MIT Joint Program on the Science and Policy of Global Change

The Cost of Climate Policy in the United States

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

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To inform processes of policy development and implementation, climate change research needs to focus on improving the prediction of those variables that are most relevant to economic, social, and environmental effects. In turn, the greenhouse gas and atmospheric aerosol assumptions underlying climate analysis need to be related to the economic, technological, and political forces that drive emissions, and to the results of international agreements and mitigation. Further, assessments of possible societal and ecosystem impacts, and analysis of mitigation strategies, need to be based on realistic evaluation of the uncertainties of climate science.

This report is one of a series intended to communicate research results and improve public understanding of climate issues, thereby contributing to informed debate about the climate issue, the uncertainties, and the economic and social implications of policy alternatives. Titles in the Report Series to date are listed on the inside back cover.

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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

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* 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]

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[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

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[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

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[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 nth 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$_2$e	10.8 GtCO$_2$e
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.

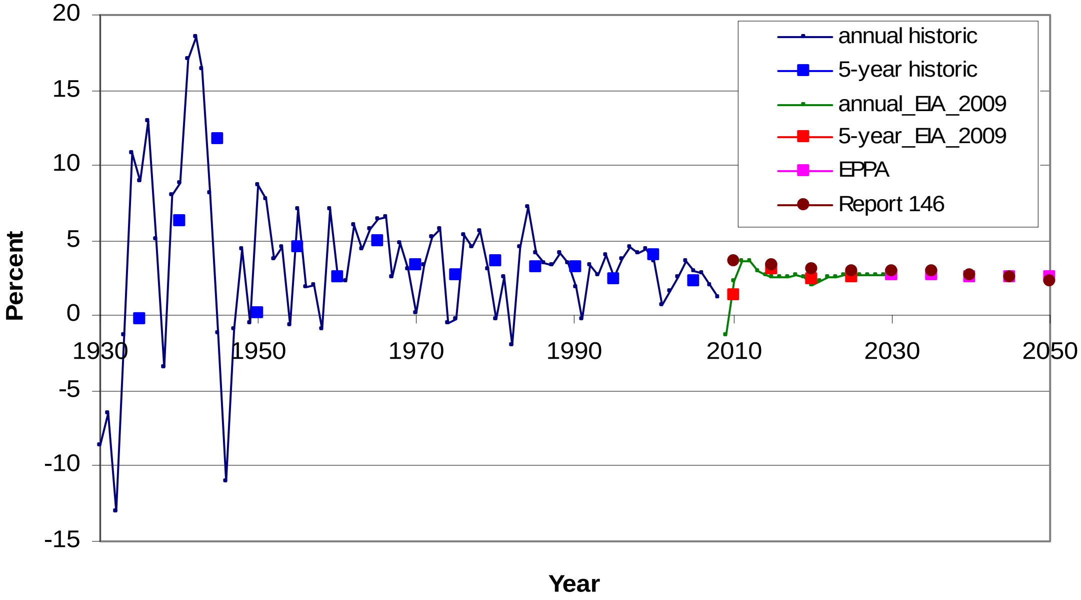


Figure 1. U.S. GDP Growth Rates, 1930 to 2008 and Projected Rates to 2050.

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.

