CEEPR Center for Energy and Environmental Policy Research

# The Cost of Climate Policy in the United States

by

Sergey Paltsev, John M. Reilly,
Henry D. Jacoby and Jennifer F. Morris

09-005 April 2009

A Joint Center of the Department of Economics,
MIT Energy Initiative, and Sloan School of Management

# The Cost of Climate Policy in the United States

Sergey Paltsev[†], John M. Reilly, Henry D. Jacoby and Jennifer F. Morris

**Abstract**

*We consider the cost of meeting emissions reduction targets consistent with a G8 proposal of a 50 percent global reduction in emissions by 2050, and an Obama Administration proposal of an 80 percent reduction over this period. We apply the MIT Emissions Prediction and Policy Analysis (EPPA), modeling these two policy scenarios if met by applying a national cap-and-trade system, and compare results with an earlier EPPA analysis of reductions of this stringency. We also test results to alternative assumptions about program coverage, banking behavior, and cost of technology in the electric power sector. Two main messages emerge from the exercise. First, technology uncertainties have a huge effect on the generation mix but only a moderate effect on the emissions price and welfare cost of achieving the assumed targets. Measured in terms of changes in economic welfare, the economic cost of 80 percent reduction by 2050 is in the range of 2 to 3% by 2050, with $CO_2$ prices between \$48 and \$67 in 2015 rising to between \$190 and \$266 by 2050. Second, implementation matters. When an idealized economy-wide cap-and-trade is replaced by coverage omitting some sectors, or if the credibility of long-term target is weak (limiting banking behavior) prices and welfare costs change substantially.*

**Contents**



## 1. INTRODUCTION

Several Congressional proposals for mitigating U.S. greenhouse gases have been put forth in recent years. Paltsev *et al*. (2008) analyzed the main proposals for cap-and-trade systems and Metcalf *et al.* (2008) did the same for $CO_2$ taxes. Paltsev *et al.* (2008) developed three paths of emissions control spanning the range of Congressional proposals, summarized in terms of the number of allowances that would be issued between 2012 and 2050, defined in terms of billions of metric tons (bmt) of $CO_2$ equivalent ($CO_2$-e). The three cases—287, 203, and 167 bmt—were

[†] Corresponding author: Sergey Paltsev (Email: paltsev@mit.edu).
MIT Joint Program on the Science and Policy of Global Change, Cambridge, MA, USA.

[*]Appendix available online at: http://globalchange.mit.edu/files/document/MITJPSPGC_Rpt173_AppendixA.xls

associated with allowance allocation schemes that, respectively, yielded constant emissions at 2008 levels or linearly reduced them to 50% and 80% below 2008 emissions by 2050. These target reductions, particularly those with deeper cuts, remain relevant to current policy discussions, but much has changed since our earlier work was completed. Here we reconsider these reduction targets using the same version of the Emissions Prediction and Policy Analysis (EPPA) model used by Patsev *et al.* (2008), but updating the underlying economic, technology, and policy assumptions to better reflect the current economic conditions and technology cost expectations.

In terms of economic outlook, the prospects for economic growth have worsened, especially in the short term, and even the long-term growth prospects considered reasonable a few years ago now seem optimistic. Lower economic activity means fewer emissions, and so less abatement will be needed to meet specific quantitative targets.

On the technology front, the prospects for carbon capture and storage (CCS) have worsened: progress in commercial demonstration has been slow, and the full cost of the technology has become clearer as these efforts have proceeded. As a result, costs are likely much higher than those drawn from earlier engineering studies and applied in our previous analysis. The prospects for nuclear power have changed as well. There are now some concrete proposals within the U.S. to build new plants, even though the technology remains an inexpensive option. In the Paltsev *et al*. (2008) analysis, the core cases severely limited nuclear growth beyond its existing capacity based on anticipated regulatory and siting limitations. U.S. nuclear expansion now appears more likely, but the costs of these plants are now seen to be more expensive than their representation in the earlier work.

Renewables, especially wind, have been expanding at a high rate, albeit from a very small base, and are looking more viable than assumed earlier. Casual observation of the rapid growth rates might suggest these sources are now competitive with conventional generation. However, that evidence does not reveal the full cost of wind or solar at a large scale. Current investment has been spurred by significant tax incentives and subsidies. While representing the after tax-incentive cost in the EPPA model might produce an accurate portrayal of current market penetration, simply lowering the cost to reflect the subsidies would underestimate the hidden costs to taxpayers and utility customers. Also, one motivation for these subsidies is to demonstrate the technology, and it is reasonable to assume they will be phased out once the technology is demonstrated. Expansion of wind or solar to larger shares of generation will also require more storage or redundant capacity to accommodate their intermittency, and an increase in the transmission network to bring this dispersed energy source to demand areas. The submodel of these sources has been revised to better capture these various influences.[1]

[1] Energy prices have also swung widely since the time of our earlier analysis of these proposals. We do not consider these effects. The previous work by Paltsev *et al*. (2008) showed a slower and gradual rise in the oil price, and did not reproduce the recent high prices, suggesting that the run-up was not supportable on long-term fundamentals. The collapse of oil prices may provide some support for that interpretation. Furthermore, the recent volatility provides little information of use in calibrating a model that solves for five-year periods.

While the previous reduction targets examined by Paltsev *et al.* (2008) remain relevant the policy details have evolved. Nearly all proposals seek to achieve major cuts in greenhouse gas emissions, so the 287 bmt case (just holding emissions constant) is not of much relevance to current discussions. The overall nationwide targets now being discussed remain within the 167 to 203 bmt range, however, with more emphasis on targets consistent with the 167 bmt case. Also, as these proposals have been reworked several subtle changes have been introduced that can affect the overall cost. For example, while it has generally been recognized that any actual cap-and-trade system is likely to leave out some emissions sources, the past proposals tended to proportionately scale allowance allocations for covered sectors, allowing the uncapped sectors to avoid restriction and possibly to grow. As a result the nominal national-level cap would be exceeded. Given increased concerns about the risk of climate change there is now interest in more than proportionately reducing allowances to capped sectors to make up for lack of control in the uncapped sectors. There is also increased interest in coupling a cap-and-trade system with regulatory policies such as a renewable portfolio standard that would give an assured boost to a subset of technologies.

Also the relationship of long-term targets to near-term actions and policy costs is a growing issue. Our earlier work showed that targets which are tightened over time tended to stimulate banking of allowances in the near term. As a result, near term targets were more than met and the near term $CO_2$-e prices rose above the level one might expect given the relatively smaller reductions required in the early years. The reason to set longer term targets is to provide clear direction on where emitters need to be in the future and thereby provide incentives for investment in aggressive mitigation options. However, policy proposals that specify an ambitious long-run goal but only provide allowances on a much shorter rolling time scale, and that show concern about cost containment, may signal to emitters that the long-term target is only an aspiration, and is easily changed. Even forward-looking firms may discount ambitious distant goals as not credible. In that case the incentive to bank allowances is much reduced, with substantial implications for short-term effort and cost.

We investigate these issues, structuring our paper in the following way. In Section 2 we briefly describe the EPPA model and focus on the specific updates we have made for this analysis. Section 3 provides a comparison of the new results for the three cases—287, 203, and 167 bmt—with our previous estimates. In Section 4 we focus on the 167 bmt case and examine how, given a national target, details of implementation or different expectations about technology can lead to significant differences in costs and the success of different technologies. In particular we focus, in turn, on (1) shortening the banking time horizon to 2030, which is consistent with the assumption that the 2050 target is not fully credible, (2) excluding hard-to-monitor sectors from the cap while tightening the constraint on the capped sectors to make up for these emissions, and (3) effects of different assumptions about the cost of CCS, nuclear and renewables. In terms of technology alternatives we focus on results for the electricity sector. Other details on economy-wide emissions and other economic indicators are provided in the on-line Appendix. We conclude in Section 5.

## 2. THE EMISSIONS PREDICTION AND POLICY ANALYSIS (EPPA) MODEL

The standard version of the EPPA model (**Table 1**) is a multi-region, multi-sector recursive-dynamic representation of the global economy (Paltsev *et al.*, 2005).[2] The recursive solution approach means that current period investment, savings, and consumption decisions are made on the basis of current period prices.

**Table 1.** EPPA Model Details.

| ***Country or Region*** † | ***Sectors*** | ***Factors*** |
|---|---|---|
| ***Developed*** | ***Final Demand Sectors*** | Capital |
| United States (USA) | Agriculture | Labor |
| Canada (CAN) | Services | Crude Oil Resources |
| Japan (JPN) | Energy-Intensive Products | Natural Gas Resources |
| European Union+ (EUR) | Other Industries Products | Coal Resources |
| Australia & New Zealand (ANZ) | Transportation | Shale Oil Resources |
| Former Soviet Union (FSU) | Household Transportation | Nuclear Resources |
| Eastern Europe (EET) | Other Household Demand | Hydro Resources |
| ***Developing*** | ***Energy Supply & Conversion*** | Wind/Solar Resources |
| India (IND) | Electric Generation | Land |
| China (CHN) | Conventional Fossil | |
| Indonesia (IDZ) | Hydro | |
| Higher Income East Asia (ASI) | Existing Nuclear | |
| Mexico (MEX) | Wind, Solar | |
| Central & South America (LAM) | Biomass | |
| Middle East (MES) | Advanced Gas | |
| Africa (AFR) | Advanced Gas with CCS | |
| Rest of World (ROW) | Advanced Coal with CCS | |
| | Advanced Nuclear | |
| | Fuels | |
| | Coal | |
| | Crude Oil, Shale Oil, Refined Oil | |
| | Natural Gas, Gas from Coal | |
| | Liquids from Biomass | |
| | Synthetic Gas | |

† Specific detail on regional groupings is provided in Paltsev *et al.* (2005).

Table 1 broadly identifies final demand sectors and energy supply and conversion sectors. Final demand sectors include five industrial sectors and two household demands, transportation and other household activities (space conditioning, lighting, etc.), as shown in the table. Energy supply and conversion sectors are modeled in enough detail to identify fuels and technologies with different $CO_2$ emissions and to represent both fossil and non-fossil advanced technologies. The synthetic coal gas industry produces a perfect substitute for natural gas. The oil shale industry produces a perfect substitute for refined oil. All electricity generation technologies produce perfectly substitutable electricity except for Wind and Solar which is modeled as

[2] The EPPA model can also be solved as a perfect foresight model. See Gurgel *et al.* (2007) and Babiker *et al.* (2008).

producing an imperfect substitute, reflecting its diurnal and seasonal variability. Biomass use is included both in electric generation and in transport where a liquid fuel is produced that is assumed to be a perfect substitute for refined oil.

There are 16 geographical regions represented explicitly in the model including major countries (the U.S., Japan, Canada, China, India, and Indonesia) and 10 regions that are an aggregations of countries. While the results in this paper focus on the U.S., economic and population growth and policies assumed to be in place abroad affect world markets, depletion of resources, and therefore the U.S. economy through international trade. In this exercise we follow the Energy Modeling Forum protocol on policy in other regions (Clarke *et al.*, 2009), with the developed countries reducing to 50% below 1990 levels by 2050; China, India, Russia, and Brazil starting in 2030 on a linear path to 50% below their 2030 emissions level by 2070; and the rest of the countries delaying action beyond the 2050 horizon of our study.

The model includes representation of abatement of non-$CO_2$ greenhouse gas emissions ($CH_4$, $N_2O$, HFCs, PFCs and $SF_6$) and the calculations consider both the emissions mitigation that occurs as a byproduct of actions directed at $CO_2$ and reductions resulting from gas-specific control measures. Targeted control measures include reductions in the emissions of: $CO_2$ from the combustion of fossil fuels; the industrial gases that replace CFCs controlled by the Montreal Protocol and produced at aluminum smelters; $CH_4$ from fossil energy production and use, agriculture, and waste, and $N_2O$ from fossil fuel combustion, chemical production and improved fertilizer use. More detail on how abatement costs are represented for these substances is provided in Hyman *et al*. (2003).

When emissions constraints on certain countries, gases, or sectors are imposed in a CGE model such as EPPA, the model calculates a shadow value of the constraint which is interpretable as a price that would be obtained under an allowance market that developed under a cap and trade system. The solution algorithm of the EPPA model finds least-cost reductions for each gas in each sector and if emissions trading is allowed it equilibrates the prices among sectors and gases (using GWP weights). This set of conditions, often referred to as “what” and “where” flexibility, will tend to lead to least-cost abatement. Without these conditions abatement costs will vary among sources and that will affect the estimated welfare cost—abatement will be least-cost within a sector or region or for a specific gas, but will not be equilibrated among them.

