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Policies and Measures to Reduce CO_2 Emissions in the United States: An Analysis of Options through 2010

A Study for World Wildlife Fund by:

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An Analysis of Options through 2010

Tellus Institute and SEI-Boston

Abstract

The Intergovernmental Panel on Climate Change has reported that in order to prevent global climate disruption and its attendant ecological, economic, geo-physical, demographic and political consequences, it is necessary to stabilize atmospheric concentrations of greenhouse gases well below the levels that would result if greenhouse gases continued to accumulate along current trends. Protecting global climate will therefore require that annual emissions of greenhouse gases be reduced by at least 60 percent below present rates. As the principal greenhouse gas is carbon dioxide, which is released in the energy production and use at the heart of industrial economies, this daunting objective will require two complementary, sustained initiatives. First, the industrialized nations must dramatically reduce their carbon emissions from current levels. Second, industrializing nations must economically develop along a path of low carbon-intensity. Arguably, the United States, whose current per capita carbon emissions are roughly five times the present global average, must radically decrease emissions as its contribution to climate protection.

This study finds that the U.S. can reduce its annual carbon emissions to 10 percent below 1990 levels by 2005 and to 22 percent below 1990 levels by 2010, at net savings to its economy relative to the present energy-intensive and fossil-based path. The U.S. can achieve this by implementing an ambitious set of targeted policies, beginning in 1998, which would overcome market and institutional barriers and stimulate more rapid introduction of advanced technologies and fuels that are cleaner and more efficient. These near-term carbon reductions, and the technologies and policies that underlie them, establish a trajectory and a basis for the much deeper long-term cuts that are needed for climate protection.

This study was commissioned by the World Wildlife Fund (WWF) as a companion to parallel studies of the European Union (Blok *et al.* 1996) and Japan (Morita *et al.* 1997), which together with the U.S. are responsible for roughly 40 percent of the world's annual carbon emissions. The study builds and expands upon another study entitled *Energy Innovations: A Prosperous Path to a Clean Environment* (EI 1997), which was recently released by five non-profit energy and environmental policy research organizations. This study strengthens, accelerates and adds to the policies identified and analyzed in *Energy Innovations* to build an augmented policy package that more aggressively captures near-term carbon emissions reductions.

This report is a revised version of *Policies and Measures to Reduce CO_2 Emissions in the United States: An Analysis of Options for 2005 and 2010* , which was released in October 1997. The underlying analysis has *not* been changed. The principal differences embodied herein are the following: i) cost-of-saved-carbon results have been provided for the policies explored; ii) the year in which constant dollars and present value dollars are reported has been changed from 1993 to 1997; iii) Table 1 has been modified to include energy savings at refineries owing to industrial sector policies; iv) Figure 8 has been revised to include additional policy-induced on-site cogeneration in the industrial sector, as well as baseline cogeneration sales to the grid; v) Figure 8b now refers to the *Climate Protection* scenario, as opposed to the electric supply-side policies alone; vi) Table 3 in the original report has been omitted; vii) small changes have been made to the text; viii) the title has been changed to reflect the intertemporal nature of the analysis; and ix) the results have been slightly refined in places.

I. Introduction and Summary

Background

At the 1992 Earth Summit in Rio de Janeiro, signatories to the Framework Convention on Climate Change committed themselves to achieving "... stabilization of greenhouse gas concentrations in the atmosphere at a level that would prevent dangerous interference with the climate system." Since that time, however, emissions of greenhouse gases have continued to rise, even as the community of climate scientists has moved toward the consensus that already Ahuman activities are having a discernible impact on global climate" (IPCC 1996).

In 1990, the current benchmark year for assessing carbon dioxide emissions and efforts to reduce them, annual carbon dioxide emissions of the industrialized countries were about 4 billion metric tons (more than 3 tons per capita), including U.S. emissions of about 1.4 billion tons (at 6 tons per capita). In the developing world, releases were about 2 billion tons (at about 0.5 ton per capita). An adequate response to the threat of global climate change will require stabilizing annual global carbon emissions at least 60 percent below current levels. However, under a business-as-usual future, in which no special attention is paid to the threat of climate change, overall annual emissions are likely to *increase* from the current 6 billion tons to about 14 billion tons by 2050, driven by conventional economic development and a near doubling of population. Avoiding this path will require that two trajectories be established and sustained to reach the required global emissions of less than 2.5 billion tons: (1) the industrialized world must reduce its annual carbon dioxide emissions from about 3 tons per capita (for the U.S., 6 tons per capita) to about 0.3 tons per capita; and (2) the industrializing world must be helped to achieve economic growth along a path of low carbon intensity.

Equity considerations aside (such as the existing carbon accumulation owing to historic industrial development, which have nearly saturated the atmosphere's capacity to absorb additional carbon without inducing large-scale climate change; and the current imbalance in per capita emissions among nations), it is essential for climate protection that the industrialized countries take vigorous action to drive down their emissions towards the levels identified above, *whether or not developing countries' emissions grow in the near term*. Indeed, recognition of these facts is implied in the commitment to action by the industrialized world, prior to that of the developing world, in the Berlin Mandate.

The Third Conference of the Parties to the Framework Convention on Climate Change, held in Kyoto in December 1997, was an historic and important, if modest, step towards establishing the deep commitments and institutional and technological momentum needed for climate stabilization. The Kyoto Protocol established a broad structure with elements, whose detailed implementation, relationships with one another, and compatibility with the overarching goals of the Convention, remain to be elaborated. The Protocol embodies near-term binding reduction commitments for the industrialized countries, flexibility mechanisms to allow for economies in meeting these commitments, and opportunities for non-industrialized countries to participate, consistent with their development objectives. At the same time, some of these mechanisms provide potentially problematic loopholes—e.g., unlimited use of such flexibility mechanisms such as trading amongst industrialized countries, joint implementation, and the clean development mechanism—and may require quantitative limits and qualitative constraints to be effective and broadly acceptable on climate protection and sustainable development grounds. For the U.S., the Kyoto Protocol requires a 7% reduction of its carbon dioxide emissions below 1990 levels by the "budget period" 2008-2012, subject to offsets via the various flexibility mechanisms.

The present study, along with parallel studies for the European Union and Japan, has been commissioned by the World Wildlife Fund (WWF) to develop a set of concrete policies and measures for emissions reductions that could realistically approach the AOSIS= proposed 20 percent reduction target by 2005. Although very little time remains to achieve this, especially as current levels of emissions exceed considerably the 1990 benchmark, it is also clear that tremendous potential exists for emissions reductions below projected "business-as-usual" levels. This study has sought to identify policies and measures that: (1) achieve significant carbon emissions reductions quickly; (2) provide overall net economic benefits, owing to the energy-cost savings that are induced, even without considering greenhouse gas, pollution and ancillary benefits; and (3), perhaps most importantly, serve as an effective transitional strategy that builds momentum and establishes a foundation for the much deeper long-term emissions reductions required for climate protection.

Methodology

The analysis reported here builds and expands upon *Energy Innovations: A Prosperous Path to a Clean Environment* (EI 1997), a collaborative effort recently released by the Alliance to Save Energy, American Council for an Energy-Efficient Economy, Natural Resources Defense Council, Tellus Institute, and Union of Concerned Scientists. The aim of *EI* was to formulate and model a set of targeted and complementary policies that would guide the U.S. economy towards lower carbon emissions, and lower cost, less polluting, more secure, and more sustainable ways of producing and using energy. The focus is on carbon dioxide, as it is by far the major greenhouse gas contributing to climate change; while not the direct focus of the policies analyzed here, some other greenhouse gases would be reduced along with carbon, owing to the carbon reduction policies.

The *EI* methodology, which we have adopted and extended for the present study, consisted of translating the selected policies into technical and economic parameters that were then used as inputs to the Energy Information Administration's National Energy Modeling System (NEMS) as the primary analytical tool (EIA 1995). Supplemental analysis was done to compensate for limitations of NEMS, as mentioned in the sections below. Experts on the technologies for the residential, commercial, industrial, transportation and electricity generation sectors reviewed the detailed specifications used in NEMS and refined them as appropriate. This report borrows heavily from the original *EI* study, which was peer-reviewed by many leading U.S. energy analysts.

This analytical approach is based on an integrated model that simultaneously considers the entire set of policies and models the direct impact of each policy along with the interactions among them. As this analytical approach yields results that are comprehensive and integrated, it is necessarily difficult to unambiguously attribute carbon reductions to specific policies or technology measures. Owing to the integrated nature of the analysis, individual measures have impacts that interact with one another, and have non-additive and sequence-dependent effects. In the sectoral descriptions below, we briefly describe the individual policies, give the modeling assumptions into which they translate, and report the resulting carbon reductions as aggregate figures for each sector. To the degree feasible, we also report the separate impacts of individual policies or groups of policies.

The baseline scenario considered in this study is essentially a "business-as-usual" projection, which was derived from the baseline scenario in *EI* by using updated fuel price projections (EIA, 1997). This scenario assumes that there are continued modest improvements in the fuel economy of new vehicles, continued decline in industrial energy intensity, and continued penetration of more efficient equipment in buildings at historical rates. However, the steady increase in demand for energy services more than compensates for these improvements, and by 2005 energy consumption increases 20 percent and carbon emissions 17 percent above 1990 levels, rising further in 2010 to 24 percent and 22 percent, respectively. (For further details regarding the baseline scenario see the respective sections below and *EI*.)

The policy-driven scenario developed in *EI* (called the *Innovation Path* in that report) projects carbon emissions to fall below the 1990 benchmark by 6 percent in 2005 and 10 percent in 2010, both substantially short of the 20 percent reduction target proposed by AOSIS for 2005. However, carbon emissions were projected to continue their decline, reaching the 20 percent reduction level by about 2015, and 45 percent by the 2030 horizon of the study.

It is interesting to note that the policies and measures modeled in the *Innovation Path* are roughly as effective as those developed for the European Union (EU) study commissioned by WWF (Blok, *et al*, 1996) – each achieving a 19 percent reduction in emissions relative to its own baseline scenario projections for 2005. The lower reductions relative to 1990 found in *EI* reflect a quicker growth of baseline emissions in the U.S. than in the EU, due in part to shifts from coal to gas made feasible by the comparable prices of these fuels in the EU.

The present study strengthens, accelerates and adds to the policies identified and analyzed in *Energy Innovations*, to build an augmented policy package that more aggressively captures near-term carbon emissions reductions. The key changes are acceleration of combined-heat- and-power (CHP) in the industrial sector, more rapid penetration of ethanol in blends with gasoline for transportation, and co-firing of biomass in coal-fired electric generation. The enhanced policy package achieves carbon emissions reductions to 10 percent below 1990 levels by 2005 and 22 percent below 1990 levels in 2010.

Policies

The *Climate Protection* scenario developed in this study is an integrated and balanced set of policies that can put the U.S. on a path of technological diffusion and innovation towards an economically and environmentally sustainable future. The sector-specific policies and programs would guide the economy toward more efficient, lower cost, less polluting, more secure, and more sustainable production and consumption of energy. Some of the key policies are:

- *Renewables content standards,* which would require an increasing proportion of renewable resources for electricity and motor fuels, implemented through credit-trading market mechanisms.

- *Pollutant emissions caps,* which would limit SO_2, NO_x, particulates and CO_2 emissions in the electric power sector through allowance trading systems.

- *Biomass co-firing expansion,* which would quickly establish a significant amount of renewable energy in the electricity supply sector without requiring substantial investment in new power plants.

- *An advanced vehicles initiative,* which would introduce stronger fuel economy and emissions standards along with pricing reform, incentives and demand management, to encourage commercialization of clean and efficient vehicles and more environmentally benign travel patterns.

- *Investment tax credits,* which would speed the adoption of modern and energy-efficient technologies for new manufacturing equipment, through an incentive that could be paid for by fees on energy purchases.

- *Research, development and technical support*, to ensure that innovation proceeds at a pace that makes improved energy-efficient and low-carbon technologies available more rapidly.

- *Market transformation incentives,* including technology demonstrations, manufacture incentives, and consumer education, which would reduce transaction costs, help move products from prototype to commercial production, and lower the key hurdles between potential and realized energy savings.

- *Initiatives to accelerate adoption of industrial combined-heat-and-power (CHP),* by refining siting protocols and ensuring market access, to fairly represent its economic and environmental benefits.

- *Appliance and building standards*, which would establish norms for equipment, design and performance that, through purchases and practices, would reduce energy used in providing services in homes and offices.

Details on these and additional policies in the *Climate Protection* scenario are provided in the relevant sections below.