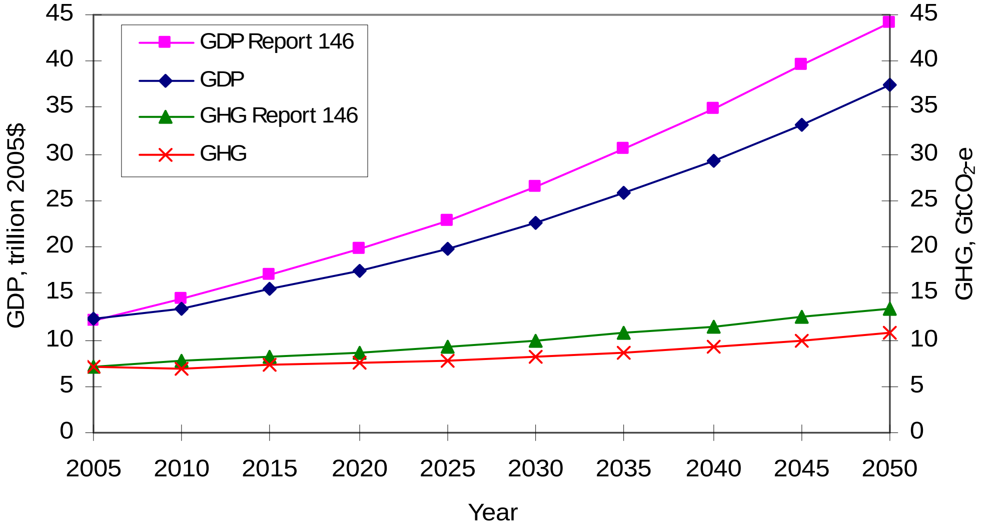


Figure 2. U.S. GDP and GHG in reference scenario.

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/tCO_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.