The mixed complementarity solution approach of the model means that least-cost is defined in terms of the tax inclusive prices (for fuels, electricity, capital, labor, and other goods) faced by producers and consumers given the technology set at any point in time. It does not necessarily lead to a welfare optimum in the presence of distortions (e.g., energy taxes) or to the extent combined actions of individual agents have macroeconomic consequences such as affecting the terms of trade of a country/region (Babiker *et al.*, 2004; Paltsev *et al.*, 2007). We simulate banking and borrowing, which implies foresight, by forcing the theoretical perfect foresight result that the $CO_2$-e price path must rise at the discount rate, assumed to be 4%. We do this by choosing an initial price so that the cumulative emissions are consistent with the policy target over the horizon of the policy. Allowing banking and borrowing is sometimes referred to as "when" flexibility. A price path rising at the discount rate means that the discounted price is equal in all time periods which is the temporal equivalent of equating the price across sectors or regions.

This approach to simulating banking approximates well the behavior of a perfect foresight model (Gurgel, *et al.*, 2007) and generates a smooth price path. Prices in real markets display volatility as observed in $CO_2$ prices in the Emissions Trading Scheme (ETS) operating in Europe. Of more relevance to the modeled price path is the observation that future prices and current prices differ by a risk free interest rate. This result is observed in the ETS and reflects the possibility of arbitrage profits where, if this interest rate differential is not met, a combination of current purchase and forward sales, or vice versa would generate risk-free profits above that which could be obtained on low risk investments such as government bonds. In a similar manner, the price simulated by the model is meant to represents the interest rate differential between current and future prices for allowances. Under different assumptions about growth, technological options, and other inputs, different prices can be obtained that can vary quite a lot. The range one would get from such variation in assumptions is more comparable to the volatility of observed prices, where that volatility occurs as new information is revealed and changes expectations about the future.

## 3. COMPARISON OF NEW RESULTS TO PREVIOUS RESULTS

### 3.1 Modeling Assumptions

As noted above, one purpose of this study is to investigate the impact of recent changes in the economic and technology outlook. **Table 2** describes the key assumptions regarding technology costs and GDP growth in our previous study compared with the assumptions used here. Average GDP growth for 2005 to 2050 is slower by 0.4% per year, in part, because we factor in the current recession. Lower GDP growth compounded over 40 years results in emissions that are nearly 20% lower in 2050.

The cost mark-up defines the cost of the advanced electricity technologies relative to electricity prices in the 1997 base year of the model. In the previous work, we applied a mark-up of 2.26 to a technology sector meant to represent a combination of wind and solar. In the revised model we have disaggregated this combined sector into two: wind and solar considered as separate sources. Also, we apply lower mark-up costs (1.0 and 1.5 respectively), implying that wind is competitive and solar costs just 50% more than conventional electricity. The biomass electricity markup is reduced from 2.1 to 1.1.

Renewables enter the electricity sector in the EPPA model as imperfect substitutes for other electricity.[3] That means that the mark-up costs are the cost of the first installations of these generation sources. We assume these are located at sites with access to the best quality resources, at locations most easily integrated into the grid, and at levels where variable resources

[3] For a description of this component of the EPPA model, see Paltsev *et al*. (2005).

can be accommodated without significant investment in storage or back-up. The elasticity of substitution creates a gradually increasing cost of production as the share of renewables increases in the generation mix. Thus, the mark-up cost strictly applies only to the first installations of these sources, and further expansion as a share of overall generation of electricity comes at greater cost. Previously the elasticity was 1.0, which effectively limited renewables to a relatively small share of generation. In these new simulations we increase it to 3.0, making it easier and less costly to expand the renewable share.

The mark-ups on nuclear and coal with CCS, which are modeled as perfect substitutes for other conventional generation, were raised from 1.25 and 1.19 to 1.7 and 1.6 respectively. Some current estimates for coal with CCS suggest even higher mark-ups but here we assume this is for the $n^{th}$ plant after some experience is gained in the technology, and assuming that experience leads to lower costs.

**Table 2.** Key Economic and Technology Assumptions.

| | **Report 146** | **Current study** |
|---|---|---|
| GDP growth, 2005-2050, rate/yr | 2.9% | 2.5% |
| 2050 baseline emissions | 13.3 $GtCO_2e$ | 10.8 $GtCO_2e$ |
| Renewable electricity | | |
| Solar mark-up | 2.26 | 1.5 |
| Wind mark-up | 2.26 | 1.0 |
| Biomass mark-up | 2.1 | 1.1 |
| Substitution elasticity | 1.0 | 3.0 |
| Advanced nuclear mark-up | 1.25* | 1.7 |
| CCS markup coal/gas | 1.19/1.17 | 1.6/1.6 |
| Adv. Natural Gas Combined Cycle | 0.95 | 1.2 |

*Except for some sensitivity cases, advanced nuclear was assumed to be unavailable.

There is much concern about the U.S. and world economy, with many indicators of economic performance suggesting a recession that could be quite severe by historic standards. In terms of GDP growth, the annual data through 2008 still does not look that dire compared to history (**Figure 1**).

In addition to historical data, the figure includes annual growth rates of GDP as forecasted by the U.S. Energy Information Administration in the central case of their early release 2009 energy outlook (EIA, 2008). They assume negative growth in 2009, some rebound in 2010, and then a return to a basically stable long-term trend. We use these same rates, averaging them over the five-year time step of the EPPA model. The five-year average rates are plotted as blue dots (historical data), red dots (EIA forecast period), pink dots (our extension of the EIA forecast which is only through 2030), and in brown are growth assumptions from our previous U.S. study. As plotted in Figure 1 the difference between our previous growth rates and the new ones look insignificant except for the first period. The appearance is driven by the scale of the graph needed to show historical rates. The actual difference is 0.5% per year or more through 2030, and that big a difference persisting for many years has a fairly significant effect on the level of the economy and emissions.

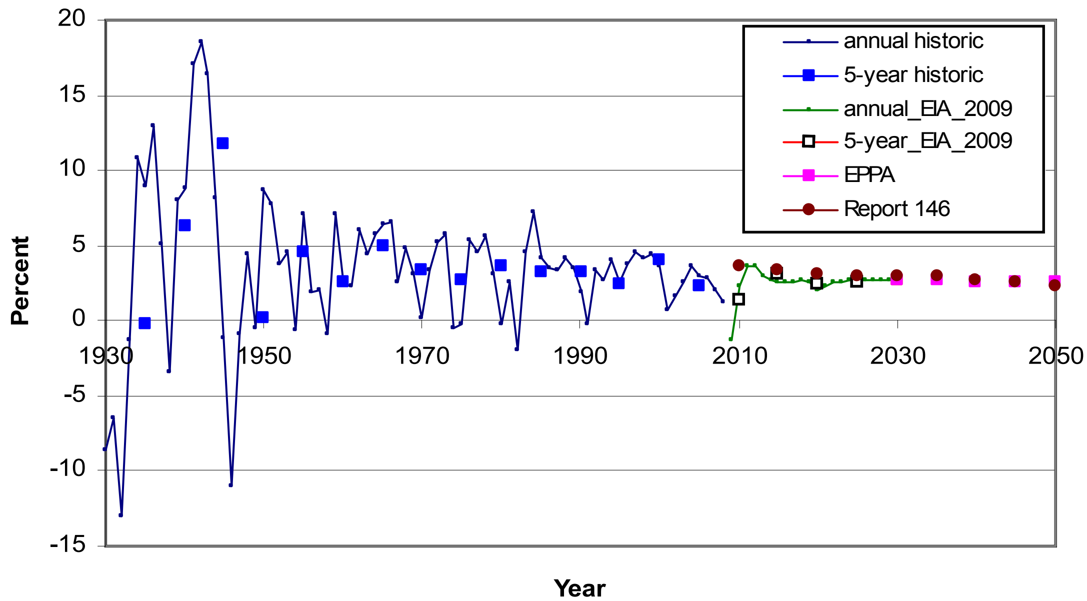


**Figure 1.** U.S. GDP Growth Rates, 1930 to 2008 and Projected Rates to 2050.

We have also adjusted down growth in other developed countries, while our long-term forecast for China and India is higher than in Paltsev, *et al.* (2008). The earlier estimates for India and China were below actual performance that was already observed since 2005. The new growth rates are still below the very high rates seen before the recent economic crises. These new growth rates include, as shown for the U.S., a near-term impact of the economic crisis but then a return to solid growth rates. The longer term growth rates for the developed countries are slower than in our past work, reflecting not so much the lasting impact of the current economic crisis, but rather a re-evaluation of long-term growth prospects, where we still are quite optimistic. Essentially we had extended through the next few decades the relatively robust growth of the late 1990's through 2005. If recovery from the current economic crisis is much slower, or signals a more fundamental change in growth prospects, then economic and emissions growth could be lower. At this point, however, the current economic problems appear to stem from a housing bubble, loose lending, and the follow-on financial problems that once worked through, would not affect productivity improvements that underlie long term economic growth.

### 3.2 Previous and New Results

The resulting U.S. GDP and greenhouse gas emissions in a "No policy" (Reference) case are presented in **Figure 2** and compared with similar results from our earlier work. Assumptions about slower economic growth lead to 15% lower GDP level (37.5 trillion instead of 44.2 trillion of 2005$) and 19% lower GHG emissions (10.7 Gt instead of 13.3 Gt $CO_2e$) by 2050.

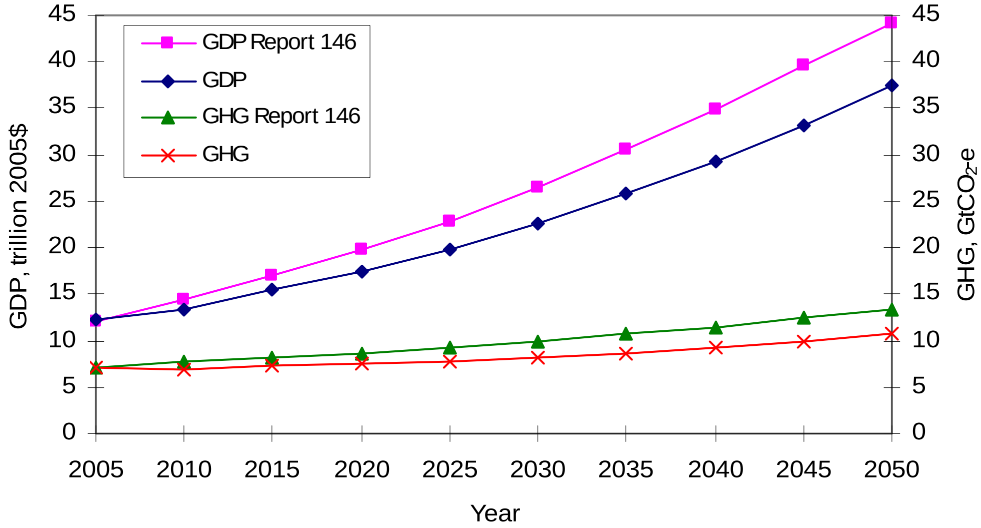


**Figure 2.** U.S. GDP and GHG in reference scenario.

**Figure 3** compares the $CO_2$-e price and welfare results from Paltsev *et al.* (2008) (Figure 3a and b) with our new results based on the changes discussed above (Figure 3c and d). For the 287 bmt case we see the strong effect of the lower economic growth assumption on the reference emissions. This abatement level requires very little action with prices starting at \$5/t$CO_2$-e and only rising to \$20 by 2050 in the new results compared with prices starting at \$18 and rising to \$70 in the old results. The revised technology assumptions have little effect in this case because these prices are insufficient to bring many of these alternatives into the picture; the cap is met by other, less expensive means.

In contrast, the $CO_2$-e prices for the 203 and 167 bmt cases are roughly equal or slightly higher in the new results than in the old. While advanced nuclear is available in these new scenarios (in Figure 3a and b simulations it was not allowed to grow), its cost is much higher than the CCS in the older results and the new CCS cost is also higher. The initial renewable installations are less expensive than in the old simulations, and also less than the old CCS cost, and these changes might be expected to lower the $CO_2$-e price and make the nuclear and CCS costs irrelevant. This does not happen because the increasing costs at higher levels of renewable penetration (as represented by the imperfect substitute assumption, even with the higher elasticity) does not allow them to completely substitute for nuclear and coal with CCS. As a result, the price in the 167 bmt case starts at \$58 in the new results compared with \$53 in the old results and by 2050 rises to \$230 instead of \$210.

