Appendixes

Appendix A
Summary of the OTA Emissions Scenarios

Introduction to the OTA CO_2 Emissions Model

OTA developed a simple energy accounting model that allows us to estimate the effectiveness of various technical options for lowering CO_2 emissions. The model is based on a much larger system of energy and economic models used by the Gas Research Institute (GRI) to forecast energy use through 2010 (19).[1]

Of all the integrated energy/economic forecasting models that we reviewed, GRI's includes the greatest detail on energy demand by specific technologies. Estimates of total residential electricity demand, for example, include breakdowns by heating, cooling, refrigerators, freezers, clothes dryers, etc. Thus, we are able to simulate the potential for lowering CO_2 emissions through specific changes in technology.

To do this, we first built a very much simplified set of models based on detailed output from GRI model simulations of energy use through 2010. For example, to estimate the energy demand for heating homes, GRI estimated the number of existing furnaces, heat pumps, and electric heaters and forecast the number that must be replaced through time (with more efficient technology) based on typical equipment lifetimes. The number of new homes to be heated is forecast based on economic conditions. Whether consumers buy gas, oil, or electric heaters is forecast in part based on economics and in part on historical buying habits.

OTA's simplified models simulate the number and energy efficiency of each technology type (e.g., gas furnaces) through time, based **only** on the GRI detailed output data, not on the economic decisions that influence the forecast. For two categories--highway vehicles and electric utilities-we felt that the GRI model did not have adequate detail for our needs. For highway vehicles, we used Oak Ridge National Laboratory's ''Alternative Motor Fuel Use Model" (27), but used GRI's oil price assumptions for consistency. For electric utilities, we built our own model using detailed data from the Energy Information Administration.

We total all the energy use and CO_2 emissions from each technology category in all sectors, which yields our Base case forecast of emissions approximately 50 percent above today's level by 2015. For our Base case, OTA implicitly assumes GRI's forecast of Gross National Product (GNP) growth (averaging 2.3 percent per year) and energy price increases (averaging 1.7 percent per year for coal, 3.7 percent per year for oil, and 4.8 percent per year for natural gas) over the next two decades. These estimates are reasonable, barring major changes in energy supply, economic, or regulatory conditions. We specify two alternatives to the Base case-the ''Moderate' and ' 'Tough" scenarios, discussed in later sections. These incorporate the effect that changes in technology or policy could have on future energy use and CO_2 emissions.

Our model, for the most part, assumes the same level of ''services' as the GRI base case. In the alternative scenarios, CO_2 emissions are reduced, for example, by using more efficient furnaces, by switching fuel, or by insulating houses but **not** by assuming people keep their homes at lower temperatures in the winter or air-condition less in the summer than they currently do. In a few cases, most notably the transportation options, all ''services' are not identical. For example, we consider the effect of reinstating a 55 mph speed limit. Under our most aggressive scenario, we assume that cars will be somewhat smaller than they are today (due to either economic incentives or fuel economy regulations). Both changes include some loss of amenity to consumers; however, the "service" (number of miles traveled in reasonably similar cars at highway speeds) remains quite similar.

U.S. Energy Consumption and CO_2 Emissions

Total U.S. energy consumption in 1989 was about 84 quads. As discussed in detail in chapter 3, oil provided about 40 percent of this, coal and gas about 23 percent each, nuclear power 7 percent, and hydroelectric power and biomass about 3 percent each.[2]

Currently about 20 percent of CO_2 emissions result from activities within our homes and apartments; 16 percent come from commercial buildings. About one-third of these emissions are from fossil fuels burned within residential and commercial buildings; two-thirds comes *from* electricity use within them. About 32 percent of emissions are transportation related and 32 percent come from industry (table A-l).

[1] The GRI modeling system has as its core the DRI U.S. Energy Model, developed by Data Resources, Inc. (DRI) The model includes four submodels: the industrial sector, residential buildings sector, commercial buildings sector, and electric utilities. Economic projections, which drive the Energy Model, come from the DRI Macroeconomic Model of the U.S. economy. Additional inputs are generated from the Industrial Sector Technology Use Model, developed by Energy and Environmental Anatysis, Inc.; the GRI Hydrocarbon Supply Model; and the RDI Coal Model, developed by Resource Data International.

[2] Data for 1989 energy consumption, except for biomass fuels, is from ref. 33a.

Table A-l-Carbon Emissions by Activity (percent of 1987 emissions)

Resldential buildings:	
Heating	9%
Appliances	5%
Hot water	3%
Cooling	2%
Lights	1 %
Subtotal	20%
Commercial buildings:	
Heating	6%
Lights	4 %
Cooling	4 %
Appliances, hot water	2 %
Subtotal	16%
Transportation:	
Cars	14%
Light trucks	6 %
Medium, heavy trucks	4 %
Air	4 %
Rail & marine	2%
Subtotal	32%
Industry:	
Motors	9 %
Steam	9 %
Process heat	6 %
Off-highway oil	2%
Heating, cooling, lights	2 %
Feedstocks	2 %
Electrolytic	1%
Lease and plant	1%
Subtotal	32%

SOURCE: Office of Technology Assessment, 1991, basedon data from Gas Reserarch institute, *Baseline Projection DateBook, 1988 GRI Baseline Projection of U.S. Energy Supply and Demand to 2010* (Washington, DC, 1988).

About 9 percent of total U.S. CO_2 emissions comes from heating our homes and another 6 percent from heating our stores and offices. About 5 percent comes from cooling buildings and another 5 percent from lighting them. Such major home appliances as refrigerators, stoves, washing machines, dryers, freezers, and dishwashers each contribute close to a percent, totaling about 5 percent occurrent emissions.

About 20 percent of emissions comes from passenger cars and light-duty trucks. Freight (truck, rail, and ship) accounts for about 10 percent of U.S. CO_2 emissions. Within industry, steam and process heat used in the basic materials industries (e.g., metals, chemicals, and petroleum refining) account for about 15 percent of CO_2 emissions. Electric motors on pumps, fans, and compressors are responsible for another 9 percent.

Carbon emissions can also be categorized by consumer purchases (table A-2).[3] About half of CO_2 emissions originate from the energy we purchase and use directly to heat our homes, run our appliances and lights, fill the gas tanks of our cars, and so on. The remainder originate from the products and services that we buy-the energy to manufacture cars, furniture, electronic equipment; to process food items; and to heat and light the stores in which we shop. As an example of the carbon emissions associated with consumer purchases, consider 100 dollars' worth of clothing. About half this amount goes for the retailers' markup, the other half goes to various manufacturers primarily within the apparel industry. Using the carbon intensities in table A-2, we can estimate that about 60 lbs of carbon were associated with the purchase of those clothes: 35 lbs to manufacture them[4] and 25 lbs to operate the store in which they are sold.

Emissions Scenarios

The OTA Base Case

OTA's Base case can be compared to several other recent forecasts (figure A-l). These include a high- and low-growth scenario developed by the Environmental Protection Agency (EPA) (34), high- and low-growth scenarios developed by the Energy Information Administration (EIA) (33), and a base case forecast developed by GRI (from which the OTA scenario was developed) (14). We generated estimates of CO_2 emissions from EIA and GRI forecasts of fuel consumption.

