# The American Way to the Kyoto Protocol:
## An Economic Analysis to Reduce Carbon Pollution

A Study For:

**World Wildlife Fund**

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## Table of Contents

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# 1 Executive Summary

This report presents a study of policies and measures that could dramatically reduce US greenhouse gas emissions over the next two decades. It examines a broad set of national policies to increase energy efficiency, accelerate the adoption of renewable energy technologies, and shift energy use to less carbon-intensive fuels. The policies address major areas of energy use in residential and commercial buildings, industrial facilities, transportation, and power generation.

This portfolio of policies and measures would allow the United States to meet its obligations under the Kyoto Protocol Together when combined with steps to reduce the emissions of non-CO2 greenhouse gases and land-based CO2 emissions, and the acquisition of a limited amount of allowances internationally. This package would bring overall economic *benefits* to the US, since lower fuel and electricity bills would more than pay the costs of technology innovation and program implementation. In 2010, the annual savings would exceed costs by $50 billion, and by 2020 by approximately $135 billion.

Currently, the Bush administration is promoting an energy strategy based on augmenting fossil fuel supplies. This strategy does not help the US shift away from diminishing fossil fuel supplies, it does not enhance US energy security, and it does not reduce the environmental impacts of energy use. America needs an energy policy that takes us forward into the 21st Century by making climate change mitigation an integrated part of the plan

Far from being the economically crippling burden that the Bush Administration alleges, ratifying the Kyoto Protocol and ambitiously reducing greenhouse gas emissions could initiate a national technological and economic renaissance for cleaner energy, industrial processes and products in the coming decades. In the United States, we therefore face an important challenge. We can embrace the challenge of climate change as an opportunity to usher in this renaissance, providing world markets with the advanced technologies needed to sustain this century’s economic growth. Or we can be followers, leaving other more forward-looking countries to assume the global leadership in charting a sustainable path and capturing the energy markets of the future.

## *Policies and measures*

The climate protection strategy adopts policies and measures that are broadly targeted across the four main economic sectors: buildings, electricity generation, transportation, and industry. The policies considered for residential and commercial buildings include strengthened codes for building energy consumption, new appliance efficiency standards, tax incentives and a national public benefits fund to support investments in high efficiency products, and expanded research and development into energy efficient technologies. For the electric sector, policies included a market-oriented “renewable portfolio standard”, a cap on pollutant emissions (for sulfur and nitrogen), and a carbon emissions permit auction. In the transport sector, policies are adopted to improve the fuel economy of passenger vehicles, freight trucks, and aircraft through research, incentives, and a strengthened vehicle fuel efficiency standards. Policies are also modeled to set a fuel-cycle greenhouse gas standard for motor fuels, reduce road travel through land use and infrastructure investments and pricing reforms, and increase access to high speed rail as an alternative to short distance air travel. In the industry sector, policies are adopted to exploit more of the vast potential for cogeneration of heat and power, and to improve energy efficiencies at industrial facilities through technical assistance, financial incentives, expanded research, and demonstration programs to encourage cost-effective emissions reductions.

*Results*

Energy use in buildings, industries, transportation, and electricity generation was modeled for this study using the U.S. Department of Energy's National Energy Modeling System (NEMS). The NEMS model version, data and assumptions employed in this study were those of EIA's *Annual Energy Outlook* (EIA 2001), which also formed the basis for the Base Case. We refined the NEMS model with advice from EIA, based on their ongoing model improvements, and drawing on expert advice from colleagues at the Union of Concerned Scientists, the National Laboratories and elsewhere.

**Table ES.1 Summary of results.**

| | **1990**[1] | **2010 Base Case** | **2010 Climate Protection** | **2020 Base Case** | **2020 Climate Protection** |
|---|---|---|---|---|---|
| **End-use Energy** (Quads) | 63.9 | 86.0 | 76.4 | 97.2 | 72.6 |
| **Primary Energy** (Quads) | 84.6 | 114.1 | 101.2 | 127.0 | 89.4 |
| **Renewable Energy** (Quads) | | | | | |
| Non-Hydro | 3.5 | 5.0 | 10.4 | 5.5 | 11.0 |
| Hydro | 3.0 | 3.1 | 3.1 | 3.1 | 3.1 |
| **Net GHG Emissions** (MtCe/yr) | 1,648 | 2,204 | 1,533 | ----- | ----- |
| Energy Carbon | 1,338 | 1,808 | 1,372 | 2,042 | 1,087 |
| Land-based Carbon | ----- | ----- | -58 | ----- | ----- |
| Non-CO2 Gases | 310 | 397 | 279 | ----- | ----- |
| International Trade | ----- | ----- | -60 | ----- | ----- |
| **Net Savings**[2] | | | | | |
| Cumulative present value (billion$) | ------ | ------ | $105 | ------ | $576 |
| Levelized annual (billion$/year) | ------ | ------ | $13 | ------ | $49 |
| Levelized annual per household ($/year) | ------ | ------ | $113 | ------ | $375 |

Table ES.1 provides summary results on overall energy and greenhouse gas impacts and economic impacts of the policy set for the *Base Case* and *Climate Protection Case* for 2010 and 2020. The policies cause reductions below in primary energy consumption that reach 11% by 2010 and 30% in 2020, relative to the Base Case in those years, through increased efficiency and greater adoption of cogeneration of heat and power (CHP). Relative to today's levels, use of

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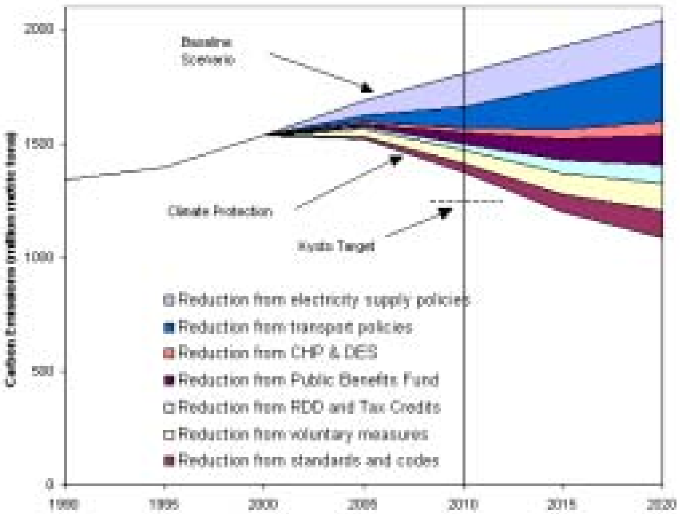
[1] Under Kyoto, the base year for three of the non-CO2 GHGs (HFCs, PFCs, SF6) is 1995, not 1990, and the 1995 levels for these emissions are reported here.

[2] Savings are in 1999 $. The 2010 savings include $2.3 billion costs per year ($9 billion cumulative through 2010) of non-energy related measures needed to meet the Kyoto target. Costs are not included in 2020 since these measures policies do not extend past 2010.

non-hydro renewable energy roughly triples by 2010 in the Climate Protection Case, whereas in the Base Case it increases by less than 50%. Given the entire set of policies, non-hydro renewable energy doubles relative to the Base Case in 2010, accounting for about 10 percent of total primary energy supplies in 2010. When the electric sector RPS is combined with the strong energy efficiency policies of this study, the absolute amount of renewables does not increase substantially between 2010 and 2020 because the percentage targets in the electric sector have already been met. A more aggressive renewables policy for the 2010-2020 period could be considered (ACEEE, 1999).

**Figure ES.1. Reductions in energy-related carbon emissions, displayed by major policy group**



The reductions in energy-related carbon emissions are even more dramatic than the reductions in energy consumption, because of the shift toward lower-carbon fuels and renewable energy. Since 1990, carbon emissions have risen by over 15%, and in the Base Case would continue to rise a total of 35% by 2010, in stark contrast to the 7% emissions *reduction* that the US negotiated at Kyoto. In the Climate Protection case, the US promptly begins to reduce energy-related carbon emissions, and by 2010 emissions are only 2.5 percent above 1990 levels, and by 2020, emissions are well below 1990 levels. Relative to the Base case, the 2010 reductions[3] amount to 436 MtC/yr.

Energy-related carbon emissions are the predominant source of US greenhouse gas emissions for the foreseeable future, and their reduction is the central challenge for protecting the climate. However, because the US has made only minimal efforts to reduce emissions since it ratified the United Nations Framework Convention on Climate Change, it may not be able to meet it's Kyoto obligation with net economic benefits based solely on reductions in energy-related carbon dioxide emissions. Therefore, in order to meet the Kyoto target, the Climate Protection case also considers policies and measures for reducing greenhouse gases other than energy-related carbon dioxide.

In the *Climate Protection* case, land-based activities, such as forestry, changes in land-use, and agriculture, yield another 58 MtC/yr of reductions. (This figure corresponds to the upper limit for the use of land-based activities in the current negotiating text proposed by the current President of the UN climate talks Jan Pronk.) Methane emissions are also reduced, through measures aimed at landfills, natural gas production and distribution systems, mines, and livestock

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[3] Throughout this report we refer to US emissions target for the year 2010 to mean the average of the five year period from 2008 to 2012.

husbandry. The potent fluorine-containing greenhouse gases can be reduced by substituting with non-greenhouse substitutes, implementing alternative cleaning processes in the semiconductor industry, reducing leaks, and investing in more efficient gas-using equipment. In total, the Climate Protection case adopts reductions of these other greenhouse gases equivalent to 118 MtC/yr by 2010.

All together the reduction measures for energy-related carbon (436 MtC/yr), land-based carbon (58 MtC/yr), and non-carbon gases (118 MtCe/yr) amount to 612 MtCe/yr of reductions in 2010. Through these measures, the United States is able to accomplish the vast majority of its emissions reduction obligation under the Kyoto Protocol through domestic actions. This leaves the United States slightly shy of its Kyoto target, with only 60 MtC/yr worth of emissions allowances to procure from other countries though the “flexibility mechanisms” of the Kyoto Protocol – (Emissions Trading, Joint Implementation, and the Clean Development Mechanism). The Climate Protection case assumes that the US will take steps to ensure that allowances procured through these flexibility mechanisms reflect legitimate mitigation activity. In particular, we assume that US restrains its use of so-called “hot air” allowances, i.e, allowances sold by countries that received Kyoto Protocol targets well above their current emissions.

In addition to greenhouse gas emission reductions, the set of policies in the *Climate Protection* case also reduce criteria air pollutants that harm human health, cause acid rain and smog, and adversely affect agriculture, forests, water resources, and buildings. Implementing the policies would significantly reduce energy-related emissions as summarized in Table ES.2. Sulfur oxide emissions would decrease the most – by half in 2010 and by nearly 75 percent in 2020. The other pollutants are reduced between 7 and 16 % by 2010, and between 17 and 29 percent by 2020, relative to *Base* case levels in those years.

**Table ES.2: Impact of policies on air pollutant emissions**

|  | **1900** | **2010 Base Case** | **2010 Climate Protection** | **2020 Base Case** | **2020 Climate Protection** |
|---|---|---|---|---|---|
| CO | 65.1 | 69.8 | 63.8 | 71.8 | 59.8 |
| NOx | 21.9 | 16.5 | 13.9 | 16.9 | 12.0 |
| SO2 | 19.3 | 12.8 | 6.2 | 12.7 | 3.3 |
| VOC | 7.7 | 5.5 | 5.1 | 5.9 | 4.9 |
| PM-10 | 1.7 | 1.5 | 1.3 | 1.6 | 1.3 |

The complete *Climate Protection* package – including measures to reduce energy-related, land-related, and non-carbon greenhouse gas emissions, as well as modest purchases of allowances – provides a net economic benefit to the US. It also positively affects public health, by reducing emissions of the key air quality-reducing pollutants, including sulfur dioxide, nitrogen oxides, carbon monoxide, particulates, and volatile organic compounds. By dramatically reducing energy consumption, the *Climate Protection* strategy reduces our dependence on insecure energy supplies, while enhancing the standing of the US as a supplier of innovative and environmentally superior technologies and practices.

## 2 Introduction

The earth's atmosphere now contains more carbon dioxide than at anytime over the past several hundred millennia. This precipitous rise in the major greenhouse gas, due to the combustion of fossil fuels since the dawn of the industrial age and the clearing of forests, has warmed the globe and produced climatic changes. What further changes will occur over the coming decades depends on how society chooses to respond to the threat of a dangerously disrupted climate. A concerted global effort to shift to energy-efficient technologies, carbon-free sources of energy and sustainable land-use practices, could keep future climate change to relatively modest levels. If, on the other hand, nations continue to grow and consume without limiting GHG emissions, future climate change could be catastrophic.

Dramatic climate change could unleash a range of dangerous physical, ecological, economic and social disruptions that would seriously undermine the natural environment and human societies for generations to come. Fortunately, a variety of effective policies, which have already been demonstrated, would mobilize current and new technologies, practices and resources to meet the challenge of climate protection. Strong and sustained action to reduce the risk of climate change could also reap additional benefits, such as reducing other air pollutants and saving money, plus help to usher in a new technological and institutional renaissance consistent with the goals of sustainable development. Here we focus on the U.S., which emits almost one-fourth of global carbon dioxide emissions. As a nation, we have both the responsibility and the capability to take the lead in climate protection, and can directly benefit from actions taken. Recently, however, the Bush Administration has gravely disappointed the international community, proposing an energy strategy that is devoid of significant steps to protect the climate.

This report presents a study of policies and measures through which the U.S. could dramatically reduce its greenhouse gas emissions over the next two decades, while spurring technological innovation, reducing pollution, and improving energy security. The study is the latest in a series to which Tellus Institute has contributed, dating back to 1990, which have shown the economic and environmental benefits of energy efficiency and renewable energy resources. It updates and refines *America's Global Warming Solutions* (1999), which found that annual carbon emissions could be reduced to 14 percent below 1990 levels by 2010, with net economic benefits and reductions in air pollution.

Unfortunately, since that study, and indeed over the past decade since the Framework Convention on Climate Change was ratified by the U.S., the promise of these technologies and resources has gone largely unfulfilled, and little has been done to stem the tide of rapidly growing energy use and carbon emissions. This delay and paucity of action has rendered even more difficult the goal of reaching our Kyoto Protocol emissions target of 7 percent below 1990 levels by 2010. Nonetheless, the present study shows the substantial carbon reduction and other benefits that could still be achieved by 2010 with sensible policies and measures, even with this delayed start, and even greater benefits over the following decade. The policy and technological momentum established through 2020 would set the stage for the further reductions needed over the longer term to ensure climate stabilization.

### *The Risk of Climate Change*

The world's community of climate scientists has reached the consensus that human activities are disrupting the Earth's climate (WGI, SPM, 2001; NAS, 2001; Int'l Academies of Science, 2001). Global emissions of $CO_2$ have steadily risen since the dawn of the industrial age, and now amount to about 6 billion tons of carbon released annually from fossil fuel combustion and 1 billion tons annually from land-use changes (mainly burning and decomposition of forest biomass). Without concerted efforts to curb emissions, atmospheric carbon dioxide levels would be driven inexorably higher by a growing global population pursuing a conventional approach to economic development.

While it is impossible to predict with precision how much carbon dioxide we will be emitting in the future, in a business-as-usual scenario annual emissions would roughly triple by the end of the century. By that time, the atmospheric concentration of carbon dioxide would have risen to three times pre-industrial levels (IPCC WGI, 2001). The climatic impacts of these rising emissions could be dramatic. Across a range of different plausible emissions futures explored by the IPCC, global average temperatures are calculated to rise between 3 to 10 degrees Fahrenheit (1.5 to 6 degrees Centigrade), with even greater increases in some regions (IPCC 2001). Such temperature changes would reflect a profound transformation of the Earth's climate system, of the natural systems that depend upon it and, potentially, of the human societies that caused the changes.

The potential consequences of such climate change are myriad and far-reaching. Sea level could rise between 3.5 to 35 inches (9 - 88 centimeters) (IPCC WGI, 2001), with severe implications for coastal and island ecosystems and their human communities. Hundreds of millions of people in the US and abroad live in coastal regions that would be inundated by a 17 inch (44 cm) rise in sea level. Most of these regions are in developing countries that can scarcely afford to expend resources on building dikes and resettling communities. Climate disruption would also entail more frequent, prolonged, and intense extreme weather events, including storms and droughts, the timing, conditions and character of which would remain unpredictable.

Under the stresses courted by continuing current energy practices, climate and ecological systems could undergo very large and irreversible changes, such as a shift in the major ocean currents. Global warming itself could increase the rate of greenhouse gas accumulation, uncontrollably accelerating global warming and its impacts. For example, a thawing of the arctic tundra could release methane at rates far beyond today's anthropogenic rates, and a warming of the oceans could shift them from a net sink to a net source of carbon dioxide.

Moreover, large and irreversible changes could occur very rapidly. Recent scientific evidence from pre-historic ice cores shows that major climate changes have occurred on the time scale of about a decade (Schneider 1998; Severinghaus *et al.* 1998). Rapid change could cause additional ecological and social disruptions, limiting our ability to adapt. This could render belated attempts to mitigate climate change more hurried, more costly, less effective, or too late. Consequently, early and sustained action, across many fronts, is needed to effect the technological, institutional and economic transitions to protect global climate and the ecological and social systems that depend on climate stability.