The welfare results mirror the $CO_2$-e price with the 2050 result in the 167 bmt case showing a 2.5% loss compared with about 1.75% loss in the old results. The new results show a smoother increase in the welfare costs over time. This change in pattern results because the old simulations had developing countries substantially increasing their reductions in 2035, and this resulted in a substantial improvement in the terms of trade for the U.S. in that period. The new simulations assume that policies abroad phase in more gradually. There still are terms of trade effects from actions abroad, but they are realized more gradually so there is not such a short-term impact as before. The welfare costs in the 287 bmt case with the new growth assumptions are lower than under the previous growth assumptions.

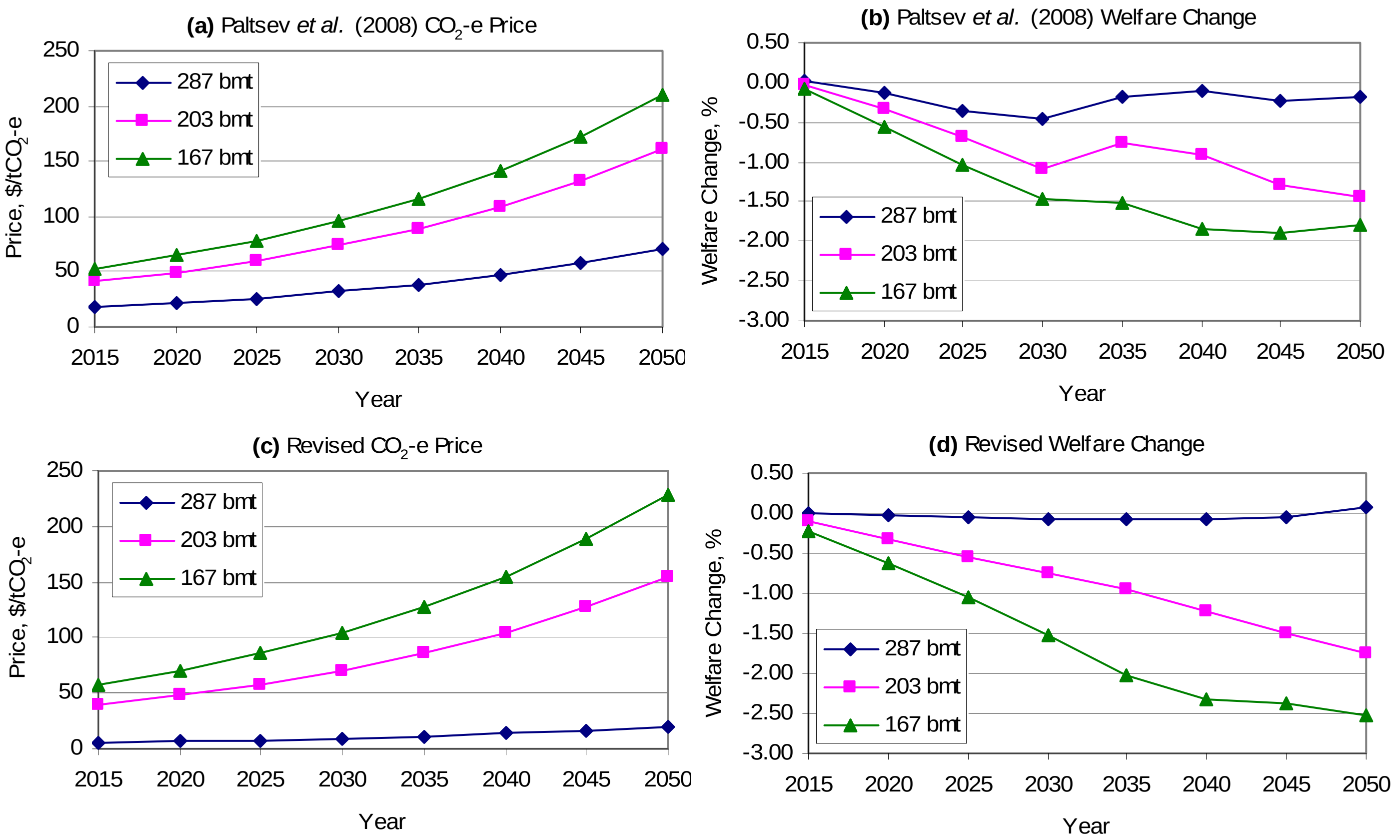


**Figure 3.** $CO_2$-e Price and Welfare Results for Three Policy Scenarios: **(a)** Paltsev *et al.* (2008) $CO_2$-e Price, **(b)** Paltsev *et al.* (2008) Welfare Change, **(c)** $CO_2$-e Price with Revised Technological and Economic Outlook, **(d)** Welfare Change with Revised Technological and Economic Outlook.

Compared to the earlier analysis, we have made changes in technology outlook in the electricity sector, so we focus on the generation sources for the no-policy reference and the three policy cases, shown in **Figure 4**. As previously, the no policy reference is strongly dominated by coal generation, with other sources basically maintaining their 2005 level. The exceptions are solar and wind, which now expand from 0.5 EJ in 2010 to 1.1 EJ by 2050 rather than from 0.2 EJ to 0.6EJ as in the previous study. However, even with that rapid expansion they remain a small share. As discussed, the 287 bmt case is insufficient to get advanced nuclear or coal with CCS. The small reductions needed are met with natural gas, an expansion of renewables and some reduction in demand. Since this is an economy-wide and all-GHG scenario some of the economy-wide reductions in all these cases are occurring in fuel use outside the electricity sector and from reductions of non-$CO_2$ GHGs.

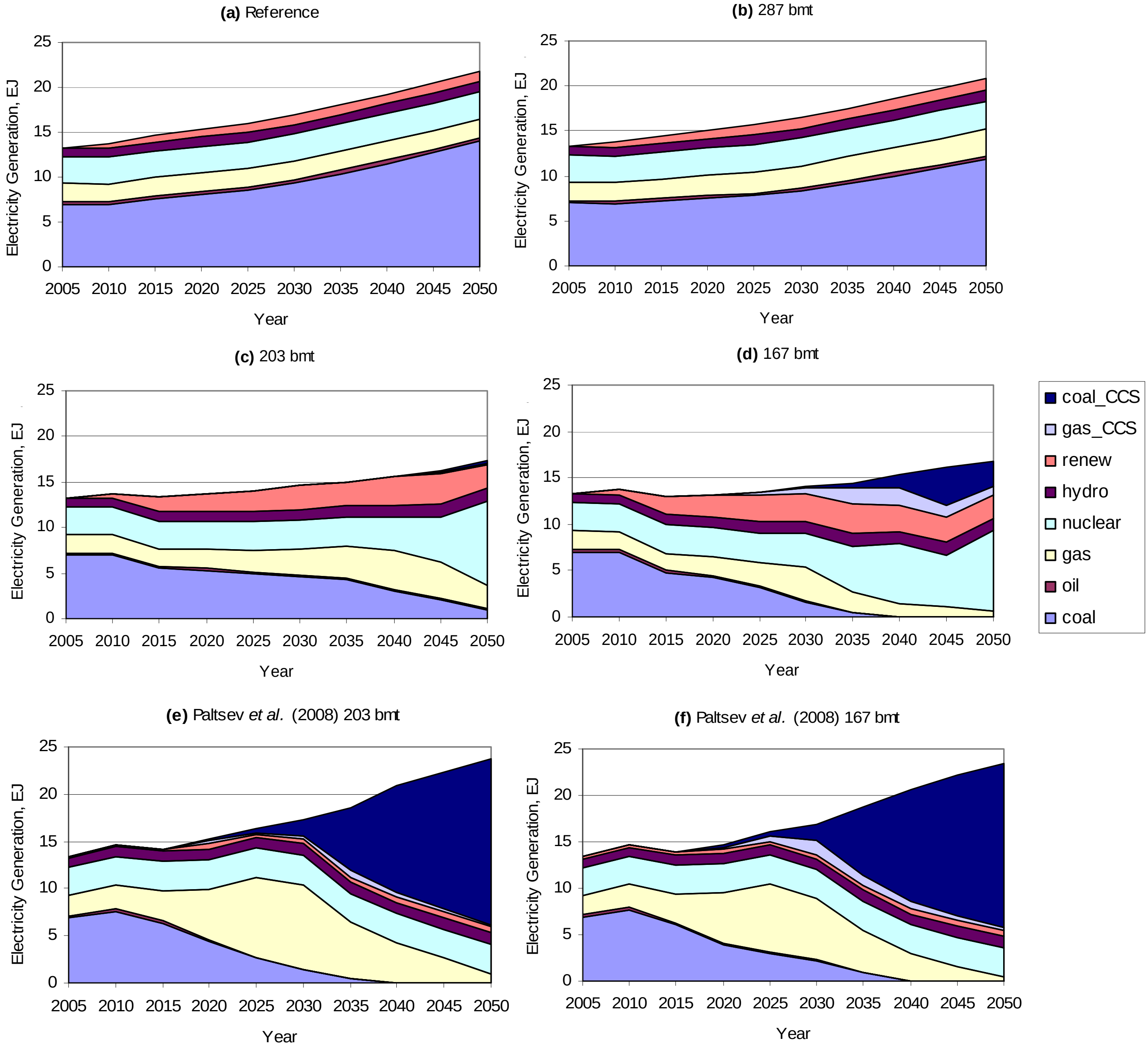


**Figure 4.** Electricity Generation by Sources in the Reference and Policy Cases: **(a)** Reference, **(b)** 287 bmt, **(c)** 203 bmt, **(d)** 167 bmt, **(e)** Paltsev *et al.* (2008) 203 bmt, **(f)** Paltsev *et al.* (2008) 167 bmt.

The impacts of the new technology assumptions are more apparent in the 203 and 167 bmt cases. Even though the nuclear mark-up is somewhat higher than the coal CCS mark-up we find that nuclear dominates in both cases. CCS exists in the 203 bmt case but the level is so small that it does not show up well in the graph. The reason for the success of nuclear over coal with CCS is that the assumption that coal CCS will capture only 90% of the $CO_2$ emissions means that the extra cost associated with allowances needed to cover those emissions raise the CCS cost, thereby favoring nuclear. Also, renewables play a much larger role, increasing to on the order of 20% of generation whereas in the old analysis they were never more than a few percent.

A not immediately intuitive result in the 167 bmt case is that, even though the constraint is tighter and $CO_2$-e prices are higher than in the 203 bmt case, CCS applied to coal and gas plays a substantial role. The reason is that, as formulated in the EPPA model, there are adjustment costs that increase for an advanced technology as the rate of expansion increases. The representation of this phenomenon is based on expansion of nuclear power in the late 1960's to the mid-1980's, when nearly all new base load capacity was nuclear. Thus what is happening in the 167 bmt case is that decarbonization of the electricity sector must proceed so rapidly to meet the economy-wide target that adjustment costs in the favored technology (nuclear) are pushing up its cost and thereby allowing the CCS technologies to compete. Since fossil sources with CCS still emit some $CO_2$, more reductions are needed elsewhere in the economy to make up for those emissions. It also means that these extra adjustment costs run up the cost of the policy, and that ultimately the CCS technologies will go away as nuclear ultimately dominates. CCS appears only because nuclear cannot expand fast enough, but once the capacity to expand nuclear catches up the CCS plants will depreciate away to be replaced by nuclear.

## 4. DETAILS OF POLICY IMPLEMENTATION AND TECHNOLOGY ASSUMPTIONS

### 4.1 System Coverage

Generally, GHG reduction targets focus on total national emissions—all emissions affect global concentrations and thus international discussions tend to focus on the national aggregate. Nonetheless, considerations of policy implementation often lead to a focus on a subset of emissions sources. Often this is because, it is argued at least, it is not worth the measurement and monitoring cost to include small and dispersed sources in a cap-and-trade system. That may be true in some policy designs: for example, the number of small sources increases the farther downstream the system is imposed. For energy-related $CO_2$ emissions, of course, it is possible to move upstream, placing the point of control at the coal mine or electric generating station, refinery gate or natural gas distribution system. Any $CO_2$ price is then passed through to final consumers as it would have been if they were directly required to surrender allowances. Such an upstream system can reduce the number of control points and thereby make including these small end-use sources less onerous. But if the implementation is downstream, small sources are an issue. In addition, in an effort to limit costs imposed directly on consumers, some proposals would omit household use of natural gas and heating oil.