Note that our Base case predicts higher emissions than the GRI model, which forecasts the demand for energy from current goods and services. However, just as 10 years ago such a "bottom up" forecast would have missed the demand for electricity from personal computers and FAX machines, so too is the GRI forecast likely to miss demand from new products by 2010. Thus for our Base case we added an increment of demand for electricity to the GRI forecast.[5] Our demand growth forecast is similar to others (i.e., EIA's) that use a statistical (' 'top down' approach based on recent economic and energy use trends.

[3] Carbon emissions from consumer purchases account for about two-thirds of total U.S. emissions in the accounting scheme that we used. Of the remainder, about one-quarter was associated with exports, onequarter with government purchases, and half with private investment in capital goods and structures. See the manufacturing chapter (ch. 6) for details on the analytical methods used to derive these estimates.

[4] The carbon (C) intensity of the apparel industry is about (),7 lbs C/$ and that of retail trade is about 0.5 lbs C/$. Thus, $50 x 0.7 lbs C/$ for the garment plus $50 x 0.5 lbs C/$ for operating the store totals 60 lbs of carbon.

[5] The GRI model forecasts that electricity demand will increase at about 1.5 percent per year through 2010. In our analysis, we added an extra increment of unspecified demand-0,75 percent per year in the base case— for a total growth in electricity demand of about 2.25 percent per year. Under our Moderate demand scenario, we add an extra 0.56 percent per year increment of unspecified electricity dernand and under our Tough scenario we add 0,38 percent per year.

Table A-2—Carbon Emissions From Goods and Services: Household Purchases Only

	Carbon emissions	Intensity (lbs C/$)
Energy:		
Petroleum refining and related industries	22.5%	NA[b]
Electric utilities	18.2%	NA
Natural gas utilities	7.4%	NA
Total	48%	NA
Manufacturing:		
Food and kindred products	7.1 %	0.8
Motor vehicles and equipment	3.1 %	0.8
Apparel	1 .9%	0.7
Drugs, cleaning and toilet preparations	1.1 %	0.8
Paper and allied products, except containers	0.8%	1.8
Rubber and miscellaneous plastic products	0.60/0	1.2
Printing and publishing	0.5%	0.7
Household appliances	0.5%	0.9
Household furniture	0.5%	0.8
Radio, TV, and communication equipment	0.5%	0.6
Other manufacturing	4.0%	
Total	20%	0.8
Transportation:		
Air transportation	1 .7%	1.8
Motor freight transport	0.7%	1.1
Water transportation	0.4%	2.6
Local transport	().4%	0.9
Railroad	0.30/'	1.0
Total	3%	1.4
Services:		
Wholesale and retail trade	1 2.0%	0.5
Health, educational & social services and nonprofit organizations	6.8%	0.5
Finance and insurance	1.60/0	0.3
Hotels: personal and repair services (except auto)	1.50/o	0.5
Real estate and rental	1.570	0.1
Automobile repair and services	1.1%	0.6
Water and sanitary services	0.7%	1.6
Amusements	0.6%	0.4
Other services	1 .0%	
Total	27%	0.4

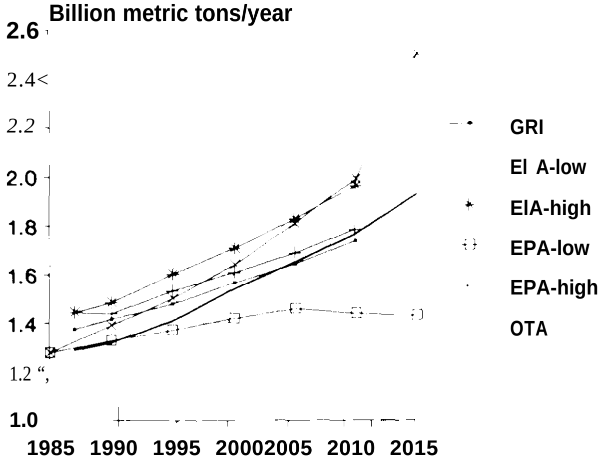
[a]Emissions expressed as percent of carbon from household purchases (about 1 billion tons per year).
[b]Not applicable.

SOURCE: Office of Technology Assessment, 1991.

Alternative Emission Scenarios

Under our Moderate scenario of energy demand, technical measures are adopted that initially require some additional capital investment but save money on fuel. Over the life of the investment, these measures typically save money or, in some cases, are of modest cost. None of the measures are technically difficult to achieve, though getting people to use them may not be easy.

Figure A-l-Comparison of Base Case Forecasts of U.S. Carbon Emissions



SOURCE: Office of Technology Assessment, 1991, calculated using energy demand forecasts in: Holtberg, P.D. et al., 1988 *GRI Baseline Projection of U. S. Energy Supply and Demand to2010* (Chicago, IL: Gas Research Institute, 1988); U.S. Department of Energy, *Annual Energy Outlook 1990*, DOE/EIA-0383(90) (Washington, DC: Energy Information Administration, January 1990); and U.S. Environmental Protection Agency, Office of Policy, Planning and Evaluation, *Policy Options for Stabilizing Global Climate*, Draft Report to Congress (Washington, DC: June 1990).

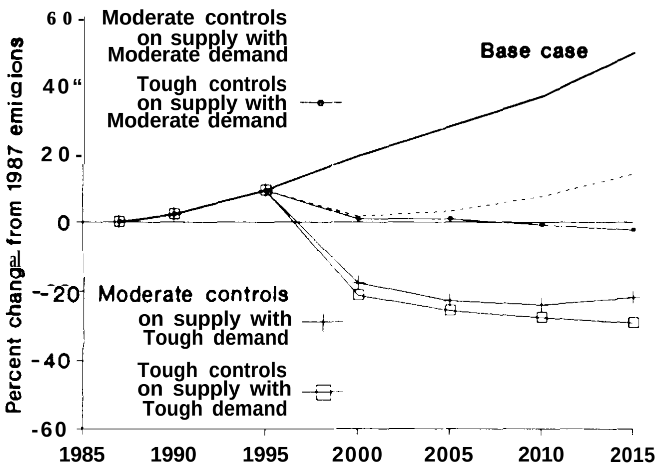
The Tough scenario measures can lower energy demand even further, but they are either technically difficult or will cost more for the same or similar service. We feel that all of the measures are technically feasible, though many will be challenging to implement. In most cases, the performance of the technology is less than that achievable by the best available prototypes, because we attempt to make judgments about what will be feasible in widespread use.

Overall **Modeling Results**

Figure A-2 presents the results of our energy modeling analysis. Under our Base case (upper line), by 2015 emissions are forecast to increase by close to 50 percent above today's level of about 1.5 billion metric tons of carbon per year. A series of Moderate control measures imposed on both the demand side and the supply side (utilities) can lower emissions to about 15 percent above today's levels by 2015.