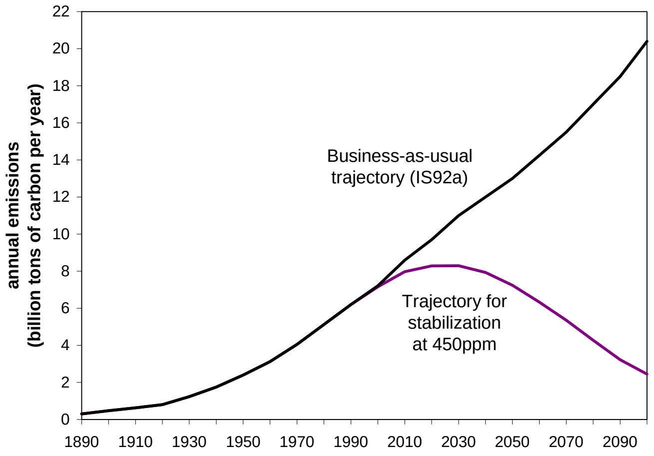
*Protecting the Climate*

The carbon dioxide already released by human activities will linger in the atmosphere for a hundred years or so. This carbon has already changed the climate, and will continue to do so as long as it remains in the atmosphere. But the degree of climate change to which we're already committed pales in comparison to the disruption that humankind would wreak if it continues to recklessly emit more carbon.

An aggressive strategy to curb emissions might limit warming to less than 2°F over the next century (on top of the ~1.0° C that has already occurred over the past century). A temperature increase of about 0.2° F per decade would still exceed natural variability, but would occur gradually enough to allow many, though not all, ecosystems to adapt (Rijsberman and Swart, 1990). To be sure, this goal would not entirely eliminate the risks of disruptive climate change. Warming in some areas would significantly exceed 2°F, the rising sea level would inundate some coastal areas, and changing rainfall patterns could make some regions more prone to drought or floods. A more ambitious stabilization target might well be warranted, but we suggest this goal as an illustration of what might be an environmentally acceptable and practically achievable climate protection trajectory.

To achieve this goal, $CO_2$ concentrations would have to be stabilized at approximately 450 ppm, which is about 60% above pre-industrial concentrations. This would require keeping total global carbon emissions within a budget of 500 billion tons of carbon over the course of the 21st century, whereas a business-as-usual trajectory would have us emitting about 1,400 billion tons. Annual global carbon emissions from fossil fuels would have to be at least halved by the end of the century, from today's 6 billion tons/yr to less than 3 billion tons/yr, and deforestation would need to be halted, in contrast to a business-as-usual trajectory which grows to 20 billion tons/yr. With a growing global population, this implies a decrease in the annual per capita emissions from today's 1 ton to about 0.25 tons, whereas the business-as-usual per capita emissions grow to almost 2 tons. Figure 2.1, which shows these two radically different emissions trajectories, conveys the ambitiousness of this target.

**Figure 2.1: Global carbon emissions from fossil fuel combustion (1890-2100) – Business-as-usual trajectory (IPCC IS92a scenario) and trajectory for climate stabilization at 450 ppm**



The industrialized countries are responsible for about two-thirds of global annual carbon, at more than 3 tons per-capita, with the US at 5.5 tons per capita, while on average developing countries emit only 0.5 tons per capita. Even if emissions in the developing countries were to vanish instantly, implying a nightmarish devolution of their economies, the industrialized world would still need to almost halve its emissions in order to protect the climate.

**Figure 2.2: Carbon emissions for stabilization of GHG concentrations at 450 ppm, broken out by developing and industrialized countries**

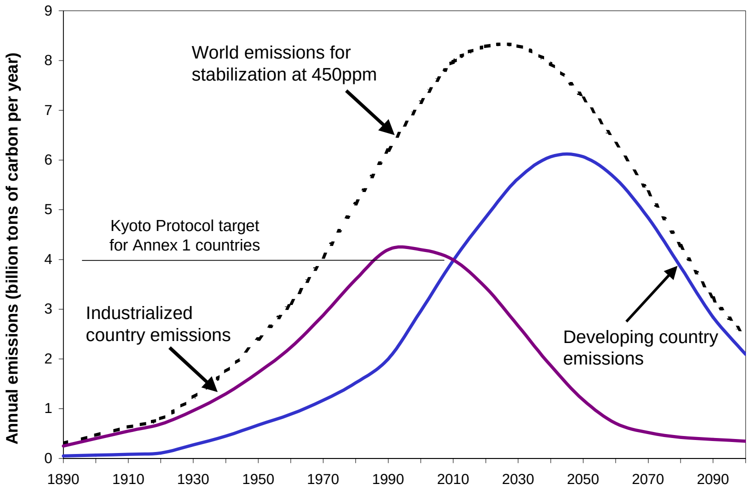


Figure 2.2 shows the global carbon trajectory for stabilization at 450 ppm, as shown in Figure 2.1, broken out into emission paths for both the industrialized and developing countries. In this illustrative allocation, emissions converge to equal per capita emissions (~0.25 tC per capita) by the end of the 21st century. Clearly, it is essential that the industrialized countries begin early and continue steadily to decrease their emissions on a trajectory to meet these climate protection requirements. Industrialized countries on the whole would have to roughly reduce their per capita emissions ten-fold, and the U.S. in particular would have to reduce by more than a factor of twenty.

Emissions from the developing countries could grow in the near term, as they undergo economic development and transition towards advanced, efficient and low-carbon technologies, and then decline rapidly during the latter half of the century. Ultimately, the developing countries would need to halve their per capita emissions relative to today's levels, notwithstanding the considerable economic growth that they are expected to realize over this century. This would involve economic development predicated upon use of energy technologies and energy resources that would entail a "leap-frogging" over the fossil-based economic development that has occurred in the industrialized countries directly to cleaner energy sources. Such a transition would require concerted technology and institutional cooperation, with associated financial assistance, among developing and industrialized countries.

Stabilization and equalization would thus be served by a dual technological transition in which the industrialized countries can take the lead, by demonstrating their commitment to addressing a problem for which it bears primary responsibility, and fostering the first wave of technological innovation from which both developing and industrialized countries could benefit.

### *The Kyoto Protocol*

Although only a first small step, the Kyoto Protocol offers a pivotal opportunity to shift away from the climate-disrupting path down which the world is now headed, and onto a climate-protecting path. It is well understood that the Kyoto Protocol is the basis for future emissions reductions as well. If it enters into force, the Kyoto Protocol will legally bind industrialized countries that ratify it to specific GHG reduction targets, to be attained during the during the five year "budget period" from 2008 to 2012. For the US, the target is 7 percent less than the 1990 emission levels. The limit is 6 percent for Japan, 0 percent for Russia, and an average of 8 percent for the European Union countries. Across all industrialized countries, the emissions budget is 5 percent below 1990 emissions rate, whereas the business-as-usual emissions rate is projected to *increase* by approximately 20 percent by 2010.

The Kyoto Protocol offers a number of options to lower the cost of meeting their targets. Many of these so-called “flexibility mechanisms” were included at the request of the US in Kyoto. They allow countries to carry out projects that reduce carbon emissions (or enhance carbon absorption) from biological stocks such as forests and possibly agricultural land, or can reduce emissions of GHGs other than carbon[4]. Countries can also undertake GHG mitigation projects in other countries[5] and acquire credits for the resulting reductions, or can simply purchase excess carbon allowances from countries that surpass their targets[6].

However, these flexibility mechanisms should be implemented with caution, lest they undermine effectiveness of the Kyoto Protocol. Given its modest reduction targets relative to the much deeper reductions ultimately needed for climate protection, the main purpose of the Protocol is to reduce greenhouse gas emissions by launching a global transition in technologies and infrastructure for energy production and use. The first budget period should end with a decisive shift away from conventional energy investments, real progress in institutional learning and technological innovation, and momentum to deepen and expand these changes over the longer term. An over-reliance on the flexibility mechanisms may permit too slow a start, and too weak a signal, to motivate this fundamental transition.

Excessive use of the flexibility mechanisms could undermine the needed transition in several ways. First, the emissions trading system is in danger of being severely diluted by cheap carbon allowances from the Russian Federation and Ukraine, whose negotiated targets are far above the emission levels they will reach by 2010 even without reduction efforts. Second, inadequate rules for credits from project-based mechanisms could generate “free-rider” credits that reflect inflated estimates of their mitigation value, thereby undermining the Protocol’s targets. Third, mitigation activities that rely on biological sequestration strain our current technical ability to reliably measure carbon changes, are based on uncertain science, and take pressure off of fossil fuel reduction. Perhaps more importantly, institutions are not yet in place to ensure that such projects do not harm biodiversity and human communities.

The attraction and rhetoric of solutions that lie outside the borders of the industrialized countries is misguided at this time. To be sure, there are important opportunities to help developing countries advance along a sustainable, low carbon path. But unfettered use overseas options, justified by lower short-term costs for the industrialized countries, would be a head-in-the-sand approach to the long-term responsibility of climate protection. The quantity of such offsets should be limited and their quality guaranteed.  Procedures should be established to help ensure that the various flexibility mechanisms help protect the climate and advance sustainable development. These include consistency with local ecological, cultural, economic conditions and constraints, guaranteed public participation in project design, certification and review, strong ecological and social criteria, human and institutional capacity-building goals, strong and equitable relationships

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[4] The GHGs that are covered by the Kyoto Protocol include carbon dioxide (CO2), methane (CH4), nitrous oxide (N2O), hydroflourocarbons (HFCs), perflourocarbons (PFCs), and sulfur hexaflouride (SF6).

[5] “Joint Implementation” (JI) is the relevant mechanism if the host country is an industrialized country with a target, and “Clean Development Mechanism” (CDM) if the host country is a developing country.

[6] Purchase of allowances is known as “Emissions Trading”.

for technology cooperation, and acceptable procedures for monitoring, verification and accreditation of offset actions and transactions. Until then it is premature to rely on the CDM for more than a very small part of the required emissions reductions.

If the U.S. relies too heavily on the flexibility mechanisms, it could forego opportunities to reap the co-benefits of decreasing carbon emissions at home. These include the reduced health and ecological damages resulting from decreased emissions of mercury, fine particulates and other pollutants, and the improvements in technologies, skills and productivity accompanying deployment and use of more advanced technologies and practices. It could also find itself in a poorer position to meet the stricter emissions reduction commitments expected for subsequent budget periods. The nation could become a follower rather than a leader in advanced technologies in domestic and world markets. Thus, it could miss the opportunity provided by the Kyoto Protocol for a national technological and economic "renaissance" with cleaner energy, processes and products in the coming decades.

## 3 Policies

This study examines a broad set of national policies that would increase energy efficiency, accelerate the adoption of renewable energy technologies, and shift to less carbon-intensive fossil fuels. This policy package contrasts sharply with the Bush Administration's energy strategy, which heavily focuses on fossil fuels and lacks any significant effort to protect the climate. The policies address major areas of energy use in the buildings, industrial, transport, and electrical sectors. Analyses of the investment costs and energy savings of policies to promote energy efficiency and co-generation in the residential, commercial, and industrial sectors were taken primarily from the American Council for an Energy Efficient Economy (1999; 2001).

Below we group these policies into the particular sector where they take effect, and describe the key assumptions made concerning the technological impacts of the individual policies. Unless otherwise indicated, each of the policies is assumed to start in 2003.

As explained further in the methodology discussion in the next section, we adapted the Energy Information Administration's 2001 Reference Case Forecast (EIA 2001) to create a slightly revised "base case." Our policies and assumptions build on those included in this base case forecast (i.e., we avoid taking credit for emissions reductions, costs, or savings already included in the EIA 2001 Reference Case). When taken together, the policies described in this section represent a *Climate Protection* Scenario that the US could pursue to achieve significant carbon reductions.

### 3.1 Policies in the Buildings and Industrial Sectors

Carbon emissions from fuel combustion in the buildings (including both residential and commercial) sector account for about 10 percent of US greenhouse gas emissions, while emissions from the industrial sector account for another 20 percent. When emissions associated with the electricity consumed are counted, these levels reaches over 35% for buildings and 30% for industry. We analyzed a set of policies that include new building codes, new appliance standards, tax incentives for the purchase of high efficiency products, a national public benefits fund, expanded research and development, voluntary agreements and support for combined heat and power.

### *Building codes*

Building energy codes require all new residential and commercial buildings to be built to a minimum level of energy efficiency that is cost-effective and technically feasible. "Good practice" residential energy codes, defined as the 1992 (or a more recent) version of the Model Energy Code (now known as the International Energy Conservation Code), have been adopted by 32 states (BCAP 1999). "Good practice" commercial energy codes, defined as the ASHRAE 90.1 model standard, have been adopted by 29 states (BCAP 1999). However, the Energy Policy Act of 1992 (EPAct) requires all states to adopt a commercial building code that meets or exceeds ASHRAE 90.1, and requires all states to consider upgrading their residential code to meet or exceed the 1992 Model Energy Code.

This policy assumes that DOE enforces the commercial building code requirement in EPAct and that states comply. We also assume that relevant states upgrade their residential energy code to either the 1995 or 1998 Model Energy Code either voluntarily or through the adoption of a new federal requirement. Furthermore, we assume that the model energy codes are significantly improved during the next decade and that all states adopt mandatory codes that go beyond current "good practice" by 2010. To quantify the impact of these changes, we assume a 20% energy savings in heating and cooling in buildings in half of new homes and commercial buildings.

### *New Appliance and Equipment Efficiency Standards*

The track record for electricity efficiency standards is impressive, starting with the National Appliance Energy Conservation Act of 1987 and continuing through the various updates that were enacted in early 2001 for washers, water heaters, and central air conditioners. These standards have removed the most inefficient models from the market, while still leaving consumers with a diversity of products. An analysis of Department of Energy figures by the American Council for an Energy Efficient Economy, estimates nearly 8% of annual electricity consumption will be saved in 2020 due to standards already enacted (Geller et al. 2001). However, many appliance efficiency standards haven't kept pace with either legal updating requirements or technological advances. The Department of Energy is many years behind its legal obligation to regularly upgrade standards for certain appliances to the "maximum level of energy efficiency that is technically feasible and economically justified."

In this study, we assume that the government upgrades existing standards or introduces new standards for several key appliances and equipment types: distribution transformers, commercial air conditioning systems, residential heating systems, commercial refrigerators, exit signs, traffic lights, *torchiere* lighting fixtures, ice makers, and standby power consumption for consumer electronics. We also assume the higher energy efficiency standards for residential central air conditioning and heat pumps than was allowed by the Bush Administration. These are all measures that can be taken in the near term, based on technologies that are available and cost-effective.

### *Tax incentives*

A wide range of advanced energy-efficient products have been proven and commercialized, but have not yet become firmly established in the marketplace. A major reason for this is that conventional technologies get "locked-in"; they benefit from economies of scale, consumer awareness and familiarity, and already existing infrastructure that make them more able to attract consumers, while alternatives are overlooked though they could be financially viable once mass-produced and widely demonstrated. Initial, temporary tax incentives can help usher advanced alternatives into the market place, which – once established – can proceed to gain significant market share without further subsidy.

In this study, we consider initial tax incentives for a number of products. For consumer appliances, we considered a tax incentive of $50 to $100 per unit. For new homes that are at least 30% more efficient that the Model Energy Code, we considered an incentive of up to $2,000 per home; for commercial buildings with at least 50% reduction in heating and cooling costs relative to applicable building codes, we applied an incentive equal to $2.25 per square foot. Regarding building equipment such as efficient furnaces, fuel cell power systems, gas-fired heat pumps, and electric heat pump water heaters, we considered a 20% investment tax credit. Each of these incentives would be introduced with a sunset clause, terminating them or phasing them out in approximately five years, so as to avoid their becoming permanent subsidies. Versions of all of the tax incentives considered here have already been introduced into bills before the Senate and/or House[7].

*National Public Benefits Fund*

Electric utilities have historically funded programs to encourage more efficient energy-using equipment, assist low-income families with home weatherization, commercialize renewables, and undertake research and development (R&D). Such programs have typically achieved electricity bill savings for households and businesses that are roughly twice the program costs (Nadel and Kushler, 2000). Despite the proven effectiveness of such technologies and programs, increasing price competition and restructuring have caused utilities to reduce these “public benefit” expenditures over the past several years. In order to preserve such programs, fifteen states have instituted public benefits funds that are financed by a small surcharge on all power delivered to consumers.

This study’s policy package includes a national level public benefits fund (PBF) fashioned after the proposal introduced by Sen. Jeffords (S. 1369) and Rep. Pallone (H. 2569) in the the 106th Congress. The PBF would levy a surcharge of 0.2 cents per kilowatt-hour on all electricity sold, costing the typical residential consumer about $1 per month. This federal fund would provide matching funds for states for approved public benefits expenditures. In this study, the PBF is allocated to several different programs directed at improvements in lighting, air conditioning, motors, and other cost-effective energy efficiency improvements in electricity-using equipment.

*Expand Federal funding for Research and Development in Energy Efficient Technologies*

Federal R&D funding for energy efficiency has been a spectacularly cost-effective investment. The DOE has estimated that the energy savings from 20 of its energy efficiency R&D programs has been roughly $30 billion so far – more than three times the federal appropriation for the entire energy efficiency and renewables R&D budget throughout the 1990s (EERE, 2000). At a time when energy issues are in the forefront of the national debates, such R&D efforts should be increased and should be thought of as a remedy for the real energy crises engendered by

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[7] The bills include those introduced by Senators Murkowski and Lott (S.389); Bingaman and Daschle (S.596), Smith (S.207), Hatch (S.760), and Representative Nussle (H.R. 1316).

continued fossil fuel dependence – climate change, environmental damage, and diminishing fossil fuel supplies.

Tremendous opportunities exist for further progress in material-processing technologies, manufacturing processing, electric motors, windows, building shells, lighting, heating/cooling systems, and super-insulation, for example. The EPA's *Energy Star* programs have also saved large amounts of energy, building on the achievements of R&D efforts and ushering efficient products into the marketplace. By certifying and labeling efficient lighting, office equipment, homes and offices, *Energy Star* has helped foster a market transformation toward much more efficient products and buildings. Currently, roughly 80 percent of personal computers, 95 percent of monitors, 99 percent of printers, and 65 percent of copiers sold are Energy Star certified (EPA, 2001; Brown *et al*, 2001). In light of these successes, EPA should be allocated the funds to broaden the scope of its Energy Star program, expanding to other products (refrigerators, motors) and building sectors (hotels, retailers), and the vast market of existing buildings that could be retrofitted. In this study, we assume that increased funding to expand research and development efforts in industry (e.g., motors) buildings (e.g., advanced heating/cooling), and transport (e.g., more fuel efficient cars and trucks) will lead to more energy-savings products becoming commercially available.