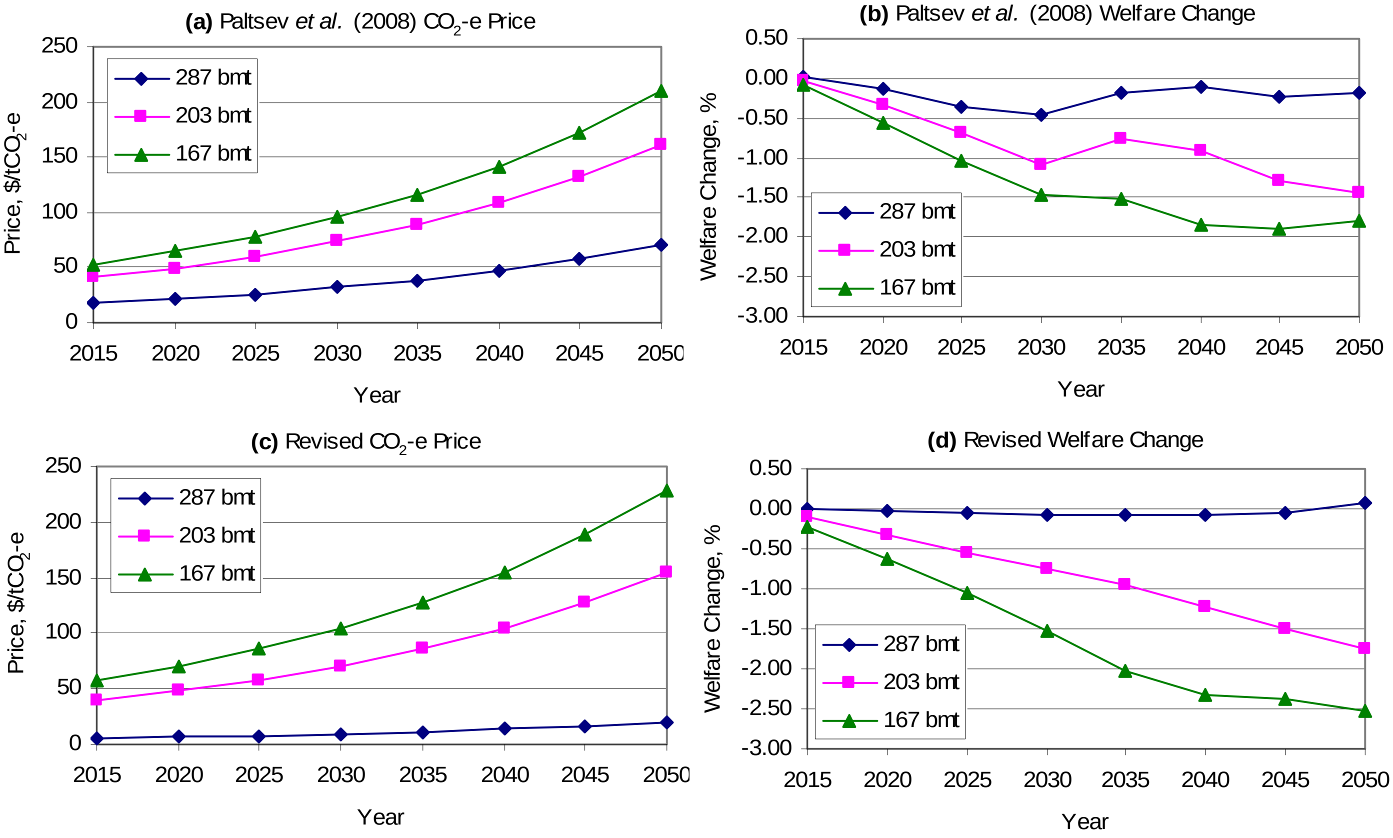


Figure 3. CO_2-e Price and Welfare Results for Three Policy Scenarios: **(a)** Paltsev *et al.* (2008) CO_2-e Price, **(b)** Paltsev *et al.* (2008) Welfare Change, **(c)** CO_2-e Price with Revised Technological and Economic Outlook, **(d)** Welfare Change with Revised Technological and Economic Outlook.

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.