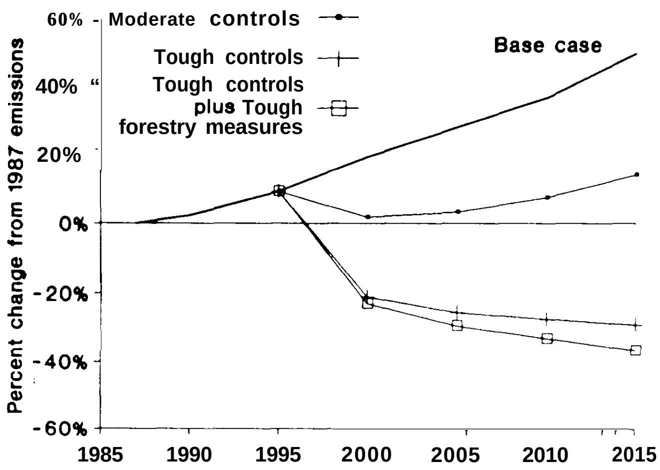
Moderate demand-side measures along with Tough supply-side measures results in holding emissions to just about current levels by 2015. Tough demand-side measures along with Moderate supply-side measures can lower emissions to about 20 percent below current levels by 2015. Finally our most stringent scenario--Tough demand-side and Tough supply-side measures--can lower emissions to 29 percent below today's levels by 2015. Note that under this scenario, CO_2 emissions are about half of

Figure A-2—Carbon Emissions Under the OTA Scenarios, Energy Measures Only



SOURCE: Office of Technology Assessment, 1991.

Figure A-3—Carbon Emissions Under the OTA Scenarios, Including Uptake From Forestry Measures



SOURCE: Office of Technology Assessment, 1991.

our Base case forecast for 2015 (i.e., 0.9 billion v. 1.9 billion metric tons of carbon per year).

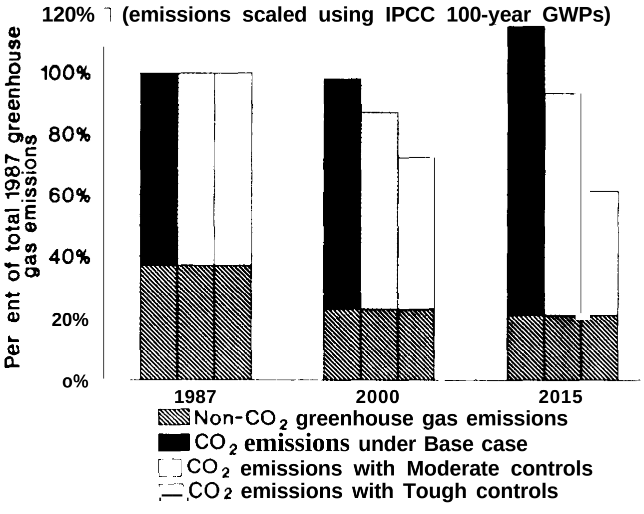
Figure A-2 incorporates only those measures that lower **emissions** of CO_2 and does not include options for **removing** additional CO_2 from the atmosphere and storing it in biomass. Figure A-3 includes all the energy-related measures discussed above and adds forestry measures that can remove CO_2 (and in some cases lower fossil fuel use as well). On this graph, we show three scenarios: 1) Base case emissions, 2) emissions assuming all Moderate energy measures **minus** the carbon offset by Moderate forestry measures, and 3) emissions after all Tough energy measures minus the carbon offset by Tough forestry measures. Under the most stringent scenario, effective 2015 "emissions" (after accounting for the offset from forestry practices) are 37 percent below current levels. This is about 55 to 60 percent below our Base case forecast for 2015.

Figure A-4 displays the effect of these measures as a percentage of all the major greenhouse gas emissions (CO_2, chlorofluorocarbons (CFCs), nitrous oxide, and methane).[6] The decline in emissions other than CO_2 is primarily due to banning CFCs under the Montreal protocol and the Clean Air Act (see ch. 2).

Results by Sector

Figures A-5, A-6, and A-7 show the change in energy-related in carbon emissions under each of our scenarios by **sector:** residential and commercial buildings, transportation, and industry. As noted, current emissions from the three sectors are roughly equal: 36

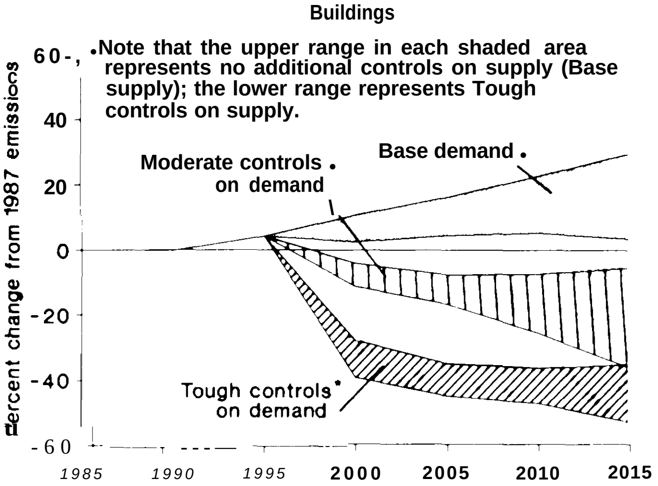
Figure A-4-Greenhouse Gas Emissions Under the OTA Scenarios, Including Carbon Dioxide, Chlorofluorocarbons, Methane, and Nitrous Oxide



SOURCE: Office of Technology Assessment, 1991. Estimates of CFC emissions from J. Wasson, ICF Inc., personal communication, Aug. 30, 1990. Estimates of methane and nitrous oxide emissions from A. Cristofaro, Air and Energy Policy Division, "The Cost of Reducing Greenhouse Gas Emissions in the United States" (Washington, DC: U.S. Environmental Protection Agency, 1990).

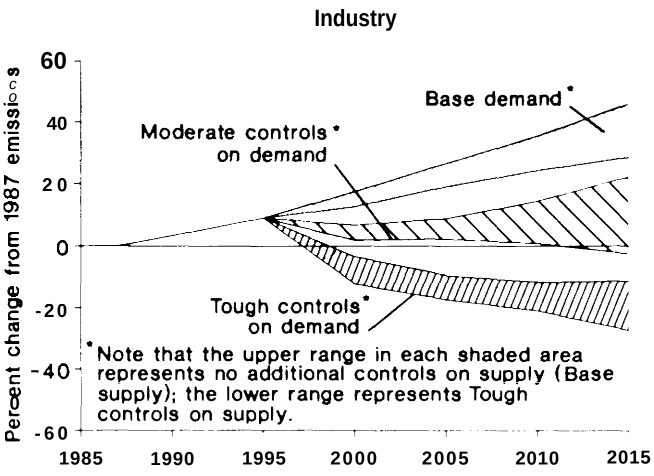
[6] To compare the effects of the various greenhouse gases, we have used the 100 year "global warming potential" (GWP) discussed in ch. 2.

Figure A-5—Carbon Emissions From Buildings Under the OTA Scenarios



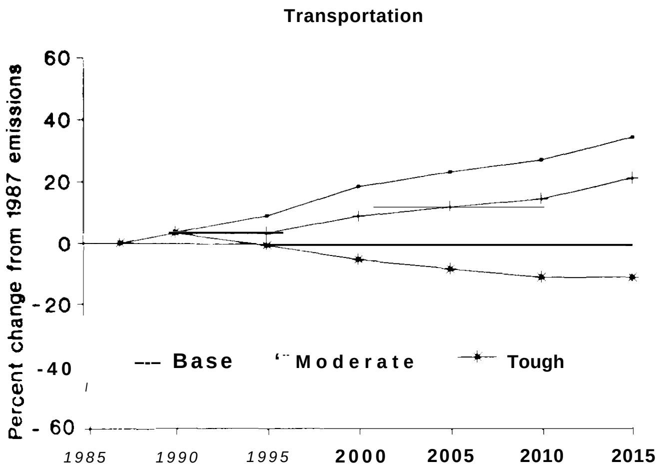
SOURCE: Off Ice of Technology Assessment, 1991.