Results

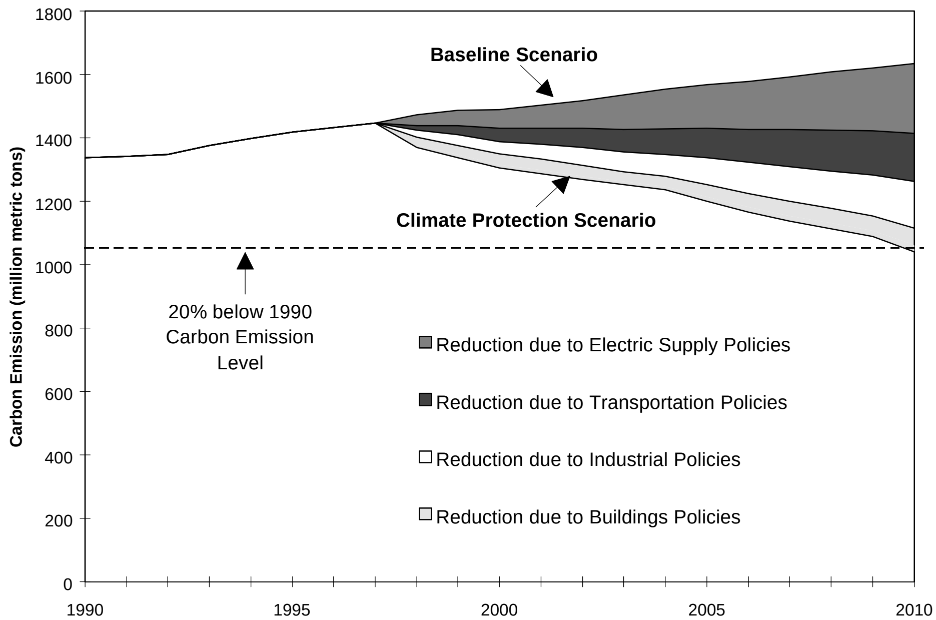
Carbon Reductions

The combined effect of the policies that comprise the *Climate Protection* scenario is a 10 percent carbon reduction in 2005, which still falls short of the AOSIS target. However, reductions reach 22 percent by 2010, with excellent momentum towards deeper long-term reductions.

The carbon emissions of the baseline and *Climate Protection* scenarios are given in Figure 1. This figure reflects the separate and combined impacts of the policies in the demand sectors (i.e., in buildings, industry, and transportation), plus the impacts of policies directed at the electricity supply sector. These policies induce decreases in energy-intensity through more efficient technologies, processes and practices, in addition to decreases in carbon-intensity through shifts to lower carbon energy sources and associated energy conversion facilities. The upper and lower curves give total carbon emissions for the two scenarios, while the shaded regions show the reductions from policies in each sector in succession. For this presentation, we adopt a convention for allocating electric sector emissions reductions that consists of first obtaining the reductions owing to electric supply policies, which decrease the carbon-intensity of electric power generation, and then obtaining the further reductions from demand sector policies, which decrease the amount of power required. The latter reductions are allocated to the demand sectors in proportion to their demand reductions.

Figure 1 shows baseline scenario carbon emissions reaching 1567 million metric tons (MtC) by 2005 and 1634 MtC by 2010, increases of 17 percent and 22 percent, respectively over the 1990 carbon emissions of 1338 MtC. The *Climate Protection* scenario projects carbon emissions that decrease to 1200 MtC in 2005 and 1041 MtC in 2010, reductions of 10 percent and 22 percent, respectively below 1990 emissions.

Figure 1. Carbon emissions versus time for the baseline scenario and *Climate Protection* scenario, showing the carbon reductions disaggregated by sector.

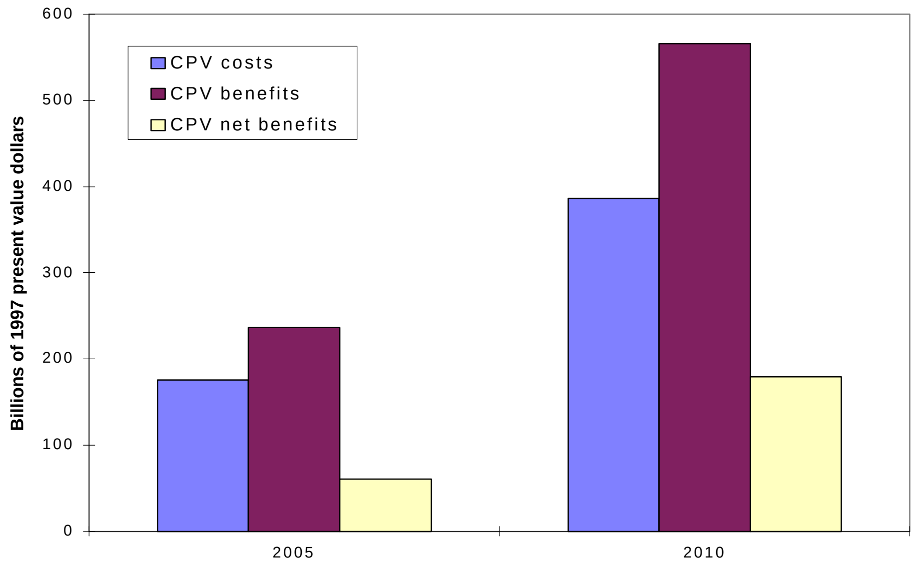


Economic Costs and Benefits

On balance, the set of policies of the *Climate Protection* are estimated to be cost-effective by a significant margin, based on cautious assumptions. This is shown in Figure 2, which provides cumulative discounted (present value) of costs, savings and net benefits through 2005 and 2010. Cumulative present value net benefits are about $60 billion through 2005 and about $180 billion through 2010 (in 1997 dollars and discounted to 1997). This magnitude of net economic benefits could be taken as leeway for yet more aggressive carbon reduction measures that have net incremental costs. The aggressive set of measures embodied in the *Climate Protection* scenario result in marginal costs of saved carbon-dioxide as high as $90 per ton (1997$) in certain years. Relaxing the reduction target for 2005, while increasing the reductions in 2010, could reduce this marginal cost and still maintain the large net economic benefits.

Identifying realistic additional measures at a reasonable cost in the time-frame of this study is difficult; further improvements in efficiency and greater reliance on alternative energy sources before 2005 are constrained by the slow capital stock turnover in the four sectors. Rather than implementing more aggressive measures that might incur substantial cost, an effective longer-term strategy would involve implementing and sustaining the policies discussed here (or variations upon them) while committing substantial resources to R&D for broad classes of promising technologies that can provide the basis for the deeper long-term carbon emissions reductions needed to prevent global warming.

Figure 2. Cumulative present value of economy-wide net benefits of the *Climate Protection* scenario.



The details of the policies, modeling assumptions, and results for each sector are given in the following sections.

II. Industry Sector

Background

The industry sector has realized ongoing declines in overall energy-intensity throughout the post-World War II period, reflected in a 1 percent/yr average improvement rate until the energy crises of the 1970s and a brief period of accelerated improvement (2.5 percent/yr) thereafter. This trend is in part attributable to improvements in the energy efficiency of production processes and equipment, due to technological innovation, which can be expected to continue into the foreseeable future. This decline is also due to changes in the goods that industry produces. The latter trend reflects a dematerialization of manufactured products in which less physical material is required to produce a product that serves a given function; this, in turn, often reduces energy requirements.

Advances continue at a slower pace now, since many of the efficiency measures with the highest rates of return have already been exploited and further investments are more difficult to justify economically in the current climate of low or declining energy prices. Nonetheless, evidence points to great technological and economic potential for further energy-efficiency improvements throughout the sector (Elliot 1994; 1997; Worrel *et al.* 1995; 1997).

The policy approach taken in this study recognizes the importance of technological innovation and dematerialization, and aims to foster both in ways that lead to increased energy-efficiency. In addition, measures are outlined for reducing barriers to the development of the largely unexploited potential for cogeneration of heat and power (CHP), made more attractive by recent technological advances.

Policies and Measures for Reducing Carbon Emissions in the Industry Sector

The policy modeling was carried out using the Long-Term Industrial Energy Forecasting Model (Ross *et al*. 1993), which was developed based on an analysis of energy-intensities and prices in thirteen industrial subsectors that provided empirical conservation supply curves. LIEF uses electricity and fuel prices to estimate the economically acceptable energy efficiency potential, and thereby determines penetration of efficiency measures based on behavior that characterizes the industrial sub-sectors. In the present study LIEF was benchmarked to the NEMS baseline projections of industrial activity and fuel use, and some of its "policy-lever" input options (such as discount rate and cost of capital equipment) were used to model specific policies.

The following four sets of policy recommendations were identified for obtaining carbon reductions in the industry sector, primarily through increased process energy-efficiency.

(1) *Implement a capital investment incentive.* As a general rule, more modern plant technology is more energy-efficient and environmentally clean, provided there exists a climate of reasonably alert environmental regulation. The rate at which technological innovation diffuses into industries depends in part on industries' ability to obtain modern production equipment and retire or upgrade old facilities that rely on outmoded processes and technologies. We recommend tax incentives for new capital investments, to help accelerate this process.

An investment tax credit of reasonable scale could be funded with a CO_2 tax levied on energy consumed by the industries. This policy would not reduce federal revenues if each firm=s investment tax incentive were to be capped at its energy tax liability. Because small- and medium-sized companies have poorer access to financial resources than larger companies, they could be assisted through loans, loan-guarantees, and interest-rate subsidies that would increase their access to capital.

This investment incentive policy was modeled by reducing the effective capital cost of new investments by 10 percent to reflect a capital investment tax credit. In addition, the discount rate applied to industrial decision-making regarding energy-efficiency measures is assumed to decrease to a level common for efficiency investments among more technologically aggressive companies. This reflects a change in corporate behavior that might result from the increased exposure to successful industrial efficiency investments and the decreased perception of risk associated with government-supported investments. Together these changes are reflected in a reduction of the effective discount rate in the LIEF model from 24.2 percent to 16 percent, or a capital recovery factor from 27.3 percent to 20.7 percent for a measure with a ten-year lifetime. The reduced capital costs and discount rate extend the frontier of economically justified efficiency investments considered in the LIEF model, and results in an accelerated decline in energy-intensity for each of the industrial sub-sectors.

(2) *Significantly expand public and private investments in RD&D.* There is a broad consensus among economists that innovation is the dominant source of long-term economic growth, with returns on R&D investments several times higher than returns from other investments. Recently, however, commitments to RD&D have diminished and funds for both federal and industrial programs have declined (Eisenhauer 1996), particularly in the energy sector (Williams 1995). Many corporations are now closing research laboratories and focusing on more near-term activities, as part of their cost-cutting initiatives. In a business climate where corporate decisions are driven by short-term profits, companies tend to underinvest in R&D because it is difficult for a firm to exclusively reap the benefits of its R&D efforts (Cohen & Noll 1991); those benefits might well be realized by competitors, or might constitute public goods (for example, a cleaner environment) that do not contribute to the firm's near-term profitability.

We recommend expanded support for RD&D at all stages of technology development and implementation. The public sector should reverse the trend of declining R&D spending and revitalize support for long-term research. This would not require a particularly painful commitment of public funds. For example, enough additional revenue to triple the budget for renewables and conservation R&D by OECD governments above the 1994 level could be raised through a tax on fossil fuel use of about 20 cents per ton of CO_2, a trivially small carbon tax that would raise the cost of energy for the average U.S. consumer by about 0.2 percent and amount to less than $5 per capita per year (Reddy *et al.* 1997).

Industry should also be motivated to increase its spending on RD&D, through tax incentives for these expenditures and cooperation with government research. Commercialization of technological advances can be accelerated through demonstrations, training, and technical support. Government can work with the private sector to create technology centers, provide technical assistance, and aid in implementation, particularly for small- and medium-sized companies that do not have the resources to identify and implement energy-efficiency opportunities. A fundamental requirement for effective RD&D is the existence of a trained pool of scientists, engineers, and technicians. It is vital that the U.S. educational system be capable of training those people upon whom future innovation relies.

In this analysis, RD&D policies were assumed to have the near- to mid-term impact of accelerating investment in efficient technologies by lowering their cost. These policies were modeled by assuming a capital cost reduction of about 10 percent in the LIEF model analysis.

(3) Promote increased availability and use of recycled feedstocks. The potential for reducing energy consumption, preserving resources, and reducing costs through materials recycling has been well documented (Hershkowitz, A 1997; Elliot 1994a; Williams, Larson & Ross 1987). Since a significant portion of the energy consumption and cost of using materials goes into feedstock separation and purification, for a recycled feedstock to maintain its value it must be kept clean, i.e., segregated by type and kept clean of foreign materials. An effective recycling system needs to produce quality feedstocks that can be efficiently used by manufacturers.