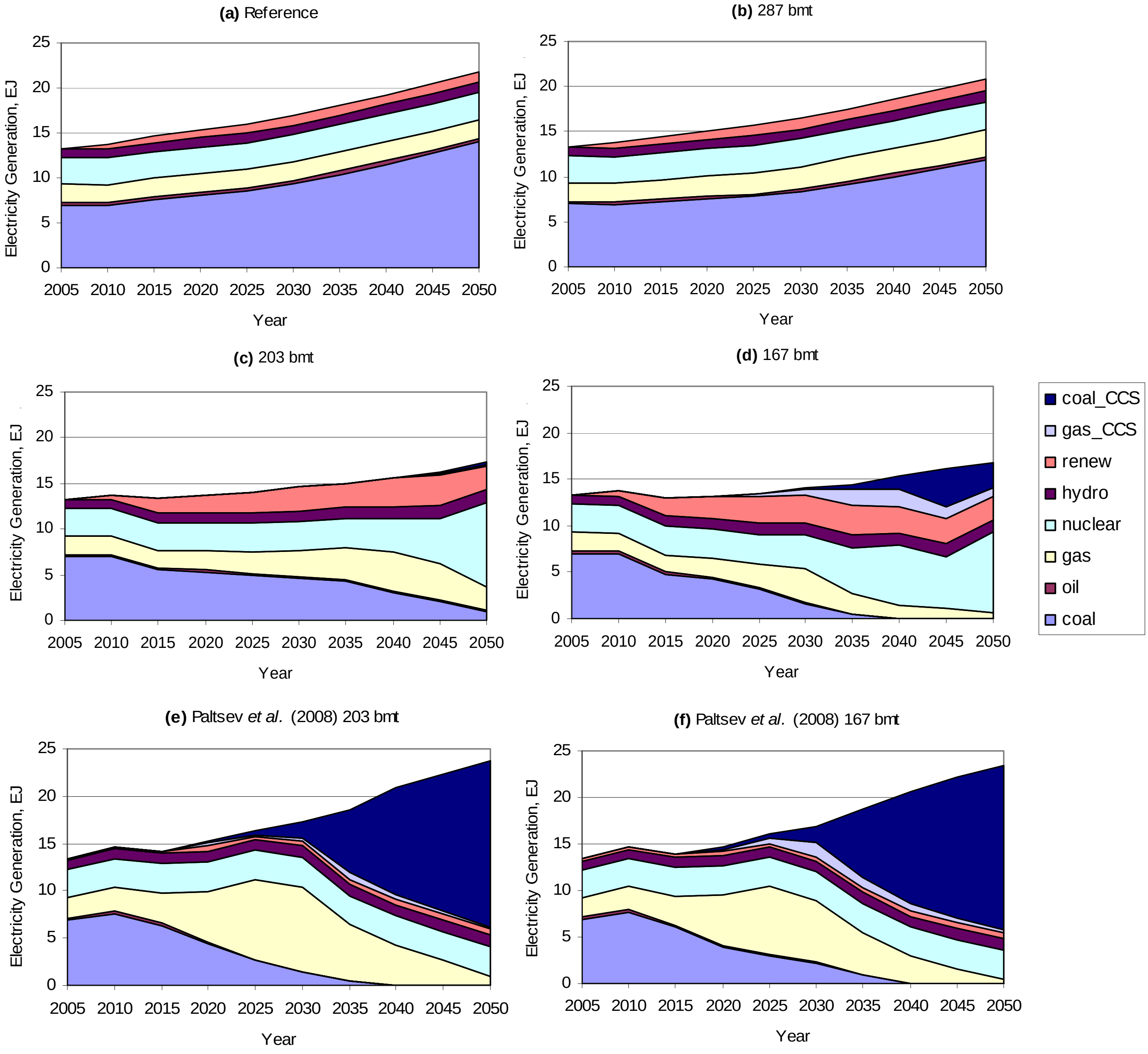


Figure 4. Electricity Generation by Sources in the Reference and Policy Cases: **(a)** Reference, **(b)** 287 bmt, **(c)** 203 bmt, **(d)** 167 bmt, **(e)** Paltsev *et al.* (2008) 203 bmt, **(f)** Paltsev *et al.* (2008) 167 bmt.

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.

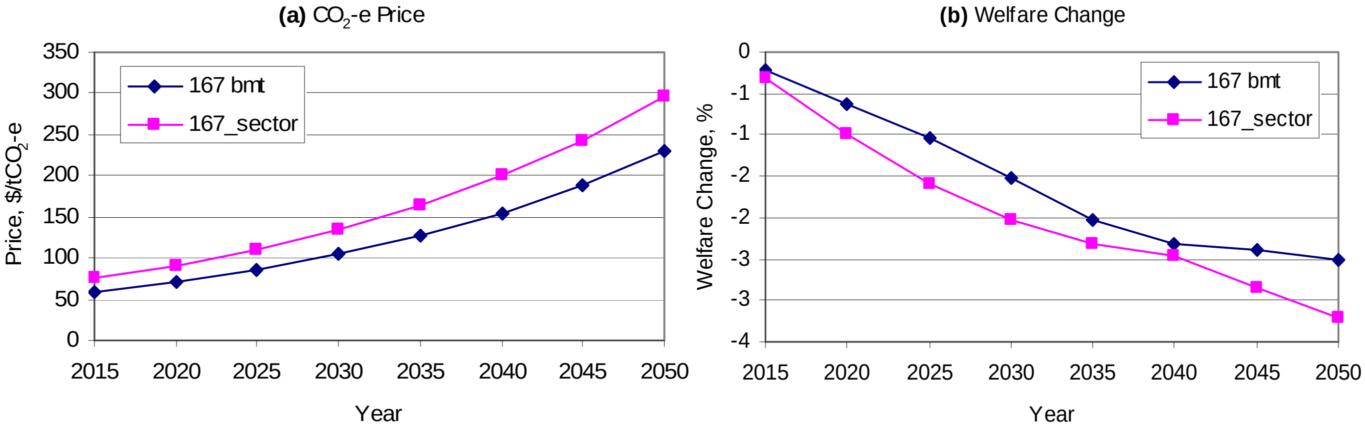
4. DETAILS OF POLICY IMPLEMENTATION AND TECHNOLOGY ASSUMPTIONS

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.


(a) CO_2-e Price

(b) Welfare Change

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.