Figure A-7-Carbon Emissions From Industry Under the OTA Scenarios



SOURCE: Office of Technology Assessment, 1991.

Figure A-6—Carbon Emissions From Transportation Under the OTA Scenarios



SOURCE: Office of Technology Assessment, 1991

percent from buildings, 32 percent from transportation, and 32 percent from industry. Each of the figures includes three bands illustrating the effect of demand-side changes within each sector. The top band is the Base case, the middle band shows the effect of the Moderate measures, and the lower band displays emissions with implementation of all the Tough measures within the sector. Within each band, the upper end assumes that utilities will continue to generate electricity as they do under the Base case; the lower end of the range assumes that utilities will adopt a series of Tough measures to lower COs emissions per kilowatt-hour of electricity generated.

Under the Base case demand for energy in residential and commercial buildings (figure A-5), emissions will increase by 5 to 30 percent by 2015 (depending on what actions are taken by electric utilities). By adopting all of our Moderate scenario measures for buildings, emissions by 2015 might decline by 5 to 35 percent below their current levels. The Tough measures might lower emissions to 35 to 55 percent below their current levels. Utility measures have such a large impact on this sector because about two-thirds of the carbon emitted as a result of energy use within buildings comes from powerplant stacks.

Transportation emissions (figure A-6) are the most difficult to control. Under our Base case, emissions go up by about 35 percent. After applying all Tough measures, emissions drop to about 10 percent below current levels. Because such a small fraction of our transportation system uses electricity, we have not shown the effect of utility measures.

Industrial emissions (figure A-7) range from a 45-percent increase by 2015 under the Base case to a 25-percent drop after applying all the Tough measures.

Reductions by Technical Option

In this report we express all reductions as a **percent of current (1987) emissions. One** “percent of current emissions’ is equal to 13 million metric tons of carbon. To hold emissions at current levels, we must achieve reductions by 2015 equal to 50 percent of current emissions; this means reducing emissions expected under Base-case forecasts by about 650 million tons per year. To lower emissions to 20 percent below current levels by

Table A-3-Measures to Lower U.S. Carbon Emissions
(expressed as percentage of 1987 total emissions)

	2000		2015	
	Moderate	Tough	Moderate	Tough
DEMAND-SIDE MEASURES				
Residential buildings				
New investments:				
Shell efficiency	0.5%	0.70/0	1.3%	2.0%
Heating and cooling equipment	0.0%	0.2%	0.1%	0.4% to 0.6%
Water heaters and appliances	0.5%	0.5%	1.2%	1.5% to 2.3%
O&M, retrofits:				
Shell efficiency	0.6%	1.7%	0.8%	0.90/0
Lights	0.4%	0.6%	0.6%	0.8%
All residential measures together	1.9%	3.7%	3.9%	5.6% to 6.6%
Commercial buildings				
New Investments				
Shell efficiency	0.9%	1.4%	2.3%	4.O%
Heating and cooling equipment	0.4%	0.5% to 1.O%	1.0%	1.2% to 1.9%
Lights	0.8%	1.1%	2.1%	3.0%
Office equipment	0.5%	0.7%	1.6%	2.1 %
Water heaters and appliances	0.10%	O.l°/O	0.1%	O.l°/O
Cogeneration	0.1%	0.4% to 0.6%	0.2%	1.5% to 2.3%
O&M, retrofits:				
Shell efficiency	0.6%	2.1%	0.8%	0.8%
Lights	0.2%	0.2%	0.5%	0.5%
All commercial measures together	3.50/o	6.6% to 7.3%	8.50/o	13% to 15%
Transportation				
New **investments:**				
New auto efficiency	0.4%	0.8% to 1.2%	0.8%	3.5% to 3.8%
New light truck efficiency	0.3%	0.5% tO 0.8%	0.5%	2.5% to 2.7%
New heavy truck efficiency	0.2%	0.7% to 0.8%	0.4%	2.4% to 2.4%
Non-highway efficiency	0.3%	0.7%	0.5%	1 .2%
O&M, retrofits:				
Improved public transit	0.1%	2.1%	0.2%	3.5%
Truck inspection & maintenance	0.3%	0.3%	0.3%	0.4%
Traffic flow improvments/55 mph	1.2%	1.2%	1.2%	1.4%
Ridesharing/parking controls	0.3%	0.5%	0.4%	1.0%
All transportation measures together	3.1%	7.% to 7.8%	4.2%	14% to 15%

(Continued on next page)

2015, we must achieve reductions equal to 70 percent of current emissions.

Measures were identified through technical reviews by OTA staff and contractors and through a series of workshops.

Buildings

For buildings (ch. 4), improved shell efficiency and lighting are two of the largest measures (see table A-3). Under the Base case, we assume that by 2015, new homes and apartments will be designed such that they need about 15 percent less heat and 8 percent less air-conditioning than current new homes. By adopting Moderate shell efficiency measures, such as thicker insulation and better windows, we estimate that new homes will require 50 percent less heat and 25 percent less air-conditioning than today's average new home (23). With Tough measures, we estimate that homes can be built to require 85 percent less heat and 45 percent less air-conditioning (17). Moderate shell improvements in new residential buildings can reduce carbon emissions by 1.3 percent of current levels by 2015. Adopting Tough measures in the North (and Moderate ones in the South) might achieve reductions of 2.0 percent. Tough measures for new commercial buildings can achieve reductions equal to 4 percent of 1987 levels by 2015.

Existing homes can also be made more efficient by installing insulation, new windows, and so forth. Under our Base case, we assume that existing homes will require 10 percent less heating and cooling by 2015 because of replacements and improvements that will happen in any case. Moderate measures boost this to 20 percent by 2015 and Tough measures boost it to 30 percent by 2000 (18). Tough measures in the North and Moderate ones in the South would reduce carbon emissions by 1.7 percent by 2000; this would drop to about half that amount by 2015 as many older homes are replaced by new ones.