The analysis of policies to increase the use of recycled feedstock is based on estimates of current recycled content levels for the primary materials of interest and projections of achievable targets for 2010 (Elliot 1994a). Based on these estimates, an annual rate of increase in recycled content and a corresponding decrease in energy intensity was projected for steel, aluminum, glass, plastic resins, and paper.

(4) Remove barriers to combined heat and power (CHP) generation. The dramatic energy-efficiency benefits of CHP have long been recognized. A significant quantity of CHP-based power is already generated in the U.S., especially in the paper and pulp industry, partially as a result of the Public Utilities Regulatory Policy Act (PURPA) of 1978 that enabled independent power producers to generate electricity for the grid. Ongoing technological developments, especially in advanced gas turbine technology, have increased the technological and economic viability of CHP. With CHP systems becoming available at higher efficiencies, lower capital cost, and smaller scales, the total potential for CHP to contribute to grid supply has grown significantly. CHP systems can now be cost-effective at turbine sizes down to 500 kW and reciprocating engine sizes down to 50 kW. However, at present the potential for CHP is largely unexploited because significant barriers discourage its adoption by industries.

Despite PURPA, potential CHP-based power facilities still face uncertain economic relationships with utilities and the transmission grid. Because of this barrier, industries predominantly use CHP to meet internal electricity demand, which can fall well below their potential generating capacity based on the size of their heat demand or the availability of on-site feedstocks such as biomass wastes. Impending utility restructuring will affect the access of CHP-based power producers to the grid for both sales and back-up power, and could, in theory, lower barriers to the adoption of CHP. Utility restructuring programs should include provisions that facilitate the expansion of CHP, for example by ensuring full access to the electricity market. New players and roles could emerge, such as third-party power producers that manage on-site CHP facilities and conventional industries (such as the pulp and paper industry) providing electricity to the grid (Nilsson et al., 1996). Initiatives in Europe are having success at advancing the role of CHP in industry (Blok and Farla, 1996).

An additional barrier to small CHP installations is the costs and constraints of the current environmental permitting process. Permitting does not vary significantly with system capacity, so it can become a dominant cost component for smaller systems and a prohibitive barrier to implementation. Small CHP projects would be easier and more economical if the permitting process were redesigned. One improvement would be instituting a mechanism for advance certification of the emissions performance of small-scale integrated CHP designs as we do now with automobiles and appliances. Environmental certification should take account of the system-wide efficiency and emissions gains from CHP, which displaces grid-based electric generation.

Policies that reduce barriers to industrial CHP are modeled by assuming a greater rate of penetration of CHP than has occurred historically. The analysis assumes that 5 percent of industrial fossil-fueled boilers are replaced by 2005, and 20 percent by 2010, with advanced natural gas CHP systems having an electric efficiency averaging 33 percent and a steam efficiency averaging 52 percent, at an incremental capital cost of $900 per kWe (1997$). The additional electric power supplied on-site is 44 TWh in 2005 and 176 TWh in 2010. An additional 19 TWh in 2005, and 75 TWh in 2010, would be realized in the paper and pulp industry, using natural gas and black liquor process residue. While the amount of fuel used on-site would increase (about 0.17 Quads in 2005 and 0.67 Quads in 2010), we have assumed that it would shift from a mix of oil, gas, and coal to gas and biomass (in the paper and pulp industry), therefore resulting in little net on-site carbon emissions change overall across the sector.

Analysis using the NEMS model of this net change in industrial electricity demand (plus avoided transmission losses of about 6 percent) projects that it would displace a combination of existing coal and new natural gas generation from the grid, with displaced carbon emissions ranging from about 0.10 to 0.27 MtC/TWh. Our analysis finds 0.16 MtC/TWh; thus, carbon emissions would be reduced by about 12 MtC in 2005 and 40 MtC in 2010. Given the incremental costs and fuel savings, these carbon reductions would likely be realized at net economic savings.

Results

In contrast to the baseline scenario, which projects a 0.8 percent/yr decline in energy, the *Climate Protection* scenario projects a decline of approximately 2.2 percent/yr due to the combined impact of the policies discussed above. In the baseline scenario, end-use energy consumption increases above 1990 levels by 20 percent by 2005 and 26 percent by 2010, and carbon emissions increase over 1990 levels by 16 percent in 2005 and 21 percent by 2010. In the *Climate Protection* scenario, end-use energy consumption decreases by about 3.3 quads, 11 percent below the baseline scenario in 2005, and about 5.6 Quads, 18 percent below in 2010. Carbon emissions decrease by about 13 percent below 1990 levels by 2005, and 28 percent by 2010. These results include the direct energy and carbon emissions impacts in the four industrial sector policies, as well as indirect impacts from reduced energy use in refineries owing to the lower demand for refined petroleum products for industrial processes, transportation and electricity generation in the *Climate Protection* scenario.

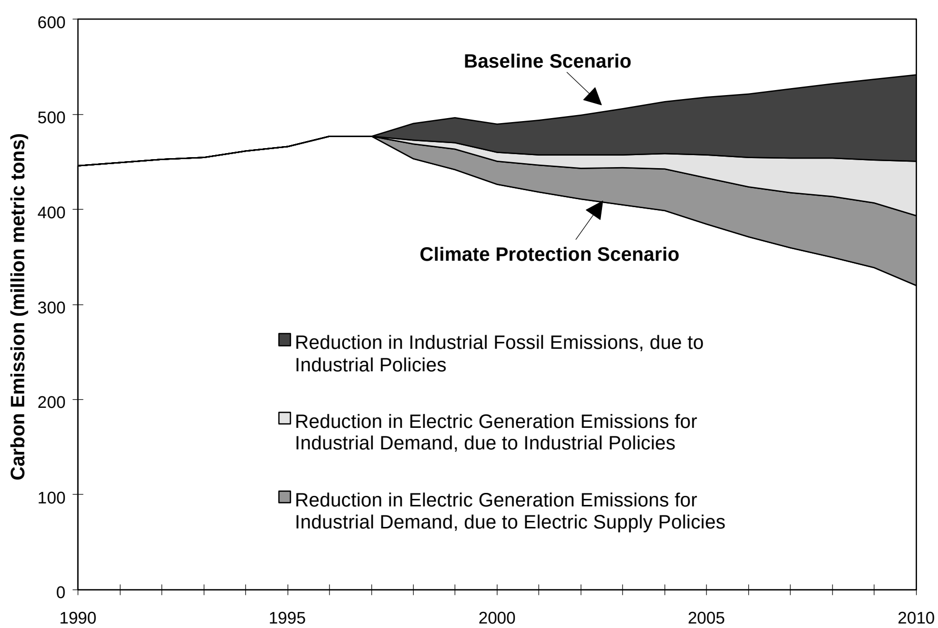
Table 1 shows the contributions from each of the four policies to fuel saving (totaling 6.5 percent and 9.4 percent in 2005 and 2010, respectively) and electricity savings (totaling 13.2 percent and 32.5 percent in 2005 and 2010, respectively) relative to their baselines. This includes energy savings in refineries due to the decrease in oil demand in more efficient industrial processes. Savings in refineries due to the decrease in oil demand in the transportation, buildings, and electricity sectors are not included in Table 1; these provide an additional 4.2 percent reduction in fossil fuel use in 2005 and 6.2 percent in 2010, and cause carbon reductions that are credited to the policies in those other sectors.

Table 1: Reductions in energy demand in the industry sector resulting from each policy.

	2005		2010	
	Fossil	**electricity**	**fossil**	**Electricity**
Investment incentive	5.1 %	5.7 %	8.5 %	9.2 %
Accelerated R&D	1.6 %	1.7 %	2.4 %	2.7 %
CHP	-0.6 %	5.3 %	-2.3 %	20.0 %
Recycling	0.3 %	0.5 %	0.6 %	0.6 %
Total	**6.5 %**	**13.2 %**	**9.4 %**	**32.5 %**

Figure 3 gives the industry sector carbon emissions for the baseline and *Climate Protection* scenarios, shown as the upper and lower boundary curves. The carbon emissions curves for the two scenarios include the industry sector's carbon emissions from on-site fossil fuel combustion as well as off-site carbon emissions due to the generation of electric power to meet the sector's electricity demand. The shaded regions separating the two curves reflect (1) the reductions of on-site carbon emissions due to industry sector policies that reduce its fossil fuel use, (2) the reductions of off-site emissions due to industrial sector policies that reduce its electricity demand, and (3) the reduction of off-site emissions due to electric sector policies that reduce the carbon-intensity of electric generation, a portion of which satisfies industrial sector electricity demand. It should be noted that the refinery savings owing to reductions in oil consumption in the buildings, transportation and electric sectors are also contained in the industrial fossil emission reductions.

Figure 3: Carbon emissions in the industrial sector for the baseline scenario and *Climate Protection* scenario, showing reductions resulting from industrial sector policies that affect fossil consumption and electricity consumption, and electric sector policies.



III. Residential and Commercial Buildings Sector

Background

Impressive improvements in energy efficiency in residential and commercial buildings have been achieved since the energy crises of the 1970s. While the use of energy-intensive services such as air-conditioning increased, energy use per household declined by about 19 percent between 1973 and 1991 (Pierce 1994). During this period, energy-conserving equipment and measures for improving the thermal integrity of buildings were developed and adopted, including compact fluorescent lights and efficient lighting ballasts, efficient refrigerators, passive cooling, and windows with good lighting and insulation characteristics.

Yet the adoption of energy-efficiency measures remains far below the cost-effective potential, because of substantial barriers to adoption (Levine *et al.* 1994). Barriers include lack of information, high transaction costs, high discount rates, limited market choice, externalized costs, a tax structure that favors energy expenses over capital investments, and landlord-tenant relationships that discourage investments in greater energy efficiency. Moreover, the current political climate is especially inhospitable toward continued public sector investment in energy efficiency. Cutbacks in government funding are threatening R&D and implementation programs that have historically enabled energy consumers to realize savings that are far greater than the public sector outlays required to support those programs (Geller and McGaraghan 1996).

One prominent exception to declining consumption across end-uses is in the rapid growth of office equipment. Addressing the rise in energy consumption of office equipment deserves special attention. There are signs that the Energy Star program is seeing success, and that the present NEMS model might overestimate the rate of growth.

Policies and Measures for Reducing Carbon Emissions in Buildings

The following policies aim to reduce carbon emissions from the buildings sector through the continued development of new energy-efficient technologies and practices, relying not only on public sector involvement in R&D but also private sector involvement inspired by commercial opportunities. Policies that facilitate R&D are complemented by policies that ensure a continued market pull for new and existing energy-efficiency products.

(1) Maintain and expand RD&D for energy efficiency and monitoring of energy use.

Government-sponsored research has played a central role in developing, demonstrating and supporting the early marketing of some key energy-efficient technologies, such as efficient windows, refrigeration systems, and electronic ballasts. Together, these three technologies, which cost about $24 million to develop, now provide $1.5 billion dollars per year in energy savings (Geller and McGaraghan 1996). Current funding for energy efficiency research programs is about one-tenth of one percent of the total U.S. energy bill of more than $500 billion per year (Mills *et al* 1995). At a minimum, the Congress should restore funds that have been cut in recent years, if necessary paying for them through cuts in fossil fuel and nuclear energy research programs.

(2) Update standards for appliances and equipment.

Existing standards were adopted through the National Appliance Energy Conservation Act of 1987 (NAECA), which imposed efficiency standards on manufacturers of refrigerators, air conditioners, water heaters, furnaces, dishwashers, clothes washers and dryers, heating equipment, kitchen ranges and ovens, pool heaters and other minor products, and the Energy Policy Act of 1992, which extended standards to lamps, office equipment, electric motors, plumbing products, and distributional transformers. These standards have proven to be cost-effective, already conserving roughly 2.5 Quads of energy and expected to save consumers $132 billion in the long run (Geller 1995). However, these standards are years behind schedule, and many of them established five to ten years ago should be updated. Stringent yet cost-effective new standards could reduce primary energy consumption by 1.3 Quads annually by 2015 (Nadel and Goldstein 1996).

(3) Develop and promulgate energy efficiency buildings codes.

States, counties, and municipalities should be required by federal law to meet or exceed the model standards for residential and commercial buildings. Government officials and engineers should regularly update and improve building energy standards so that they maximize the cost-effective energy saving potential of evolving building technologies, designs and materials.

States that have already implemented state-of-the-art building codes can vastly improve enforcement and compliance (Vine 1996). For example, codes can be revised to make them easier to understand and follow; utilities can expand and improve their existing new construction programs to expedite code compliance; and utilities, code enforcement authorities, and professional organizations can cooperate to better train building contractors in code compliance.