For non-energy emissions of other greenhouse gases, and of $CO_2$ from land use change, control must be imposed at the point of emissions because going upstream or downstream can lead to an inefficient result. That is because incentives for available reduction options may not be provided by prices imposed upstream or downstream of that point. For example, implementation of the cap-and-trade system could be upstream and apply allowances to fertilizer sales, thereby reducing $N_2O$ emissions from inorganic fertilizer use. The allowances required could vary by the form of the fertilizer if there were evidence that emissions of $N_2O$ varied by the type applied. (Applied as anhydrous ammonia there are probably more $N_2O$ emissions than if applied in a solid form.) Unfortunately, this approach would not provide incentives to apply the fertilizer at times of the year when less would be volatized as $N_2O$. Methane emissions from livestock are even more difficult. Allowances could be required for each head of cattle sold, based on estimated methane emissions, but this would not provide incentives to reduce rates of methane emission per head but only the number of livestock. Or, if there were relatively easy ways to reduce methane emissions from manure handling, a policy that simply reduced the number of livestock would not efficiently get at that abatement option.

Following the definitions appearing in some current policy discussions, we explore a policy design where agriculture, services, and the household sector (ex. personal transportation) are left uncapped. This leaves out of the system many of the diffuse sources in the service sector and non-GHG emissions from agriculture and waste. Transportation, including the private automobile, is included through an upstream cap. This design is similar to that in the Warner-Lieberman Bill submitted to the previous session of Congress and analyzed by Paltsev *et al.* (2008). Interpretations of that bill were that the percentage reductions would apply only to the included sectors, and thus national emissions would not fall by that percentage as the uncapped sectors might grow—or at least would not fall. Here we consider the case where additional reductions are imposed on the capped sectors so that the overall percentage reduction targets are met for the economy.

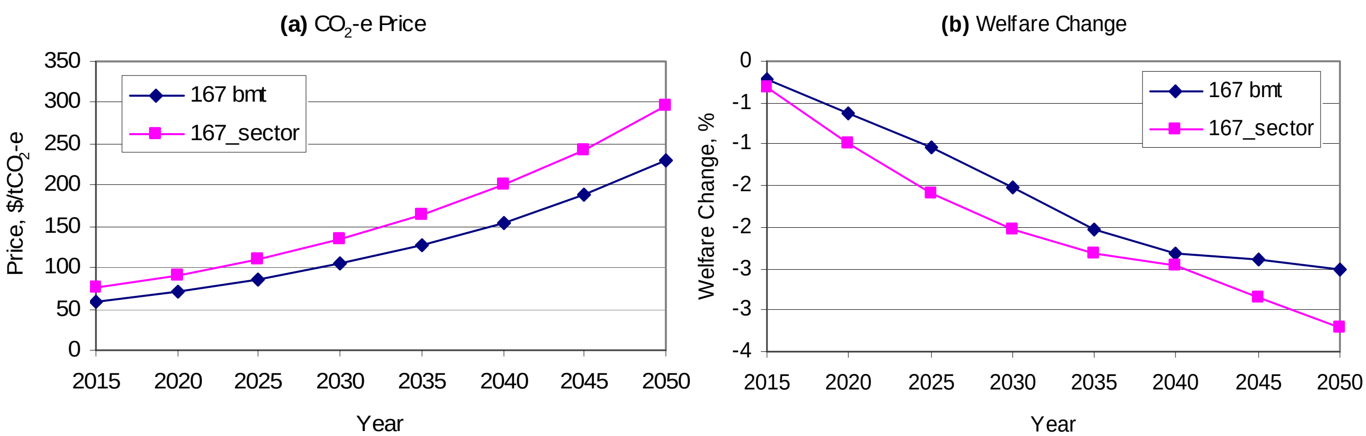


**Figure 5.** Effects of Meeting a National Target with Agriculture, Services and Household Sectors Excluded from Cap: **(a)** $CO_2$-e Price, **(b)** Welfare Change.

Our main interest is how much this approach increases the cost of meeting an emissions target, and **Figure 5** shows the effect on $CO_2$-e prices and the welfare cost for the 167 bmt case with excluded sectors (167_sector) compared with the case where we achieve the nation-wide target by including all sources. The omitted sectors emissions are about 17% of base-year emissions; in the no-policy reference they are growing more slowly than other emissions and so they fall to about 13% of economy-wide GHG emissions by 2050. Excluding these emissions from the cap, and forcing more reductions in the capped sectors, has a more than proportional impact on costs. The $CO_2$-e price goes up by about 30% and the welfare cost is increased by different amounts in different years but by as much as 30 to 50% in many years. This more-than-proportional response should not be surprising as (1) we are not taking advantage of low-cost reductions in the excluded sectors, and (2) we are forcing more high-cost reductions in the capped sectors.

### 4.2 Target Credibility and Banking Behavior

The next simulation considers truncation of the banking horizon to 2030. The resulting welfare and $CO_2$-e prices are shown in **Table 3.** GHG prices are reduced by more than one-half and the welfare effects are reduced to less than one-third of the loss compared to the case with the 2050 banking horizon. Thus, the near-term targets are relatively modest, and with banking over the full horizon it is the post-2030 reductions that are driving near term prices to higher levels. If the long term targets are ignored then much less needs to be done in the near term, and the costs are lower. With forward looking behavior, future reductions will affect near term prices but the effect will depend on how strong a reduction is required in the longer term and the representation of technological options. As noted earlier, if market participants view the long term targets as not credible then they may not bank for the future, expecting looser targets and lower prices. Or, if our representation of technology in the long term is much more pessimistic than that held by market participants then current prices would not be driven up as much as we have simulated in the 2050 banking case.

**Table 3.** Effects of a Shorter Banking Horizon.

| | 2015 | 2020 | 2025 | 2030 |
|---|---|---|---|---|
| Welfare cost | | | | |
| 167 bmt | -0.22 | -0.63 | -1.05 | -1.52 |
| 167_2030 | -0.03 | -0.18 | -0.30 | -0.41 |
| $CO_2$-e price | | | | |
| 167 bmt | 58 | 71 | 86 | 105 |
| 167_2030 | 25 | 31 | 37 | 45 |

The results with the shorter banking horizon give an idea of the importance of these effects on current prices. Obviously, long term targets could be changed in either direction, leading to higher or lower prices than those obtained assuming the long term target is met exactly. Similarly, market participants could be more pessimistic about technology in the long term than we have represented. If so, near term costs would be higher than we have estimated in the 2050 banking case, not lower. Also, the 2030 banking case is on the low end of what costs could be in these cases, assuming our representation of pre-2030 technology options is accurate. To get lower pre-2030 prices based on optimism about technology or skepticism about the policy in the post-2030 period it would have to be possible to borrow from the future, and most legislation limits such borrowing. We should also note that the 2050 horizon also truncates the banking horizon. Banked allowances are being used in 2050, so that actual emissions are above the allocated allowances in that year. Thus, even if annual allowance allocations remained at the 2050 level in the post-2050 period further sharp cuts from the simulated 2050 emissions level would be needed. Hence, if we simulated over a longer horizon we would likely see further banking and even higher prices in the near term.

**Figure 6** shows what the shorter banking horizon does to the generation choices. The effects are dramatic. In the standard 167 bmt case coal is largely phased out even by 2030 and renewables have expanded substantially. Advanced CCS and nuclear are small but beginning to be developed in this case. With the 2030 horizon, very little of that change takes place. Coal use stays high and there is no CCS or nuclear expansion. These results illustrate the role of long term targets. With them, important preparations for deeper cuts after 2030 are put in place by 2030 but if they are ignored as not credible then it will be that much more difficult to achieve the deeper cuts. With the lower prices, taking seriously only the targets through 2030, the needed transformation of the electricity sector to non-fossil alternatives is barely started. Also, if the future targets are ignored then there is little incentive to do the demonstration and research that might bring about cheaper technology. These results reveal an important aspect of the policy challenge of providing credible long term targets while trying to keep near term economic costs manageable.

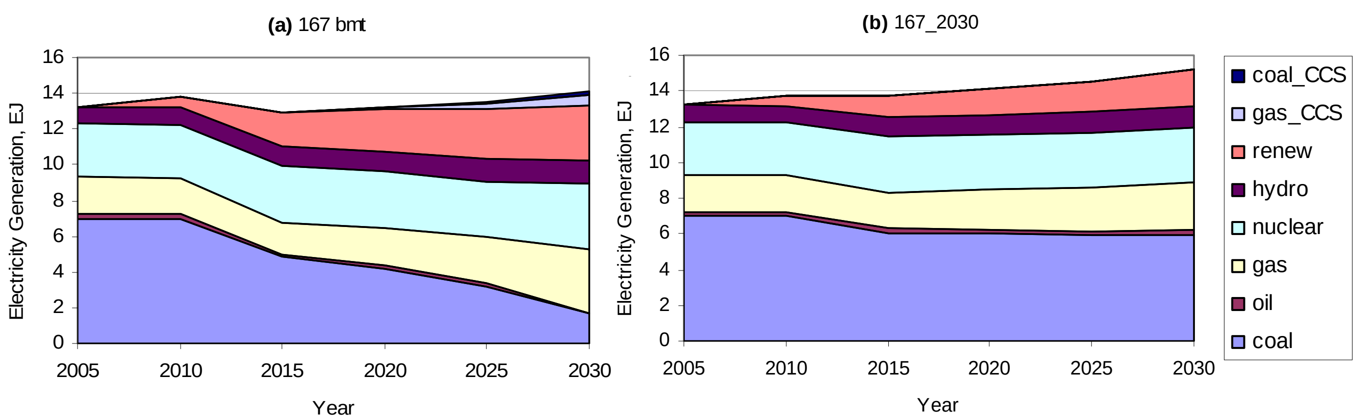


**Figure 6.** Electricity Generation Choices with a Shorter Banking Horizon: **(a)** 167 bmt, **(b)** 167_2030.

Another argument sometimes put forward for ignoring the long term targets in simulation exercises of this type is that planning horizons of firms only extend 20 years or so into the future. However, the short planning horizon argument appears fallacious to us. A source of confusion on this issue is that observers fail to take account of the fact that we will gradually approach these longer term goals, and as we approach them they will become more relevant to decisions at that point in time. Thus, the effect of the post-2030 reductions on 2015 emissions, seen by comparing Figure 6a with Figure 6b, is noticeable but not that extreme. Coal use drops a little faster and renewables penetrate a bit more when the horizon is 2050. The bigger differences begin occurring in 2020, but by that time 2030 is only 10 years away. Assuming those making decisions about generation investments are still looking ahead 20 years, their planning period will include 10 years beyond 2030, and by that time the technology and policy environment after 2030 will be much clearer.

Of course, it may be that the clearing picture will include either a less ambitious target or market expectations of advances in technology beyond what we have represented in our modeling effort. However, progress on these technologies would have to come quickly. Many of the advanced technologies we represent have been in development for many years already. A radically new technology will require testing and demonstration and then will only gradually penetrate the market, especially in the electric sector where investments are long-lived. The other factor to consider is that the planning horizon of individual firms that must abate is not necessarily relevant to whether long term expectations will affect near term prices. Unless allowances ownership is restricted, anyone can acquire allowances and hold them on the expectation that the asset will appreciate. Investors of all types, with a variety of expectations, will determine how future targets affect current prices.

### 4.3 Other Policy Implementation Issues

There are other policy implementation issues that could have strong effects on costs. One feature in most proposed cap and trade systems are credits from reductions outside the system either from trading with a foreign region that is capped (e.g., the ETS) or from projects in uncapped domestic sectors (e.g., land use emissions) or in countries without caps (e.g., Clean Development Mechanism credits). These are often seen as measures that would significantly reduce costs. The effects of such credits on domestic costs are very difficult to assess and it is easy to overestimate their contribution to lower costs for several reasons: (1) The value of trading with other regions depends on the autarkic price in those regions. If other regions are taking similar cuts then the autarkic price may be similar to domestic autarkic prices and trading will provide very little advantage. (2) The amount of project credits from uncapped sectors and regions are easy to overestimate because the project assessment and baseline establishment tends to be onerous and as a result these credit systems appear to generate only a small fraction of the credits one might expect from these sectors if they were capped. (3) For CDM-type credits the goal is to have these regions eventually take on real caps, and as they do the pool of potential credits is lowered. (4) There will be international competition for credits and for foreign allowances that will bid up the prices for them. Often in analysis of domestic policies competition for foreign credits is not considered, and it is assumed that these foreign credits will come in at prices substantially below the autarkic domestic price, with the difference maintained by limits on the use of credits. In Paltsev *et al*. (2008) we considered some of these issues with credits and international emissions trading.