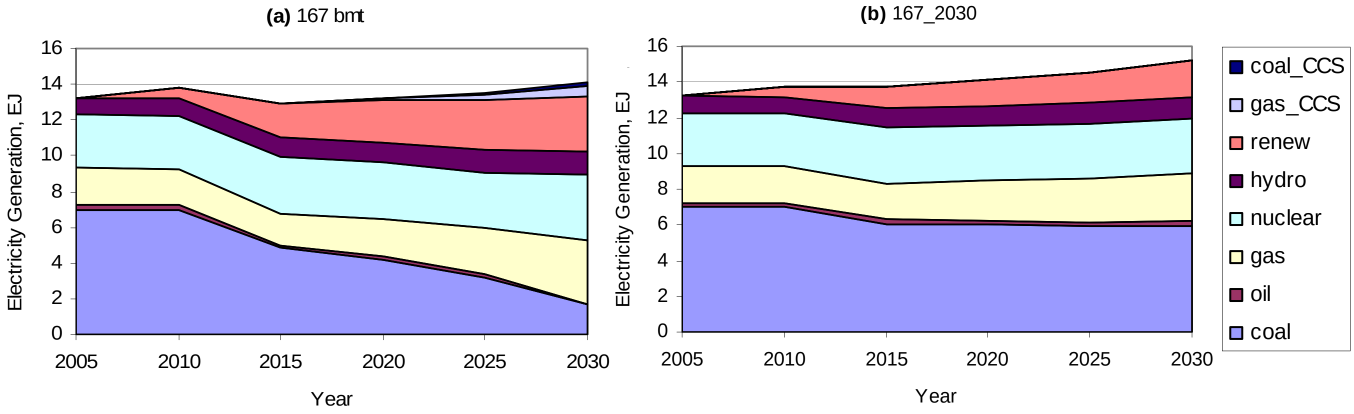


Figure 6. Electricity Generation Choices with a Shorter Banking Horizon: **(a)** 167 bmt, **(b)** 167_2030.

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.