### *Industrial Energy Efficiency through Intensity Targets*

There is remarkable quantity of untapped, cost-effective energy efficiency potential in today's industrial facilities (Elliott 1994), and some corporate managers have shown impressive initiative in moving to realize that potential. In 1995, Johnson and Johnson set a goal of reducing its energy costs 10% by 2000 through adoption of "best practices" in its 96 U.S. facilities. Building on this work, in 2000 Johnson & Johnson pledged to reduce global warming gases by seven percent below 1990 levels by the year 2010, with an interim goal of four percent below 1990 levels by 2005.

In 1998, British Petroleum announced it would voluntarily reduce its carbon emissions to 10 percent below 1990 levels by 2010, representing almost a 40 percent reduction from projected emissions levels in 2010 given "business-as-usual" emissions growth (Romm 1999). And in September 1999, DuPont announced it would reduce its GHG emissions worldwide by 65 percent relative to 1990 levels, while holding total energy flat and increasing renewable energy resources to 10 percent of total energy inputs, by 2010. DuPont appears to be on track for achieving earlier commitments to reduce energy intensity 15 percent and total GHG emissions 50 percent, relative to 1990 levels, by 2000 (Romm 1999). Companies as diverse as Alcoa, Kodak, Polaroid, IBM and Royal Dutch Shell also find it cost-effective to establish worldwide greenhouse gas reduction targets. The practices these companies are developing make them better prepared for an economy that places a value on carbon reductions.

There is substantial potential for cost-effective efficiency improvement in both energy-intensive and non-energy intensive industries (Elliott 1994). For example, an in-depth analysis of 49 specific energy efficiency technologies for the iron and steel industry found a total cost-effective energy savings potential of 18% (Worrell, Martin, and Price 1999).

We consider in this study federal initiatives to motivate and assist industry to identify and exploit energy efficiency opportunities. Government agencies can support industry by providing technical and financial assistance, and by expanding federal R&D and demonstration programs.

In addition to these carrots, government may need to brandish a stick in order to induce a large fraction of industries to make serious energy efficiency commitments. If industry does not respond to the federal initiatives at a level sufficient to meet certain energy efficiency targets, a mandatory, binding energy intensity standard should be triggered to ensure the required targets are attained.

*Support for Co-generation*

Cogeneration (or, combined heat and power – CHP) is a super-efficient means of co-producing two energy-intensive products that are usually produced separately – heat and power. The technical and economical value of CHP has been widely demonstrated, and some European countries rely heavily on CHP for producing power and providing heat to industries, businesses, and households. The thermal energy produced in co-generation can also be used for (building and process) cooling or to provide mechanical power.

While CHP already provides about 9 percent of all electricity in the US, there are considerable barriers to its wider cost-effective implementation (Elliott and Spurr, 1999). Environmental standards should be refined to recognize the greater overall efficiency of CHP systems, for example by assessing facility emissions on the basis of fuel input, rather than useful energy output. Non-uniform tax standards discourage CHP implementation in certain facilities. Moreover, utility practices are generally highly hostile to prospective CHP operators, through discriminatory pricing and burdensome technical requirements and costs for connecting to the grid.

In this study, we consider the impact of introducing policies that would establish a standard permitting process, uniform tax treatment, accurate environmental standards, and fair access to electricity consumers through the grid. Such measures would help to unleash a significant portion of the enormous potential for CHP. In this study we assumed 50 GW of new CHP capacity by 2010, and an additional 95 GW between 2011 and 2020. With electricity demand reduced by the various energy efficiency policies adopted in this study, co-generated electricity reaches 8% percent of total remaining electricity requirements in 2010 and 36% percent in 2020.

### 3.2 Policies in the Electric Sector

A major goal of US energy and climate policy will be to dramatically reduce carbon and other pollutant emissions from the electric sector, which is responsible for more than one-third of all US greenhouse gas emissions. We analyzed a set of policies in the electric sector that include standards and mechanisms to help overcome existing market barriers to investments in technologies that can reduce emissions. Three major policies -- a renewable portfolio standard, a cap on pollutant emissions, and a carbon cap and trade system -- were considered as described below.

*Renewable Portfolio Standard*

A Renewable Portfolio Standard (RPS) is a flexible, market-oriented policy for accelerating the introduction of renewable resources and technologies into the electric sector. An RPS sets a schedule for establishing a minimum amount of renewable electricity as a fraction of total generation, and requires each generator that sells electricity to meet the minimum either by producing that amount of renewable electricity in its mix or acquiring credits from generators that exceed the minimum. The market determines the portfolio of technologies and geographic distribution of facilities that meet the target at least cost. This is achieved by a trading system that awards credits to generators for producing renewable electricity and allows them to sell or purchase these credits. Thirteen states – Arizona, Connecticut, Hawaii, Iowa, Maine, Massachusetts, Minnesota, Nevada, New Jersey, New Mexico, Pennsylvania, Texas, and Wisconsin – already have RPSs, and Senator Jeffords introduced a bill in the 106th Congress (S. 1369) to establish a national RPS.

The RPS provides strong incentives for suppliers to design the lowest cost, most reliable renewable electricity projects, and to identify niche applications and consumers where the projects will have the greatest value. It also provides assurance and stability to renewable technology vendors, by guaranteeing markets for renewable power, allowing them to capture the financial and administrative advantages that come with planning in a more stable market environment. Yet it still maintains a competitive environment that encourages developers to innovate. Finally, by accelerating the deployment of renewable technologies and resources, the RPS also accelerates the learning and economies of scale that allow renewables to become increasingly competitive with conventional technologies. This is particularly important, as the demands of climate stabilization in coming decades will require more renewable energy than we can deploy in the next two decades.

In this study, we have applied an RPS that starts at a 2 percent requirement in 2002, grows to 10% in 2010, and to 20% in 2020, after all efficiency policies are included. Wind, solar, geothermal, biomass, and landfill gas are eligible renewable sources of electricity, but environmental concerns exclude municipal solid waste (owing to concerns about toxic emissions from waste-burning plants) and large-scale hydro (which also raises environmental concern and need not be treated as an emerging energy technology as it already supplies nearly 10% of the nation’s electricity supply).

As a modest addition to the RPS we provide a subsidy to grid-connected solar photovoltaic electricity generation. The purpose of this subsidy is to introduce a small amount of this technology so that it can play a role in the generation mix, seeking to induce technology learning, performance improvement and scale economies, and ultimately increased fuel diversity and another zero emissions option for the longer term. The level is kept small so that costs and price impacts are minimal.

### *Tightening of $SO_2$ and $NO_x$ Emission Regulations*

Acid rain and urban air pollution remain serious problems in the US. The 1990 Clean Air Act Amendments attempted to address these problems, by introducing a cap-and-trade system to roughly halve the electric sector’s $SO_2$ emissions by 2000, and imposing technology-specific standards for $NO_x$ emissions. Compliance with the $SO_2$ standard proved markedly cheaper than initially expected; initial estimates were mostly based on investments in “scrubbers” but the discovery of large low-sulfur coal reserves in the Wyoming basins and a sharp decline in the cost of rail transport resulted in lower costs.

Despite the improvements brought about by the Clean Air Act and its Amendments, recent studies have confirmed that $SO_2$ and $NO_x$ continue to harm lake and forest ecosystems, decrease agricultural productivity and affect public health through its damaging affects on urban air quality (Clean Air Task Force, 2000). The Clean Air Act only calls for minimal reductions in the cap by 2010 and no reductions after that.

In this study, we tighten the $SO_2$ cap so as to reduce sulfur emissions to roughly 40% of current levels by 2010 and one third of current levels by 2020. We also impose a cap-and-trade system on $NO_x$ emissions in the summertime, when $NO_x$ contributes more severely to photochemical smog. This system expands the current cap and trade program, which calls on 19 states to meet a target in 2003 that then remains constant, to include all states with a cap that is set first in 2003 but decreases in 2010, relative to 1999 levels. The cap results in a 25% reduction of annual $NO_x$ emissions by 2003, and a 50% reduction by 2010.

### *Carbon Cap-And-Trade Permit System*

This study introduces a cap-and-trade system for carbon in the electric sector; with the cap set to achieve progressively more stringent targets over time, starting in 2003 at 2% below current levels, increasing to 12% below current by 2010 and 30% below by 2020. Restricting carbon emissions from electricity generation has important co-benefits, including reduced emissions of $SO_2$ and $NO_x$, as discussed above, fine particulate matter, which is a known cause of respiratory ailments, and mercury, which is a powerful nervous system toxin and already contaminates over 50,000 lakes and streams in the US. A progressively more stringent target also reduces demand for coal, and hence mining-related pollution of streams and degradation of landscapes and terrestrial habitats.

In the $SO_2$, $NO_x$, and $CO_2$ trading systems, permits are distributed through an open auction, and the resulting revenues can be returned to households (e.g., through a tax reduction or as a rebate back to households). Recent analyses suggest that an auction is the most economically efficient way to distribute permits, meeting emissions caps at lower cost than allocations based on grandfather allowances or equal per kWh allowances (Burtraw, *et al.* 2001). Implementing such auctions for the electric sector will also clear the way for an economy-wide approach in future years based on auctioning. In this study, the price of auctioned carbon permits reaches $100 per metric ton carbon.

While not specifically targeted by the trading programs, the operators of the 850 old "grandfathered" coal plants built before the Clean Air Act of 1970, which emit 3-5 times as much pollution per unit of power generated than newer coal power plants, will likely retire these plants rather than face the cost of purchase the large amount of credits necessary to keep them running. When the Clean Air Act was adopted, it was expected that these dirty power plants would eventually be retired. However, utilities are continuing to operate these plants beyond their design life, and have in fact increased their output over the last decade. By subjecting these old plants to the same requirements as newer facilities, as has been done or is being considered in several states including Massachussetts and Texas, operators would be obliged to modernize the old plants or to retire them in favor of cleaner electric generation alternatives.

With a cap and trade system in place for CO2, SOx and NOx, this scenario reduces multiple emissions from power plants, in a manner similar to that adopted in the Four Pollutant Bill currently before the House (H.R., 1256) and the Senate (S. 556). The reductions in these three pollutants are as deep as those imposed in the Four Pollutant bills, and are achieved within a comparable time frame. (The Department of Energy's NEMS model unfortunately does not explicitly track mercury, making it impossible to compare the results of this study to the mercury requirement in the Four Pollutant Bill.[8])

## 3.3 Policies in the Transport Sector

Another goal of US energy and climate policy will be to reduce carbon emissions from the transport sector, which is responsible for about one-third of all US greenhouse gas emissions. We analyzed a set of policies in the transportation sector that include improved efficiency (light duty vehicles, heavy duty trucks and aircraft), a full fuel-cycle GHG standard for motor fuels, measures to reduce road travel, and high speed rail.

### *Strengthened CAFE Standards*

Today's cars are governed by fuel economy standards that were set in the mid-1970s. The efficiency gains made in meeting those standards have been entirely wiped out by increases in population and driving, as well as the trend toward gas-guzzling SUVs. When the fuel economy standards were implemented, light duty trucks only accounted for about 20 percent of vehicle sales. Light trucks now account for nearly 50 percent of new vehicle sales; this has brought down the overall fuel economy of the light duty vehicle fleet, which now stands at its lowest average fuel economy since 1981. If the fuel economy of new vehicles had held at 1981 levels rather than tipping downward, American vehicle owners would be importing half a million fewer barrels of oil each day.

We introduce in this study a strengthened Corporate Average Fuel Economy standard for cars and light trucks, along with complementary market incentive programs. Specifically, fuel economy standards for new cars and light trucks rise from EIA's projected 25.2 mpg for 2001 to 36.5 mpg in 2010, continuing to 50.5 mpg by 2020. This increase in vehicle fuel economy would save by 2020 approximately twice as much oil as could be pumped from Arctic National Wildlife Refuge oil field over its entire 50-year lifespan (USGS, 2001).[9] Based on assessments of near-term technologies for conventional vehicles, and advanced vehicle technologies for the longer-term, we estimate that the 2010 CAFE target can be met with an incremental vehicle cost of approximately $855, and the 2020 CAFE target with an incremental cost of $1,900. To put these incremental costs in perspective, they are two to three times less than the fuel savings at the gasoline pump over the vehicle's lifetime[10].

### *Improving Efficiency of Freight Transport*

We also consider policies to improve fuel economy for heavy duty truck freight transport, which accounts for approximately 16% of all transport energy consumption. A variety of improvements such as advanced diesel engines, drag reduction, rolling resistance, load reduction strategies, and low friction drivetrains offer opportunities to increase the fuel economy of freight trucks. Many of these technologies are available today while other technologies like advanced diesel and turbine engines have been technically demonstrated but are not yet commercially available.

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[8] On December 15, 2000, the EPA announced that mercury emissions need to be reduced, and that regulations will be issued by 2004.

[9] Assuming a mean value at a market price of oil of $20/barrel.

[10] Assuming a retail price of gasoline of $1.50/gallon, a 10-year life of the vehicle, and 12,000 miles per year.

To accelerate the improvement in heavy duty truck efficiency, we have considered measures that expand R&D for heavy duty diesel technology, vehicle labeling and promotion, financial incentives to stimulate the introduction of new technologies, efficiency standards for medium- and heavy-duty trucks, and fuel taxes and user-fees calibrated to eliminate the existing subsidies for freight trucking. Together, it is estimated that these policies could bring about a fuel economy improvement of 6% by 2010, and 23% by 2020, relative to today's trucks.

### *Improving Efficiency of Air Travel*

Air travel is the quickest growing mode of travel, and far more energy intensive than vehicle travel. One passenger mile of air travel today requires about 1.7 times as much fuel as vehicle travel.[11]. We consider here policies for improving the efficiency of air travel, including R&D in efficient aircraft technologies, fuel consumption standards, and a revamping of policies that subsidize air travel through public investments.

We assume that air travel efficiency improves by 23% by 2010, and 53% by 2020. This is in contrast to the Base Case where efficiency increases by 9% by 2010 and 15% by 2020, owing to a combination of aircraft efficiency improvements (advanced engine types, lightweight composite materials, and advanced aerodynamics), increased load factor, and acceleration of air traffic management improvements (Lee et el, 2001; OTA, 1994; Interlaboratory Working Group, 2000). While we assume that air travel can reach 82 seat-miles per gallon by 2020 from its current 51, it is technologically possible that far greater efficiencies approaching 150 seat-miles/gal could be achieved, if not in that time period then over the longer term. (Alliance to Save Energy et al, 1991).

### *Greenhouse Gas Standards for Motor Fuels*

Transportation in the US relies overwhelmingly on petroleum-based fuels, making it a major source of GHG emissions. We introduce here a full fuel-cycle GHG standard for motor fuels, similar in concept to the RPS for the electric sector. The standard is a cap on the average GHG emissions from gasoline, and would be made progressively more stringent over time. Fuel suppliers would have the flexibility to meet the standard on their own or by buying tradable credits from other producers of renewable or low-GHG fuel.

The policy adopted in this study requires a 3 percent reduction in the average national GHG emission factor of fuels used in light duty vehicles in 2010, increasing to a 7 percent reduction by 2020. The policy would be complemented by expanded R&D, market creation programs, and financial incentives. Such a program would stimulate the production of low-GHG fuels such as cellulosic ethanol and biomass- or solar-based hydrogen.

For this modeling study, we assume that most of the low-GHG fuel is provided as cellulosic ethanol, which can be produced from agricultural residues, forest and mill wastes, urban wood wastes, and short rotation woody crops (Walsh et al 1998; Walsh, 1999). As cellulosic ethanol can be co-produced along with electricity, in this study we assume that electricity output reaches 10 percent of ethanol output by 2010 and 40 percent by 2020 (Lynd, 1997). Due to the accelerated development of the production technology for cellulosic ethanol, we estimate that the

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[11] Assuming typical load factors of 0.33 for autos and 0.6 for air

price falls to $1.4 per gallon of gasoline equivalent by 2010 and remains at that price thereafter (Interlaboratory Working Group, 2000).

### *Improving Alternative Modes to reduce Vehicle Miles Traveled*

The amount of travel in cars and light duty trucks continues to grow due to increasing population and low vehicle occupancy. Between 1999 and 2020, the rate of growth in vehicle miles traveled is projected to increase in the Base Case by about 2% per year. The overall efficiency of the passenger transportation system can be significantly improved through measures that contain the growth in vehicle miles traveled through land-use and infrastructure investments and pricing reforms to remove implicit subsidies for cars, which are very energy intensive.

We assume that these measures will primarily affect urban passenger transportation and result in a shift to higher occupancy vehicles, including carpooling, vanpooling, public transportation, and telecommuting. We consider that the level of reductions of vehicle miles traveled that can be achieved by these measures relative to the Base Case are 8% by 2010 and 11% by 2020.

### *High Speed Rail*

High speed rail offers an attractive alternative to intercity vehicle travel and short distance air travel. In both energy cost and travel time, high speed rail may be competitive with air travel for trips of roughly 600 miles or less, which account for about one-third of domestic air passenger miles traveled. Investments in rail facilities for key inter-city routes (such as the Northeast corridor between Washington and Boston, the East cost of Florida between Miami and Tampa, and the route linking Los Angeles and San Francisco) could provide an acceptable alternative and reduce air travel in some of the busiest flight corridors (USDOT, 1997).

High speed rail can achieve practical operating speeds of up to 200 mph. Prominent examples include the French *TGV*, the Japanese *Shinkansen*, and the German *Intercity Express*. An emerging advanced transport technology is the maglev system in which magnetic forces lift and guide a vehicle over a specially designed guideway. Both Germany and Japan are active developers of this technology.