Another feature of many proposals are a host of complementary policies such as renewable portfolio standards, fuel standards, public infrastructure investments such as in alternative transit systems, building codes, and efficiency regulations among other things. These are difficult to assess because the number of things considered can be nearly endless. One might consider these measures in three categories: (1) Redundant measures focused narrowly on advancing particular technologies, (2) Policies designed to address market failures, and (3) Investment in public infrastructure that under higher energy prices brought about by GHG mitigation policy might be justified.

Renewable Portfolio Standards (RPS) and Renewable Fuels Standards (RFS) or Low Carbon Fuel Standards (LCFS) are examples of measure that are at best redundant—the GHG cap-and-trade would get to the RPS or RFS goal without the standards—or they add to the economy-wide cost of the policy by shifting investment away from the least-cost options and toward meeting these specific standards. In this case they can reduce the $CO_2$ price while raising the welfare cost of the policy.

Building codes, appliance standards, and similar measures may fall into category 2 because it is not implausible that the average household may not fully understand the source of energy costs in the household and how to control them. Such standards and codes already exist. Anticipating that energy prices will rise with implementation of a cap-and-trade system means that current codes should be revised if such measures were justified in the first place. We are skeptical that there are massive no cost options here. For one thing, code development, appliance labeling, and standards development in response to changing prices is reflected in estimates of price elasticities from periods that included these measures as a response to earlier periods of higher prices. To the extent elasticity estimates we use in the model already include such responses, if there are not similar complementary policies of this type costs may be higher than we estimate.

Finally, the transportation system and development patterns are strongly affected by public investment. To the extent those public investments respond to demands of citizens, which are likely to change with higher energy prices, one might expect that the nature of public investment and zoning and planning that shape development of urban areas should change. More public transportation, support for pedestrian or bicycle traffic, or zoning changes that allow for denser development are public decisions that may respond to changed demands of a citizenry facing higher energy prices brought on by a GHG cap-and-trade system. Thus, in principle such investments can be complementary to the GHG policy, providing cost-effective options to more energy intensive life styles.

The caricatures of each of the measures above do not do justice to these complex issues. If there is hope that an RPS can overcome initial development costs and lead eventually to technologies that compete on their own there may be some justification for them. In the codes and standards or public investment areas it is not hard to go too far and legislate standards that are not in the interest of fully informed consumers or to invest in infrastructure that is underutilized or for which the marginal value is below the marginal cost. To fully investigate the role of these complementary measures requires a much more careful assessment than is possible here.

### 4.4 Technology Costs

We next consider the effect of different cost assumptions about nuclear, CCS, and renewables. In a nuclear case (167_nuclear) we give the cost advantage to nuclear, assuming its mark-up is 1.5, somewhat lower than CCS at 1.6. In a case favoring CCS (167_ccs) we increase the nuclear mark-up to 2.0. In a third case (167_wind_gas) we assume that neither nuclear or CCS will be available at all. This last case is motivated by the possible difficulties in siting nuclear plants or potential regulatory hurdles for the development of storage for captured $CO_2$. In a fourth case (167_wind_slow) we go back to our original elasticity of 1.0 for renewable sources which slows renewable penetration on the basis that expansion requires a significant additional cost for storage and back-up generation. The price and welfare effects are shown in **Table 4** and compared with the basic 167 bmt case.

**Table 4.** Effects of Alternative Technology Assumptions.

| | 2015 | 2020 | 2025 | 2030 | 2035 | 2040 | 2045 | 2050 |
|---|---|---|---|---|---|---|---|---|
| Welfare Change | | | | | | | | |
| 167 bmt | -0.22 | -0.63 | -1.05 | -1.52 | -2.03 | -2.32 | -2.38 | -2.52 |
| 167_nuclear | -0.15 | -0.68 | -1.27 | -1.65 | -1.91 | -1.99 | -2.01 | -1.96 |
| 167_ccs | -0.23 | -0.65 | -1.08 | -1.56 | -1.98 | -2.29 | -2.38 | -2.54 |
| 167_wind_gas | -0.28 | -0.73 | -1.17 | -1.63 | -1.97 | -2.16 | -2.63 | -2.99 |
| 167_wind_slow | -0.17 | -0.54 | -1.05 | -1.60 | -2.04 | -2.32 | -2.38 | -2.60 |
| $CO_2$-e Price | | | | | | | | |
| 167 bmt | 58 | 71 | 86 | 105 | 127 | 155 | 188 | 229 |
| 167_nuclear | 48 | 59 | 71 | 87 | 106 | 129 | 157 | 190 |
| 167_ccs | 59 | 72 | 88 | 107 | 130 | 159 | 193 | 235 |
| 167_wind_gas | 67 | 82 | 100 | 121 | 148 | 180 | 218 | 266 |
| 167_wind_slow | 60 | 73 | 88 | 108 | 131 | 159 | 194 | 236 |

The direction of price and welfare with these changes, compared to earlier assumptions, is as expected though care is needed in interpretation of the results. The nuclear case has a lower welfare cost because we assumed nuclear was less expensive, and the CCS case is more expensive because CCS comes in by virtue of the fact that we raised the nuclear cost. If instead we had dropped the CCS cost to something more substantially below nuclear, then the welfare costs in that case would have fallen.

Perhaps more interesting is the 167_wind_gas case. The exclusion of CCS and nuclear rule out two big low-carbon options, which should make the task of achieving these goals much harder. While excluding these options raises the cost substantially the simulation results suggests it does not make the target unachievable—by 2050 the welfare loss is higher, compared to the 167 bmt case by about 0.5 percent and the 2015 $CO_2$-e price is about $10 per ton higher. Similarly, the 167_wind_slow case increases the cost, but relatively modestly. Since raising the price of one option, or even making some options unavailable, just leads to use of other options, the cost impact is moderated. Assuming that any one option becomes very inexpensive would have a big impact on costs, or assuming that none of the options are available or were very costly would increase the costs much more. The ranges we explore here appear to capture ranges one might reasonably expect.

We turn next to the generation choices in these scenarios to see better how these targets are achieved under different cost assumptions (**Figure 7**). In the 167_nuclear case the relatively small cost advantage for nuclear allows it to dominate and at the 1.5 markup it also substantially limits renewable expansion. Even gas is driven out. This result may be unrealistic as it is not clear where peak and shoulder generation would come from in this case since nuclear cannot be flexibly dispatched. In the 167_ccs case, both coal and gas CCS play a role and natural gas use expands. With only a 90% capture rate on the CCS technologies, more gas, and a slightly slower phase out of conventional coal, it is clear that in this case emissions from the electricity sector are higher than under the 167_nuclear assumptions.

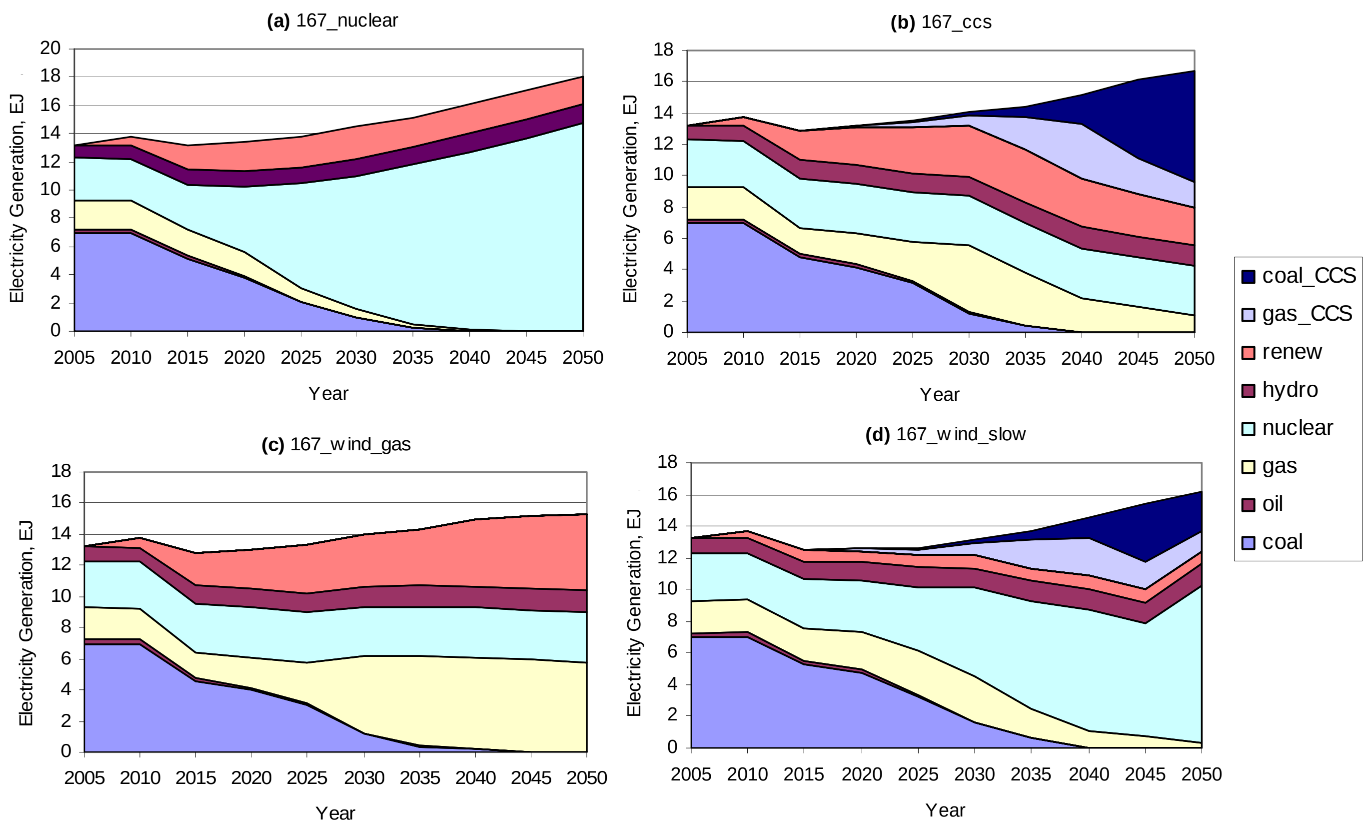


**Figure 7.** Alternative Technology Assumptions and Generation Choices: **(a)** 167_nuclear, **(b)** 167_ccs, **(c)** 167_wind_gas, **(d)** 167_wind_slow.

Since we are focusing here only on the electricity sector, it is important to keep in mind that this is an economy-wide policy. Thus, when there are cheaper options in the electricity sector as in the 167_nuclear case the electricity sector does more of the abatement and takes pressure off emissions elsewhere in the economy. In the 167_ccs case the electricity options are more expensive and the CCS technologies are not completely carbon free. As a result more of the reduction is pushed into the rest of the economy. If neither advanced nuclear nor the CCS technologies are available then, as shown in the 167_wind_gas case, renewables and gas provide about two-thirds of the generation and existing nuclear and hydro power fill in the rest. As we noted above, meeting the 167 bmt target through the 2050 horizon without new nuclear or CCS is possible without increasing the costs dramatically.

It should be noted that the viability of the 167_wind_gas case is questionable if the analysis is extended beyond 2050 in scenarios that require stabilization of GHG concentrations. This level of gas use in this case would eventually become problematic as very low levels of $CO_2$ emissions are allowable. In addition, another way the target is accomplished is by raising the near term prices and abating more immediately thus making room for emissions from natural gas generation in the 2040-2050 period. If the horizon is shifted further, and the 80 percent reduction goal is maintained or increased, more and more of the reduction would need to be shifted forward, and there is an obvious limit to how much shifting can occur. Thus, in the longer term the reliance on gas is probably not tenable.

The broader lesson from these alternative technology cases is that fairly small changes in the relative costs of different technology options can lead to a very different set of generation choices. The effect on the economy-wide cost is moderated if one or another option ends up more expensive or unavailable because there are other choices. The value of broad economic incentive-based policy, as opposed to policies that focus on a particular technology, is that we do not need to guess which technology is going to succeed.