Table A-3-Measures to Lower U.S. Carbon Emissions-Continued
(expressed as percentage of 1987 total emissions)

	2000		2015	
	Moderate	Tough	Moderate	Tough
DEMAND-SIDE MEASURES				
Industry				
New investments:				
Efficient motors	0.3%	1.0% to 1.1%	1.2%	3.7% to 4.0%
Lighting	0.1%	0.2%	0.5%	0.7% to 0.8%
Process change, top 4 industries	0.7%	2.2%	3.0%	8.2%
Fuel switch to gas	0.0%	0.5% to 0.7%	0.0%	2.4% to 2.7%
Cogeneration	0.3%	1.1% to 1.4%	0.8%	5.2% to 5.8%
O&M, retrofits:				
Housekeeping	0.6%	1.5%	1.9%	2.0%
Lighting	0.1%	0.1%	0.1%	0.2%
All industry measures together	2.2%	6.1% to 6.7%	7.6%	17% to 18%
UTILITY SUPPLY-SIDE MEASURES				
Existing plant measures:				
Improved nuclear utilization	1.3%	1.3%	4.1%	4.1%
Fossil efficiency improvements	1.7%	1.7%	1.7%	1.7%
Upgraded hydroelectric plants	0.6%	0.6%	0.5%	0.5%
Natural gas co-firing	—	3.7%	—	3.7%
New plant measures:				
No new coal higher fraction of new nonfossil sources	—	0.0%	—	0.0% to 4.7%
CO_2 emission rate standards	0.0%	0.0%0	0.4%	0.0% to 0.1%
All utility measures together	3.4%	6.50/0	6.6%	9.9% to 14%
FORESTRY MEASURES				
Afforestation:				
Conservation Reserve Program	0.2%	0.2%	0.2%	0.2%
Urban trees...	—	0.1%	—	0.7%
Additional tree planting	—	0.6%	—	2.3%
Increased tree productivity	—	0.8%	—	3.1%
Increased use of biomass fuels....	—	0.3%	—	1.2%
All forestry measures together	0.2%0	2.0%	0.2%	7.5%

SOURCE: Office of Technology Assessment, 1991

Improving the efficiency of lighting in commercial buildings is another technical option that can yield substantial reductions. Our Tough measures-a combination of high-efficiency fluorescent bulbs and ballasts, improved reflectors, and better use of daylight--can lower lighting energy needs by 60 percent in new buildings and 50 percent in existing ones (15). This translates to a 3-percent reduction in emissions by 2015.

Replacing heavily used bulbs in homes with compact fluorescent (16) and using high-efficiency fluorescent in existing fixtures in commercial buildings (15) can lower emissions by 1.3 percent.

Transportation

For transportation (ch. 5), the major reductions come from higher auto and truck efficiency, better control of traffic speed, and, under the Tough scenario, improved public transit (see table A-3). Our Base case assumes that new cars will average about 32 miles per gallon (mpg) by 2000 and 36.5 mpg by 2010. Under the Moderate scenario, new car efficiency averages 35 mpg by 2000 (7) and 39 mpg by 2010 (8). By 2015, reductions of about 0.8 percent of current U.S. carbon emissions are possible.

We have constructed a range of Tough new car efficiencies. Efficiencies of 39 mpg by 2000 and 55 mpg by 2010 might be possible assuming that consumers maintain their current size class preferences (8). By 2015, reductions amount to 3.5 percent of current emissions. If consumers are willing to purchase smaller cars, new car fleet average efficiencies of 42 mpg by 2000 and 58 mpg by 2010 might be achievable (8). Assuming such efficiencies, and policies that encourage people to scrap their old cars an average of 3 years earlier than they would otherwise, reductions of about 3.8 percent might be achieved by 2015. Reductions of about 2.7 percent from light trucks and another 2.4 percent from medium- and heavy-duty trucks are achievable under our Tough scenario as well.

Traffic speed affects fuel consumption, too. By reinstating the 55 mph speed limit to slow down travel on highways and by improving traffic congestion in urban areas to speed up travel, reductions of 1.2 percent by 2000 are possible.[7] We consider both of these to be Moderate measures.

Measures to move people out of their cars and into mass transit under the Tough scenario would yield reductions of about 3.5 percent. To achieve this, however, urban auto traffic would have to be reduced by 10 percent through urban light rail, busways, and improved urban design. High-speed intercity rail would lower interurban car travel by 5 percent.

Industry

For industry (ch. 6), three types of technical improvements offer the greatest promise (see table A-3). Cogenerating electricity and steam for industrial processes is one. About two-thirds of the energy from burning fuel for electricity is released as heat. If electricity is generated at industrial sites where the heat can be used, the efficiency of fossil fuel use can be increased dramatically. Under our Tough scenario, we assume that 90 percent of new industrial steam boilers will cogenerate electricity. Such measures can lead to reductions equivalent to about 5.5 percent of current emissions. More efficient motors are another technical improvement that can lead to substantial improvements. Moderate improvements might improve motor efficiencies by 10 percent and Tough ones by 20 percent (3), yielding reductions of about 1.2 percent by 2015 under the Moderate scenario and 4 percent under the Tough one,

The four top manufacturing energy consumers are the paper industry, chemicals, petroleum, and primary metals, Between 1980 and 1985, these industries managed to improve their energy efficiency by between 2.3 and 4.3 percent per year (10). If this pace can be maintained, reductions equal to about 8 percent of current emissions will result.

Electricity Generation

Measures that lower the rate of carbon emissions per kilowatt-hour of electricity generated can achieve substantial reductions. All of the Moderate utility supply-side measures can lower emissions by about 6.6 percent (see table A-3). The two with the greatest reduction potential are: 1) increasing the efficiency of fossil-fuel-fired plants (by about 5 percent) through improved maintenance (9) and 2) operating existing nuclear powerplants 70 percent of the time (similar to Western Europe and Japan) (13) and extending their useful life to 45 years.

A series of Tough measures eliminate coal use wherever possible. A combination of renewable energy sources, improved nuclear designs that may be available after 2005, and high-efficiency gas turbines are the only technologies allowed for new utility plants built after 2000. However, if all the Tough demand-side measures are implemented, demand for electricity is so low that very few new plants are needed through 2015. Thus, to lower emissions from electricity generation (beyond the Moderate measures) one must either cofire existing coal plants with 50-percent natural gas or retire existing fossil-fuel plants after 40 years of operation (rather than the typical 60 years), replacing them with renewable, nuclear, or high-efficiency natural gas. The former measure would yield reductions of about 3.7 percent of current levels by 2015 and the latter would yield reductions of about 4.7 percent.

Forestry

The forestry measures (ch. 7) with the greatest potential include increasing the productivity of existing forests and planting trees in new areas (afforestation) (see table A-3). Genetically selected seedlings, fertilization, and improved management might double forest productivity on timber industry lands and increase productivity by 50 percent on other private holdings.[8] The increased carbon uptake would be equivalent to emissions reductions of about 3.1 percent of current levels by 2015. Planting 33 million hectares (ha) (125,000 square miles) of new forests and wood lots (35) as well as additional urban trees (1) would be equivalent to emissions reductions of about 3 percent of current levels by 2015.

Estimating the Costs of OTA's Tough Scenario

This section includes rough estimates of the costs of control measures included under OTA's "Tough" scenario. Table A-3 listed the emissions reductions associated with each of the control measures. Detailed descriptions of each of the measures are documented in tables 3-6, 4-2, 5-6, 6-4, and 7-1 in the energy, buildings, transportation, industry, and forestry chapters, respectively. Table A-4 lists fuel *savings* from the demand-side measures (in trillion Btus and billions of dollars) for both the Moderate and Tough scenarios, Projected fuel prices are listed in table A-5.

All costs presented in this section are in 1987 dollars. A 7-percent discount rate is used to annualize capital costs (typically over 30 years unless noted otherwise).

[7] OTA calculations based on data in ref. 38, for 55 mph speed limit and ref. 5 for congestion.

[8] OTA Calculation based on refs. 4, 24, 30.