In this analysis we have taken the DOT's recent estimates of the potential high speed rail ridership which, based on projected mode shifts from air and automobile travel in several major corridors of the US, reaches about 2 billion passenger miles by 2020 (DOT, 1997). While this level of HRS ridership provides relatively small energy and carbon benefits by 2020, it can be viewed as the first phase of a longer-term transition to far greater ridership and more advanced, faster and efficient electric and MAGLEV systems in the ensuing decades.

## 4 Methods and Assumptions

The modeling for this study was based primarily on the National Energy Modeling System (NEMS) of the U.S. Department of Energy, Energy Information Administration (DOE/EIA) (EIA, 2001). The NEMS model version, data and assumptions employed in this study were those of EIA's *Annual Energy Outlook* (EIA 2001), which also formed the basis for the Base Case. We refined the NEMS model with advice from EIA, based on their ongoing model improvements, and drawing on expert advice from colleagues at ACEEE and the Union of Concerned Scientists, the National Laboratories and elsewhere.[12]

The NEMS model takes account of the interactions between electricity supply and demand (aggregated residential, commercial and industrial), taking account of the mix of competitive and still regulated pricing in the US. It accounts for the feedback effects between electricity market and power plant construction decisions, as well as the links between fuel demands, supplies and prices.

Our use of NEMS for this project focused on the Electricity Market Module (EMM), complemented by the Oil and Gas Supply Module (OGSM). The EMM starts with the detailed fleet of existing power plants in the thirteen electric sector regions of the U.S, and also represents power imports from neighboring Canadian regions. It makes dispatch, construction, inter-regional purchase and retirement decisions based upon the regional electricity demands and the cost and performance characteristics of existing and new electric supply options, adhering to national pollutant caps and any state-level RPS requirements. It also takes account of cost reductions of new power plants with increased units in operation (learning and scale economies). The OGSM tracks changes in prices of natural gas and petroleum fuels based on changes in their demand.

Analyses of the costs and demand impacts of policies to promote energy efficiency and co-generation in the residential, commercial, and industrial sectors were taken primarily from American Council for an Energy Efficient Economy (ACEEE, 1999; ACEEE, 2001). The electric generation, fuel, emissions and monetary savings from these policies were obtained using NEMS, to take account of all of the interactive and feedback effects described above. NEMS was used also to obtain the interactive effects of the policies affecting electricity demand and those, such as renewable, carbon and emission standards, which affect the electricity supply mix.

For example, we used information from ACEEE to lower the fuel and electricity demand within NEMS based on policies in the demand sectors. We ran NEMS to determine the new mix of electricity generation (based on changes in both electricity demand and the electricity sector policies). This resulted in decreased demand for oil and gas, leading to lower prices. NEMS iterates internally between energy supply and demand to seek a consistent solution.

Analyses of the policy impacts in the transportation sector took account of vehicle stock turnover, fuel-efficiencies and travel indices, and were benchmarked to the structure, data and baseline projections of the AEO2001. Following assumptions for light duty vehicle efficiency in ACEEE (2001) and other sources (DeCicco, Ross and An, 2001), we accounted for both autonomous and policy-induced vehicle efficiency improvement, shifts between transport modes, and changes in demand for transport services.

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[12] More detailed discussions of the approach taken for sectoral policy analyses upon which this study was based can be found in *Energy Innovations* (EI 1997), the *Energy Policy, Special Issue on Climate Strategy for the United States* (1998), and Bernow *et al.* (1998 and 1999).

## 5 Results

Carbon dioxide emissions in the United States have been rising over the past decade, and now exceed by more than 15 percent the 1990 emission rate of 1338 MtC/yr (EIA, 2001b). The US Department of Energy (EIA, 2001a) business-as-usual scenario projects that these emissions will to continue to rise to 1808 MtC/yr in 2010 – a 35 percent increase above 1990 levels. This is in stark contrast to the emissions limit that the US negotiated at Kyoto – a 7 percent decrease below 1990 levels.

### 5.1 Overview of Results

Table 5.1 provides summary results on overall energy and carbon impacts, pollutant emissions impacts, and economic impacts for the *Base* and *Climate Protection* cases for 2010 and 2020. The portfolio of carbon-reducing policies and measures composed for this *Climate Protection* scenario brings the US a long way toward meeting its Kyoto target, reducing carbon emissions

**Table 5.1 Summary of results.**

| | **1990[13]** | **2010 Base Case** | **2010 Climate Protection** | **2020 Base Case** | **2020 Climate Protection** |
|---|---|---|---|---|---|
| **End-use Energy** (Quads) | 63.9 | 86.0 | 76.4 | 97.2 | 72.6 |
| **Primary Energy** (Quads) | 84.6 | 114.1 | 101.2 | 127.0 | 89.4 |
| **Renewable Energy** (Quads) | | | | | |
| Non-Hydro | 3.5 | 5.0 | 10.4 | 5.5 | 11.0 |
| Hydro | 3.0 | 3.1 | 3.1 | 3.1 | 3.1 |
| **Net GHG Emissions** (MtCe/yr) | 1,648 | 2,204 | 1,533 | ----- | ----- |
| Energy Carbon | 1,338 | 1,808 | 1,372 | 2,042 | 1,087 |
| Land-based Carbon | ----- | ----- | -58 | ----- | ----- |
| Non-CO2 Gases | 310 | 397 | 279 | ----- | ----- |
| International Trade | ----- | ----- | -60 | ----- | ----- |
| **Net Savings[14]** | | | | | |
| Cumulative present value (billion$) | ------ | ------ | $105 | ------ | $576 |
| Levelized annual (billion$/year) | ------ | ------ | $13 | ------ | $49 |
| Levelized annual per household ($/year) | ------ | ------ | $113 | ------ | $375 |

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[13] Under Kyoto, the base year for three of the non-CO2 GHGs (HFCs, PFCs, SF6) is 1995, not 1990, and the 1995 levels for these emissions are reported here.

[14] Savings are in 1999 $. The 2010 savings include $2.3 billion costs per year ($9 billion cumulative through 2010) of non-energy related measures needed to meet the Kyoto target. Costs are not included in 2020 since these measures policies do not extend past 2010.

from today’s level to 1372 MtC/yr by 2010 – but still 2.5 percent above 1990 levels. Reductions continue beyond 2010, and national emissions are reduced to 1087 MtC/yr in 2020, well below 1990 levels.

Overall, the national policies and measures were estimated to achieve an 11 percent reduction in primary energy use by 2010, and a nearly 30% reduction by 2020, while maintaining the same level of energy services to consumers. The use of renewable energy is doubled in 2010 relative to the Base case and remains roughly at that level through 2020.[15]

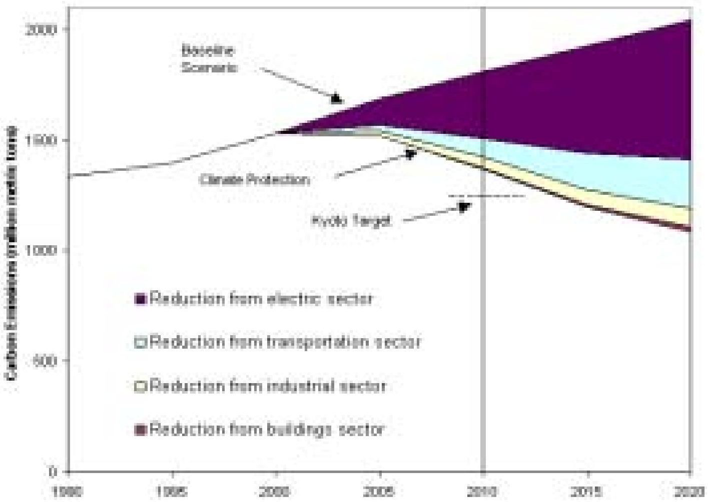
The policies would also produce reductions in air pollutant emissions owing to reduced fossil fuel consumption and greater use of renewable energy. This is most evident for SO2 for which 2010 levels in the *Climate Protection* case are almost half of *Base* case levels, due in great part to the effect of the more stringent cap in the electric sector.

The analysis showed that national savings in energy bills would exceed the net incremental investments in more efficient technologies and expenditures for low carbon fuels. By 2010, the average savings exceed the additional costs of new equipment by $13 billion per year, or nearly $113 per household.

## 5.2 Sectoral Impacts

Figures 5.1a and 5.1b compare the carbon trajectories for the *Base* and *Climate Protection* scenarios, and shows the carbon reductions obtained by the policies to reduce energy-related carbon emissions. Carbon emissions reductions can be reported by where they are emitted (i.e., by source, 5.1a) or by the sectors to which the policies are directed (i.e., by policy, 5.1b).

**Figure 5.1 Carbon emissions**
**a) Reductions by source of emissions**



Thus, for example: the refinery emissions reductions owing to decreased transportation oil use are attributed to the transport policies, while the refinery emissions reductions owing to decreased industrial oil use are attributed to the industrial policies; the electric generation emissions reductions and emissions increased on-site fuel use, owing to increased CHP are attributed to the industrial policies.

The first graph, Figure 5.1a, shows the emissions reductions in the sectors of their origin, that is, in

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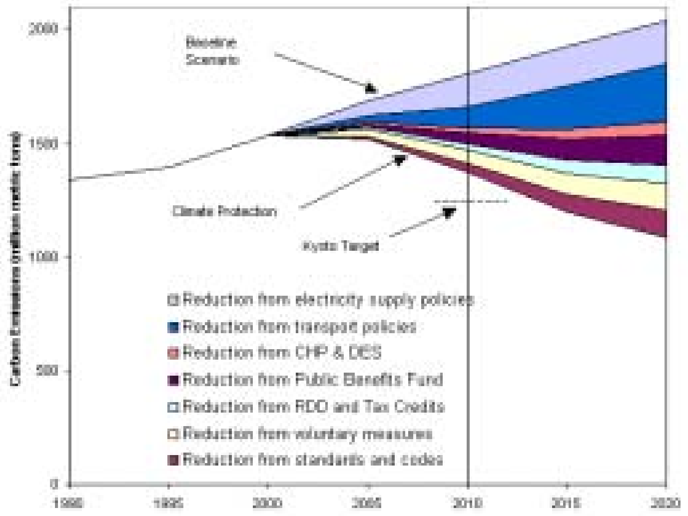
[15] This takes account of the percentage levels required by the Jeffords Bill for the electric sector (10% renewables by 2010, and 20% by 2020). However, when this RPS is combined with the strong energy efficiency policies of this study, the absolute amount of renewables in the electric sector does not increase substantially between 2010 and 2020 because the percentage targets have already been met. A more aggressive renewables policy for the 2010-2020 period could be considered (ACEEE, 1999).

which the combustion of fossil fuels occurs. Thus, it shows emissions from on-site fossil fuel combustion in buildings, industry, transportation and electricity production. The largest reductions arise in the electric sector, owing to the end-use energy efficiency policies that reduce demand, plus the emissions and renewables policies for power supply that change the generation mix for electricity generation. Figure 5.1b shows the reductions from the various sectoral policies.



**b) Reductions by major policy group**

Table 5.2 summarizes the cost of saved carbon for each policy for 2010 and 2020. These costs were computed by summing the incremental annualized capital costs, administrative costs, incremental O&M and fuel costs, and subtracting O&M and fuel cost savings. A 5% discount rate was used for both costs and carbon emissions.[16] Overall, the cost of saved carbon for the Climate Protection policy package results in net savings of $115/tC in 2010, and $576/tC in 2010. The net savings for the demand policies more than offset the incremental costs of saved carbon for the electric supply policies. Details regarding the impact of the policies within the sectors are summarized in the following sections.

### *Building and Industrial Sectors*

The efficiency improvements in residential and commercial buildings, induced through enhanced building codes, strengthened standards for appliances and equipment, tax incentives, as well as policies to encourage CHP, leads to a decrease in net electricity usage of 19 percent by 2010 and nearly 50 percent by 2020. Despite the additional natural gas required to fuel CHP in buildings, on-site fuel use declines by 3 percent in 2010 and 10 percent in 2020, relative to the *Base* case. The net impact is a decline in carbon emissions by nearly one-third in 2010, and two-thirds by 2020, relative to the *Base* case.

Industrial energy efficiency measures undertaken largely through voluntary measures and tax incentives, cause the industrial sector to reduce it’s direct energy consumption by 9 percent in 2010 and 14 percent in 2020 in the *Climate Protection* case relative to the *Base* case. In addition, largely because of the aggressive introduction of cogeneration, net electricity consumption is lower dramatically, by 30 percent in 2010 and 70 percent in 2020. The combined impact of these

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[16] Carbon emissions are discounted based on the presumption that they will have a commodity value within some form of tradable permits regime.

**Table 5.2. Carbon reductions, net costs, and cost per saved carbon in 2010 and 2020**

| | 2010 | | | 2020 | | |
|---|---|---|---|---|---|---|
| | Carbon Savings MtC/yr | Cumulative Net Cost (present value) billion (1999)$ | Cost of saved carbon (1999)$ per tC | Carbon Savings MtC/yr | Cumulative Net Cost (present value) billion (1999)$ | Cost of saved carbon (1999)$ per tC |
| **Buildings & Industry Sectors** | | | | | | |
| Appliance standards | 29 | -$24 | -$315 | 45 | -$84 | -$256 |
| Building Codes | 7 | -$5 | -$353 | 13 | -$23 | -$244 |
| Voluntary measures | 61 | -$50 | -$229 | 78 | -$112 | -$179 |
| Research and design | 21 | -$18 | -$257 | 37 | -$53 | -$186 |
| Public Benefits Fund | 50 | -$29 | -$224 | 73 | -$101 | -$187 |
| Tax Credits | 4 | -$4 | -$292 | 7 | -$8 | -$152 |
| CHP and DES | 21 | -$53 | -$611 | 33 | -$151 | -$554 |
| *subtotal* | **193** | **-$183** | **-$301** | **285** | **-$533** | **-$121** |
| **Electric Sector** | | | | | | |
| RPS | Aggregated below | | | Aggregated below | | |
| $NO_x/SO_2$ Cap and Trade | | | | | | |
| Carbon trading | | | | | | |
| *subtotal* | **147** | **$140** | **$258** | **180** | **$258** | **$188** |
| **Transport Sector** | | | | | | |
| Travel Reductions | 29 | -$50 | -$496 | 37 | -$126 | -$495 |
| LDV efficiency improvements | 38 | -$19 | -$270 | 136 | -$149 | -$296 |
| HDV efficiency improvements | 8 | -$3 | -$179 | 33 | -$22 | -$214 |
| Aircraft efficiency improvements | 10 | -$3 | -$106 | 28 | -$14 | -$129 |
| Greenhouse Gas Standards | 11 | $4 | $136 | 22 | $11 | $99 |
| *subtotal* | **95** | **-$71** | **-$283** | **255** | **-$301** | **-$279** |
| ***TOTAL*** | 436 | -$114 | -$82 | 721 | -$576 | -$124 |

is that carbon emissions due to the industrial sector are lower by 26 percent in 2010 and 46 percent in 2020, relative to the *Base* case.

Across both sectors, the policies result in combined fuel and electricity savings of 9.6 quads in 2010 and 24.6 quads by 2020. The cumulative investment in efficiency measures to achieve these savings is $80 billion by 2010 and $365 billion by 2020 (discounted 1999$).

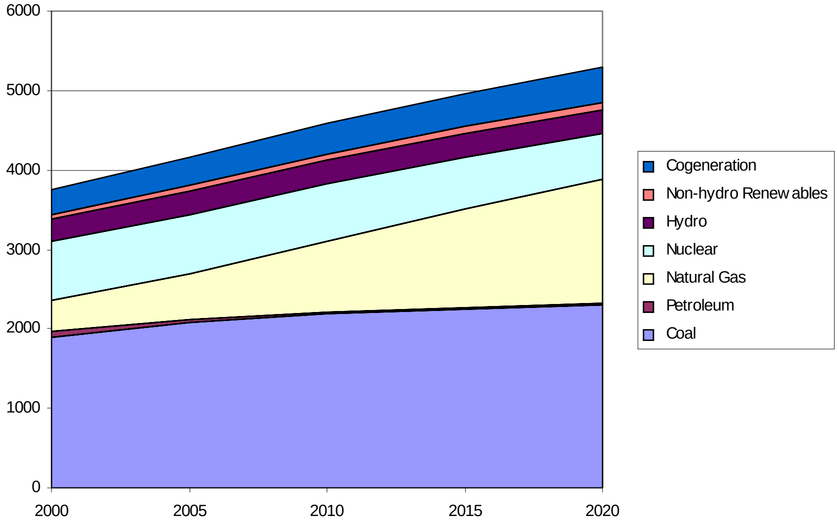
### *Electric Sector*

The policies in the buildings and industrial sectors lead to major reductions in the total amount of electricity required from the nation's power stations. This impact is illustrated in Figure 5.2a and shows that energy efficiency measures entirely displace growth in electricity demand after 2005. Relative to today's level, electricity demand declines 15 percent by 2010 and 35 percent by 2020

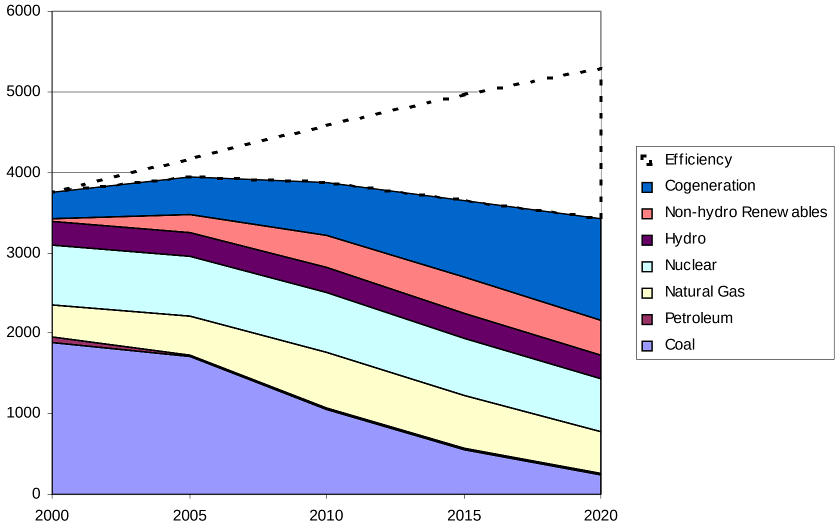
In addition to this reduced demand for electricity, the mix of fuels used to generate electricity changes dramatically, as shown in Figure 5.2b. The electric sector policies shift the generation mix away from a heavy reliance on coal, and avoid the rapid build-up of natural gas generation, by relying much more on renewable energy and, especially, cogeneration. Cogeneration grows from roughly 300 TWh today to 660 TWh in 2010, and 1260 in 2020, whereas in the *Base* case cogeneration increases modestly to 380 TWh in 2010 and 440 TWh in 2020. Non-hydro renewable energy consumption increases almost five times by 2010 over the *Base* case, and remains roughly at this level through 2020.