## 5. CONCLUSIONS

In this paper, we updated an earlier analysis of the cost of GHG mitigation policy in the U.S. We focused on three policy scenarios described by the allowable emissions through 2050: 287, 203, and 167 billion metric tons (bmts). Since the time of the earlier analysis, a variety of conditions have changed that are likely to affect the cost of mitigation policy in the U.S. The economic recession has dimmed the outlook for economic growth, likely leading to lower reference emissions which would tend to reduce the costs of meeting the policy. At the same time, however, the costs and prospects for key low carbon technologies have changed. Nuclear and CCS costs are now seen to be considerably higher than we estimated just a few years ago. On the positive side, however, some utilities are moving ahead with plans to build new nuclear power plants. Thus, we have allowed an advanced generation of nuclear power plants to take market share if they can compete at the relatively higher costs. Also, renewables are expanding rapidly and some progress has been made on the technologies. It is unclear what the current rapid expansion of renewables means for the longer term because it is spurred by direct subsidies and favorable tax treatment. Also, the domestic policy discussion has focused on the deeper emissions cuts and so the 287 bmt case is not that relevant to current legislative proposals.

Combining all of these factors causes our estimates of the difficulty of meeting the 203 and 167 bmt cases to rise somewhat. In the 167 bmt case the $CO_2$-e price starts at \$58/t$CO_2$-e compared with $53 in the old results and by 2050 rises to $230 instead of $210. The welfare results mirror the $CO_2$-e price with the 2050 result in the 167 bmt case showing a 2.5% loss compared with about 1.75% loss in the old results. The increase is similar in the 203 bmt case. The new results for the 287 bmt case actually have lower costs because the lower reference emissions resulting from slower economic growth dominate the changes in the technology cost assumptions.

A number of questions have also arisen as to how the policy might be implemented. For a variety of reasons, many proposed measures only directly control emissions on a subset of activities while international negotiations on emissions reductions tally up emissions from all sources. Thus, to meet an agreed national target with a less than comprehensive cap-and-trade system would require tightening the cap to make up for the omitted sectors. Most of the current proposals allow for credits from uncapped sectors to be brought into the cap-and-trade system. If these offsets created incentives to reduce in the non-capped sectors as effectively as actually including those sectors under the cap, then further tightening of the cap on the controlled sectors and allowing these offsets to flow in would be equivalent to having a comprehensive national cap. However, credit systems can be very ineffective, failing to create effective incentives for control with reductions in some projects offset by increased "leakage" emissions from other part of the sector. We construct a case where the capped sectors must make up entirely for the failure to cap some sectors. We leave out agriculture, households, and the service sector that together account for about 17% of emissions, falling in our no policy case to 13% by 2050. We find the cost impact to be more than proportional. $CO_2$-e prices increase by about 30%, and welfare costs increase as much as 30% to 50%, varying over the time horizon. Omissions are costly because we fail to take advantage of low cost reductions in these sectors, and we force more high cost reductions in the capped sectors.

There are also skeptics of banking over long periods. Are these very long targets credible? Might we be too pessimistic in our representation of long term technology options? Do firms even look that far into future when making near term plans? To consider these questions, we solved the model with banking only through 2030 implying that the targets and potential cost of meeting them after 2030 were ignored. One assumption that would justify this under-banking behavior would be if the expectation was that abatement would be such after 2030 that the $CO_2$-e price would continue to rise smoothly at the discount rate from the price solved in 2030 with the truncated horizon. The truncated banking case cut near term welfare costs by two-thirds and the $CO_2$-e price by more than one-half. Thus, at least as we represent the economy and the technology choices available to it over this period, the post-2030 targets are a large driver of the near term costs of the policy. If the policy is enacted, the market may have different expectations for technology options or be skeptical that these targets will be maintained, and so of course actual market results may differ from our representation. In looking at the electricity sector, if investors simply ignore the distant targets and proceed as if all that mattered were targets through 2030, then they would not begin the transformation that was actually needed to meet the long term targets.

We then consider several alternative assumptions about the cost and availability of nuclear, CCS, and renewables. We find that varying the relative costs of these over what we think are sensible ranges does not have a large effect on the overall cost to the economy. If one or another of these generation sources is assumed to be costly or unavailable, other options are available for greater expansion and some of the reduction task can be shifted to other parts of the economy. Obviously, assuming nothing would work or that a miracle happens and a costless way to produce energy without carbon comes along would give a very costly or a very cheap solution, but there is not much sense in simulating such fantasy scenarios. The important lesson is that a broad cap-and-trade system will let the market choose the set of options that is least costly, and so if any one or two are available the costs will remain under control. Policies that instead attempt to pick particular technologies run the risk of picking ones that may not pan out and those approaches to mitigation would then be more costly.

**Acknowledgements**

Development of the EPPA model used in this study was supported by the U.S. Department of Energy, U.S. Environmental Protection Agency and by a consortium of industry and foundation sponsors.

## 6. REFERENCES

Babiker, M., J. Reilly and L. Viguier, 2004: Is International Emissions Trading Always Beneficial? *Energy Journal*, **25**(2): 33-56.

Babiker, M., A. Gurgel, S. Paltsev and J. Reilly, 2008: A Forward-Looking Version of the MIT emissions Prediction and Policy Analysis (EPPA) Model. MIT Joint Program on the Science and Policy of Global Change *Report 161*. Cambridge, MA. Available at: http://globalchange.mit.edu/files/document/MITJPSPGC_Rpt161.pdf

Clarke, L., J. Edmonds, V. Krey, R. Richels, M. Tavoni and S. Rose, 2009: EMF-22 overview, Energy Economics, (forthcoming).

EIA [Energy Information Administration], 2008: Annual Energy Outlook 2009 Early Release, Energy Information Administration, U.S. Department of Energy, Washington, DC.

Gurgel, A., S. Paltsev, J. Reilly and G. Metcalf, 2007: U.S. GHG Cap-and-Trade Proposals: Application of a Forward-Looking Computable General Equilibrium Model. MIT Joint Program on the Science and Policy of Global Change, *Report 150*. Cambridge, MA. Available at: http://globalchange.mit.edu/files/document/MITJPSPGC_Rpt150.pdf

Hyman, R., J. Reilly, M. Babiker, A. De Masin and H. Jacoby, 2003: Modeling Non-$CO_2$ Greenhouse Gas Abatement, *Environmental Modeling and Assessment*, **8**(3): 175-186.

Metcalf, G., S. Paltsev, J. Reilly, H. Jacoby and J. Holak, 2008: Analysis of U.S. Greenhouse Gas Tax Proposals. MIT Joint Program on the Science and Policy of Global Change, *Report 160*. Cambridge, MA. Available at: http://globalchange.mit.edu/files/document/MITJPSPGC_Rpt160.pdf

Paltsev, S., J. Reilly, H. Jacoby, R. Eckaus, J. McFarland, M. Sarofim, M. Asadoorian and M. Babiker, 2005: The MIT Emissions Prediction and Policy Analysis (EPPA) Model: Version 4. MIT Joint Program on the Science and Policy of Global Change, *Report 125*. Cambridge, MA. Available at: http://globalchange.mit.edu/files/document/MITJPSPGC_Rpt125.pdf

Paltsev, S., J. Reilly, H. Jacoby and K-H. Tay, 2007: How (and Why) Do Climate Policy Costs Differ Among Countries? In: Human-Induced Climate Change: An Interdisciplinary Assessment, M. Schlesinger, et al (eds), Cambridge University Press, Cambridge, UK.

Paltsev, S., J. Reilly, H. Jacoby, A. Gurgel, G. Metcalf, A. Sokolov and J. Holak, 2008: Assessment of U.S. GHG cap-and-trade proposals. *Climate Policy*, **8**(4): 395–420.

## APPENDIX A: DETAILED RESULTS

* ***Only a sample page is attached here***. The full version of the Appendix in Excel format is available at: http://globalchange.mit.edu/files/document/MITJPSPGC_Rpt173_AppendixA.xls.

| *Reference* | *2000* | *2010* | *2020* | *2030* | *2040* | *2050* |
|---|---|---|---|---|---|---|
| ***ECONOMY WIDE INDICATORS*** | | | | | | |
| *Population (billion)* | 0.28 | 0.31 | 0.34 | 0.37 | 0.41 | 0.44 |
| *GDP (trillion 2005$)* | 11.09 | 13.25 | 17.48 | 22.57 | 29.25 | 37.53 |
| *% Change GDP from Reference* | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| *Market Consumption (trillion 2005$)* | 7.77 | 9.03 | 11.83 | 15.16 | 19.59 | 25.09 |
| *% Change Consumption from Reference* | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| *Welfare (trillion 2005$)* | 9.12 | 10.62 | 14.30 | 18.67 | 24.23 | 31.12 |
| *% Change Welfare from Reference (EV)* | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| *$CO_2$-E Price (2005$/t$CO_2$-e)* | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| ***PRICES*** | | | | | | |
| *Oil (2005$/barrel)* | 32.00 | 65.09 | 88.20 | 120.47 | 142.83 | 159.32 |
| *Natural Gas (2005$/GJ)* | 4.40 | 6.75 | 8.08 | 10.21 | 13.66 | 18.35 |
| *Coal (2005$/GJ)* | 1.50 | 1.46 | 1.55 | 1.62 | 1.71 | 1.80 |
| *Electricity (2005$/kWh)* | 0.08 | 0.09 | 0.11 | 0.12 | 0.12 | 0.13 |
| ***GHG EMISSIONS*** *(GT $CO_2$-e)* | | | | | | |
| *GHG Emissions* | 6.96 | 6.96 | 7.59 | 8.17 | 9.22 | 10.74 |
| *$CO_2$ Emissions* | 5.85 | 5.90 | 6.50 | 7.02 | 8.03 | 9.45 |
| *$CH_4$ Emissions* | 0.58 | 0.55 | 0.55 | 0.55 | 0.55 | 0.56 |
| *$N_2O$ Emissions* | 0.42 | 0.35 | 0.32 | 0.30 | 0.28 | 0.29 |
| *Fluorinated Gases Emissions* | 0.13 | 0.19 | 0.28 | 0.39 | 0.48 | 0.59 |
| *HFCs* | 0.10 | 0.16 | 0.25 | 0.37 | 0.46 | 0.57 |
| *PFCs* | 0.02 | 0.01 | 0.01 | 0.01 | 0.01 | 0.01 |
| *SF6* | 0.02 | 0.02 | 0.02 | 0.01 | 0.01 | 0.01 |
| ***PRIMARY ENERGY USE*** *(EJ)* | | | | | | |
| *Oil* | 40.2 | 41.4 | 45.8 | 48.7 | 54.9 | 62.5 |
| *Gas w/o CCS* | 21.8 | 22.3 | 24.3 | 25.1 | 24.8 | 23.7 |
| *Gas w/ CCS* | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| *Coal w/o CCS* | 22.7 | 22.2 | 24.4 | 27.5 | 33.3 | 39.7 |
| *Coal w/ CCS* | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| *Biomass Liquids (primary energy eq)* | 1.0 | 2.1 | 1.8 | 2.0 | 2.5 | 3.1 |
| *Nuclear (primary energy eq)* | 8.3 | 8.9 | 8.5 | 8.2 | 8.1 | 8.0 |
| *Total Non-Biomass Renewables (prim en eq)* | 3.0 | 4.3 | 5.2 | 5.9 | 5.7 | 5.8 |
| *Wind (primary energy eq)* | 0.0 | 1.2 | 2.1 | 2.8 | 2.6 | 2.5 |
| *Solar (primary energy eq)* | 0.0 | 0.1 | 0.2 | 0.3 | 0.3 | 0.3 |
| *Hydro (primary energy eq)* | 3.0 | 2.9 | 2.8 | 2.8 | 2.9 | 3.0 |
| *Total Primary Energy Use* | 97.0 | 101.1 | 109.9 | 117.5 | 129.3 | 142.8 |
| *Reduced Use from Reference* | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| ***ELECTRICITY PRODUCTION*** *(EJ)* | | | | | | |
| *Oil* | 0.3 | 0.3 | 0.3 | 0.3 | 0.4 | 0.4 |
| *Gas w/o CCS* | 2.0 | 2.0 | 2.1 | 2.1 | 2.2 | 2.1 |
| *Gas w/ CCS* | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| *Coal w/o CCS* | 6.7 | 7.0 | 8.1 | 9.3 | 11.5 | 14.0 |
| *Coal w/ CCS* | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| *Biomass* | 0.1 | 0.1 | 0.0 | 0.0 | 0.0 | 0.0 |
| *Nuclear* | 3.0 | 3.0 | 3.0 | 3.0 | 3.0 | 3.0 |
| *Total Non-Biomass Renewables* | 0.9 | 1.4 | 1.8 | 2.2 | 2.2 | 2.2 |
| *Wind* | 0.0 | 0.4 | 0.8 | 1.0 | 1.0 | 0.9 |
| *Solar* | 0.0 | 0.0 | 0.1 | 0.1 | 0.1 | 0.1 |
| *Hydro* | 0.9 | 1.0 | 1.0 | 1.0 | 1.1 | 1.2 |
| *Total Electricity Production* | 13.0 | 13.8 | 15.3 | 17.0 | 19.2 | 21.8 |
| *Carbon Storage (GT $CO_2$-e)* | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |

## APPENDIX B: MEASURING THE COST OF CLIMATE POLICY

This note provides an overview of different measures of costs of climate policy. While in our studies we stress emissions prices and welfare changes, here we illustrate the measures in most common use, showing results for the 167 bmt scenario from Paltsev *et al* (2009). Similar results for the other scenarios can be derived from Appendix A to that report. These are studies of mitigation costs only and do not consider climate benefits and potential ancillary non-climate benefits of greenhouse gas mitigation, e.g., through reduced urban air pollution.