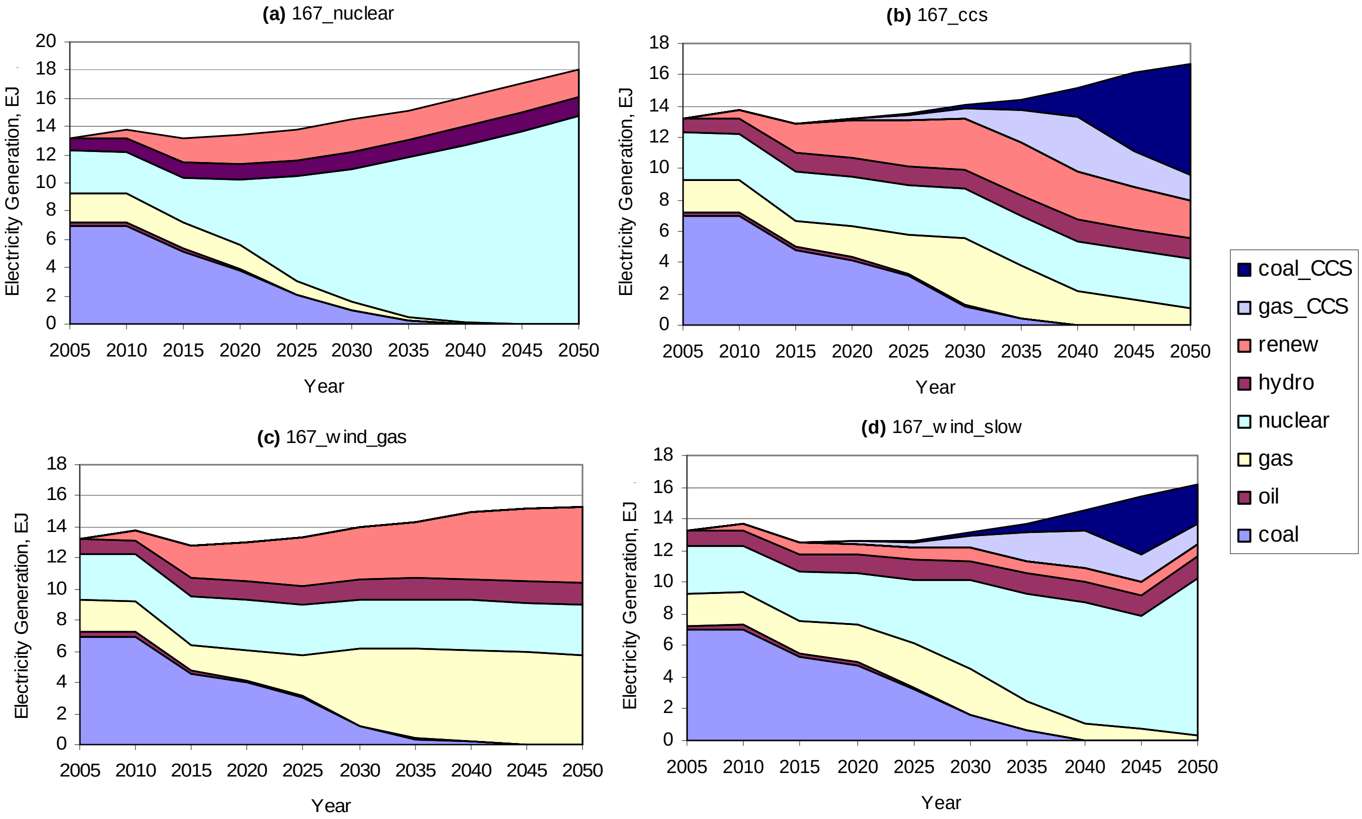


Figure 7. Alternative Technology Assumptions and Generation Choices: **(a)** 167_nuclear, **(b)** 167_ccs, **(c)** 167_wind_gas, **(d)** 167_wind_slow.

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/tCO_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

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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[*]

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

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.[1] Since the GWP index uses CO_2 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 B1**.

Table B1. CO_2-e Price.

	2020	2030	2040	2050
CO_2-E Price (2005\$/tCO_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

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[*] This is an appendix to Paltsev *et al.* (2009): The Cost of Climate Policy in the United States, MIT Joint Program on the Science and Policy of Global Change, *Report 173* (http://globalchange.mit.edu/pubs/abstract.php?publication_id=1965).

[1] 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.

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 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, whereas with milk production we can simply measure how much milk was produced.[2] 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[3], 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 B2**.

Table B2. 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

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[2] 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.

[3] Change is measured in comparison to welfare without a climate policy.

tax interaction effect.[4] 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 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.[5]

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.[6] 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

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

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

[6] 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).

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.

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 B3**.

Table B3. 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 are 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 consumption 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 (e.g. education and 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 B4**.

Table B4. 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[7] 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 B5**.[8] 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 B6** 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.

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[7] 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.

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

Table B5. 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 B6. 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 B7** 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 B7. 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 price increases 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 B8** 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 B8. 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).

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Appendix C: Cost of Climate Policy and the Waxman-Markey American Clean Energy and Security Act of 2009 (H.R. 2454)[1]

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

Abstract

The American Clean Energy and Security Act (H.R.2454) passed the House of Representatives after the completion of the main report (MIT Joint Program Report 173). In this Appendix we provide an analysis of the Act's provisions as they relate to key features governing the cap-and-trade system, the renewable electricity standard (RES), limits on new coal power plants and support for carbon capture and storage(CCS), applying the Emissions Prediction and Policy Analysis (EPPA) model used in the main report. While the overall economy-wide target in H.R. 2454, of no more than 161 billion metric tons of CO_2*-equivalent released through 2050, is similar to the 167 bmt case analyzed in the main report, other features of the Bill significantly affect projections of its cost. We find that the large allowance for outside credits could reduce the cost if indeed these are forthcoming (and inexpensive). Other provisions, such as how the revenue and allowances will be distributed, will have important distributional consequences as well, but their analysis is beyond the scope of the study presented here.*