Table A-4-Changes in Fuel and Power Use and Costs

		Energy (trillion Btu)			Cost (billion 1987$, 2015 prices)		
			Change:			Change:	
	1987	Base 2015	Moderate 2015	Tough 2015	Base 2015	Moderate 2015	Tough 2015
Residential buildings:							
Natural gas	4,462	4,198	-639	-1,320	$48	-$7	-$15
Electricity	2,854	3,323	-597	-1,067	$110	-$20	-$35
Oil	1,590	1,124	-174	-374	$11	-$2	-$4
Coal	74	62	-8	-13	$0	-$0	-$0
Wood	837	1,516	-353	-897			
Total	8,980	8,707	-1,418	-2,774	$169	-$29	-$54
Commercial buildings:							
Natural gas	2,421	3,387	416	387	$36		$4
Electricity	2,525	4,264	-1,572	-2,922	$119	-$44	-$81
Oil	1,086	922	-259	-649	$9	-$3	-$6
Coal	107	114	-23	-43	$0		-$0
Total	6,139	8,687	-2,270	-3,226	$164	-$51	-$84
industry:							
Coal	2,678	4,598	-1,299	-3,088	$13	-$4	-$9
Natural gas	7,044	7,685	-227	-24	$69	-$2	-$0
oil	4,725	5,041	-627	-1,742	$40	-$5	-$14
Biomass	2,230	3,520	-298	-1,370			
Electric	2,679	4,398	-685	-1,686	$97	-$15	-$37
Total	19,355	25,242	-3,136	-7,909	$219	-$26	-$60
Transportation:							
Gasoline	13,393	16,380	-2,008	-6,927	$244	-$30	-$103
Distillate oil	3,338	5,140	-420	-1,586	$51	-$4	-$16
Jet fuel	2,872	4,686	-317	-1,327	$70	-$5	-$20
Aviation gas	45	48	0	0	$1	$0	
Residual oil	817	1207	0	0	$10	$0	$0
Natural gas	571	724	0	0	$8	$0	$0
Electricity	17	28	0	104			$3
Total	21,053	28,213	-2,745	-9,736	$39	-$136	-$136
Exogenous electricity	0	2,527	-632	-1,263	$69	-$17	-$35
All sectors:							
Natural gas	14,497	15,994	–1,282	-957	$160	-$14	-$11
Electricity	8,074	12,013	-2,855	-5,571	$396	-$96	-$186
oil	27,866	34,548	-3,805	-12,605	$436	-$48	$163
Coal	2,859	4,774	-1,330	-3,143	$14	-$4	-$9
Biomass	3,067	5,036	-651	-2,267			
Total	56.364	72,365	-9,923	-24,543	$1,006	-$162	-$369

SOURCE: Office of Technology Assessment, 1991.

Total Costs

Adding results documented below by sector yields the following **net** annual costs (i.e., annualized capital and operating costs minus fuel savings):

Utilities: +$35 billion

Residential buildings: –$25 to–$15 billion

Commercial buildings: –$28 to+$22 billion

Transportation: –$35to+$38 billion

Industry: +$21 to+$58 billion

Forestry: +$l0 to +$13 billion

Total: -$22 to+$150 billion

GNP in 2015 is forecast to be about $8.4 trillion (1987 dollars).[9] Thus, our Tough scenario may entail net savings of a few tenths of a percent of GNP upwards to costs equal to about l.8 percent of GNP.

Again, note these are net costs. The fuel savings for the Tough scenario are about $370 billion in 2015 assuming our projected 2015 fuel prices. Thus, annualized capital and operating costs fall in the range of about $350 to $520 billion per year--somewhere between 5 percent less than and 40 percent more than expected fuel savings.

The fuel savings for the Moderate scenario are about $160 billion in 2015 assuming 2015 prices. Thus, even

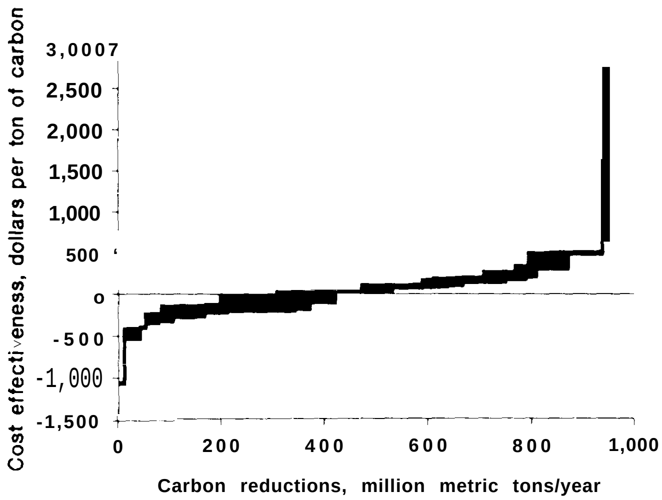
[9] We obtain this estimate by extrapolating GRI's 2010 GNP forecast using their estimate of GNP growth between 2005 and 2010.

Table A-5--Projections of Future Fuel Prices (1987 dollars per million Btu)

	1987	2010	2015
Oil:			
Residual fuel	$2.83	$6.50	$8.00
Distillate fuel	$3.83	$8.30	$10.00
Gasoline (retail)	$7.65	$13.20	$14.90
Natural gas:			
Residential	$5.40	$9.60	$11.40
Commercial	$4.58	.$8.80	$10.50
Industrial	$2.48	$730	$9.00
Utility	$2.23	$6.70	$8.30
Coal:			
Utility	$1.50	$220	$2.30
Industrial	$1.63	$2.60	$2.90
Electricity:			
Residential	$21.83	$25.70	$28.80
Commercial	$20.46	$22.40	$24.20
Industrial	$14.11	$17.40	$19.20
Average	$18.74	$21.60	$23.80

SOURCE: Prices for 1987 and 2010 from Gas Research Institute, *Baseline Projection of U.S. Energy Supply and Demand to 2010* (Washington, DC: 1988). Prices for 2015 extrapolated by OTA.

Figure A-$-Cost Effectiveness of Control Measures Under the Tough Scenario



SOURCE: Office of Technology Assessment, 1991.

under the Moderate scenario, very large sums of money change hands.

The cost effectiveness of these measures (i.e., tons of carbon avoided per dollar of net costs) varies widely (see figure A-8). Between about one-third to one-half of the reductions either save money or are of very low cost. About one-quarter of the reductions have costs exceeding $200 per ton of carbon avoided. The costs and cost effectiveness of the individual measures are discussed below.

Other groups have tried to estimate the costs of CO_2 reductions, but with different control scenarios. For example, the Congressional Budget Office (CBO) estimated the reductions and economic impacts from a carbon tax (28a), CBO looked at two economic models that forecast energy use past 2000, one used by EPA and the other by the Electric Power Research Institute (EPRI). Although they widely diverge by 2100, primarily due to assumptions about Base case growth, at 2015 they are reasonably similar to each other and to our own Base case and thus offer a useful comparison of the costs of reductions. The EPA model forecasts that holding emissions to 10 to 15 percent below current levels would lower GNP by about 1 to 1.3 percent by the year 2015. The EPRI model forecasts that holding emissions to 20 percent below current levels would lower GNP by about 3 percent by that year. Results from the EPA model seem consistent with our own cost estimates; the EPRI economic estimates appear to be somewhat higher than our own. Note, however, that we estimate compliance costs (annual capital and operating costs minus fuel savings) while the CBO results are estimates of changes in GNP. The two are not directly comparable, but studies of the effect of other environmental control costs on the economy indicate that the estimates should fall within a factor of two of each other. **All** of the analyses of the costs of controlling CO_2 attempted to date should be considered as only rough estimates and in need of considerable refinement.