### 1. Emissions Price

A price on greenhouse gas (GHG) emissions is usually stated per metric ton of $CO_2$, or in the case of multiple gases, per metric ton of $CO_2$-equivalent, or $CO_2$-e. Such a price may be established through a market that develops for emissions allowances issued under a cap-and-trade system (the allowance price) or through an emissions tax set directly by a regulating agency. Because $CO_2$ is the largest contributor among the long-lived greenhouse gases, the $CO_2$-e concept has come to be widely used. $CO_2$-e prices use Global Warming Potential (GWP) indices that take account of the different lifetimes and direct climate effects to calculate the amount of $CO_2$ that would have the same effect as, for example, a ton of methane or nitrous oxide.[4] Since the GWP index uses CO2 as the numeraire (i.e., its index value is 1.0), there is no difference in $CO_2$ or $CO_2$-e prices for $CO_2$. The value of the $CO_2$-e measure is that it makes prices for other GHGs comparable, in terms of the warming avoided per ton, to that of $CO_2$. An example of $CO_2$-e prices for the 167 bmt scenario is provided in **Table A1**.

**Table A1**. $CO_2$-e Price

| | ***2020*** | ***2030*** | ***2040*** | ***2050*** |
|---|---|---|---|---|
| *$CO_2$-E Price (2005\$/t$CO_2$-e)* | 70.68 | 104.62 | 154.86 | 229.23 |

Emissions prices measure marginal cost, that is, the cost of an additional unit of emissions reduction. Emissions prices are an indicator of the relative scarcity of the allowances compared with the demand for them, but they are not a measure of “total cost” to the economy. Just as, for example, the price of a gallon of milk does not provide an indication of the total cost of all the milk produced in the country. That is, prices convey no information about the physical volumes to which they apply or the magnitude of the cost compared to the level of activity (e.g., size of

[4] The convention in recent years has been to report prices per ton of $CO_2$. An earlier convention was to report prices in tons of C—counting only the carbon weight in the $CO_2$ molecule. A residual effect of this earlier convention is to sometimes see a reference to the “carbon price” applied even in the case where the price is stated per ton of $CO_2$ rather than per ton C. To convert from a per ton C price to a per ton $CO_2$ price multiply by the molecular weight of the $CO_2$ molecule (44) divided by the molecular weight of the carbon atom (12), or 3.667. A price of \$27.27/ton $CO_2$ is thus the same as \$100/ton C.

the firm or of the total economy). Just as the total cost of milk production depends on how much milk was produced, the total cost to the economy of greenhouse gas emissions reduction policy depends on how much reduction occurred. Note that what is being “produced” with a cap-and-trade system is abatement of emissions, i.e., emissions reduction. Determining the emissions reduction requires an assessment of what emissions would have been without the policy where with milk production we can simple measure how much milk was produced.[5] Prices can also be a misleading indicator of the cost when they interact with other policies and measures — either those directed at greenhouse gas reduction (for example, renewable portfolio standards or subsidies to carbon-free technologies) or simply other policy instruments such as other taxes on energy, labor, or capital. This is no different than for other prices in the economy — our price of milk, for example. If there are no other policy measures the price of milk will fully reflect the marginal cost, but if there are farm subsidies or price supports, the milk price will be a poor indicator of the marginal cost.

## 2. Welfare Change

For many economists the preferred measure of total economic cost of greenhouse gas abatement or of other policy measures is the change in consumer welfare, measured in terms of “equivalent variation”, as this measure considers the GHG price and the amount of abatement and can include the effect of interactions with other policy measures to the extent these other policy measures are modeled. And, whereas the $CO_2$ price measures the marginal cost, a welfare measure takes into account the fact that many of the reductions likely cost less than the last ton abated. Welfare is also generally a measure that is broader than just market activity and as such the change in welfare includes changes in both labor and leisure time. Leisure is considered a good and in models like EPPA it is represented by the monetary value of the non-working time. In coming up with a measure of change in welfare any reductions (increases) in the amount of work time are offset by increases (decreases) in the amount of leisure time. The welfare change in the 167 bmt scenario is provided in **Table A2**.

**Table A2**. Welfare Change

| | ***2020*** | ***2030*** | ***2040*** | ***2050*** |
|---|---|---|---|---|
| *% Change Welfare from Reference (EV)* | -0.63 | -1.52 | -2.32 | -2.52 |

Many features of the EPPA model (level of aggregation, nesting structure, elasticities, etc.) affect this result, but a couple of features are worth special mention. One is the influence of the tax interaction effect.[6] A price on greenhouse gases will increase producers’ costs, effectively reducing the real returns to the factors of production, such as capital, labor, and energy. If, as is

[5] The caution here is to avoid the temptation to estimate the cost to the economy on the basis of how many allowances were issued which is directly observable.

[6] For a summary of issues that arise in assessment of the cost of environmental policies see Goulder (2000).

common, there are pre-existing taxes on these factors, the GHG price has the effect of an increase in factor taxes, compounding the distortion caused by the prior tax system. This tax interaction effect will influence both the net government revenue from an allowance auction or emissions tax and the welfare effect of the policy. This is an effect missed by single-sector analyses of environmental policy. It is, however, captured by the EPPA model (subject to possible limitations imposed by its level of sectoral aggregation) because of its multi-sector general equilibrium structure and the fact that pre-existing taxes are included in the underlying data base.[7]

A second feature concerns the effect of assumptions about the distribution of auction proceeds from a cap-and-trade system or the revenue from an emissions tax. In the EPPA model, a single agent represents the demands and behavior of the consumer side of the economy, and the value of emissions allowances (or tax revenue) is assumed to be returned to this representative consumer in a lump-sum transfer, equivalent to giving the allowances away for free in a lump sum manner. With lump-sum distribution the auction or tax revenues do not, by themselves, change the amount of total tax revenue or the size of the government. However, because overall economic activity (which is the tax base for all other taxes) is generally lower under a policy, the amount of total tax revenue and the size of a government will be lower unless tax rates are raised to compensate for the drop in the tax base. In analyses conducted here, we hold tax rates constant and allow the size of government revenue and expenditures to vary.

Many other assumptions about auction and tax revenue are possible and would lead to different estimates of welfare change. For example, if rather than lump-sum redistribution the revenue is used to reduce other taxes, the effect will be to lower the welfare cost because it reduces the distortionary effect of these taxes.[8] Free distribution of allowances raises the possibility that one may need to raise other tax rates to keep the total tax revenue constant so that the existing level of government can be maintained, and the higher taxes will increase the welfare cost by increasing the distortionary effect of these taxes. If, on the other hand, revenue is used for other purposes—e.g., supporting research and development (R&D), subsidizing low-emitting technologies, compensating low income consumers or affected industries, or funding unrelated government programs—then the welfare cost will depend on how effectively the funds are spent. If revenue is used for R&D, which is effectively directed to projects with high returns, welfare effects can be positive. But if allowance or tax revenue is spent on poorly managed programs of the little value, then the funds will be mostly wasted, raising the welfare cost. The value of government expenditure are difficult to measure and so there are widely differing views on whether and under what circumstances additional revenue can be used effectively. The debate on use of GHG auction or tax revenue taps into the conventional debate about the appropriate size and role of the government. Other cost measures, described below, are similarly influenced by the tax interaction effect and assumptions about revenue and/or permit distribution.

---

[7] For an example of this effect, when a carbon charge is imposed on top of high fuel taxes, see Paltsev et al. (2004).

[8] A perfect foresight version of the EPPA model has been applied to exploration of the use of such revenue to the reduction of labor and/or capital taxes, see Gurgel et al. (2007) and Babiker et al. (2008).

### 3. Consumption Change

Changes in macroeconomic consumption as a measure of cost is closely related to welfare changes described above. The only difference is that consumption change considers only the market impacts and so excludes changes in leisure time (i.e., the monetary value of the change in non-working time) that occur in response to the policy. The consumption change is usually larger than the welfare change because an increase in the price of consumption (due to an increase in energy prices) leads to a reallocation of time to non-market activities. The magnitude of the shift depends on the labor supply elasticity. Also, consumption change in percentage terms is higher than the welfare measure in percentage terms because the base (total consumption) excludes a value of leisure time and so the base against which the percentage is calculated is lower. The consumption change in the 167 bmt scenario is provided in **Table A3**.

**Table A3.** Consumption change

| | *2020* | *2030* | *2040* | *2050* |
|---|---|---|---|---|
| *% Change Consumption from Reference* | -1.13 | -2.24 | -3.25 | -3.49 |

### 4. GDP Change

The change in Gross Domestic Product (GDP) is a measure of cost often used by non-economists because GDP is the measure of economic activity that is most familiar to a general audience. It is a less satisfactory indicator of cost than welfare loss or consumption change for several reasons. It is useful to recognize that GDP is defined as Consumption (as in Section 3 above) + Investment + Government + (Exports-Imports). The welfare and consumption measures preferred by economists because they measure the amount of goods people consume. GDP is a measure of output, which is not necessarily consumption. Investment goods produced in a given year add to the availability of consumptions goods over many years and hence changes in investment are not directly comparable to a loss of consumption in a year. Government is not a final consumer but through transfer programs (e.g., Social Security) or provision of public services (education, police) provides money or goods and services to final consumers. As for international trade, how many foreign goods can be bought for a given amount of domestic money is more relevant to consumption than the net of exports over imports. The amount of foreign goods depends on how the terms-of-trade (i.e., the price of domestic to foreign goods) changes. Higher terms-of-trade means we can purchase more foreign goods for every dollar, whereas deteriorating terms-of-trade means we can purchase less. As climate policy affects energy prices, for large energy exporters or importers, these trade effects may be substantial but are not captured by the GDP measure as normally computed. Moreover, what is relevant for welfare is the consumption of the imports and how income from exports is used for consumption today or for investment and future consumption. Direct consumption of imports by households (and indirect use of imports through their use as intermediate inputs to domestic goods) is included in the measure of consumption described in Section 3. Any net export income that is saved and invested contributes to future consumption. While many of these changes net out, GDP changes can lead to double counting of the cost of a policy, particularly if GDP impacts over time are considered. Then the change in investment is counted in the year when investment is affected (i.e., reduced) because it is part of GDP and that effect is counted again in future years as reduced consumption because of the lower capital stock due to less investment in earlier years. The GDP changes in the 167 bmt scenario are provided in **Table A4**.

**Table A4.** GDP change

| | *2020* | *2030* | *2040* | *2050* |
|---|---|---|---|---|
| *% Change GDP from Reference* | -1.45 | -2.45 | -3.34 | -3.70 |

## 5. Per Capita and Per Family Costs

Whereas we reported the above changes in welfare, consumption and GDP as percentage changes, these can also be converted into absolute dollar levels and then divided by population or the number of households to arrive at a per capita or per household cost. This measure can then be compared with GDP per capita[9] or household income and may be a number that is more compelling to the average person or family. The GDP per capita cost in the 167 bmt scenario is provided in **Table A5**.[10] A similar per capita calculation can be made for welfare or consumption.