(4) Catalyze voluntary adoption of efficiency measures.

The U.S. Environmental Protection Agency (EPA) has coordinated a set of energy-efficiency programs aimed reducing market barriers. The programs offer technical assistance and/or Agreen@ certification in return for participation in a number of initiatives, including programs to install lighting retrofits (the Green Lights program), to construct or retrofit efficient homes and buildings (the Energy Star Homes and Buildings programs), and to develop efficient computers, monitors, printers and other equipment (the Energy Star Office

Equipment program). The administrative costs of these programs is trivial relative to the overall net savings that they realize through the efficiency measures. As this experience amply demonstrates that government can effectively catalyze successful voluntary measures, such programs should be thoughtfully expanded in scope and adequately funded.

(5) Stimulate market entry of new energy-efficient products.

Utilities and energy conservation groups have organized and sponsored successful programs that encourage manufacturers to develop more efficient products and introduce them into the market. For example, in response to a $30 million incentive provided by a consortium of utilities, one appliance manufacturer designed and commercialized a refrigerator that is about 30 percent more efficient than the 1993 standards, and subsequently introduced yet more efficient models (Levine *et al* 1994). Not only did this refrigerator design result directly in energy savings through its adoption, but it also led to the further strengthening of efficiency standards for refrigerators in early 1997.

(6) Expand information and outreach efforts.

While information programs alone rarely suffice to spur businesses and residential consumers into energy-efficiency purchases, they can be very effective when coupled with regulatory measures and market-based incentives. For example, the Texas LoanSTAR program provides technical recommendations for retrofits in state buildings, offers project financing, and monitors project effectiveness. Similar information and financing programs have been implemented for commercial businesses and the public sector by a number of states and utilities. Programs can be targeted at the residential market, such as the Consumer Home Energy Efficiency Rating System, which deploys a certified inspector to rate homes and provide retrofit recommendations that include economic details and energy-savings estimates. Financing the recommended retrofits is made much easier if the required investments can be added to the homeowner=s mortgage.

Other types of information program, such as rating systems and labels for windows and roofing materials, can help overcome the barrier of insufficient knowledge about energy-efficient products. Labeling systems should be expanded beyond the states where they are now mandatory, and should encompass a greater range of products.

(7) Preserve utility planning and energy management programs.

Electric utility integrated resource planning (IRP) and demand-side management (DSM) programs are responsible for a substantial fraction of the energy efficiency improvements already realized in the buildings sector. When public utility commissions began to allow utilities to recover the costs of lost energy sales and administrative overhead from energy efficiency programs, utilities were able to profit from successful energy-efficiency programs, ranging from rebates for purchasers of efficient lightbulbs and air conditioners, to efficient design services provided by utilities to architects, builders, and consumers (Rosenfeld *et al.*,1995).

However, movement toward electric utility restructuring in several states has motivated utilities to reduce DSM program funding dramatically. In California, for example, funds for utility DSM programs fell almost 40 percent between 1994 and 1995. It is clear that in a purely price-driven market for energy, particularly under retail competition, a number of DSM programs would simply disappear. As electric utility restructuring is carried out, mechanisms should be implemented for ensuring that these services are preserved (such as the systems benefits charge, discussed later).

(8) Expand government procurement of energy-efficient technologies.

Because government procurement accounts for so large a volume of purchases of energy-using products, government can provide a substantial market pull and accelerate the market penetration of energy-efficient products. The federal government buys $70 billion in supplies each year, of which $10 to $20 billion are energy-using products. Including state and local governments, the purchasing power is about three to four times higher (Casey-McCabe & Harris 1994). In addition, the federal government can also expand its support for the Federal Energy Management Program and accelerate its efforts to make the federal building stock as energy-efficient as possible.

A promising policy area not modeled in the present exercise is promotion of district energy systems using cogeneration to provide steam, hot water or chilled water, along with electricity, to meet district energy needs. If regulatory, institutional, economic and infrastructural requirements are met, net carbon reduction reductions can be effected. Spurr (1996) estimates that about 9 MtC could be realized by 2010.

The modeling of these policies for the buildings sector was conducted using the NEMS residential and commercial demand modules, which use engineering-economic analysis based on a range of end-use technology options, each of which has a corresponding efficiency, cost, first and last year of availability, and average lifetime. Each technology has a discount rate, or hurdle rate, associated with it, which determines its lifecycle economic attractiveness compared to other technologies for the same end-use. The NEMS residential and commercial modules are founded on a model of consumer decision-making in which the hurdle rates are purported to encompass a wide range of phenomena reflecting consumer choice. While such hurdle rates arguably reflect past consumer energy decisions, they need not be extrapolated into the future, particularly in the context of aggressive and sustained energy and climate policy.

In the *Climate Protection* scenario, we model impact of market transformation policies, which are intended to affect consumer adoption of efficiency measures by shifting the spectrum of hurdle rates downward. We assumed that the hurdle rate for technologies in the residential sector is 20 percent, while in the commercial sector one-third of consumers make decisions using a 33 percent rate, one-third using a 13 percent rate, and one-third using a 5 percent rate. The administrative costs of the policies is estimated as a 10 percent adder on the investment costs for efficiency measures. Energy-efficient technologies are assumed to be available one year earlier in the *Climate Protection* scenario than the baseline scenario, as a result of accelerated advances through R&D.

Results

In the baseline scenario, combined fuel and electricity use in buildings is projected to grow approximately 11 percent by 2005 and 14 percent by 2010, with carbon emissions following the same trajectory. The *Climate Protection* policies are projected to lead to a reduction of energy consumption in buildings below the baseline projections by 10 percent in 2005 and 15 percent in 2010, with roughly one-third of this reduction in residential buildings and two-thirds in commercial buildings. Carbon emissions relative to 1990 decline by 20 percent by 2005, and 33 percent in 2010, almost all from reduced electricity demand. The greatest gains are due to technological innovations in water heating, cooling, lighting, and especially space heating, which alone accounts for half of total end-use energy savings in both 2005 and 2010.

Figure 4 gives the buildings sector carbon emissions for the baseline and *Climate Protection* scenarios, shown as the upper and lower boundary curves. The carbon emissions curves for the two scenarios include the building sector's on-site carbon emissions from fossil fuel combustion as well as off-site carbon emissions due to the generation of electric power to meet the sector's electricity demand. The shaded regions separating the two curves reflect (1) the reductions of on-site carbon emissions due to buildings sector policies that reduce its fossil fuel use, (2) the reductions of off-site emissions due to building sector policies that reduce its electric power demand, and (3) the reduction of off-site emissions due to electric sector policies that reduce the carbon-intensity of electric power generation, a portion of which satisfies buildings sector electricity demand.

Figure 4: Carbon emissions in the buildings sector for the baseline scenario and *Climate Protection* scenario, showing reductions resulting from buildings sector policies that affect fossil consumption and electricity consumption, and electric sector policies.

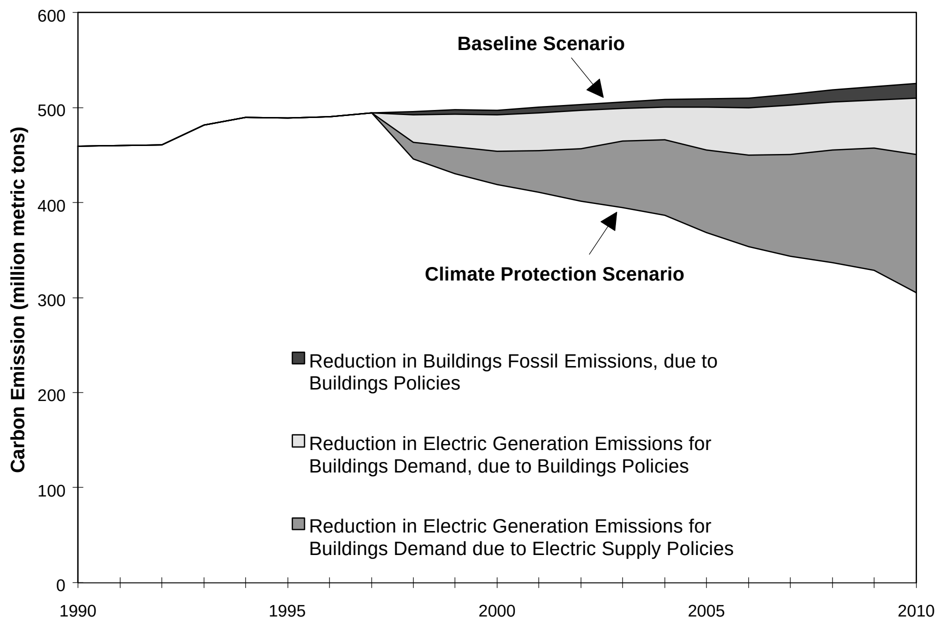
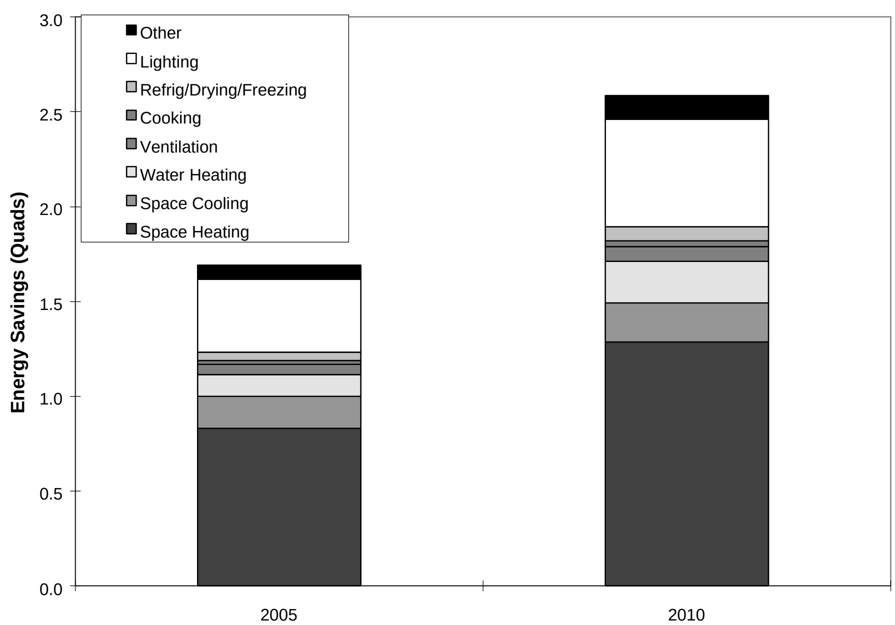


Figure 5. Breakdown of delivered energy savings by end-use in the buildings sector. Notice the significant contributions of water heating, cooling, lighting and especially space heating.



IV. Transport Sector

Background

Before 1973, transportation energy use grew in step with population and economic activity. That link was severed following the energy crises of the mid- and late 1970s, as consumers responded to high and volatile fuel prices and policies such as fuel economy standards were implemented. Thus, from 1972 to 1992, growth in transportation energy use averaged only 1.1 percent per year, well below the 2.7 percent average annual economic growth. Since 1992, however, transportation energy use is again growing rapidly, propelled in part by a growing proportion of heavier and more powerful vehicles on the road, faster travel speeds, and rapidly expanding air travel.

Fuel taxes are unlikely by themselves to be an effective means of adequately lowering energy consumption, as the price-elasticity of fuel demand is low, and the income-elasticity is generally much higher. Thus fuel price changes would have to be very high to induce energy savings that are great enough to compensate for the expected increases in demand for transport services. Significant progress can be made, however, when pricing mechanisms are used in conjunction with strategies that help introduce dramatically improved vehicle and fuel technologies to the market, and that focus on structural changes in land-use planning and infrastructure investments. Thus, fuel taxes can help provide revenue for funding policies that advance transportation technology and for investments in infrastructure associated with innovative changes in land-use. The availability of convenient alternatives to single occupancy vehicles could stimulate mode shifts directly and also amplify the elasticity effects of pricing reform.

Policies and Measures for Reducing Carbon Emissions in the Transport Sector

The policies that are considered in the *Climate Protection* scenario are organized thematically into the six sets described below. Although their focus is to reduce carbon emissions, they can have other benefits such as reduced local air pollution, diminished acid precipitation, enhanced energy security, and improved health and safety, which could be enhanced by complementary policies that directly address these concerns.

(1) Promote advanced light-duty vehicle (LDV) technologies.

There are tremendous opportunities to improve the fuel economy of passenger vehicles (DeCicco and Ross 1996), ranging from minor design changes in conventional vehicles to the development of radically different propulsion technologies such as hybrid-electric (DeCicco and Lynd 1997) or fuel cell drive trains (Mark 1997). The recommended policy approach is to couple supply-side initiatives aimed at developing advanced transport technologies with demand-side efforts to accelerate the commercialization of those technologies.