Electricity Supply

We estimate that the Tough electricity supply-side scenario will cost about $35 billion per year (1987$) by the year 2015, assuming it is implemented along with all Tough demand-side measures. This is the cost of the Tough supply-side measures alone and does not include the costs of lowering electricity demand (which are discussed in the following three sections).

Low ***Cost Measures That Apply to Existing Plants—Our*** Tough scenario includes the following measures that we estimate are low cost (or save money):

1. modestly improving the efficiency of existing fossil-fuel-fired plants (9),
2. increasing the output of existing hydroelectric plants by adding additional generating units to capture energy from water currently bypassing the plants (6), and
3. increasing utilization of existing nuclear power plants and lengthening their useful life to 45 years (13).

We assign no net costs for these measures.

Cofiring Coal Boilers With Natural Gas—About half of this sector's total costs come from cofiring existing coal plants with natural gas. By 2015, we estimate that natural gas will cost about $6 per million British thermal units (Btu's) more than coal. Cofiring coal boilers with 50-percent natural gas will increase generation costs by about $0.03 per kilowatthour (kWh). In 2015, costs would total about $18 billion per year, at a cost effectiveness of about'$510 per ton of carbon avoided.

Early Retirement of Existing Facilities With a Moratorium on New Coal Plants-Most of the remaining costs for this sector come from forcing existing fossil-fuel-fired plants to retire after 40 years of operation and replacing them with natural gas and nonfossil sources. Forcing coal-fired plants to retire early and replacing them with highly efficient natural gas-fired combined cycle turbines could increase electricity costs at affected plants by $0.04 to $0.05 per kWh. Forcing existing oil and natural gas plants to retire early saves money—about $0.01 to $0.02 per kWh--because the replacement facilities are so much more efficient, Costs are based on the projected 2015 fuel prices presented in table A-5; efficiencies and capital and operation and maintenance costs are from the Electric Power Research Institute (EPRI) (12). Because existing facilities are fully depreciated after 30 years, no capital charges are applied to electricity generated from existing plants.

Note, however, that once these existing facilities retire, costs must be compared to replacement coal or natural gas plants. Electricity from new natural-gas-fired combined cycle turbines (assuming our 2015 fuel prices) would cost about $0.02 per kWh more than electricity from a new coal-fired powerplant, less than half the cost premium over existing plants. Note, too, that costs are sensitive to fuel prices. Costs are about $0.01 per kWh lower assuming 2010 prices.

We have assumed that the cost of electricity from nonfossil sources (either renewable sources or nuclear power) will be about comparable to natural-gas-fired combined cycle turbines. The cost of early retirement of existing fossil-fuel-fired sources and replacement with natural gas and nonfossil sources is about $17 billion per year, at a cost effectiveness of $280 per ton of carbon eliminated.

Buildings

Costs for all Tough measures that are applicable to buildings in both the residential and commercial sectors fall in a range between net **savings** (i.e., equipment costs minus fuel savings) of $53 billion per year to net **costs** of $7 billion per year (1987$).

Residential Buildings—Costs for the residential sector are best estimated by household. By 2015, there will be about 115 million households, 35 million built after 1995 and 80 million built before. We estimate that shell improvements to pre-1995 houses under our Tough scenario will cost about $2,300 per single family house in northern climates and $1,000 per single family houses in southern ones.[10] Costs for shell improvements to pre-1995 multifamily dwellings (about one-quarter of households) will average about $1,200 per dwelling in northern climates and $600 in southern climates. All costs are incremental costs for improvements over our assumed Base case efficiencies. Northern climates include the New England, Mid-Atlantic, North Central, and northern Mountain Census regions.

The costs of shell improvements in post-1995 houses under our Tough scenario are somewhat higher. In northern climates, costs might be in the range of $6,000 to $8,000 per house; in the South, costs might be about $2,500 per house. Shell improvements in new multifamily dwellings might cost $2,000 to $3,000 in northern climates and $1,200 in southern ones.

Costs for more efficient furnaces and appliances might total about $1,000 to $1,500 per household, based on the following estimates of additional costs: furnace ($750), water heater ($45), refrigerator ($1 85), air conditioner ($300), freezer ($50), washer ($28), dryer ($70), dishwasher ($18),[11]

Assuming the shell improvements have a 30-year life and the more efficient appliances average a 15-year life, total costs for the residential sector will be in the range of $30 to $40 billion per year. However, fuel savings from these measures are about $55 billion per year assuming 2015 fuel prices. Thus, the net costs for the residential sector fall in the range of **savings** of $15 billion to $25 billion per year. The cost effectiveness of these reductions is in the range of –$175 to –$300 per ton of carbon (i.e., savings of $175 to $300 per ton of carbon).

Commercial Buildings-By 2015, we anticipate the United States having about 72 billion square feet of commercial building space (up from about 45 billion today). Though costs of energy efficiency improvements vary by building type, they appear to cluster in the range of $5 to $11 per square foot for a package similar to our Tough measures.[12] These are the most aggressive measures considered by the Northwest Power Planning Council and include somewhat better lighting improvements than we assumed, reasonably equivalent shell improvements and heating and cooling efficiencies for several building types, but lower improvements for others than we assumed for other building types.

[10] The costs of our Tough scenario are estimated primarily from data in ref. 26, tables 3-13, 3-14, and 3-36.

[11] All appliance estimates from ref. 26; except for furnaces from ref. 12.

[12] Costs are derived from ref. 26, tables 54A through 54H.

Costs for these improvements total about $30 to $65 billion per year but fuel savings are approximately $55 billion per year at 2015 fuel prices. Thus net costs for these measures fall between savings of $25 billion per year and costs of $10 billion per year. The cost effectiveness of these reductions ranges between –$190 per ton and $75 per ton of carbon avoided.

By 2015, we assume the commercial sector will be able to install 25 GW of cogeneration systems. We assign a cost premium of $0,02 to $0.05 per kWh to cogenerated electricity, the same cost we derive for cogeneration within industry (see below). Costs total about $2.5 to $6 billion per year, at a cost effectiveness of $85 to $210 per ton of carbon.

For the remaining reductions (from office equipment and water heaters and appliances), we assume a range of costs equal to the range of commercial measures discussed above: –$200 to $200 per ton of carbon. Net costs for the remainder total between –$5.5 to $5.5 billion per year.

Total costs for the commercial sector are between savings of $28 billion per year to costs of $22 billion per year. The cost effectiveness of these reductions falls in the range of –$150 to $120 per ton of carbon avoided.