Our central estimate shows the CO_2*-e price starting at $21 per ton in 2015 and rising to about $84 by 2050. We decompose the welfare costs into a total cost including H.R. 2454 and recent legislation that was motivated in part for its GHG benefits (the Energy Independence and Security Act of 2007 and American Recovery and Reinvestment Act of 2009) vs. the additional cost of H.R 2454 itself given these preexisting measures. The national welfare cost of reaching the emissions targets outlined in H.R. 2454, attributable to the bill itself, rise from about 0.1 percent to 1.45 percent over the period 2015-2050. We estimate average annual net present value cost of H.R. 2454 of about $400 per household over this horizon, but given different assumptions about the availability of offsets this estimate ranges from as low as $180 to as high as $470. A rough comparison of costs with analyses by the CBO, EIA and EPA shows results in the same general range, though our estimates are higher.*

Contents

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[1] This is an appendix to Paltsev *et al.* (2009): The Cost of Climate Policy in the United States, MIT Joint Program on the Science and Policy of Global Change, *Report 173* (http://globalchange.mit.edu/pubs/abstract.php?publication_id=1965).

C1. FEATURES OF H.R. 2454 AND IMPLEMENTATION IN THE EPPA MODEL

We rely on a version of the bill as passed by the House of Representatives on June 26, 2009, recognizing that final legislation will depend on details of a Senate bill and reconciliation with the House version. H.R. 2454 is composed of five main titles. Title I deals with clean energy, setting up a combined efficiency and renewable electricity standard as well assistance for various advanced technologies. Title II focuses further on energy efficiency, creating a number of programs and standards for buildings, lighting, and appliances. Title III establishes a cap-and-trade system for greenhouse gases (GHGs). Title IV addresses the transition to a clean economy and competitiveness issues. Title V deals with agricultural and forestry related offsets.

General Provisions

Title III, establishing the cap-and-trade system, is the main focus of our analysis. The cap covers seven GHGs: carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O, hydrofluorocarbons (HFCs), perfluorocarbons (PFCs), sulfur hexafluoride (SF_6), and nitrogen trifluoride (NF_3). Covered entities include large stationary sources emitting more than 25,000 tons of GHGs per year, producers (i.e., refineries) and importers of all petroleum fuels, distributors of natural gas to residential, commercial and small industrial users (i.e., local gas distribution companies), producers of “F-gases,” and other specified sources. The cap is intended to ultimately cover 84.5% of total U.S. GHG emissions. The cap gradually reduces aggregate GHG emissions for all covered entities to 3% below 2005 levels in 2012, 17% below 2005 levels in 2020, 42% below 2005 levels in 2030, and 83% below 2005 levels in 2050. Commercial production and imports of HFCs are to be covered under a separate cap, which we do not assess. Previous analysis of such a separation suggests that it raises the costs of meeting the targets by a substantial amount considering that HFC emissions represent a small share of the GHG total. The bill also establishes economy-wide goals for all sources.

For the capped sectors, the bill lays out year-by-year allowances. We simplify the policy by assuming that a cap-and-trade system covers all emissions, and so the allowance path is prescribed to align with the economy-wide reduction goals laid out in the bill: 80% of 2005 levels by 2020, 58% by 2030, and 17% by 2050. We thus assume that measures directed at sectors not covered by the cap will be effective at achieving reductions, in a manner as economically efficient as if they were under the cap (i.e. the marginal costs of reduction in the capped and uncapped sectors would be comparable). With banking and borrowing, the most important aspect of the allowance path is its cumulative emissions over the life of the policy (2012-2050), which are 161 billion metric tons (or, gigatons, Gt) CO_2-e. Since the cap and trade system is covering an estimated 85% of US emissions we expect the additional 15% coverage to have a relatively small effect on the overall costs. Allowances for covered sectors alone amount to 132 Gt CO_2-e of cumulative emissions. The allowance path and economy-wide goals are presented in **Figure C1**. The highly non-linear sectoral allowance path in the early years reflects the fact that not all sectors are immediately covered by the cap, and so actual allowances are proportionately lower. In our simplified path, representing the national economy goals, all sectors are covered from the start.