While effective at reducing carbon emissions, the electric sector policies do so at a net economic cost, increasing the average unit cost of electricity by about 2 cents / kWh in 2010. This effect diminishes over time as the electric sector is able to respond to the new policies and electricity demand reductions lead to fewer new power plants; by 2020, the electricity price is only about 1 cent / kWh higher than the base case. This price increase primarily reflects the fact that continued operation of existing coal plants, and construction and operation of new ones, remain economically attractive in the emerging price-competitive restructured industry. In part, this is because the use of coal for electricity generation doesn't include environmental externalities.

**Figures 5.2. Generation mix in (TWh)**
**(a) in the *Base* case**



**(b) in the *Climate Protection* case**



By 2010, a total of 4.3 quads of fossil fuel reductions are achieved at power stations, and 6.5 quads by 2020. The cumulative investment to achieve these savings and greater utilization of renewable energy is

$166 billion by 2010 and $333 billion by 2020 (discounted 1999$). Although the costs per unit of electricity increase, measures for demand-side efficiency lead to an overall decrease in end-users' electricity bills, and in the overall costs of electricity services.

*Transportation*

The vehicle efficiency and transportation demand management initiatives in the *Climate Protection* case result in energy savings of 4.6 quads in 2010, and 12.6 quads by 2020 (12 percent in 2010 and 28 percent in 2020, respectively, relative to the *Base* case). Carbon emissions fall slightly more relative to the base case (13 percent in 2010 and 31 percent in 2020) due to the small shift to less carbon-intensive fuels (specifically, cellulosic ethanol). By 2010, ethanol is contributing about 2 percent of transport fuel demand, and 4 percent in 2020. As in other biomass-intensive industries, this enables the co-production of electricity, thereby increasing the carbon benefits of this measure to the extent that it displaces fossil-fuel derived electricity. Reduced fuel production also adds to the carbon benefits, because it reduces emissions from refineries.

The cumulative investment to achieve these savings and greater utilization of renewable energy is $52 billion by 2010 and $213 billion by 2020 (discounted 1999$). The transport efficiency measures result in net savings, because fuel cost savings offset the slight increase in investment costs. These net savings more than offset the cost of the transportation fuel carbon content standard – which is the only net-cost transportation policy considered here. The overall net economic benefit achieved by the entire set of transportation policies provides an opportunity to pursue the carbon content standard, which begins a process of progressive technological improvement that is a critical element of obtaining the much deeper carbon emissions reductions in the transport sector needed later.

## 5.3 Air Pollution Reductions

A variety of air pollutants, associated with the use of fossil fuels, can cause or exacerbate health problems and damage the environment. Reducing use of fossil fuels would reap important local health benefits by lowering the amount of air pollutants inhaled. Recent scientific findings confirm that pollutants such as fine particulates, carbon monoxide, ozone (formed by a mix of volatile organic compounds and nitrogen oxides in presence of sunlight) can lead to health damages, including premature death. Research shows that small children and the elderly are particularly at risk from these emissions (Dockery et al., 1993; Schwartz and Dockery, 1992).

The policies would reduce national, regional and local pollution, owing to reduced fossil fuel use, providing important environmental benefits and health benefits, especially for small children and the elderly. Table 5.3 summarizes the impacts of the policies on criteria air pollutant emissions. Sulfur-dioxide emissions are about 52 percent lower in 2010 than the Base case, and about 68 percent below 1990 levels. Nitrogen oxides are 16 percent lower in 2010, and about 37 percent below 1990 levels. Particulates are about 13 percent lower in 2010, and about 24 percent below 1990 levels. Carbon monoxide emissions are about 9 percent lower in 2010, and about 2 percent below 1990 levels. Finally, volatile organic compounds are about 7 percent lower in 2010, and about 33% below 1990 levels.

Table 5.3: Impact of policies on air pollutant emissions

| | | 2010 **Base Case** | 2010 **Climate Protection** | 2020 **Base Case** | 2020 **Climate Protection** |
|---|---|---|---|---|---|
| CO | 65.1 | 69.8 | 63.8 | 71.8 | 59.8 |
| NOx | 21.9 | 16.5 | 13.9 | 16.9 | 12.0 |
| SO2 | 19.3 | 12.8 | 6.2 | 12.7 | 3.3 |
| VOC | 7.7 | 5.5 | 5.1 | 5.9 | 4.9 |
| PM-10 | 1.7 | 1.5 | 1.3 | 1.6 | 1.3 |

Figure 5.3 shows the impacts of the *Climate Protection* policies over time. The large reductions in particulates emissions arise from the substantial decrease in coal generation in the policy cases. Sulfur-dioxide decreases in the baseline projections arising from the cap/trade provisions of the 1990 Clean Air Act Amendments, are augmented by the policies. Similarly, baseline declines in nitrogen oxides, volatile organic compounds and carbon monoxide, which arise from tailpipe emissions standards as new cars enter the fleet, are augmented by the policies that affect vehicle travel patterns.

The reductions in nitrogen, sulfur, and carbon are similar to those introduced in the Four Pollutant Bill currently before the House and the Senate. The Climate Protection scenario achieves the required levels of reduction a few years earlier (for carbon) or later (for nitrogen and sulfur) than the Four Pollutant Bill's 2007 target date, with substantially deeper reductions continuing thereafter.

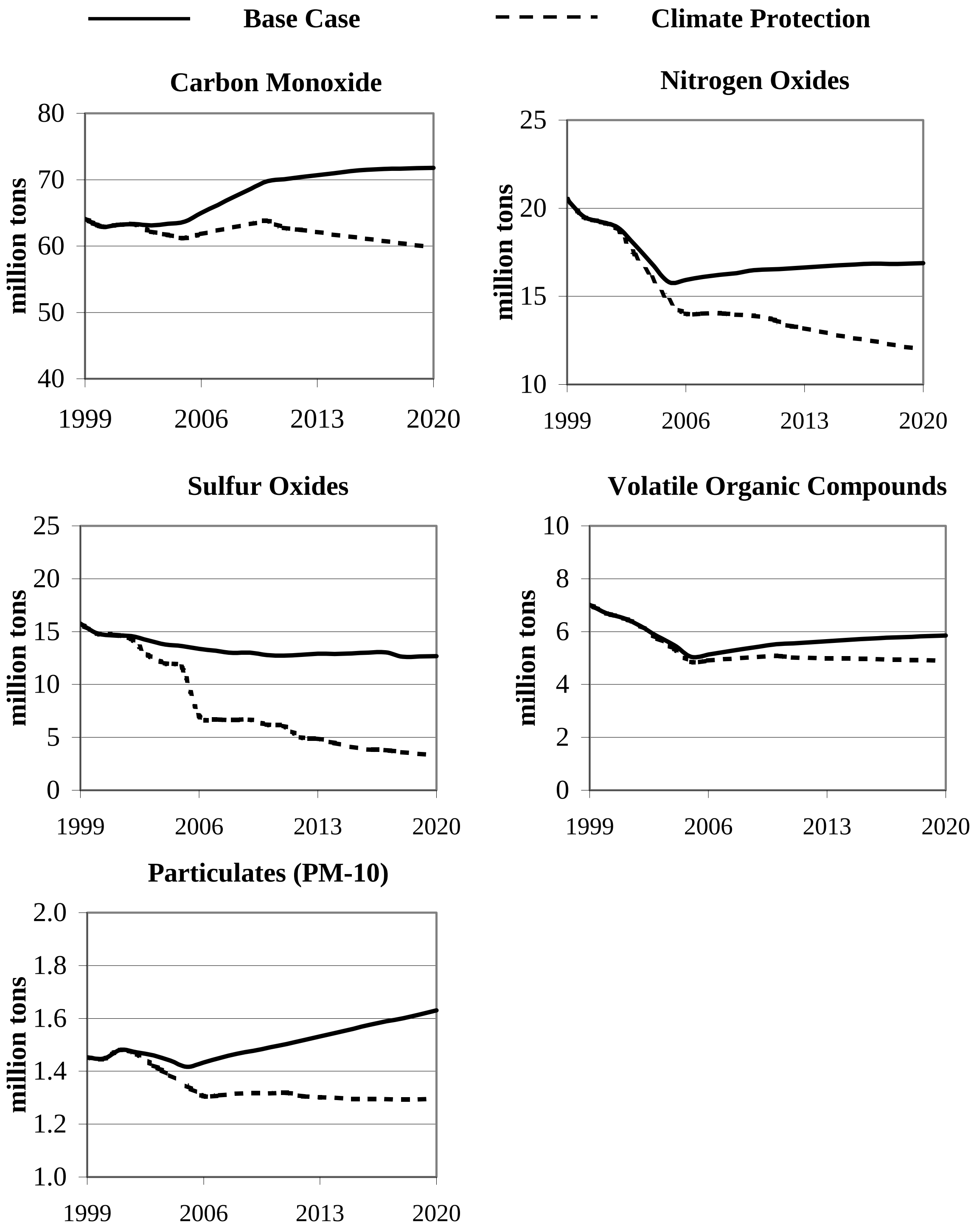
## 5.4 Economic Impacts

The portfolio of policies and measures considered here is a very aggressive package that goes a long way toward meeting the US Kyoto Protocol obligation and continues to reduce emissions beyond the initial target period. Despite the ambitiousness of this package and the impressive carbon impacts, it would bring net economic *benefits* to the US.

Figure 5.4 shows the benefits and costs at similar levels up to 2010 but benefits significantly outpacing costs in later years, reflecting in part the longer term benefits of reduced costs as new technologies are commercialized and as the system adjusts to the new policies. The costs derive from additional investments in more efficient lighting, high efficiency motors, more efficient automobiles, and other technologies that reduce the reliance on high carbon fuels. The savings derive from the avoided fuel costs. Both the additional investment and the net savings create additional income and jobs in the industries and services (and their suppliers) in which these funds are spent.

Figures 5.5 (demand side policies) and 5.6 (supply side policies) provide additional details regarding the costs effectiveness of the policies in 2010 and 2020. These figure indicate the allocation of costs and benefits between equipment investments and fuel savings and between demand and supply sectors. The policies in the demand sector, where large savings exist for energy efficiency measures, are very cost-effective, and yield substantial net benefits. Fuel and O&M savings are over 3 times the investment costs the in 2010 and about two and half times in

Figure 5.3: Emissions of Major Air Pollutants: 1999-2020



2020, yielding cumulative discounted net benefits of $259 billion and $844 billion, respectively, in those years.

On the other hand, the supply sector policies are not cost-effective on their own and result in net costs. These costs, in capital, fuel, and O&M, are due to moving from coal generation to cleaner fuels like renewables and natural gas. The result is that cumulative discounted net costs for electric sector policies reach of $144 billion in 2010 and $268 billion in 2020.

**Figure 5.4. Cumulative undiscounted costs and savings from all policies and measures (1999$)**

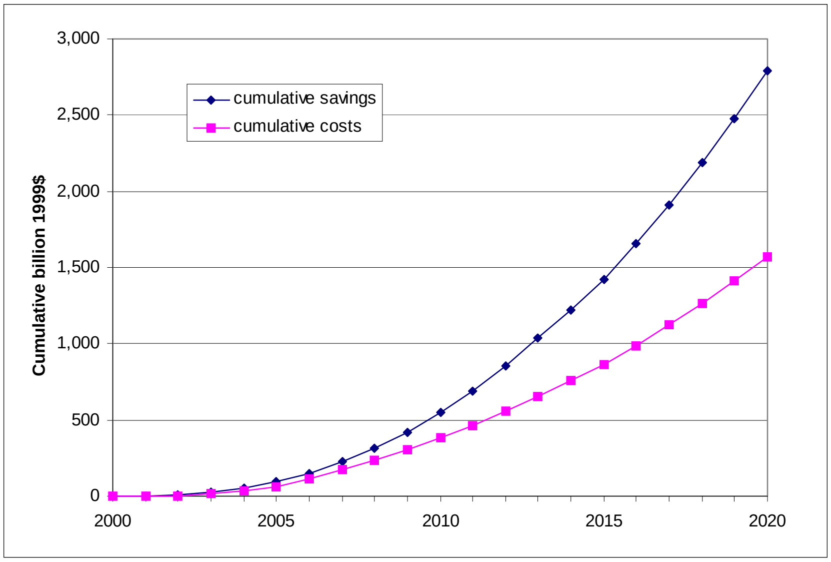
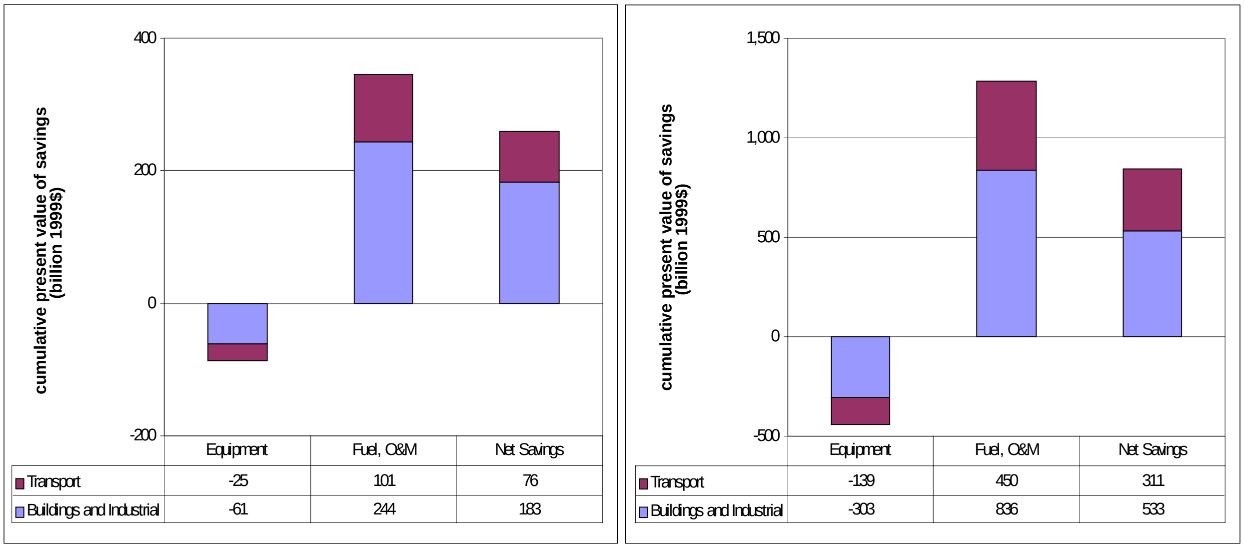


**Figure 5.5: Cost-effectiveness of demand policies in 2010 and 2020**

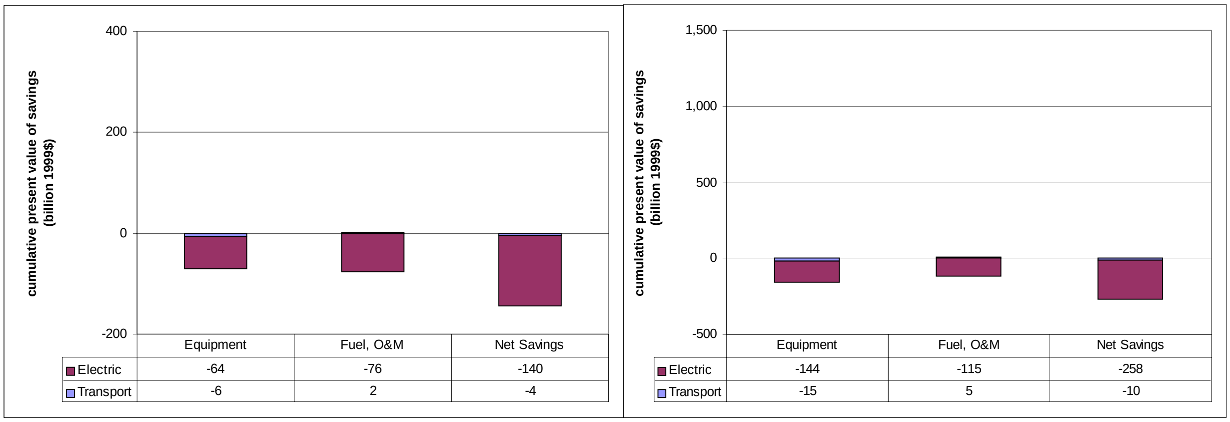


| | Equipment | Fuel, O&M | Net Savings |
|---|---|---|---|
| ■ Transport | -25 | 101 | 76 |
| ■ Buildings and Industrial | -61 | 244 | 183 |

| | Equipment | Fuel, O&M | Net Savings |
|---|---|---|---|
| ■ Transport | -139 | 450 | 311 |
| ■ Buildings and Industrial | -303 | 836 | 533 |

When all policies are combined, the cumulative savings exceed the costs by $114 billion in 2010, and by 2020 the net benefits amount to approximately $576 billion. While the savings estimated here are significant, they are relatively small in comparison to overall economic activity. For instance, the annual net savings in 2010 of $48 billion is a small fraction of the $13.2 trillion projected GDP in that year.