- Make substantial commitments to R&D to strengthen the technological basis for advances in vehicle design and construction. These investments should be directed toward technological goals whose implementation horizons range from the near-term (advances in emissions monitoring and control, improvements to conventional vehicles such as reduced-drag designs, etc.) to the long-term (explorations of next-generation vehicle technologies). Federal and state efforts to realize R&D goals should be better coordinated.

- Progressively strengthen the Corporate Average Fuel Economy (CAFE) standards to induce automobile manufacturers to incorporate efficiency improvements into their product lines and, thereby, effect ongoing increases in new fleet fuel economy. In the *Climate Protection* scenario, CAFE standards are increased by 1.5 mpg/yr from 1998 to 2010, consistent with exploiting all currently cost-effective vehicle efficiency measures (DeCicco and Ross 1996). In contrast, the baseline scenario projects increases averaging roughly 0.3 mpg/yr. Although the strengthened standards lead to a fuel economy of 45 mpg for new light duty vehicles by 2010, the actual fleet fuel economy would climb to only 27 mpg by that year, owing to the time lag associated with stock turnover.

- Implement a revenue-neutral fee and rebate system for vehicle purchases at federal and state levels, to provide incentives for selling cleaner and more efficient vehicles that are funded by penalties for poor performers. Such a Afeebate@ system, which would help establish a market for vehicles with improved environmental performance, would be pinned to the evolving CAFE standards. A market introduction program for clean, efficient vehicles should be established, whereby government and interested private entities would commit to purchase vehicles with above average efficiency and emissions performance.

(2) Improve environmental performance of freight trucking.

- Maintain and expand the government and industry R&D investment in near-term improvements and advanced vehicles. The *Climate Protection* scenario analysis assumes an efficiency improvement of 0.9 percent/yr for freight truck stock, whereas efficiency in baseline scenario improves at 0.5 percent/yr.

- Help move technological advances to the market, through measures that support demonstrations and recognize users of improved vehicles (i.e., extending the EPA=s Energy Star program to commercial shipping firms). Such activities should be complemented by regulatory measures, including strengthened standards for efficiency and emissions, and financial instruments, such as fuel taxes and user-fees calibrated to eliminate the existing subsidies for freight trucking (FHWA 1982).

(3) Improve the efficiency of intercity travel and intermodal transport.

The global warming impacts of air travel--the most rapidly growing transportation mode--are greater than its 9 percent share of transport sector GHG emissions because emissions at cruising altitudes have many times the radiative forcing effect of emissions at ground level. Limiting the total amount and impact of air travel should be a critical element of climate protection policy for the transport sector. An effective policy would aim to increase the convenience and efficiency of movement by rail as an alternative to energy-intensive long distance road and air transport for passengers and freight.

- Provide R&D and commercialization incentives so as to realize the substantial potential for ongoing efficiency improvements in aircraft (Greene 1997) and trains (Cataldi 1997). In the *Climate Protection* scenario, jet aircraft efficiency is assumed to increase 58 percent by 2010, compared to 14 percent in the baseline scenario, from both increases in fuel economy (2.8 percent/yr) and improved load factor. Rail energy-intensity is assumed to decline by 1.4 percent/yr (half the rate experienced from 1972 to 1992), compared to a baseline decline of 0.3 percent/yr. Water and pipeline freight energy-intensity are assumed to improve at 0.6 percent/yr, whereas the baseline improvement is 0.06 percent/yr (EIA 1991).

- Re-evaluate the existing government policies that promote the expansion of air travel through public investments, subsidies, operations of airports and air traffic control, and publicly supported R&D. An Aintegrated resource planning@ approach, which internalizes environmental and social costs and considers alternatives to air travel for long-distance passenger and freight transport, should be adopted for the design, expansion and investments in transportation infrastructure (NRC 1996; OTA 1994). High-speed rail offers an attractive option in many regions and may be competitive with air travel (in both energy cost and travel time) at distances roughly 600 miles or less, which account for about one-third of domestic air passenger miles traveled. A wide effort to invest in rail facilities for appropriate inter-city routes could use public funds to leverage larger private investments. The capacity of rail to contribute to passenger and freight transport would be greatly increased if the efficiency of intermodal transport is taken into consideration when infrastructure investments are planned (STPP 1995). In the *Climate Protection* scenario, we assume that 2.5 percent of air passenger travel projected for 2005 in the baseline would shift to rail, growing to 5 percent by 2010. Freight ton-miles are assumed to shift from truck to rail at a rate 10 percent greater than the baseline rate.

(4) Develop and commercialize renewable alternatives to petroleum-based fuels.

Fuels that can economically offer measurable efficiency and emissions benefits using current vehicle technology can play important roles in the near term, and could contribute to an effective transition toward a transportation system based on next-generation vehicle technology and a very low-carbon fuel cycle. For example, the expanded use of alcohols in today=s combustion engines can provide carbon emissions benefits, provided the alcohol is supplied via an efficient process that relies on few fossil fuel inputs (in contrast to today=s commercial processes for producing methanol from natural gas and ethanol from corn). But, perhaps more importantly from the standpoint of achieving deep long-term carbon reductions, it would initiate development of an infrastructure for a fuel that is well-suited for use in next-generation vehicles based on high-efficiency hybrid-electric or fuel cell drive trains.

Once advanced vehicles are widely commercialized, fuel strategies that are not economically viable based on today=s vehicles could prove attractive. For example, if highly efficient fuel cell vehicles that place a high market value on hydrogen are deployed, an infrastructure could be established for producing hydrogen from fossil fuels and sequestering the carbon dioxide by-product in depleted oil fields, natural gas fields, or deep saline aquifers. This strategy has been identified as a way to use fossil fuels without carbon emissions at incremental costs that are much lower than would be the case if the carbon were sequestered after the costly process of separating it from fossil fuel power plant flue gases. (Blok 1997; Kaarstad and Audus 1997; Williams 1996). This might be an effective strategy for allowing fossil fuels to contribute to energy supplies in a greenhouse-constrained world.

- Expand R&D commitments to low-GHG fuels production, distribution, storage, and utilization technologies. An alternative fuels R&D program must be closely integrated with the aforementioned R&D efforts to advance vehicle technologies, and must be similarly unprejudiced in allowing a winner to emerge from the various options.

- Implement commercialization incentives for low-GHG alternative fuels, alternative fuel vehicles, and supporting infrastructure. Early markets such as vehicle fleets are a natural domain for such incentives.

- Restrict the carbon intensity of the motor fuels market by imposing a full fuel cycle GHG emissions standard or a carbon cap with tradable emissions permits. By themselves, R&D, fleet programs, and marginal pricing changes are unlikely to substantially lower the transition barriers faced by new fuels technologies. A carbon cap, however, could be an effective tool for stimulating investment in infrastructure for new fuels that would otherwise be hard-pressed to compete with incumbent petroleum-based fuels.

The renewable fuels policy considered here is ambitious but is formulated to remain flexible with respect to choice of alternative fuel. We have chosen to model the impacts of this policy in the *Climate Protection* scenario by assuming the standard would be met by ethanol produced from cellulosic feedstocks. Ethanol produced from cellulosic feedstocks has excellent long-term prospects to become competitive with gasoline (DeCicco and Lynd 1996), offers significant GHG benefits, and can comprise a large renewable fuel resource that is compatible with advanced vehicles.

We have modeled a carbon emissions standard or carbon cap that corresponds to displacing the gasoline consumed in light and heavy duty vehicles by an amount that rises to 4.4 percent in 2005 and 10.3 percent in

2010 (on an energy content basis), displacing 0.56 quads of oil in 2005 and 1.2 quads in 2010. The biomass feedstock required for ethanol production in 2010 is approximately 2.9 Quads, or 170 million dry tons. We assume that ethanol is introduced in gasoline blends and calculate the carbon reductions based on the difference between full fuel cycle carbon emissions from cellulosic ethanol and gasoline. We also account for electricity in excess of plant power requirements generated at a rate given by the base case technology in Lynd *et al.* (1996) -- 2.2 kWh per gallon of ethanol. Casten, *et al* (1997) have investigated an advanced ethanol process using a much more efficient power cycle that could quadruple the amount of exported electricity without increasing the cost of ethanol. This could eventually make it possible for cellulosic ethanol technology to simultaneously make a significant contribution to electricity supply and transport fuel supply.

The cost incurred by this policy arises from the difference in price of gasoline and ethanol plus the cost of the accelerated research that would be required in order to achieve technical and economic goals for ethanol production. The RD&D costs needed were estimated at $150 million per year for five years (Majority Report 1995; Lynd 1997). Cellulosic ethanol might first displace corn-based ethanol before gasoline, which would reduce the cost of this policy while improving the carbon benefits. We assume that ethanol decreases from a current price of $2.70 to $1.45 per gallon of gasoline equivalent by 2010 (1997$). These cost projections correspond with the costs given by DeCicco & Lynd (1996) in their Aaccelerated production@ case. The required capital investment of roughly $0.75 billion/yr (Lynd, Elander & Wyman 1996) may seem daunting, but should be seen in the context of an existing subsidy for corn-based ethanol amounting to roughly $0.75 billion/yr and a motor fuels industry that spends an estimated $11 billion annually for expansion and maintenance of capital equipment (Mark 1996). This policy saves about 16 MtC in 2005 and 32 MtC in 2010, at costs that decrease to $45 per ton of CO_2 by 2005 and about $25 per ton of CO_2 by 2010. The large net savings for the other transportation policies far outweigh the marginal net cost of this policy.

(5) Plan for regional land-uses that are more transport-efficient.

While technological advances will play important roles in reducing the environmental costs of transportation, such supply-side approaches must be complemented by demand-side measures that involve smarter planning of land-use and infrastructure investments aimed at improving system efficiency and equity without limiting accessibility. The 1990 Clean Air Act Amendments (CAAA) and 1991 Intermodal Surface Transportation Efficiency Act (ISTEA) provide federal mechanism that can promote regional planning that is more transport-efficient, for example by focusing development in transit corridors, removing incentives for sprawl, and encouraging infill.

- Implement transportation and land-use reforms to reduce vehicle-miles traveled (VMT), such as eliminating workplace parking subsidies, adopting location-efficient mortgage guidelines and other measures to encourage infill and discourage sprawl, providing secure funding for investment and operation of fixed-route and on-demand transit services, and improving pedestrian and bicycle access (Majority Report 1995; Carlson, Wormser & Ulberg 1995). It is assumed in the C*limate Protection* scenario that short-term measures are only implemented in areas facing air quality constraints, while longer-term measures such as location-efficient mortgages and other measures to foster less auto-dependent community designs are applied across the nation. Effects of demand-side system efficiency policies are captured in their calculated impacts on VMT, which amount to a reduction of 3.9 percent in 2000 and 9.2 percent in 2010 relative to the baseline VMT figures, which are projected to grow at 1.8 percent/yr.

(6) Institute transportation pricing reforms.

Pricing measures for the transportation sector would shift federal, state, and local road subsidies and other hidden, fixed or indirectly paid costs of driving, to fuel taxes or VMT-based fees. All tax shifting approaches raise distributional issues that must be acknowledged and carefully addressed. Pricing reforms should be formulated with extensive public participation in order to ensure that equitable policies are enacted with substantial public support.

- Recommended measures include pay-as-you-drive insurance (see, e.g., Sugarman 1993), and freight trucking regulations and taxes that fairly account for damage and motivate efficiency improvements. Revenues from increased fuel taxes can be allocated among city, county, and state governments in a manner that is linked to their efforts to increase transport system efficiency, not just VMT activity. We model these pricing reforms in terms of a transfer of costs to fuel, by introducing a gasoline tax of $0.30/gal in 2000, increasing to $0.54/gal in 2010 (1997$), with comparable taxes for diesel fuel. These magnitudes are motivated by a number of rationales including road-related expenditures not now covered by user fees and a portion of insurance costs plus unpaid monetary costs of accidents, as well as external environmental costs. (Note: a tax of $25 per ton of CO_2 amounts to $0.22/gal for gasoline.)

