance between achieving economic and social progress and maintaining a sound ecological system between industrialization and environmental protection. We are ready to learn from other countries whatever is useful to us in preserving our environment. However, due to financial and technological constraints, we cannot apply the same standards of environmental protection that the developed countries use.

You may be interested to learn about China's energy picture. In 1990 China's total energy consumption amounted to 980 million tons of standard coal. The breakdown is as follows: coal, 75.6 per cent; crude oil, 17 per cent; natural gas, 2.1 per cent; and hydropower, 5.3 per cent.

You can see from these figures that coal plays a predominant role in China's energy consumption. There was a time in the 1970s and early 1980s when Chinese factories switched from coal burning to oil burning. But before long, China learnt that it could not afford to do this, since exploration of oil requires far greater capital input than the mining of coal. So we switched back to coal burning. While we continue to rely heavily on coal for energy consumption, we plan to make use of nuclear power and tap China's rich hydroelectric resources on a much larger scale. To this end, a nuclear power station is under construction at Da Ya Wan in Southern China and plans are under way for the building of more hydropower stations. Although economic development remains China's overriding concern, increasing attention is being given to environmental protection. In this regard, there is a great deal for China to learn from the advanced