**Figure 5.6: Cost-effectiveness of supply policies in 2010 and 2020**



## 6 Achieving Kyoto

The foregoing analysis addressed policies to curb emissions of carbon dioxide from energy use in the U.S. Energy-related CO2 emissions are the predominant source of US greenhouse gas emissions for the foreseeable future, and their reduction is the central and ultimate challenge for protecting the climate. However, because of its delayed and weak emissions mitigation policies heretofore, and delayed ratification of the Kyoto Protocol, the US may not be able to rely solely on energy sector policies and technologies to meet its Kyoto obligation of emissions 7% reduction below 1990 levels with no net economic cost. As our analysis has shown, such efforts, if aggressively pursued, would slow our growth in energy sector CO2 emissions from a projected 35% to 2.5% above 1990 levels by 2010 and still achieve a small net economic benefit. This would be a major accomplishment, but would still leave us 128 MtC/yr short of achieving a target of 1244 MtC/yr by 2010, if the Kyoto target were confined only to the domestic energy sector. A tighter carbon cap for the electric sector could increase domestic energy-related emission reductions to meet the Kyoto requirement, but this would incur incremental costs that could eliminate the net benefit and lead to a modest overall net cost.

Of course, there is more to the Kyoto agreement. The Kyoto targets cover six gases – methane (CH4), nitrous oxide (N2O), perfluorocarbons (PFCs), hydrofluorocarbons (HFCs), sulfur hexafluoride (SF6) and carbon dioxide (CO2) . The use of these gases is currently growing, due to the ongoing substitution of ozone depleting substances (ODS) with HFCs, and to a lesser extent, to growth in CH4 emissions from livestock and coal and natural gas systems, in $N_20$ from fertilizer use, and in PFC emissions from semiconductor manufacture (EPA, 2000).

The US commitment requires emissions of all six gases, in aggregate, to be reduced to 7% below their baseline levels.[17] When all of the six "Kyoto gases" are considered, baseyear emissions amount to 1680 MtCe/yr, making the -7% Kyoto reduction target equal to 1533 MtCe/yr, as shown in the third column of Figure 6.1. The projected 2010 emissions for all six gases is 2204 MtCe/yr (first column), thus the total required reduction is expected to be 672 MtCe/yr. The

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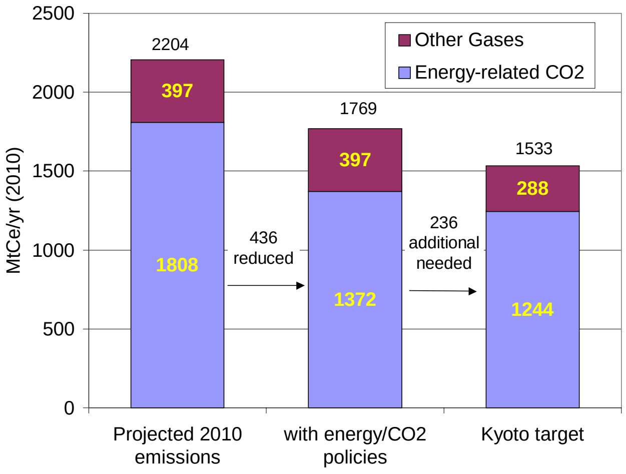
[17] These gases can be controlled interchangeably, using 100 year Global Warming Potentials (GWP), so long as the total carbon-equivalents ($C_e$) are reduced to 93% of their baseline levels. In contrast to the main three gases (CO2, CH4, and N2O), which have a 1990 base year, the high GWP gases have a base year of 1995.

**Figure 6.1: Projected emissions, 2010, all gases**



energy-CO2 policies described in the previous sections yield 436 MtCe/yr in reductions by 2010 (second column), leaving the US with 236 MtCe/yr additional reductions to achieve from other policies and measures.

The Kyoto agreement provides us with several options for obtaining the additional 236 MtCe/yr of reductions. Two of these options involve domestic reductions: the control of non-CO2 gases ("multi-gas control") and the use of "sinks" or biotic sequestration, through the land use, land use change and forestry options allowed under the Protocol. The other options involve obtaining credits and allowances from international sources. Under the Kyoto Protocol, countries can purchase credits and allowances through the Clean Development Mechanism (CDM), Joint Implementation, or Emissions Trading (ET) to offset domestic emissions exceeding our 7% reduction target. This section examines how we might meet the Kyoto target through the use of these options, and what the costs and other implications might be.

## 6.1 Domestic options

### *Article 3.3/3.4 and Sinks*

GHG emissions and removals from land use and land use change and forestry (LULUCF) are a subject of great controversy and scientific uncertainty. The Kyoto Protocol treats LULUCF activities in two principal categories: afforestation, reforestation, and deforestation under Article 3.3, and "additional human-induced activities" such as forest and cropland management under Article 3.4. Different interpretations of these two articles can have widely varying impacts on the US reduction commitment.[18] For instance, the US estimate of business-as-usual forest uptake during the first commitment period is 288 MtCe/yr. If fully credited as an Article 3.4 activity, this uptake could provide credit equal to more than 40% of the US reduction requirement, with no actual mitigation effort. However, the vast majority of countries do not interpret the Protocol as allowing credit for business-as-usual offsets, and therefore believe they should be excluded.

The starting point of our LULUCF analysis is the assumed adoption of the "consolidated negotiating text" of Jan Pronk, President [of COP6], as issued on June 18, 2001.[19] The so-called "Pronk text" reflects an attempted compromise among various parties on a number of

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[18] For instance, different accounting methods and rules have been considered regarding: a) what constitutes a forest; b) which biotic pools and lands are counted; c) which activities are considered eligible for crediting under Article 3.4; and d) uncertainties in measuring above and below ground carbon stocks.

[19] See "Consolidated negotiating text proposed by the President", as revised June 18, 2001, FCCC/CP/2001/2/Rev.1, http://www.unfccc.int/resource/docs/cop6secpart/02r01.pdf

contentious issues. The most relevant here is the proposal for Articles 3.3 and 3.4.[20] In short, the Pronk text would cap total US crediting from Article 3.4 activities and afforestation and reforestation projects in the CDM and JI at roughly 58 MtCe/yr.[21] Domestic forest management activities would be subject to an 85% discount. Thus, if one assumes the US estimate above, the Pronk rules would result in 42 MtCe/yr of essentially zero-cost credit for forest management activities that are expected to occur anyway.[22] In addition, agricultural management (e.g. no-till agriculture, grazing land management, revegetation) would be allowed under a net-net accounting approach that would allow the US to count another expected 10 MtCe/yr of business-as-usual, i.e. zero-cost, credit towards the cap. In sum, the Pronk proposal translates to 52 MtCe/yr of "free" carbon removals, and another 6 MtCe/yr that could be accrued through new domestic forest or agricultural management activities.[23] Based on a recent summary of LULUCF cost estimates, we assume that this relatively small amount of offsets could be purchased for \$10/tCe.[24] A total of 58 MtCe/yr of LULUCF credit would therefore be available to help meet the reduction requirement of 236 MtCe/yr remaining after having adopted the energy-related CO2 policies described above.

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[20] Our assumption of Pronk conditions is a matter of "what if" analysis, rather than a tacit approval. The Pronk text may be insufficient in a number of ways, but the analysis and critique of the Pronk text is not the focus of this report.

[21] The Pronk text would prohibit first commitment period crediting of CDM projects that avoid deforestation. It also

[22] This figure is drawn from the Annex Table 1 of the April 9 draft of the Pronk text, which adopts Pronk adopts the accounting approach for Article 3.3. activities suggested by the IPCC Special Report of LULUCF. This approach yields an Article 3.3 debit of 7 MtCe/yr from net afforestation, reforestation, and deforestation activity, which under the Pronk approach could be offset fully by undiscounted forest management activities. Thus the 42 MtCe/yr estimate is based on 85% x (288 – 7) MtCe/yr.

[23] The Pronk proposal also allows this cap to be filled through afforestation and deforestation activities in the CDM.

[24] Missfeldt and Haites (2001) use a central estimate of 50 MtCe/year at \$7.50/tCe for CDM afforestation and reforestation projects. They also assume the availability of 150 MtCe/year at \$15/tCe for Article 3.4 sinks in Annex B countries. Note however that the Pronk 85% discount on forest management projects would, in principle, increase their cost accordingly (by 1/.15 or 6.7 times). However, given the relatively small quantity (6 MtCe) that could be purchased, lower cost opportunities in cropland management or the CDM should more than suffice.

*Multi-gas control*

Multi-gas control is a fundamental aspect of the Protocol, and its potential for lowering the overall cost of achieving Kyoto targets has been the subject of several prominent studies (Reilly et al, 1999 and 2000). Table 6.1 shows baseline and projected emission levels for the non-CO2 gases.[25]

**Table 6.1: Baseline and Projected Emissions for the non-CO2 Kyoto Gases (MtCe/yr)**

| Gas | Base Year (1990/95) | 7% Below Base Year | Projected 2010 | Reductions Required[(a)] | Sources |
|---|---|---|---|---|---|
| Methane | 170 | 158 | 186 | 28 | (EPA 1999) |
| Nitrous Oxide | 111 | 103 | 121 | 18 | (Reilly et al 1999b; EPA 2001a) |
| High GWP Gases (HFC, PFC, SF6) | 29 | 27 | 90 | 63 | (EPA 2000) |
| Total | 310 | 288 | 397 | 109 | |

(a) These are the reductions that would be needed if each gas were independently required to be 7% below its base year level.

Methane emissions are expected to grow by only 10% from 1990 to 2010, largely because of increased natural gas leakage and venting (due to increased consumption), enteric fermentation and anaerobic decomposition of manure (due to increased livestock and dairy production). Methane from landfills, which accounted for 37% of total methane emissions in 1990, are expected to decline slightly as a consequence of the Landfill Rule of the Clean Air Act (EPA, 1999), which requires all large landfills to collect and burn landfill gases.

Several measures could reduce methane emissions well below projected levels. USEPA estimates that capturing the methane from landfills not covered by the Landfill Rule, and using it to generate electricity, is economically attractive at enough sites to reduce projected landfill emissions by 21% (USEPA, 1999). At a cost of $30/tCe, the number of economically attractive sites increases sufficiently that 41% of landfill emissions can be reduced. Similarly, USEPA has constructed methane reduction cost curves for reducing leaks and venting in natural gas systems, recovering methane from underground mines, using anaerobic digesters to capture methane from manure. and reducing enteric fermentation by changing how livestock are fed and managed.

We have used a similar USEPA study to estimate the emissions reductions available for the high GWP gases (USEPA, 2000). Table 1 shows that the high-GWP gases, while only a small fraction of baseline emissions (first column), are expected to rise so rapidly that they will account for majority of net growth in non-CO2 emissions relative to the 7% reduction target (last column). In many applications, other gases can be substituted for HFCs and PFCs, new industrial process can implemented, leaks can be reduced, and more efficient gas-using equipment can be installed. For instance, minor repairs of air conditioning and refrigeration equipment could save an estimated 6.5 MtCe/yr in HFC emissions by 2010 at cost of about $2/tCe. New cleaning processes for semiconductor manufacture could reduce PFC emissions by 8.6 MtCe/yr by 2010

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[25] USEPA (1999, 2000) expects voluntary Climate Change Action Plan (CCAP) activities to reduce 2010 methane and high GWP gas emissions by about 10% and 15%, respectively, reductions that are not included in their 2010 projections shown in Table 1. Instead these reductions are embodied in both their and our cost curves.

at an estimated cost of about $17/tCe. In all, USEPA identified 37 measures for reducing high GWP gases, a list which is likely to be far from exhaustive given the limited experience with and data on abatement methods for these gases.

The major source of nitrous oxide in the US is the application of nitrogen fertilizers, which results in about 70% of current emissions. Given the tendency of farmers to apply excess fertilizer to ensure good yields, effective strategies for N2O abatement from cropping practices has thus far been elusive. Thus, aside from measures to reduce N2O from adipic and nitric acid production (amounting to less than one MtCe/yr), and from mobile sources as a result of transportation policies (see below), we have not included a full analysis of N2O reduction opportunities (USEPA, 2001).

Relying largely on recent USEPA abatement studies (1999, 2000, 2001b), we developed the cost curve for reducing non-CO2 gases depicted in Figure 2 below.[26] In addition to what is covered in the USEPA studies, we assumed that:

- Only 75% of the 2010 technical potential found in the USEPA studies would actually be achieved, and that policies and programs needed to promote these measures would add a transaction cost of $5/tCe.
- The savings in 2010 fossil fuel use resulting from the policies and measures implemented in the energy sector will yield corresponding benefits for several categories of non-CO2 emissions. In particular, we assumed that a) reduced oil use in the transport sector (down 14%) will lead to a proportional decrease in N2O emissions from mobile sources[27]; b) reduced natural gas demand (down 13%) will result in proportionately fewer methane emissions from leaks and venting; and c) reduced coal production (down 49%) will lead to decreased underground mining and its associated emissions. [28]

Figure 6.2 shows that domestic options, taken together, are insufficient to reaching the Kyoto target. The line on the left is the “supply curve” of non-CO2 abatement options, and the line on the right is the reduction requirement after both energy-related and Article 3.3/3.4 sinks are accounted for. Under current conditions (only 9 years left until 2010), the supply of remaining domestic options appears insufficient to satisfy demand. This gap ranges from 107 MtCe/yr at $10/tCe to 60 MtCe/yr at $100/tCe as shown. Therefore, to meet our Kyoto obligations, we are now in a situation of looking to the international market to fill this gap.

## 6.2 International options

The Kyoto Protocol creates are two principal types of greenhouse gas offsets in the international market: the purchase of surplus allowances from countries that are below their Kyoto targets and the creation of carbon credits through project-based mechanisms, CDM and JI.

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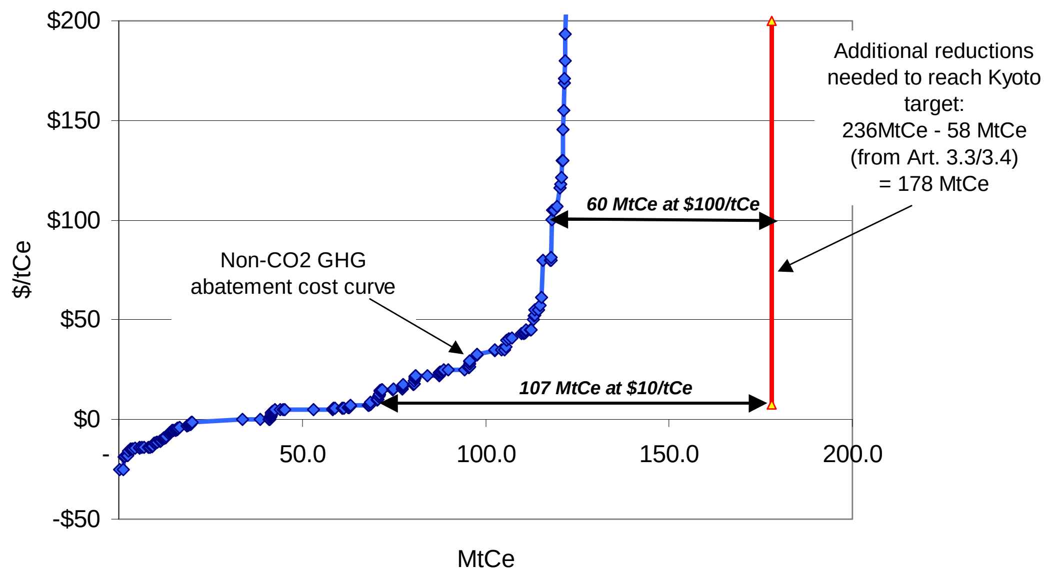
[26] The result is a cost curve that is similar and more up-to-date than that used in widely cited multiple gas studies (Reilly et al, 1999a; Reilly et al, 1999b; EERE, 2000).

[27] A similar assumption is used by European Commission (1998). Approximately fifteen percent of N2O emissions are a byproduct of fuel combustion, largely by vehicles equipped with catalytic converters (USEPA, 2001a).

[28] We assume that coal production is a proportional to coal use (i.e. we ignore net imports/exports). USEPA expects that the marginal methane emissions rate will increase with production as an increasing fraction is expected to come from deeper underground mines (USEPA, 1999).

**Figure 6.2: Non-CO2 GHG emissions reductions, cost and potential, 2010**



*Emissions allowance trading/hot air*

The combination of emission targets based on circa 1990 emissions and the subsequent restructuring and decline of many economies in transition (EITs) means that these countries could have a large pool of excess emissions allowances, typically referred to as “hot air”. Estimates of available hot air during the first commitment period range from under 100 MtCe/yr to nearly 500 MtCe/yr, largely from Russia and Ukraine.[29] This source of offsets could fulfill a significant fraction of the US demand for additional reductions at very low cost (depending upon the level of competing demands of other Annex 1 parties for these allowances).[30] We assume however, that relevant actors in government and/or private sector charged with meeting emissions obligations will effectively limit the use of hot air. Relying heavily or entirely on hot air would be poor climate policy; as hot air supplants legitimate mitigation activity. It is also bad public relations; hot air has a stigma arising from years of negotiations controversy. Therefore, we assume that hot air will constitute no more than 50% of all international trading, and we assume a maximum availability of 200 MtCe/yr, based on a recent analysis (Victor et al, 2001).