Results

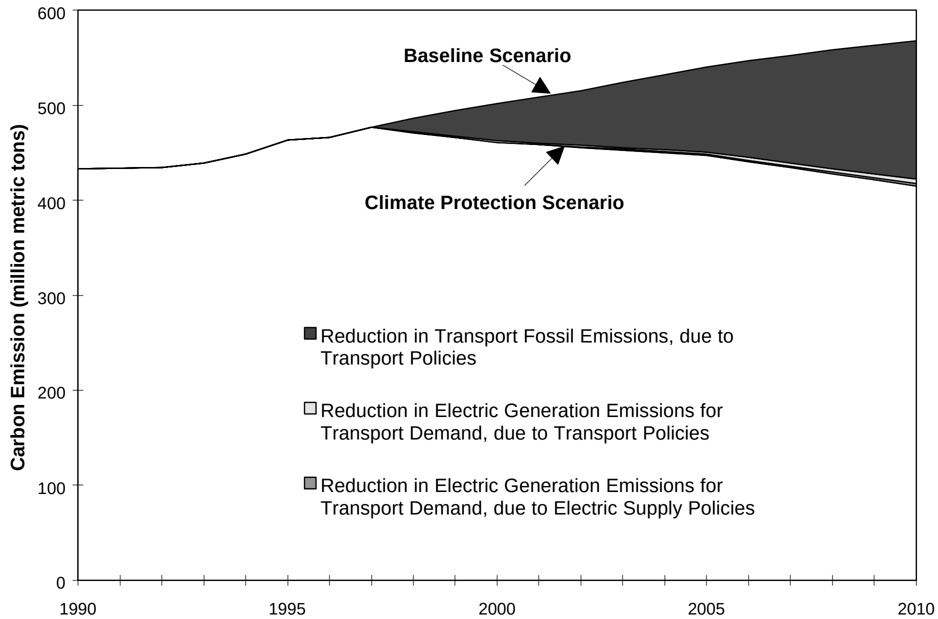
In the baseline scenario, energy grows 25 percent by 2005 and 31 percent by 2010. This baseline probably underpredicts growth and overestimates efficiency improvements, particularly in light of rising light truck market shares. Because of a small decline in carbon intensity due to small assumed increases in natural gas, corn-based ethanol, and electric vehicles, growth in carbon emissions is lighter slowed, increasing 23 percent by 2005 and 29 percent by 2010 relative to 1990 levels.

In the *Climate Protection* scenario, energy consumption falls below the baseline by 4.2 quads or 15 percent in 2005, and 6.5 quads or 23 percent in 2010). An additional 0.8 quads in 2005 and 1.4 quads in 2010 are saved in refineries (in the industrial sector) owing to these oil demand reductions. These energy savings arise from fuel-efficiency improvements (from policies promoting advances in vehicle technology) coupled with slower VMT growth (from policies that shift costs, favor more transport-efficient land-use planning, and encourage less energy-intensive transportation); in 2005 energy savings are split about evenly between fuel-efficiency and VMT reduction, while by 2010 it the contribution from fuel-efficiency increases to 60 percent owing to the steady entry of new vehicles into the fleet.

Despite this substantial decrease in energy consumption relative to the baseline and the greatly accelerated introduction of renewable fuels, the decrease in carbon emissions relative to 1990 levels is still relatively small, (3 percent in 2005 and 7 percent in 2010), because of the very rapid growth in demand for transport services. The major obstacle to greater reductions in energy consumption and carbon emissions in the near term is the slow rate of turnover in vehicle stock, and the resulting lag in improvement in average vehicle efficiency. Similarly, the substantial investment in existing fuel infrastructure and the relative technological immaturity of alternative fuels implies that a highly aggressive policy is needed if low-carbon alternatives are to make even modest contributions as soon as 2005.

Figure 6 gives the transport sector carbon emissions for the baseline and *Climate Protection* scenarios, shown as the upper and lower boundary curves. The difference between the curves is almost entire due to reduced Aon-site@ (i.e., tailpipe) carbon emissions due to transport sector policies that reduce fossil fuel demand. There is a trivial contribution due to transport sector policies that reduce electricity demand and electric sector policies that reduce the carbon-intensity of electric power generation.

Figure 6: Carbon emissions in the transport sector for the baseline scenario and *Climate Protection* scenario. Almost the entire difference Is due to transport sector policies that affect fossil fuel demand.



The policies that help achieve carbon emissions reductions below the baseline level can broadly be categorized as leading to (1) improved efficiency in the transport sector, (2) introduction of renewable fuels, and (3) reduction of VMT. These policies cause direct reductions in carbon emissions of about 91MtC in 2005 and 146 MtC in 2010. Table 2 shows the relative importance of each policy by giving their approximate contributions to these direct carbon reductions relative to the baseline scenario in those years.

Table 2. Carbon emissions reductions in the transport sector by policy category, relative to the baseline scenario in 2005 and 2010.

	2005	**2010**
Vehicle efficiency improvements	8%	13%
Renewable fuels	2%	4%
VMT reductions	7%	9%
Total	**17%**	**26%**

In addition to these direct carbon reductions, there are reductions owing to electricity cogenerated in the ethanol process of 15 TWh for 2.4 MtC in 2005 and 32 TWh for 5.1 MtC in 2010 (accounted for in the power sector results), and from reduced refinery fuel use of 20 MtC in 2005 and 32 MtC in 2010 (accounted for in the industrial sector results).

V. Electric Sector

Background

The U.S. electric sector alone is responsible for about one-third of U.S. carbon dioxide emissions and 8 percent of global carbon dioxide emissions, owing to the large role played by coal in the generation mix. However, there is tremendous potential to dramatically reduce this unsustainably high rate of emissions by decreasing electricity requirements through improved demand-side efficiency (as discussed in sections on industry and buildings), and by evolving toward less carbon-intensive electricity generation through the expanded electric generation based on renewables and advanced natural gas-fired technologies.

In the not-to-distant future, advanced gas turbines and fuel cells could provide power from natural gas at efficiencies about twice the average efficiency of thermal coal power plants today (Williams & Zeh, 1996). Coupled with the lower carbon content of natural gas, such facilities would provide electricity with carbon emissions per kilowatt-hour at about one fourth the emission rate of today's coal plants and less than half the average emission rate of the entire sector. Electric generating technologies using renewable resources, such as wind, solar, geothermal and biomass, have essentially no net carbon emissions. Thus, a future electric generating system with a 50/50 mix of renewable and advanced gas technologies would have a carbon emissions intensity of about one-eighth that of existing coal and one fifth that of the existing electric system.

In regions with access to natural gas, the thermal power technology of choice for new capacity has already become gas turbine/steam turbine combined cycles, since they are rapidly advancing in efficiency, declining in cost, and improving in pollutant emissions characteristics. Steady R&D has brought fuel cell technologies very far as well, advancing them beyond the niche applications in aerospace and military to which their high cost had previously confined them. Fuel cells are now receiving the attention and resources of automobile manufacturers and the electric power industry, who have been attracted by the good prospects for fuel cells to economically provide energy efficiently with zero emissions of local pollutants (Dunnison & Wilson 1994; A.D. Little 1995; Mark 1996).

Interest in renewables surged in the 1970s and 1980s following the energy crises, but declined as gas and oil prices declined. In the late 1980s and early 1990s, private and government investment in renewables technologies rose once again, this time motivated by the growing economic competitiveness of renewable technologies coupled with strong public concern about the environment. The cost and performance of wind, geothermal, solar, biomass and other renewable sources have been rapidly improving, owing to technological innovation spurred by government support, incentives, regulatory action, and growing commercial opportunities (Brower *et al.* 1993; WEC 1994; Ishitani & Johansson 1996; Reddy *et al*. 1997).

Several long-standing market barriers continue to hinder the commercialization of renewable energy technologies. These market barriers include lack of adequate financing for renewables, institutional reluctance to develop renewables given lack of information, an energy market that does not internalize either the environmental or political costs of fossil fuel consumption, and utility decision-making that doesn=t recognize certain non-price benefits of renewables such as energy source diversification and distributed generation benefits (Golove & Eto 1996; Wiser and Pickle 1997; Brower and Parsons 1997; Brower *et al* 1997). In addition, renewables have to compete with power from natural gas, the price of which has steadily decreased as projected natural gas prices and gas turbine equipment capital costs have declined over recent years.

Restructuring of the electric sector towards a price-competitive industry could makes things significantly more difficult for renewables, *or* it could help usher them into the market, depending on policy decisions that will be made in the near future. A simplistic drive to retail competition could mean that investment decisions will focus upon even shorter time horizons, with correspondingly less attention to cost-effective efficiency improvements and renewables, and environmental goals and costs. Competitive forces alone cannot be relied on to address the legitimate concern for long-term sustainability – a myopic pursuit of the lowest possible short-run electricity commodity prices poses the threat that any benefits from restructuring would flow to a few large industrial consumers and that new cleaner entrants into the generating market would be excluded.

Policies and Measures for Reducing Carbon Emissions in the Power Sector

In the electric sector as in the other sectors, R&D will be critical for advancing the energy options that will make long-term emissions reductions possible. A crucial aspect of advancing renewables and efficiency measures will be the creation of secure markets that make Alearning by doing@ possible. Technology-forcing initiatives that establish a small but significant demand for pre-competitive technologies make it possible for those technologies to benefit from economies of scale, bringing down costs and advancing technologies in ways that cannot happen through laboratory experience alone. It is possible to carry out electric industry restructuring in ways that assure a sufficient market pull for renewables to allow this institutional learning process to happen. This highlights the role of policy in breaking out of situations of technology Alock-in@ or Alock-out,@ in which historic winners maintain advantages that could preempt superior options in the future (Cowan & Kline 1996).

The policies recommended here aim to reduce the barriers that have historically faced renewables, making it possible for them to contribute modestly to electric power generation in the short-term and to advance along the learning curve so that they can contribute substantially in the long-term.

(1) Create market pull to complement renewables R&D.

- Extend the Energy Policy Act of 1992 (EPACT) Renewables Incentive, which is due to expire in 1999. This would continue the existing 1.5 cent/kWh production incentive for wind and closed-loop biomass. In the present analysis, it is assumed that the credit for wind continues past 1999 until 2005, that the credit is extended to all biomass.

- Impose a renewables portfolio standard (RPS) requiring that a certain percentage of all generation come from renewable resources. The RPS requirement could be formulated such that generating companies could satisfy it by any combination of generating their own renewable power, purchasing renewable power directly from renewables developers, and purchasing credits in the secondary market. An RPS would provide assurance and stability to developers of renewables by guaranteeing markets for their power, allowing them to capture the financial and administrative advantages that come with planning in a stable economic environment. The RPS framework provides strong incentives for suppliers to find the lowest-cost, most reliable renewables projects, and to find niche applications and consumers where the projects will have the greatest value.

- Levy a system benefits charge (SBC) on retail electricity sales as an alternative or a complement to an RPS. Under cost-of-service ratemaking the SBC has until now appeared as a small component (1 to 5 percent) of consumers= total electricity bills intended to fund the delivery of public interest services, including low-income services, end-use efficiency, and renewables R&D. However, as the main purpose of these important services is not to generate profit in a competitive electricity market, they might not be delivered in a restructured industry unless explicitly introduced into restructuring legislation. Part of an SBC could be allocated to Abuying-down@ the cost of renewables to a price where they would be competitive with conventional generating sources. This SBC policy would promote as much renewables development as possible with a fund of a pre-determined magnitude, whereas an RPS policy would prescribe a minimum level of renewables generation.

In the present analysis, we assumed a hybrid SBC/RPS approach. The revenues raised by a 0.2 cent/kWh SBC were used to buy down a broad set of renewables to the cost of the least expensive conventional generating option in a given year. Thus the hybrid policy can be viewed as an RPS in which the level of renewable purchases required of utilities is set so that ratepayers pay a premium of no more than 0.2 cent/kWh in their electricity bills and also in which no single technology accounts for more than half the market share.

Aside from providing the immediate environmental benefits of the accelerated penetration of renewables, the SBC/RPS policy serves a technology-forcing role that helps renewables to achieve a level of penetration that their comparatively high early costs would not otherwise permit. Technological learning and economies of scale in their manufacture can then reduce the costs of renewable technologies to competitive levels more quickly than would otherwise occur. This technology-forcing effect is captured in the NEMS model used here, which incorporates DOE/IEA learning curves for energy technologies.

(2) Impose limits on emissions of criteria pollutant emissions.

Emissions caps were modeled for SO_2 (reducing emissions from 12 million tons/yr in 1995 to below 4 million tons/yr by 2010), NO_x (reducing emissions from 7 million tons/yr to about 4 million tons/yr by 2010) and particulates (reducing PM10 emissions from 0.25 million tons/yr to 0.16 million tons/yr by 2010). Because NEMS cannot explicitly model caps on NO_x and particulates, as it can for SO_2, we apply revenue neutral externalities as a proxy for either an ecological tax reform package or a cap and trade system for these two pollutants. The externalities taxes are phased in linearly from 1998 to 2010, and reach values in 2010 of $2,500/ton and $10,000/ton (1993$), for NO_x and particulates, respectively. This translates into cost adders in 2010 of about 2.0 cents/kWh for existing coal and oil and about 0.2 cent/kWh (1993$) for existing gas. Although bolt-on control technologies such as SO_2 scrubbers and low-NO_x burners that reduce criteria pollutant emissions may actually cause efficiency penalties that increase carbon emissions, this effect is more than compensated for by a shift away from coal.