Costs per household are similar where instead of dividing by population one divides by the number of households (or by population and then multiply by average household size or for different assumed household sizes — family of four for instance). **Table A6** provides a cost for a household with a family size of four and family size of 2.57 (an average U.S. household size in 2005). A similar calculation for household welfare change can be made for households of different sizes.

[9] This study focuses on the US. Sometimes there is an interest in comparing absolute costs among countries. For this reason it is important to consider the relative purchasing power of different currencies as market exchange rates are highly variable and can provide misleading indication of relative well-being among countries. To reflect differences in relative incomes among countries when incomes are expressed in common monetary units, several indexes can be constructed. The most popular is a purchasing-power parity (PPP) index. Conventionally in using these indices the U.S is set to 1.0, so per capita GDP measured at PPP or at market-exchange rates is the same. For other countries these two measures may differ. Although widely accepted estimates of current PPP rates are available, there is no standard method for projecting how they may change in the future.

[10] All the caveats about the GDP measure described in Section 4 are applied here as well. GDP calculation is provided here for illustrative purposes to compare with a popular measure of GDP per capita. As discussed above, welfare and consumption calculation is preferred.

**Table A5.** GDP per capita cost

| | *2020* | *2030* | *2040* | *2050* |
|---|---|---|---|---|
| *Population (billion)* | 0.34 | 0.37 | 0.41 | 0.44 |
| *Reference GDP (trillion 2005$)* | 17.48 | 22.57 | 29.25 | 37.53 |
| *Policy GDP (trillion 2005$)* | 17.23 | 22.02 | 28.28 | 36.15 |
| *Change in GDP from Reference (trillion 2005$)* | -0.25 | -0.55 | -0.98 | -1.39 |
| *Reference Per capita GDP (2005$)* | 51271 | 60513 | 72050 | 85496 |
| *Per capita GDP cost (2005$)* | 745 | 1480 | 2405 | 3160 |

**Table A6.** Change in Household Consumption

| | *2020* | *2030* | *2040* | *2050* |
|---|---|---|---|---|
| *Reference Consumption (trillion 2005$)* | 11.83 | 15.16 | 19.59 | 25.09 |
| *Policy Consumption (trillion 2005$)* | 11.70 | 14.82 | 18.95 | 24.22 |
| *Change in Consumption (trillion 2005$)* | -0.13 | -0.34 | -0.64 | -0.88 |
| *Change in Consumption per family of 4 (2005$)* | -1565 | -3635 | -6279 | -7983 |
| *Change per U.S. Average Household Consumption (2005$)* | -1005 | -2336 | -4034 | -5129 |

## 6. Discounted Costs

Climate policies are typically specified over a period of several years or even decades, and because the level of the policy is changing over time the costs are changing from year to year. To compare costs over time, conventional economic practices apply a discounts rate to future costs on the basis that money today would earn a return over time. One also may be interested in a summary measure of the cost to be borne over the life of the policy. A useful measure is thus the average annual discounted GDP, welfare, or consumption change either as a percentage, an aggregate total or per household. A key variable in this calculation is a discount rate, i.e., how much less we value the future payments in comparison to the present payments of the same size, and there are different views on what the appropriate rate is for climate policy (see, for example, Nordhaus (2007) for a discussion about a discount rate). **Table A7** provides the discounted household welfare to 2005 using a 4% discount rate, for the policy effects to 2050, for an average U.S. household. One can also calculate an average discounted welfare change for a certain period of time (which, for 2020-2050, is a reduction of $700 compared to an average discounted household welfare of about $44,000 in the 167 bmt scenario). A similar calculation for a discounted GDP and consumption change can be made. A related measure is a net present value (NPV) of welfare (consumption, GDP) or welfare change, where all variables are summed over a certain period and discounted to the present values.

**Table A7.** Discounted household welfare change

| | *2020* | *2030* | *2040* | *2050* |
|---|---|---|---|---|
| *Reference Welfare (trillion 2005$)* | 14.30 | 18.67 | 24.23 | 31.12 |
| *Policy Welfare (trillion 2005$)* | 14.21 | 18.38 | 23.67 | 30.33 |
| *Change in Welfare (trillion 2005$)* | -0.09 | -0.28 | -0.56 | -0.78 |
| *Change per U.S. Average Household Welfare (2005$)* | -680 | -1960 | -3564 | -4582 |
| *Change per U.S. Average Household Welfare (2005$), discounted to 2005 at 4 percent* | -378 | -735 | -903 | -784 |

## 7. Change in Energy Prices

Prices of all goods will change in the economy as a result of climate policy and in response to these changes consumers will adjust their consumption of goods. Climate policy will have the strongest effect on energy prices as fossil-based fuels will have an additional charge due to their carbon content and that change in price can have strong effects on the demand for these fuels. As a result, there is often interest in how fuel and electricity prices will change. That said, it is important to note that changes in energy prices are not a cost in addition to those discussed above (welfare, GDP, consumption): to the extent fuel and electricity prices rises lead to an increase expenditure on energy by consumers or reduce the income and rents received by producers of energy, these effects are captured in broader measures of economic cost discussed above. $CO_2$ pricing will in general increase the wedge between the prices consumers pay (which includes the $CO_2$ charge) and the price producers receive for fuels. Consumers will face higher $CO_2$-inclusive prices for energy and reduce their demand for fossil fuels. This will tend to lower the producer price received for fuels. **Table A8** provides energy prices in the reference (i.e., no climate policy) scenario, producer prices (exclusive of carbon charge), and consumer prices (inclusive of carbon charge) in the case of the 167 bmt policy. The consumer prices are calculated based on the $CO_2$ price and the carbon content of the fuel, here using factors from the US CCSP scenario study (see Table 4.7 in US CCSP, 2007). Electricity price effects depend on abatement costs and $CO_2$ emissions from electricity which change significantly because the intent of the policy is to greatly reduce these emissions. EPPA models the impact on the electricity price directly.

**Table A8**. Energy prices

| *Natural Gas Price ($/tcf)* | *Reference* | *Policy Producer Price* | *Policy Consumer Price* |
|---|---|---|---|
| 2010 | 7.09 | 7.09 | 7.09 |
| 2020 | 7.70 | 6.85 | 10.75 |
| 2030 | 9.72 | 8.55 | 14.32 |
| 2040 | 13.01 | 9.36 | 17.90 |
| 2050 | 17.47 | 9.10 | 21.75 |
| *Crude Oil price ($/bbl)* | *Reference* | *Policy Producer Price* | *Policy Consumer Price* |
| 2010 | 65.09 | 65.09 | 65.09 |
| 2020 | 88.20 | 82.10 | 114.03 |
| 2030 | 120.47 | 109.45 | 156.72 |
| 2040 | 142.83 | 125.28 | 195.26 |
| 2050 | 159.32 | 139.20 | 242.78 |
| *Coal Price($/short ton)* | *Reference* | *Policy Producer Price* | *Policy Consumer Price* |
| 2010 | 32.23 | 32.23 | 32.23 |
| 2020 | 34.00 | 31.17 | 175.93 |
| 2030 | 35.70 | 30.67 | 244.95 |
| 2040 | 37.59 | 31.13 | 348.31 |
| 2050 | 39.71 | 32.06 | 501.56 |
| *Electricity Price (c/kWh)* | *Reference* | | *Policy Consumer Price* |
| 2010 | 9.14 | | 9.14 |
| 2020 | 10.82 | | 16.21 |
| 2030 | 12.05 | | 18.49 |
| 2040 | 12.49 | | 18.97 |
| 2050 | 12.85 | | 19.02 |

## 8. Marginal Abatement Cost (MAC)

A Marginal Abatement Cost (MAC) curve is a relationship between tons of emissions abated and the $CO_2$ (or GHG) price. Under highly simplified assumptions, the area under a MAC curve provides an estimate of total cost — but this is best seen as the direct cost of abatement undertaken in that year as it does not capture distortion costs and terms-of-trade effects among other economy-wide effects (for a discussion, see for example, Paltsev *et al.*, 2004). MACs derived from the EPPA model are described in detail in Morris *et al.* (2008). Some studies show a negative part of MACs, like, for example McKinsey and Co analysis (2007), where "almost 40 percent of abatement could be achieved at "negative" marginal costs". Jacoby (1998) discusses some of the ways such bottom-up based engineering studies can be misleading as a guide to an economy-wide policy. For more on a comparison of EPPA and a McKinsey MAC curve, see Appendix B of the MIT Joint Program Report 164 (available at: *http://globalchange.mit.edu/pubs/abstract.php?publication_id=972*).

In economy-wide modeling studies, zero cost or beneficial efficiency improvements are recognized through an exogenous energy efficiency improvement over time and so these are captured in the reference/no policy scenario. Thus, they do not appear as part of a policy scenario and, therefore, a MAC constructed from an economy-wide model generally does not have a negative cost component. However, in countries with positive terms-of-trade effects or if auction revenue is used to cut existing distortionary taxes, there can be welfare gains from climate policy even with a positive $CO_2$ price, especially for smaller reductions (e.g., see Babiker *et al*., 2003).

## References for Appendix B


Babiker, M., A. Gurgel, S. Paltsev, J. Reilly (2008), A Forward Looking Version of the MIT Emissions Prediction and Policy Analysis (EPPA) Model, MIT Joint Program on the Science and Policy of Global Change, Report 161, Cambridge, MA (available at: http://globalchange.mit.edu/files/document/MITJPSPGC_Rpt161.pdf).

Babiker, M., G. Metcalf, and J. Reilly (2003), Tax distortions and global climate policy, *Journal of Economic and Environmental Management*, 46: 269-287.

Creyts, J., A. Derkach, S. Nyquist, K. Ostrowski, J. Stephenson (2007), Reducing U.S. Greenhouse Gas Emissions: How Much at What Cost? McKinsey and Company (available at: http://www.mckinsey.com/clientservice/ccsi/pdf/US_ghg_final_report.pdf).

Gurgel, A., S. Paltsev, J. Reilly, G. Metcalf (2007), U.S. Greenhouse Gas Cap-and-Trade Proposals: Application of a Forward Looking Computable General Equilibrium Model, MIT Joint Program on the Science and Policy of Global Change, Report 150, Cambridge, MA (available at: http://globalchange.mit.edu/files/document/MITJPSPGC_Rpt150.pdf).

EPA [Environmental Protection Agency] (2009), EPA Preliminary Analysis of the Waxman-Markey Discussion Draft, Washington, DC (available at: http://www.epa.gov/climatechange/economics/economicanalyses.html).

Goulder, L. (2008), Economic Impacts of Environmental Policies, NBER Research Summary, http://www.nber.org/reporter/spring00/goulder.html.

Jacoby, H. (1998), The Uses and Misuses of Technology Development as a Component of Climate Policy, MIT Joint Program on the Science and Policy of Global Change, Report 43, Cambridge, MA (available at: http://globalchange.mit.edu/files/document/MITJPSPGC_Rpt43.pdf).

Morris, J., S. Paltsev, J. Reilly (2008), Marginal Abatement Costs and Marginal Welfare Costs for Greenhouse Gas Emissions Reductions: Results from the EPPA model, MIT Joint Program on the Science and Policy of Global Change, Report 164, Cambridge, MA (available at: http://globalchange.mit.edu/files/document/MITJPSPGC_Rpt164.pdf).

Nordhaus, W. (2007). A Review of the Stern Review on the Economics of Climate Change, *Journal of Economic Literature*, 45(3): 686-702.

Paltsev, S., J. Reilly, H. Jacoby, K. Tay (2004), The Cost of Kyoto Protocol Targets: The Case of Japan, MIT Joint Program on the Science and Policy of Global Change, Report 112, Cambridge, MA (available at: http://globalchange.mit.edu/files/document/MITJPSPGC_Rpt112.pdf).

Paltsev, S., J. Reilly, H. Jacoby, J. Morris (2009), The Cost of Climate Policy in the United States, MIT Joint Program on the Science and Policy of Global Change, Report 173, Cambridge, MA (available at: http://globalchange.mit.edu/files/document/MITJPSPGC_Rpt173.pdf).

US CCSP [US Climate Change Science Program] (2007), U.S. Climate Change Science Program Synthesis and Assessment Product 2.1 a: Scenarios of Greenhouse Gas Emissions and Atmospheric Concentrations, L. Clark et al, Washington, DC (available at: http://www.climatescience.gov/Library/sap/sap2-1/default.html).