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[29] A range of 100-350 MtCe/yr is cited in Vrolijk and Grubb, 2000. Missfeldt and Haites, 2001 use a base estimate of approximately 240 MtCe/yr, with high estimate of 480 MtCe/yr. For this analysis, we assume the availability of 200 MtCe/yr, based on a recent analysis by Victor et al (2001).

[30] Since these credits are a form of windfall credits, it has been suggested that these economies could help protect the environmental integrity of the agreement by dedicating the income from “hot air” sales to energy projects that will bring about additional emissions reductions.

### *CDM and JI*

CDM and JI projects, can be an important part of a comprehensive climate policy, providing they truly contribute to sustainable development in the host countries and create genuine, additional GHG benefits. It is reasonable to expect that the US government and other stakeholders will want to develop the CDM and JI market in order to involve developing countries, engage in technology transfer, develop competitive advantages, and prepare for future commitment periods.

With the rules yet to be established on critical issues like additionality and baselines for CDM[31], and with a limited understanding of CDM/JI markets and transaction costs at high volumes of activity, cost and volume estimates for CDM and JI remain highly speculative. As with all GHG mitigation analysis exercises, both bottom-up and top-down methods can be used to develop such estimates. We have examined the data and literature for both approaches in coming up with a rough, aggregate cost curve for CDM and JI.

A bottom-up CDM/JI cost assessments can examine emerging project-based GHG trading markets – private broker transactions, the Prototype Carbon Fund (PCF), the Dutch ERUPT program, GEF activity, and so on – to get a sense of current “real-world” prices and transaction costs. However, the size of this market remains very small in comparison with the total flows that are likely once CDM and JI are underway.[32] The type of activities being undertaken today, such as the first PCF project, a landfill gas capture effort in Latvia, could well represent “low-hanging fruit” that would be unable to supply the several hundreds MtCe/yr of CDM and JI activity that are expected under some Kyoto compliance scenarios (Missfeldt and Haites, 2001; Grubb and Vrolijk, 2000).

To get a better sense of the costs of projects available at higher volumes, these “early project” estimates can be combined with non-Annex B “country studies” – the many national GHG abatement studies performed with support from UNEP, UNDP, US Country Studies, and other bilateral and national programs. A study by the Dutch Energy Foundation (ECN, et al ,1999) provides a good example of such an analysis. Extrapolating from GEF projects along with 25 country studies, this study found that 440 MtCe/yr of non-Annex 1 reductions could be available at less than $22/tCe.

However, the uncertainty related to these bottom-up studies is fundamentally quite high. National studies typically exclude a significant number of abatement options due to sheer lack of data, resources, or necessity. At the same time, abatement costing studies may understate transaction and barrier removal costs, especially those specific to CDM and JI projects. For instance, transaction costs for project preparation, baselines, certification, and monitoring and evaluation could also change from current levels, once the CDM and JI markets take off and

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[31] CDM projects are required to be “additional” emissions reductions but rules have not been agreed to which would determine what is additional. In addition, credits will be given based on reductions in comparison to a baseline. A methodology for establishing baselines is also the subject of ongoing negotiations.

[32] For instance, anecdotal evidence suggests that the current international GHG emission credit market is at about $25 million in transactions per year. In addition the PCF and ERUPT have committed another $225 million over the next few years. This figure compares with the $10-20 billion/year market (about 400-500 MtCe/year at $20-40/tCe) that some analysts project under CDM alone (Missfeldt and Haites, 2001).

clear rules are established. Finally, the ultimate approach adopted for deciding on project additionality and baselines could have a major impact on the size and shape of the market.

Similarly, the possibility of limited crediting lifetimes, or discounting of carbon reductions in future projects years, as proposed by some, could increase the effective cost per tCe. In a recent analysis, Bernow *et al*. (2000) illustrated how different approaches to standardizing baselines could lead to differences in additional power sector activity (tCe) of a factor of 4. These types of considerations are rarely included in CDM/JI analyses, either bottom-up or top-down.

Many climate policy assessments rely on CDM and JI cost curves developed by a handful of "top-down" modelers. Ellerman and Decaux (1998) applied the MIT-EPPA computable general equilibrium model to develop parameterized cost curves for five non-Annex 1 regions, which have since been widely used (Reilly et al, 1999; Haites, 2000; Krause et al, 2001; Missfeldt and Haites, 2001; Grutter, 2001). Applications of the ABARE-GTEM model have been used in a similar manner (Vrolijk and Grubb, 2000; Grutter, 2001; EMF, 1999). While compared with bottom-up studies, the EPPA and GTEM model runs provide more comprehensive assessments of reduction potential and cost from an economy-wide perspective, they do a poorer job of reflecting the dynamics of project-based investments.

It turns out that the GTEM, EPPA, and bottom-up ECN studies, do yield rather similar results. At $20/tCe, the total CDM potential under the GTEM run is 470 MtCe/yr, while under EPPA it is 480 MtCe/yr, and as noted above, and for ECN et al (1999), the figure is closer to 440 MtCe/yr.[33] Given the small differences, we adopt the GTEM results, since they provide a fuller CDM curve, include multiple gases, and provide a cost curve for JI investments as well.

### 6.3 Combining the options

There are two ways to combine the available options to meet our Kyoto target. We can prioritize which options to rely on more heavily, based on their strategic advantages and co-benefits, as we have done for energy/CO2 policies. Or we can simply seek lowest-cost solution for the near-term. A long-term climate policy perspective argues for the former approach. For example, rules and criteria for JI, and especially CDM, should be designed so that additionality, sustainability, and technology transfer are maximized. Ideally, our cost curves for CDM and JI would reflect only investments that are consistent with those criteria. However, our current ability to reflect such criteria in quantitative estimates of CDM and JI potential is limited.[34]

It is possible to model priority investment in the domestic reductions of non-CO2 gases by implementing some measures that are higher cost than the global market clearing carbon price. Just as energy/CO2 measures like a Renewable Portfolio Standard can be justified by the

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[33] The EPPA and GTEM figures are drawn from the CERT model described in Grutter, 2001. The EPPA scenario used here includes only CO2, while the GTEM scenario includes all gases. All of these studies exclude sinks, which is largely consistent with the implications of the Pronk proposal.

[34] We did briefly examine the potential contribution of a CDM fast track for renewables and efficiency, as embodied in the Pronk text. Applying the power sector CDM model developed by Bernow et al (2001), we found that a carbon price of $20/tCe would induce only 3 MtCe/yr of new renewable energy project activity by 2010. At a price of $100/tCe, this amount rises to 18 MtCe/yr. Given that a large technical potential for energy efficiency projects exists at low or negative cost per tCe, fast track efficiency projects (under 5 MW useful energy equivalents according to Pronk text) could significantly increase the amount available at lower costs.

technological progress, long-term cost reductions, other co-benefits that they induce, so too can some non-CO2 measures. While we have not attempted to evaluate specific policies for non-CO2 gases as we have for CO2, we have picked a point on the non-CO2 cost curve, \$100/tCe, to reflect an emphasis on domestic action. At \$100/tCe, domestic non-CO2 measures can deliver 118 MtCe/yr of reductions, still about 60 MtCe/yr short of the Kyoto goal, to which we must turn to the international market.

To model the global emissions trading market, we used the CDM/JI cost curves, and hot air assumptions described above, together with assumptions regarding the demand for credits and allowances from all Annex B parties.[35] This model yields market-clearing prices and quantities for each of the three principal flexible mechanisms: CDM, JI, and ET/hot air.[36] The results are shown in Table 6.2.

**Table 6.2: Reductions available in 2010 up from various sources (in MtCe)**

| | Domestic Options | | International Trade | | | |
|---|---|---|---|---|---|---|
| | Non-CO2 gases | Sinks | CDM | JI | Hot air (ET) | Total |
| Amount available at < or = \$0/tCe (MtCe) | 41 | 52 | | | | 93 |
| Amount available at \$0-\$100 (MtCe) | 77 | 6 | | | | 83 |
| Amount available at \$8 (MtCe) | | | 30 | 6 | 25 | 60 |
| Annual costs (\$Million) | \$1,783 | \$60 | \$235 | \$48 | \$196 | \$2,322 |

The first row of the table shows that 93 MtCe/yr are available at net savings or no net cost, over half from the non-additional or "anyways" forest management and other Article 3.4 sinks activities implicit in the Pronk text. Another 77 MtCe/yr of non-CO2 gas savings are available as we climb the cost curve from \$0-100/tC (second row). The net result is that nearly \$1.8 billion per year is invested in technologies and practices to reduce non-CO2 GHG emissions by 118 MtCe/yr in 2010. Another \$60 million per year is directed toward the 6 MtCe/yr of expected additional sinks projects allowed under the Pronk proposal. The third row shows that of the 60 MtCe/yr of international trading, half comes from CDM projects, and much of the rest from hot air. The model we use estimates a market-clearing price of about \$8/tCe for this 60 MtC/yr of purchased credits and allowance, amounting to a total annual cost of less than \$500 million.[37]

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[35] For the estimated demand for CDM, JI, and ET/hot air from other Annex 1 parties, we used a combination of EPPA and GTEM cost curves.[35] (Reilly et al, 1999b, and Ellerman and Decaux, 1998; Vrolijk and Grubb, 2000; Grutter, 2001).

[36] Our approach is similar to that used in a few other recent studies (Grutter, 2001; Haites, 2000; Missfeldt and Haites, 2001; Krause et al, 2001; Vrolijk and Grubb, 2000).

[37] The market clearing price is lower here than in other similar studies, due in large part to a much lower US demand for international trade, which results from of our aggressive pursuit of domestic abatement options and the fact that we assume that domestic policies and investments should be done as a matter of sound energy and environmental policy (i.e. they are price-inelastic).

In summary, of the 672 MtCe/yr in total reductions needed to reach Kyoto by 2010, nearly 65% comes from energy sector CO2 reduction policies, 18% from domestic non-CO2 gas abatement, 9% from domestic sinks, and 9% from the international market. The net economic benefits deriving from the energy-related carbon reductions reach nearly $50 billion/yr in 2010. The total annual cost for the 35% of 2010 reductions coming those last three options – non-CO2 control, sinks, and international trading – is estimated at approximately $2.3 billion, making the total package a positive economic portfolio by a large margin. Had we taken the other approach noted at the beginning of the section – aiming for the lowest near-term compliance cost – we would rely more heavily on international trading. We modeled this scenario, and found that it would nearly double the amount of international trading, and lower the overall annual cost to $0.9 billion, and reduce the amount of non-CO2 control by over 40%. This additional benefit is minor in comparison to the economic and environmental benefits of the entire policy portfolio.

## 7 Conclusions

This study shows that the United States can achieve its carbon reduction target under the Kyoto Protocol – 7 percent below 1990 levels for the first budget period of the Protocol. Relying on national policies and measures for greenhouse gas reductions, and accessing the flexibility mechanisms of the Kyoto Protocol for a small portion of its total reductions, the US would enjoy net economic savings as a result of this Climate Protection package. In order to achieve these reductions, policies should be implemented as soon as possible to accelerate the shift away from carbon-intensive fossil fuels and towards energy efficient equipment and renewable sources of energy. Such action would lead to carbon emission reductions of about 24 percent by 2010 relative to the Base Case, bringing emissions to about 2.5 percent above 1990 levels. Furthermore, emissions of other pollutants would also be reduced, thus improving local air quality and public health.

Adopting these policies at the national level through legislation will not only help America meet its Kyoto targets but will also lead to economic savings for consumers, as households and businesses would enjoy annual energy bill reductions in excess of their investments. These net annual savings would increase over time, reaching nearly $113 per household in 2010 and $375 in 2020. The cumulative net savings would be about $114 billion (present value 1999$) through 2010 and $576 through 2020.

Greenhouse emissions in the US are now about 15% higher than they were in 1990. Together with the looming proximity of the first budget period, and a realistic start date no earlier than 2003 for the implementation of the national policies, reductions in energy-related carbon would have to be augmented by other greenhouse gas reduction options in order to reach the Kyoto target. In total, the Climate Protection case in 2010 includes 436 Mtc/yr energy-related carbon reductions, 58 MtC/yr domestic land-based carbon reductions, 118 MtC/yr reductions in domestic non-carbon greenhouse gases, and 60 MtC/yr in allowances purchased through the “flexibility mechanisms” of the Kyoto Protocol.

While implementing this set of policies and additional non-energy related measures is an ambitious undertaking, it represents an important transitional strategy to meet the long-term requirements of climate protection. It builds the technological and institutional foundation for much deeper long-term emission reductions needed for climate protection. Such actions would stimulate innovation and invention here in the U.S. while positioning the U.S. as a responsible international leader in meeting the global challenge of climate change.

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# Appendix 1: Energy and Carbon Summaries

## 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 | 0.05 | 0.07 | 2.62 | 0.00 | 21.43 | 24.18 |
| Oil | 1.42 | 0.66 | 9.95 | 29.06 | 0.32 | 41.41 |
| Gas | 5.46 | 3.71 | 10.43 | 0.83 | 5.41 | 25.84 |
| Nuclear | 0.00 | 0.00 | 0.00 | 0.00 | 7.90 | 7.90 |
| Hydro | 0.00 | 0.00 | 0.00 | 0.00 | 3.08 | 3.08 |
| Non-Hydro | 0.43 | 0.08 | 2.42 | 0.03 | 1.10 | 4.06 |
| **Primary Total** | **7.36** | **4.52** | **25.42** | **29.91** | **39.25** | **106.46** |
| Electricity | 4.49 | 4.34 | 3.90 | 0.09 | | 12.82 |
| **End-UseTotal** | **11.85** | **8.86** | **29.32** | **30.00** | | **80.04** |

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

| | Residential | Commercial | Industrial | Transportation | Electricity | Total |
|---|---|---|---|---|---|---|
| Coal | 0.05 | 0.07 | 2.25 | 0.00 | 17.26 | 19.63 |
| Oil | 1.41 | 0.64 | 9.40 | 27.80 | 0.23 | 39.49 |
| Gas | 5.35 | 3.74 | 10.27 | 0.83 | 4.48 | 24.67 |
| Nuclear | 0.00 | 0.00 | 0.00 | 0.00 | 7.90 | 7.90 |
| Hydro | 0.00 | 0.00 | 0.00 | 0.00 | 3.12 | 3.12 |
| Non-Hydro | 0.43 | 0.08 | 2.42 | 0.21 | 4.03 | 7.17 |
| **Primary Total** | **7.23** | **4.53** | **24.35** | **28.84** | **37.03** | **101.98** |
| Electricity | 4.27 | 4.01 | 3.38 | 0.09 | | 11.75 |
| **End-UseTotal** | **11.50** | **8.54** | **27.73** | **28.93** | | **76.70** |

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

| | Residential | Commercial | Industrial | Transportation | Electricity | Total |
|---|---|---|---|---|---|---|
| Coal | 0.05 | 0.07 | 2.62 | 0.00 | 22.41 | 25.16 |
| Oil | 1.29 | 0.67 | 10.55 | 31.74 | 0.19 | 44.43 |
| Gas | 5.70 | 3.89 | 11.14 | 0.99 | 6.97 | 28.69 |
| Nuclear | 0.00 | 0.00 | 0.00 | 0.00 | 7.69 | 7.69 |
| Hydro | 0.00 | 0.00 | 0.00 | 0.00 | 3.08 | 3.08 |
| Non-Hydro | 0.43 | 0.08 | 2.64 | 0.04 | 1.60 | 4.79 |
| **Primary Total** | **7.47** | **4.71** | **26.95** | **32.77** | **41.94** | **113.84** |
| Electricity | 4.95 | 4.86 | 4.17 | 0.12 | | 14.10 |
| **End-UseTotal** | **12.42** | **9.57** | **31.12** | **32.89** | | **86.00** |

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

| | Residential | Commercial | Industrial | Transportation | Electricity | Total |
|---|---|---|---|---|---|---|
| Coal | 0.05 | 0.07 | 2.09 | 0.00 | 10.74 | 12.95 |
| Oil | 1.26 | 0.62 | 9.15 | 27.38 | 0.28 | 38.70 |
| Gas | 5.39 | 3.93 | 10.73 | 0.99 | 6.33 | 27.37 |
| Nuclear | 0.00 | 0.00 | 0.00 | 0.00 | 7.91 | 7.91 |
| Hydro | 0.00 | 0.00 | 0.00 | 0.00 | 3.12 | 3.12 |
| Non-Hydro | 0.43 | 0.08 | 2.64 | 0.54 | 7.02 | 10.71 |
| **Primary Total** | **7.13** | **4.71** | **24.62** | **28.91** | **35.40** | **100.76** |
| Electricity | 4.12 | 3.79 | 2.91 | 0.12 | | 10.93 |
| **End-UseTotal** | **11.25** | **8.49** | **27.52** | **29.03** | | **76.29** |

## Percentage Difference in Primary Consumption by 2010 Relative to 1990

| | Residential | Commercial | Industrial | Transportation | Electricity | Total |
|---|---|---|---|---|---|---|
| Coal | -13% | -28% | -24% | NA | -34% | -32% |
| Oil | -1% | -32% | 10% | 26% | -77% | 15% |
| Gas | 19% | 42% | 27% | 45% | 120% | 42% |
| Nuclear | NA | NA | NA | NA | 28% | 28% |
| Hydro | NA | NA | NA | NA | 4% | 4% |
| Non-Hydro | -48% | -8% | 28% | NA | 1304% | 207% |
| **Primary Total** | **7%** | **22%** | **14%** | **29%** | **18%** | **19%** |
| Electricity | 31% | 32% | -10% | 1081% | | 18% |
| **Total** | **14%** | **26%** | **11%** | **29%** | | **19%** |