(3) Establish a target for co-firing biomass with coal in existing thermal power plants.

One of most readily available measures for reducing electric sector carbon emissions is to increase the renewable contribution to electric power production by partial replacement of coal consumed in an existing power plants with biomass. This is an attractive near-term option, as it would not require the effort and cost of constructing new generating facilities dedicated exclusively to biomass. Biomass can displace up to approximately 15 percent of coal feedstock in a conventional power plant without significant impact on plant performance or efficiency. We model a policy that requires that biomass displaces 5 percent of coal used in power plants by 2005, and 10 percent by 2010.

This level of biomass co-firing results in generation from biomass growing from the 1992 level of 42 TWh/yr (Hohenstein & Wright 1994) to approximately 64 TWh/yr of power in 2005 and 108 TWh/yr in 2010. Approximately 1.0 Quad, or 60 million dry tons of additional biomass would be needed in 2010 to satisfy this requirement. This amount of biomass, in addition to the 170 million dry tons consumed to satisfy the alternative fuels requirement for transport (see section IV), is presumed to be available at $2.75/MMBtu (1997$) from agricultural residues, municipal waste, logging residues, and energy crops (Walsh *et al* 1997; McKeever 1997). Carbon emissions reductions from this policy would be about 16 MtC in 2005 and 27 MtC in 2010, decreases of 3.4 percent and 5.7 percent, respectively, from 1990 electric sector emissions. At conservative estimates of the incremental fuel and O&M costs, the carbon emissions reductions would be achieved at about $30 per ton of CO2 (1997$).

(4) Impose limits on carbon emissions from electric generation.

We modeled a policy that corresponds to imposing a cap on emissions of carbon from the electric sector and distributing tradable emissions permits to electricity suppliers through some equitable process, allowing them to find the optimal manner of complying with the cap. The cap was applied at a level that provided emissions reductions about 25 percent below 1990 levels and a carbon intensity roughly one-third below that of 1990.

Results

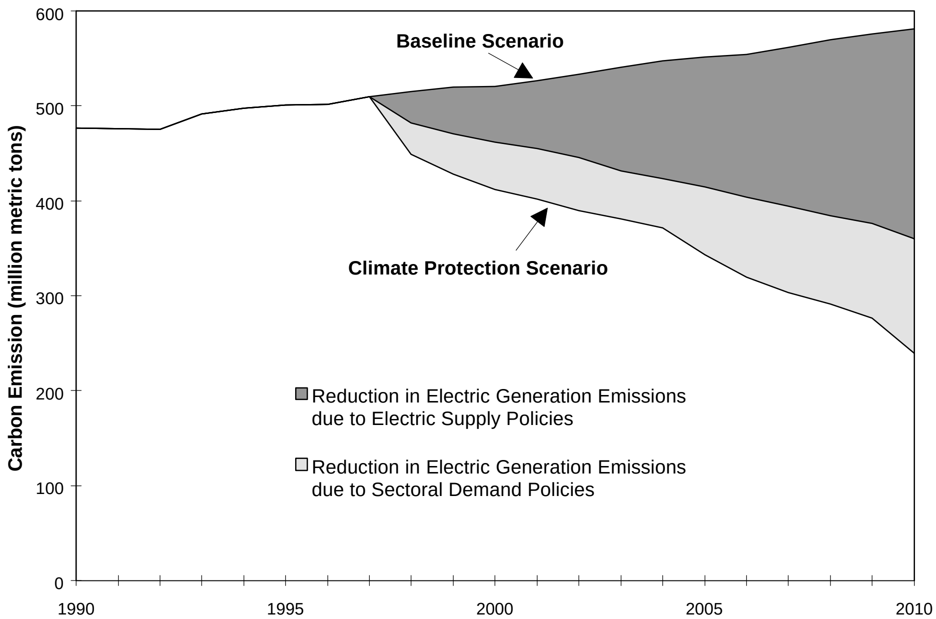
Electric power consumption in the baseline scenario grows 20 percent by 2005 and 26 percent by 2010, which is slightly slower than in the recent past. Carbon emissions rise at a somewhat slower rate because of a significant increase in the share of natural gas and decline in the share of coal, increasing above the 1990 level by 16 percent in 2005 and 22 percent in 2010. Electricity prices remain fairly stable.

The SBC/RPS policy leads to the introduction of non-hydro renewables amounting to 16 percent of total power produced in 2010, up from 1 percent in 1990. These SBC revenues amounted to about $6.6 billion (1997$) per year from 1998 to 2010, which would be sufficient to buy down 80,000 MW of renewables by $1100/kW. This level of deployment serves to bring down the cost of renewables considerably, so by 2010 wind, solar thermal and central-station photovoltaics are essentially competitive in their respective markets (baseload generation for wind and intermediate for solar).

The electric sector supply policies cause a shift from coal, primarily to gas by 2005, and to gas and renewables by 2010. Relative to 1990 levels, gas generation increases by 184 percent by 2005 and by 193 percent by 2010, non-hydro renewable generation increases more than seven-fold by 2005 and almost twenty-fold by 2010, while coal generation declines by about 28 percent by 2005 and by 38 percent by 2010. Carbon emissions are reduced by about 13 percent below 1990 levels by 2005 and by about 24 percent below 1990 levels by 2010. The carbon intensity of the sector decreases from 0.161 MtC/TWh in 1990 to 0.100 MtC/TWh in 2010, rather than remaining constant as in the Base Case. Relative to baseline levels, carbon emissions are reduced by 25 percent in 2005 and 38 percent in 2010.

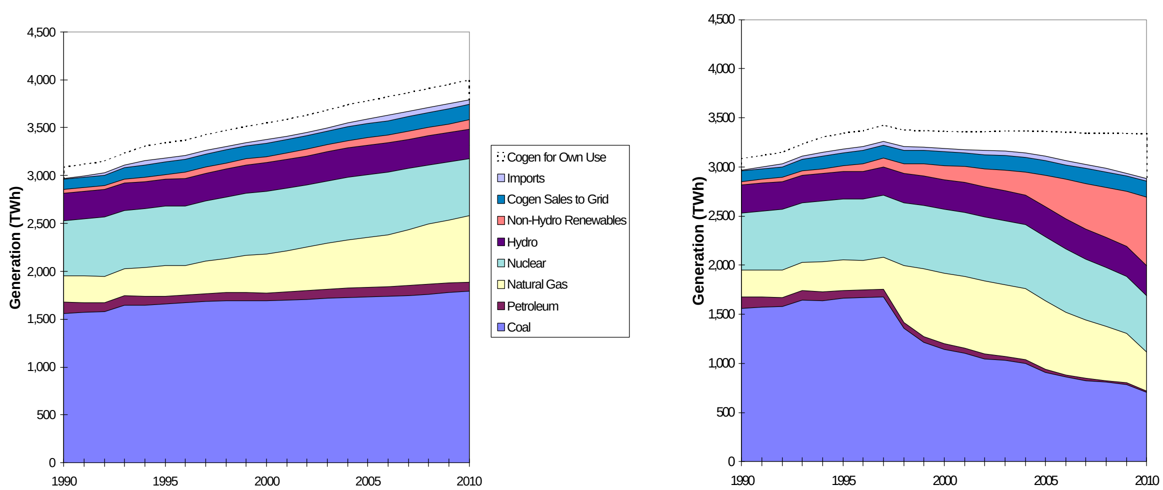
In the *Climate Protection* scenario, electricity demand is 13 percent lower than the baseline scenario in 2005 and 24 percent lower in 2010 due to demand-side policies. The combined effects of reduced demand and decreased carbon intensity leads to a decline in carbon emissions relative to 1990 levels by 28 percent in 2005 and 50 percent in 2010, as seen in Figure 7. Coal decreases its fraction in the generation mix considerably, while there is substantial growth in non-hydro renewables, including the co-fired biomass. Total generation from natural gas remains roughly constant between the baseline and the *Climate Protection* scenario (see Figure 8).

Figure 7: Carbon emissions in the electric power sector for the baseline scenario and *Climate Protection* scenario, separated into carbon reductions due to electric power sector policies that reduce carbon intensity, and policies in the demand sectors that reduce electricity demand.



The price of electricity (including the SBC) is marginally higher in the *Climate Protection* path than in the baseline path in 2010, due predominantly to the shift away from some inexpensive coal-based power to new gas-fired generation in response to the caps on carbon and criteria pollutants, and the introduction of renewables before they are fully competitive, albeit while driving down their costs via learning and scale economies. However, summing the demand-side electric equipment investment costs and the electricity savings, we find that the environmental and technology benefits are achieved with a net savings. Additionally, by 2010 the emissions of SO_2, NO_x, and particulates decline by approximately 75 percent, 50 percent, and 33 percent, respectively.

Figure 8. Electric generation by fuel, a) baseline and b) *Climate Protection* supply side policies.



VI. Conclusions

The objective of this study has been to identify a carbon reduction strategy that would: (1) attain significant carbon reductions quickly; (2) be a cost-effective package in which energy-cost savings more than compensate for incremental investments; and (3) perhaps most importantly, serve as an effective transitional strategy that establishes a foundation and builds momentum toward the much deeper long-term emissions reductions required for climate protection. The policies and measures that comprise the *Climate Protection* scenario achieve these three ends.

First, the *Climate Protection* scenario demonstrates how the U.S. can diverge from the Abusiness-as-usual@ path with its steadily rising carbon emissions. By 2005, instead of further increasing carbon emissions by 17 percent above its already excessive 1990 levels, the U.S. could reverse this trend and reduce emissions by 10 percent -- a difference in carbon emissions that is nearly three-quarters the amount that would be required to meet the AOSIS target of 20 percent reductions. By 2010, the AOSIS target would have been surpassed.

Second, owing to the large energy-cost savings that are induced by the policies and measures of the *Climate Protection* scenario, the package is economically beneficial even without considering greenhouse gas, pollution and ancillary benefits. The discounted present value of the cumulative net benefits is estimated to be roughly $60 billion through 2005 and $180 billion through 2010 (1997$). This margin by which the strategy is cost-effective could be taken as leeway for yet more aggressive near-term carbon reduction measures that have net costs. While the rather aggressive set of measures already embodied in the *Climate Protection* scenario have costs of saved carbon-dioxide at the margin of over $90 per ton, relaxing the reduction target for 2005 while increasing the reductions in 2010, would likely result in lower marginal costs and higher net savings, while achieving the same cumulative carbon reductions over that period. However, identifying realistic additional measures at a reasonable cost would be difficult, largely owing to the nearness of the 2005 target date -- further improvements in efficiency and greater reliance on alternative energy sources before 2005 are constrained by the slow capital stock turnover in the four sectors.

As an alternative to implementing even more aggressive measures that would incur substantial cost, it might be advisable instead to commit those same resources toward R&D for broad classes of promising technologies that will provide the basis for future reductions and toward investments in infrastructure that can accommodate those technologies as they arrive. As global climate scientists have concluded that climate impacts will depend primarily on the cumulative greenhouse gases emitted up until the time when atmospheric concentrations are stabilized, investing now in future carbon reductions would be an effective complement to investing in immediate reductions.

Third, in addition to reversing the trend in U.S. carbon emissions and achieving significant reductions, the *Climate Protection* scenario is a promising transitional strategy. It does not exhaust the opportunities for carbon reductions, arriving at the 2010 horizon with lower emissions but few remaining options for attaining the much deeper long-term carbon reductions ultimately needed to prevent global warming. Rather, it builds momentum toward continued reductions by several means. For example, the Climate Protection Scenario (1) actively fosters a vibrant RD&D process in the public and private sectors that would stimulate continued innovation; (2) ushers renewables and other energy technologies into the market, propelling them along their learning curves and realizing scale economies in their production, so that they can increasingly contribute to energy supplies in the U.S. and abroad; (3) eliminates existing barriers to cost-effective efficiency measures; (4) establishes market-pull mechanisms that will accelerate the deployment of new process, practices and technologies, as well as inspire continued innovation; (5) influences infrastructure development and societal attitudes relating to recycling, resource consumption, alternate transport options, and more efficient land-use planning; and (6) through pricing and performance standards, renders local pollution, greenhouse gas emissions, and non-renewable resource depletion more costly.

A strategy such as the one outlined in this study, if implemented with the timely resolve that is unquestionably warranted by the threat of global climate change, can help the U.S. fulfill its obligation not only to the Framework Convention on Climate Change, but also to its future citizens.