Transportation

We estimate that the net costs of the Tough transportation measures fall in a range between **savings** of about $35 billion per year to costs of about $38 billion per year (1987$) in 2015,

Highway Vehicle Efficiency--The new-vehicle efficiency measures will save money by 2015, assuming the expected rise in the price of gasoline (about $1.85 per gallon in 1987$). They are considered "Tough" primarily because they are technically challenging goals. We assume that the additional cost of fuel-efficiency improvements to achieve a 55 mpg new car fleet average by 2010 will be in the range of ***$.500* to** $750 per car (1987$) (8). Achieving a 58 mpg car fleet by encouraging consumers to buy smaller can; might require a subsidy of about $250 to $500 per vehicle (7). Thus we use $750 to $1,250 as our range of new car costs. We assume light-duty truck efficiency improvements under the Tough scenario will cost $500 to $750 per vehicle (i.e., the same as new cars without subsidies for smaller cars). Assuming 168 million cars and 74 million light trucks and amortizing the costs over 7 years, we estimate the increase in passenger vehicle costs will be about $30 to $50 billion per year,

However, the higher efficiency under the Tough scenario saves about $58 billion in fuel costs per year. Thus, **net** costs for improved light-duty vehicle efficiency are in the range of savings of $8 to $28 billion per year. The cost effectiveness of the Tough fuel efficiency measure for cars is in the range of –$220 to –$110 per ton of carbon avoided; for light trucks, the range is –$510 to –$410 per ton.

Lacking estimates for the costs of heavy-duty truck improvements, we assume similar dollar per ton costs as light-duty vehicles. Savings amount to between $3 billion and $9 billion per year. For lack of a better estimate, we assume that the cost of the aircraft efficiency improvements will equal fuel savings.

Mass Transit—We estimate that travel by mass transit costs about $0.13 to $0.21 per passenger mile more than travel in cars. Mass transit costs were in the range of $0.45 per passenger mile for 1988.[13] Passenger car operating costs were about $0.382 per vehicle mile in 1989 (25). Using a range of 1.6 passengers per vehicle (a 1983 urban average from ref. 36 for all travel) to 1.2 passengers per vehicle (urban work commuting average) yields costs of $0.24 per passenger mile for all urban car travel and $0.32 per passenger mile for work commuting by car. Assuming the per-mile travel premium derived above, mass transit and intercity rail costs under our Tough scenario total $26 to $55 billion per year, or about $1,150 to $2,300 per ton of carbon.

Other Measures—Urban traffic flow improvements, truck inspection and maintenance programs, and improved urban planning are all probably low cost measures. Fuel savings from these programs amount to about $15 billion per year, which we use as our estimate of the net cost of these measures.

The remaining measures-55 mph speed limit, ridesharing, parking controls, etc.—all lead to fuel savings but have associated inconvenience costs as well. We assume that these fall somewhere in the range between 50 percent less than and 50 percent greater than fuel savings. Because fuel savings from these measures are about $18 billion per year, net costs fall in the range of savings of $9 billion per year to costs of $9 billion per year.

Industry

We estimate that the cost of all the Tough industrial control measures falls in the range of $18 billion to $55 billion per year.

Motors and Lights—Use of more efficient motors, lighting, and general housekeeping improvements are all measures that are either low cost or save money due to

[13]Assumes a 5-year average capital cost from ref. 2, table 38 (Federal contribution is assumed to be 7S percent of total). Operating costs and passenger miles traveled from ref. 37, tables 2.09 and 2.13.

large electricity savings. The Electric Power Research Institute estimates that more efficient motors can save $0.03 per kWh and more efficient lighting can save $0.04 per kWh over the life of the equipment (22). We have simply assumed that these two measures cost half of the amount they save in electricity costs. We assume that general housekeeping costs as much as it saves in energy. Net cost savings from these measures total about $6 billion per year. The cost effectiveness of the reductions from motors and lights is about –$130 per ton of carbon avoided.

Lower ***Emitting Fuels--A*** moratorium on new coal industrial boilers (assuming natural gas is the fuel of choice) would increase natural gas use by about 2.3 quads over the Base case. At our 2015 prices, this costs about $14 billion per year, with a cost effectiveness of about $520 per ton.

Cogeneration--While in many situations industrial cogeneration will save money, assuming that 90 percent of all new and replacement boilers would cogenerate might add a cost penalty, on average, of $0.02 to $0.05 per kWh. The higher cost is an EPA-contractor estimate[14] assuming that all noncogenerating industrial boilers (existing and new) that burn oil or natural gas will cogenerate; the lower estimate assumes that the most expensive 7 percent of such boilers are exempt from the requirement. Requiring in addition that all cogeneration systems use equipment equal in efficiency to Intercooled Steam Injected Gas Turbines might add another $0.01 to $0.02 per kWh. We add the $0.01 to $0.02 per kWh premium to all cogenerated electricity, including the amount assumed to occur under our Base case, Costs for cogeneration total about $3 to $7 billion per year. The cost effectiveness of these reductions is in the range of $55 to $120 per ton of carbon.

Process ***Change--The*** largest share of the industrial reductions comes from process change. We have no source of estimates for the cost of these reductions. We assumed a range of $120 per ton to $520 per ton (the upper bound of the cost effectiveness of cogeneration to the cost effectiveness of fuel switching from coal to natural gas). Total costs for process changes thus would fall in the range of about $10 to $43 billion.

Forestry

We estimate that implementing our Tough forestry-related measures would cost in the range of $10 to $13 billion per year. The cost effectiveness of these measures averages $105 to $135 per ton of carbon sequestered.

Afforestation-Afforestation is estimated to cost about $2.7 billion per year (about $1.6 billion for urban trees, $0.3 billion for the Conservation Reserve Program (CRP), and $0.8 billion for general afforestation). The cost effectiveness of the CRP and general afforestation averages about $35 per ton of carbon sequestered; the cost effectiveness for urban tree planting averages about $180 per ton.

For urban trees, we estimate maintenance at $10 per tree per year (based on ref. 21), and planting of saplings at $75 per tree (including time, transportation, and labor). Planting and maintaining 100 million trees then would cost $1.6 billion per year.

For the CRP, the total cost for a 10-year contract is an estimated $1,420 per hectare (based on data in ref. 31). Assuming that the current legislative goal of planting trees on 2.3 million hectares is met, then costs would be $0.3 billion per year.

For general afforestation, we estimate costs for land, seedling and soil preparation, and labor at about $325 per hectare (based on refs, 31, 32). Planting 30 million hectares would cost $0.8 billion per year.

Increased Productivity-We estimate maintenance costs in programs to increase productivity at about $10 per hectare per year, exclusive of credits for sales or taxes (based, for example, on ref. 28); and site preparation and planting costs at about $420 to $600 per ha (based on ref. 39). Given this range in site preparation and planting costs, increasing productivity on 140 million hectares of already forested lands would cost between $6 and $8 billion per year. The cost effectiveness of these reductions is in the range of $150 to $200 per ton of carbon sequestered.

Biomass Fuels—We estimate biomass fuel to cost $2 to $3 per million Btu; this assumes that fuel costs $68 to $102 per ton carbon (40) and that biomass fuels contain 55 to 60 lb of carbon per million Btu. We assign biomass fuels a premium over coal (for use in utility or industrial boilers) of roughly $1 to $2 per million Btu, including a penalty for drop in efficiency. Given this premium, 1 quad of biomass fuel would cost $1 to $2 billion per year. The cost effectiveness of these reductions is in the range of $67 to $133 per ton of carbon sequestered.

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