**Total Energy Consumption by Fuel and by Sector in 2015 (Quads), Base Case**

| | Residential | Commercial | Industrial | Transportation | Electricity | Total |
|---|---|---|---|---|---|---|
| Coal | 0.05 | 0.07 | 2.62 | 0.00 | 22.97 | 25.72 |
| Oil | 1.24 | 0.67 | 11.15 | 34.29 | 0.18 | 47.52 |
| Gas | 5.99 | 4.05 | 11.78 | 1.12 | 9.37 | 32.32 |
| Nuclear | 0.00 | 0.00 | 0.00 | 0.00 | 6.79 | 6.79 |
| Hydro | 0.00 | 0.00 | 0.00 | 0.00 | 3.07 | 3.07 |
| Non-Hydro | 0.43 | 0.08 | 2.86 | 0.04 | 1.59 | 5.01 |
| **Primary Total** | **7.71** | **4.88** | **28.41** | **35.45** | **43.97** | **120.42** |
| Electricity | 5.36 | 5.30 | 4.44 | 0.15 | | 15.25 |
| **End-UseTotal** | **13.08** | **10.18** | **32.85** | **35.60** | | **91.70** |

**Total Energy Consumption by Fuel and by Sector in 2015 (Quads). Policy Case**

| | Residential | Commercial | Industrial | Transportation | Electricity | Total |
|---|---|---|---|---|---|---|
| Coal | 0.05 | 0.07 | 1.99 | 0.00 | 5.70 | 7.81 |
| Oil | 1.18 | 0.58 | 8.70 | 25.65 | 0.13 | 36.25 |
| Gas | 5.31 | 4.05 | 11.48 | 1.12 | 5.85 | 27.81 |
| Nuclear | 0.00 | 0.00 | 0.00 | 0.00 | 7.60 | 7.60 |
| Hydro | 0.00 | 0.00 | 0.00 | 0.00 | 3.11 | 3.11 |
| Non-Hydro | 0.43 | 0.08 | 2.86 | 0.79 | 7.50 | 11.67 |
| **Primary Total** | **6.98** | **4.79** | **25.03** | **27.56** | **29.89** | **94.26** |
| Electricity | 3.77 | 3.20 | 2.18 | 0.15 | | 9.29 |
| **End-UseTotal** | **10.75** | **7.99** | **27.21** | **27.71** | | **73.66** |

**Percentage Difference in Primary Consumption by 2015 Relative to 1990**

| | Residential | Commercial | Industrial | Transportation | Electricity | Total |
|---|---|---|---|---|---|---|
| Coal | -16% | -26% | -28% | NA | -65% | -59% |
| Oil | -7% | -37% | 5% | 18% | -89% | 8% |
| Gas | 18% | 47% | 35% | 65% | 103% | 44% |
| Nuclear | NA | NA | NA | NA | 23% | 23% |
| Hydro | NA | NA | NA | NA | 4% | 4% |
| Non-Hydro | -48% | -8% | 38% | NA | 1400% | 234% |
| **Primary Total** | **5%** | **24%** | **16%** | **23%** | **0%** | **11%** |
| Electricity | 20% | 12% | -33% | 1355% | NA | 0% |
| **Total** | **9%** | **19%** | **10%** | **23%** | **NA** | **15%** |

## Total Energy Consumption by Fuel and by Sector in 2020 (Quads), Base Case

| | Residential | Commercial | Industrial | Transportation | Electricity | Total |
|---|---|---|---|---|---|---|
| Coal | 0.05 | 0.08 | 2.62 | 0.00 | 23.50 | 26.24 |
| Oil | 1.21 | 0.66 | 11.78 | 36.77 | 0.20 | 50.62 |
| Gas | 6.31 | 4.14 | 12.38 | 1.24 | 11.40 | 35.48 |
| Nuclear | 0.00 | 0.00 | 0.00 | 0.00 | 6.09 | 6.09 |
| Hydro | 0.00 | 0.00 | 0.00 | 0.00 | 3.06 | 3.06 |
| Non-Hydro | 0.44 | 0.08 | 3.08 | 0.05 | 1.62 | 5.27 |
| **Primary Total** | **8.01** | **4.96** | **29.86** | **38.06** | **45.87** | **126.76** |
| Electricity | 5.80 | 5.59 | 4.79 | 0.17 | | 16.34 |
| **End-UseTotal** | **13.81** | **10.54** | **34.65** | **38.23** | | **97.23** |

## Total Energy Consumption by Fuel and by Sector in 2020 (Quads). Policy Case

| | Residential | Commercial | Industrial | Transportation | Electricity | Total |
|---|---|---|---|---|---|---|
| Coal | 0.05 | 0.08 | 1.90 | 0.00 | 2.45 | 4.48 |
| Oil | 1.13 | 0.52 | 8.34 | 25.15 | 0.07 | 35.21 |
| Gas | 5.26 | 4.09 | 12.38 | 1.24 | 4.63 | 27.61 |
| Nuclear | 0.00 | 0.00 | 0.00 | 0.00 | 6.90 | 6.90 |
| Hydro | 0.00 | 0.00 | 0.00 | 0.00 | 3.11 | 3.11 |
| Non-Hydro | 0.44 | 0.08 | 3.08 | 1.05 | 7.18 | 11.84 |
| **Primary Total** | **6.88** | **4.77** | **25.71** | **27.45** | **24.35** | **89.15** |
| Electricity | 3.46 | 2.49 | 1.45 | 0.17 | | 7.56 |
| **End-UseTotal** | **10.34** | **7.26** | **27.15** | **27.61** | | **72.37** |

## Percentage Difference in Primary Consumption by 2020 Relative to 1990

| | Residential | Commercial | Industrial | Transportation | Electricity | Total |
|---|---|---|---|---|---|---|
| Coal | -19% | -24% | -31% | NA | -85% | -77% |
| Oil | -11% | -43% | 0% | 15% | -94% | 5% |
| Gas | 16% | 48% | 46% | 83% | 61% | 43% |
| Nuclear | NA | NA | NA | NA | 12% | 12% |
| Hydro | NA | NA | NA | NA | 4% | 4% |
| Non-Hydro | -47% | -8% | 49% | NA | 1337% | 239% |
| **Primary Total** | **3%** | **24%** | **19%** | **22%** | **-19%** | **5%** |
| Electricity | 10% | -13% | -55% | 1559% | NA | -18% |
| **Total** | **5%** | **8%** | **9%** | **23%** | **NA** | **13%** |

**Carbon Emissions in 1990 (Million metric tons)**

| Sector | Gas | Oil | Coal | Indirect Electric | Totals |
|---|---|---|---|---|---|
| **Electric** | 41.2 | 26.8 | 408.8 | NA | 476.8 |
| **Residential** | 65.0 | 24.0 | 1.6 | 162.4 | 253.0 |
| **Commercial** | 38.7 | 18.1 | 2.3 | 147.5 | 206.6 |
| **Industrial** | 119.6 | 91.9 | 67.8 | 166.3 | 445.6 |
| **Transportation** | 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** | 77.9 | 7.0 | 544.0 | NA | 628.9 |
| **Residential** | 78.6 | 26.9 | 1.3 | 220.4 | 327.1 |
| **Commercial** | 53.5 | 12.9 | 1.8 | 212.9 | 281.0 |
| **Industrial** | 150.2 | 99.6 | 66.6 | 191.3 | 507.7 |
| **Transportation** | 11.9 | 557.2 | 0.0 | 4.3 | 573.5 |
| **Totals** | 372.1 | 703.6 | 613.6 | 0.0 | 1,689.3 |
| **Fossil Fuel Share** | 22.0% | 41.7% | 36.3% | | |
| **Elect. Share** | | | | | 37.2% |

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

| Sector | Gas | Oil | Coal | Indirect Electric | Totals |
|---|---|---|---|---|---|
| **Electric** | 64.7 | 5.1 | 438.5 | NA | 508.3 |
| **Residential** | 77.0 | 26.6 | 1.3 | 178.4 | 283.2 |
| **Commercial** | 53.8 | 12.5 | 1.8 | 173.2 | 241.3 |
| **Industrial** | 147.9 | 89.6 | 57.2 | 150.4 | 445.1 |
| **Transportation** | 11.9 | 533.1 | 0.0 | 4.3 | 549.4 |
| **Totals** | 355.3 | 666.9 | 498.8 | 0.0 | 1,521.1 |
| **Fossil Fuel Share** | 23.4% | 43.8% | 32.8% | | |
| **Elect. Share** | | | | | 33.4% |

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

| Sector | Gas | Oil | Coal | Indirect Electric | Totals |
|---|---|---|---|---|---|
| **Electric** | 100.4 | 4.2 | 568.8 | NA | 673.4 |
| **Residential** | 82.0 | 24.4 | 1.3 | 236.5 | 344.3 |
| **Commercial** | 56.0 | 13.1 | 1.9 | 232.2 | 303.2 |
| **Industrial** | 160.4 | 105.9 | 66.4 | 199.0 | 531.8 |
| **Transportation** | 14.2 | 608.9 | 0.0 | 5.6 | 628.7 |
| **Totals** | 413.1 | 756.4 | 638.5 | 0.0 | 1,808.0 |
| **Fossil Fuel Share** | 22.9% | 41.8% | 35.3% | | |
| **Elect. Share** | | | | | 37.2% |

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

| Sector | Gas | Oil | Coal | Indirect Electric | Totals |
|---|---|---|---|---|---|
| **Electric** | 91.1 | 6.4 | 274.7 | NA | 372.1 |
| **Residential** | 77.6 | 23.8 | 1.3 | 128.5 | 231.2 |
| **Commercial** | 56.6 | 12.2 | 1.9 | 127.8 | 198.4 |
| **Industrial** | 154.6 | 80.0 | 53.0 | 106.4 | 394.0 |
| **Transportation** | 14.2 | 525.1 | 0.0 | 5.6 | 545.0 |
| **Totals** | 394.0 | 647.5 | 330.9 | 0.0 | 1,372.3 |
| **Fossil Fuel Share** | 28.7% | 47.2% | 24.1% | | |
| **Elect. Share** | | | | | 27.1% |

**Percentage Difference in Carbon Emissions in 2010 Relative to 1990**

| Sector | Gas | Oil | Coal | Indirect Electric | Totals |
|---|---|---|---|---|---|
| **Electric** | 121% | -76% | -33% | NA | -22% |
| **Residential** | 19% | -1% | -16% | -21% | -9% |
| **Commercial** | 46% | -33% | -20% | -13% | -4% |
| **Industrial** | 29% | -13% | -22% | -36% | -12% |
| **Transportation** | 44% | 24% | NA | 706% | 26% |
| **Totals** | 44% | 11% | -31% | NA | 3% |

**Carbon Emissions in 2015 -- Base Case (Million metric tons)**

| Sector | Gas | Oil | Coal | Indirect Electric | Totals |
|---|---|---|---|---|---|
| **Electric** | 77.9 | 7.0 | 544.0 | NA | 628.9 |
| **Residential** | 86.2 | 23.4 | 1.3 | 253.9 | 364.9 |
| **Commercial** | 58.4 | 13.1 | 1.9 | 250.9 | 324.3 |
| **Industrial** | 169.6 | 112.2 | 66.4 | 210.3 | 558.6 |
| **Transportation** | 16.2 | 657.6 | 0.0 | 6.9 | 680.6 |
| **Totals** | 408.3 | 813.3 | 613.6 | 0.0 | 1,835.3 |
| **Fossil Fuel Share** | 22.2% | 44.3% | 33.4% | | |
| **Elect. Share** | | | | | 34.3% |

**Carbon Emissions in 2015 -- Policy Case (Million metric tons)**

| Sector | Gas | Oil | Coal | Indirect Electric | Totals |
|---|---|---|---|---|---|
| **Electric** | 64.7 | 5.1 | 438.5 | NA | 508.3 |
| **Residential** | 76.5 | 22.3 | 1.3 | 78.7 | 178.8 |
| **Commercial** | 58.3 | 11.3 | 1.9 | 79.1 | 150.6 |
| **Industrial** | 165.3 | 67.0 | 50.4 | 65.6 | 348.3 |
| **Transportation** | 16.2 | 491.4 | 0.0 | 6.9 | 514.5 |
| **Totals** | 380.9 | 597.1 | 492.2 | 0.0 | 1,470.2 |
| **Fossil Fuel Share** | 25.9% | 40.6% | 33.5% | | |
| **Elect. Share** | | | | | 34.6% |

**Percentage Difference in Carbon Emissions in 2015 Relative to 1990**

| Sector | Gas | Oil | Coal | Indirect Electric | Totals |
|---|---|---|---|---|---|
| **Electric** | 57% | -81% | 7% | NA | 7% |
| **Residential** | 18% | -7% | -19% | -52% | -29% |
| **Commercial** | 51% | -38% | -17% | -46% | -27% |
| **Industrial** | 38% | -27% | -26% | -61% | -22% |
| **Transportation** | 63% | 16% | NA | 884% | 19% |
| **Totals** | 39% | 2% | 2% | NA | 10% |

**Carbon Emissions in 2020 -- Base Case (Million metric tons)**

| Sector | Gas | Oil | Coal | Indirect Electric | Totals |
|---|---|---|---|---|---|
| **Electric** | 77.9 | 7.0 | 544.0 | NA | 628.9 |
| **Residential** | 90.9 | 22.9 | 1.3 | 271.6 | 386.6 |
| **Commercial** | 59.6 | 12.9 | 2.0 | 261.6 | 336.0 |
| **Industrial** | 178.3 | 119.4 | 66.5 | 224.0 | 588.2 |
| **Transportation** | 17.9 | 705.1 | 0.0 | 7.8 | 730.8 |
| **Totals** | 424.6 | 867.2 | 613.7 | 0.0 | 1,905.6 |
| **Fossil Fuel Share** | 22.3% | 45.5% | 32.2% | | |
| **Elect. Share** | | | | | 33.0% |

**Carbon Emissions in 2020 -- Policy Case (Million metric tons)**

| Sector | Gas | Oil | Coal | Indirect Electric | Totals |
|---|---|---|---|---|---|
| **Electric** | 64.7 | 5.1 | 438.5 | NA | 508.3 |
| **Residential** | 75.8 | 21.2 | 1.3 | 44.0 | 142.3 |
| **Commercial** | 58.9 | 10.2 | 2.0 | 42.5 | 113.6 |
| **Industrial** | 178.3 | 55.7 | 48.3 | 36.4 | 318.7 |
| **Transportation** | 17.9 | 481.4 | 0.0 | 7.8 | 507.1 |
| **Totals** | 395.6 | 573.7 | 490.0 | 0.0 | 1,459.2 |
| **Fossil Fuel Share** | 27.1% | 39.3% | 33.6% | | |
| **Elect. Share** | | | | | 34.8% |

**Percentage Difference in Carbon Emissions in 2020 Relative to 1990**

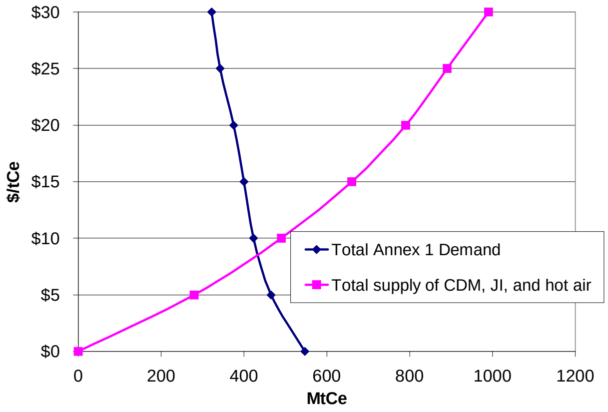
| Sector | Gas | Oil | Coal | Indirect Electric | Totals |
|---|---|---|---|---|---|
| **Electric** | 56.9% | -80.9% | 7.3% | NA | 6.6% |
| **Residential** | 16.6% | -11.6% | -21.7% | -72.9% | -43.8% |
| **Commercial** | 52.2% | -43.6% | -15.0% | -71.2% | -45.0% |
| **Industrial** | 49.1% | -39.4% | -28.8% | -78.1% | -28.5% |
| **Transportation** | 81.1% | 14.0% | NA | 1009.4% | 17.1% |
| **Totals** | 44.2% | -1.6% | 2.0% | NA | 9.1% |

## Appendix 2. Modeling Global Carbon Markets

We first construct an aggregate Annex 1 demand curve for international emissions reductions from CDM, JI, and ET/hot air. This demand curve represents how short, at a given price, Annex 1 countries are from meeting their Kyoto target using only domestic options (energy sector CO2, non-CO2 gas, and Article 3.3/3.4options). We can then compare this demand curve with the supply curve for CDM, JI, and ET/hot air (based on the assumptions described above) to find the market-clearing price. Our approach is similar to that used in a few other recent studies (Grutter, 2001; Haites, 2000; Missfeldt and Haites, 2001; Krause et al, 2001; Vrolijk and Grubb, 2000).

To create the Annex 1 demand curve, we combine a US demand curve -- the "additional required reductions" line in Figure 6.2 minus the cost curve or amount available from non-CO2 measures at a given price -- with estimated demand for CDM, JI, and ET/hot air from other Annex 1 parties, excluding EITs. We estimate the non-US demand using a combination of EPPA and GTEM cost curves.[38] There is a resulting asymmetry in this approach, since the non-US cost curves we use do not embody the aggressive pursuit of domestic energy sector reductions found in our analysis for the US. As a result the total demand for and use of international trading, as well as the resulting market clearing price, is significantly higher than it would be were we to have looked at a similarly aggressive approach in all Annex 1 countries. The result is shown in the figure at right.

**Figure 3. Supply and demand for international emissions credits and allowances, 2010.**



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[38] The first scenario is based on EPPA cost curves (Reilly et al, 2000 and Ellerman and Decaux, 1998) and RIIA 1990 emission estimates (Vrolijk and Grubb, 2000), and yields an estimated 2010 demand from Annex II countries of 507 MtC. The second scenario uses GTEM results and assumed 1990 emissions reported via personal communication from the model developers, and yields an estimated 2010 demand from Annex II countries of 344 MtC. As found in Grutter (2001).