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Appendix A

Summary of Carbon Reductions from Policies
Million metric tons Carbon (MtC)

	2005	**2010**
Industry		
ITC	39	57
RD&D	12	18
Recycling	1	2
CHP	12	40
sub-total	64	117
Buildings		
Residential	10	19
Commercial	40	51
sub-total	49	70
Transportation		
Efficiency	50	90
Demand Reduction	48	61
Renewable Fuels	16	32
sub-total	114	183
Electric Power		
Renewables	24	37
SO_2 Cap	24	44
NO_x/PM reduction	26	34
Biomass/Coal Cofiring	16	27
Carbon Cap	51	82
sub-total	141	224
Total	**368**	**593**

Appendix B

Cost of Saved Carbon Analysis

The cost of saved carbon for each policy was computed on a real levelized basis, using a 5% discount rate.

First, the net costs of each policy were found by summing the incremental annualized capital costs, administrative costs, incremental O&M and fuel costs, and subtracting O&M and fuel cost savings. Then capital costs were annualized in nominal dollars as in "mortgage" payments through a capital recovery factor that reflects the rate of interest and lifetime of the investment. These year-by-year costs from 1998 through 2010 reflect stock turnover and the phase-in of policies and their impacts. The carbon savings are the year-by-year reductions in carbon emissions relative to the baseline projections.

Finally, using the year-by-year streams of net costs as well as carbon savings of each policy, real levelized costs of saved carbon (RLCSC) were derived using the following formula:

Cumulative Present Value of Net Costs

$$= \sum_{n=1998}^{2010} \frac{(Incremental\ \ Costs)_n}{(1+d)^{(n-1998)}}$$

$$= \sum_{n=1998}^{2010} \frac{RLCSC \cdot (Carbon\ \ Reduction)_n}{(1+d)^{(n-1998)}}$$

Real Levelized Cost of Saved Carbon (RLCSC)

$$= \frac{\sum_{n=1998}^{2010} \frac{(Incremental\ \ Costs)_n}{(1+d)^{(n-1998)}}}{\sum_{n=1998}^{2010} \frac{(Carbon\ \ Reduction)_n}{(1+d)^{(n-1998)}}}$$

This is the ratio of the cumulative present value of net costs and the cumulative present value of carbon reductions. Clearly, the overall expression is sensitive to the discount rate used (e.g., whether the discount rate reflects a private or social value), as well as to the actual net costs and carbon savings.

The discounting of both costs and carbon reductions at the same rate, notwithstanding their derivation from an apparently conventional definition of unit levelization, may be questioned. If it is meant to connote the costs of a physical object that has commodity status (as is the case with kWh of electricity savings) there appears to be no ambiguity, e.g, if carbon reductions had commodity value within a regime of tradable permits (or carbon taxes). However, in the absence of tradable permits or their equivalent, it is arguable that the cost and physical quantities could be discounted at different rates to reflect, for example, different time values or perception of risk with regard to the carbon reductions.[1]

The use of a zero discount rate for carbon reductions, while maintaining the 5% discount rate for net costs, would reduce the costs of saved carbon by a factor of around 30% .

[1] Note that another approach, which we find problematic, is to place the ultimate impacts of carbon emissions (or the net impacts of their reduction) into the monetary framework (e.g., the neoclassical economic framework in which they are monetized according to projected consumer preferences), and thus to value and discount these impacts (or carbon as their surrogate/indicator) as if they were commodities.

Cost-of-Saved-Carbon for Policies
($/ton CO_2)

	Cost of saved CO_2 ($/ton CO_2)
Industry	
Efficiency (ITC and RD&D)	-$28
Recycling	-$42
CHP	-$31
Buildings	
Residential & Commercial	-$62
Transportation	
Efficiency	-$115
Demand Reduction	$0
Renewable Fuels	$48
Electric Power	
Renewables	$26
SO2 Cap	$27
Nox/PM reduction	$10
Biomass/Coal Cofiring	$29
Carbon Cap	$59

Appendix C: Primary Fuel Consumption for the Base Case and Policy Case by Sector and Fuel, 1990, 2005, and 2010

Total Energy Consumption by Fuel and by Sector in 1990 (Quads)

	Residential	Commercial	Industrial	Transportation	Electricity	Total
Coal	0.06	0.10	2.75	0.00	16.20	19.11
Oil	1.27	0.91	8.31	21.81	1.23	33.53
Gas	4.52	2.76	8.47	0.68	2.88	19.31
Nuclear	0.00	0.00	0.00	0.00	6.19	6.19
Hydro	0.00	0.00	0.00	0.00	2.99	2.99
Non-Hydro	0.83	0.09	2.07	0.00	0.50	3.49
Primary Total	**6.68**	**3.86**	**21.60**	**22.49**	**29.99**	**84.62**
Electricity	3.15	2.86	3.24	0.01		9.26
End-Use Total	**9.83**	**6.72**	**24.84**	**22.50**		**63.89**

Total Energy Consumption by Fuel and by Sector in 2005 (Quads) - Base Case

	Residential	Commercial	Industrial	Transportation	Electricity	Total
Coal	0.06	0.10	2.65	0.00	17.73	20.53
Oil	1.11	0.70	9.71	26.94	1.18	39.64
Gas	5.27	3.06	10.82	0.97	5.34	25.47
Nuclear	0.00	0.00	0.00	0.00	6.96	6.96
Hydro	0.00	0.00	0.00	0.00	3.16	3.16
Non-Hydro	0.73	0.03	2.66	0.06	1.90	5.38
Primary Total	**7.16**	**3.89**	**25.84**	**27.98**	**36.27**	**101.14**
Electricity	3.73	3.60	4.07	0.13		11.53
End-UseTotal	**10.89**	**7.48**	**29.92**	**28.11**		**76.40**

Total Energy Consumption by Fuel and by Sector in 2005 (Quads) - Policy Case

	Residential	Commercial	Industrial	Transportation	Electricity	Total
Coal	0.05	0.10	2.33	0.00	9.09	11.57
Oil	1.11	0.66	7.80	22.28	0.39	32.23
Gas	5.15	2.65	10.51	0.92	7.60	26.84
Nuclear	0.00	0.00	0.00	0.00	6.96	6.96
Hydro	0.00	0.00	0.00	0.00	3.16	3.16
Non-Hydro	0.57	0.08	2.44	0.57	4.30	7.95
Primary Total	**6.87**	**3.48**	**23.09**	**23.77**	**31.50**	**88.71**
Electricity	3.45	2.89	3.54	0.08		9.95
End-UseTotal	**10.32**	**6.36**	**26.62**	**23.85**		**67.15**

Appendix C (continued)

Total Energy Consumption by Fuel and by Sector in 2010 (Quads) - Base Case

	Residential	Commercial	Industrial	Transportation	Electricity	Total
Coal	0.06	0.10	2.69	0.00	18.20	21.04
Oil	1.05	0.68	10.14	28.12	1.14	41.13
Gas	5.30	3.12	11.40	1.11	6.61	27.54
Nuclear	0.00	0.00	0.00	0.00	6.36	6.36
Hydro	0.00	0.00	0.00	0.00	3.16	3.16
Non-Hydro	0.73	0.03	2.84	0.11	2.26	5.98
Primary Total	**7.14**	**3.93**	**27.07**	**29.34**	**37.72**	**105.20**
Electricity	3.89	3.79	4.32	0.18		12.18
End-Use Total	**11.03**	**7.73**	**31.39**	**29.52**		**79.66**

Total Energy Consumption by Fuel and by Sector in 2010 (Quads) - Policy Case

	Residential	Commercial	Industrial	Transportation	Electricity	Total
Coal	0.04	0.10	1.84	0.00	7.26	9.23
Oil	1.01	0.63	6.69	20.62	0.22	29.17
Gas	4.93	2.58	11.84	1.01	4.07	24.42
Nuclear	0.00	0.00	0.00	0.00	6.11	6.11
Hydro	0.00	0.00	0.00	0.00	3.16	3.16
Non-Hydro	0.53	0.11	2.50	1.19	8.15	12.49
Primary Total	**6.50**	**3.42**	**22.87**	**22.82**	**28.97**	**84.58**
Electricity	3.52	2.72	2.91	0.07		9.23
End-Use Total	**10.02**	**6.14**	**25.78**	**22.89**		**64.84**

Percentage Difference in Primary Consumption by 2010 Relative to 1990

	Residential	Commercial	Industrial	Transportation	Electricity	Total
Coal	-8%	-3%	-2%	NA	12%	10%
Oil	-17%	-25%	22%	29%	-7%	23%
Gas	17%	13%	35%	63%	130%	43%
Nuclear	NA	NA	NA	NA	3%	3%
Hydro	NA	NA	NA	NA	6%	6%
Non-Hydro	-12%	-63%	37%	NA	352%	71%
Primary Total	**7%**	**2%**	**25%**	**30%**	**26%**	**24%**
Electricity	23%	33%	33%	1723%		32%
Total	**12%**	**15%**	**26%**	**31%**		**25%**

Appendix D: Carbon Emissions in the Base Case and Policy Case by Sector and Fuel, 1990, 2005, and 2010

Carbon Emissions in 1990 (Million metric tons)

Sector	Gas	Oil	Coal	Indirect Electric	Totals
Electric	41.2	26.8	408.8	NA	476.8
R	65.0	24.0	1.6	162.4	253.0
C	38.7	18.1	2.3	147.5	206.6
I	119.6	91.9	67.8	166.3	445.6
T	9.9	422.3	0.0	0.7	432.9
Totals	274.4	583.1	480.5	0.0	1,338.0
Fossil Fuel Share	20.5%	43.6%	35.9%		
Elect. Share					35.6%

Carbon Emissions in 2005 -- Base Case (Million metric tons)

Sector	Gas	Oil	Coal	Indirect Electric	Totals
Electric	77.0	24.9	449.9	NA	551.8
R	75.8	21.2	1.5	178.3	276.8
C	44.1	14.0	2.2	172.2	232.6
I	151.8	105.1	65.8	195.0	517.6
T	14.0	520.0	0.0	6.3	540.4
Totals	362.7	685.3	519.5	0.0	1,567.4
Fossil Fuel Share	23.1%	43.7%	33.1%		
Elect. Share					35.2%

Carbon Emissions in 2005 -- Policy Case (Million metric tons)

Sector	Gas	Oil	Coal	Indirect Electric	Totals
Electric	109.4	8.3	225.5	NA	343.2
R	74.2	21.6	0.7	118.9	215.4
C	38.1	12.7	2.5	99.5	152.8
I	147.5	69.1	45.7	122.0	384.3
T	13.3	431.1	0.0	2.7	447.2
Totals	382.6	542.9	274.3	0.0	1,199.7
Fossil Fuel Share	24.4%	34.6%	17.5%		
Elect. Share					28.6%

Appendix D (continued)

Carbon Emissions in 2010 -- Base Case (Million metric tons)

Sector	Gas	Oil	Coal	Indirect Electric	Totals
Electric	95.2	24.1	461.8	NA	**581.2**
R	76.3	20.0	1.4	185.4	**283.2**
C	44.9	13.7	2.2	181.1	**242.0**
I	159.9	108.8	66.7	206.0	**541.4**
T	16.0	543.2	0.0	8.7	**567.8**
Totals	**392.3**	**709.9**	**532.2**		**1634.4**
Fossil Fuel Share	24.0%	43.4%	32.6%		
Elect. Share					35.6%

Carbon Emissions in 2010 -- Policy Case (Million metric tons)

Sector	Gas	Oil	Coal	Indirect Electric	Totals
Electric	58.6	4.7	176.3	NA	**239.6**
R	71.0	19.7	0.5	91.4	**182.6**
C	37.2	12.3	2.5	70.7	**122.7**
I	166.1	44.0	34.4	75.7	**320.2**
T	14.6	398.9	0.0	1.8	**415.2**
Totals	**347.3**	**479.6**	**213.7**		**1040.6**
Fossil Fuel Share	33.4%	46.1%	20.5%		
Elect. Share					23.0%

Percentage Difference in Carbon Emissions in 2010 Relative to 1990

Sector	Gas	Oil	Coal	Indirect Electric	Totals
Electric	42.1%	-82.5%	-56.9%	NA	-49.8%
R	9.2%	-17.9%	-67.7%	-43.7%	-27.8%
C	-4.0%	-31.9%	8.0%	-52.1%	-40.6%
I	38.9%	-52.1%	-49.3%	-54.5%	-28.1%
T	47.1%	-5.6%	NA	157.6%	-4.1%
Totals	26.6%	-17.8%	-55.5%	NA	-22.2%