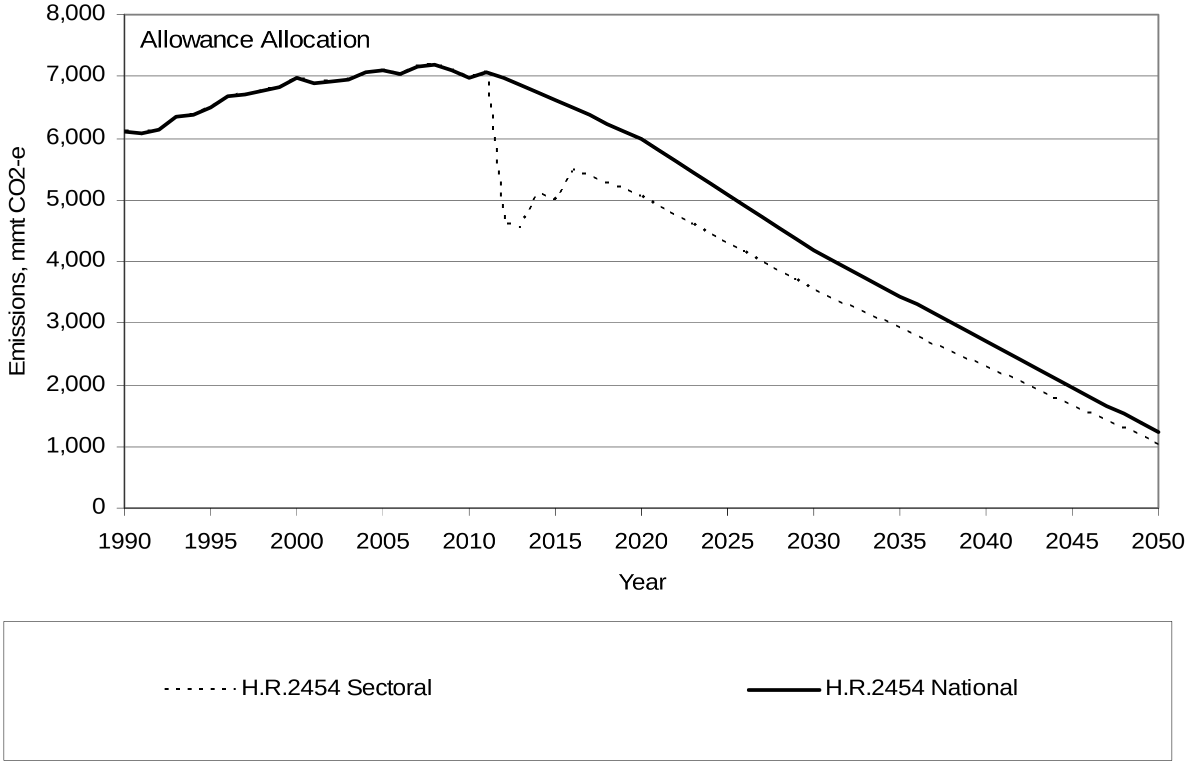

Figure C1. Allowance Allocation for Covered Sectors and National Emissions Goals.

Cost Containment

Several cost-containment measures are included in the bill. Up to two billion tons (or gigatons—Gt) of credit offsets can be used each year in lieu of allowances—1 Gt from domestic sources and 1Gt from international sources. However, if the domestic supply of offsets is insufficient, EPA can raise the international limit up to 1.5 Gt, but the 2 Gt total limit still applies. For international offsets, beginning in 2018, 1.25 offset credits would be required for each ton of emissions compliance. The EPA would determine the list of eligible offset projects based on recommendations from an Offsets Integrity Advisory Board. Title V of the bill establishes an offset program specific to domestic agriculture and forestry sources, to be administered by the Secretary of Agriculture.

While credits are allowed, the actual amount forthcoming in any year will depend on how they are defined, the extent to which their definition will avoid the traditional bureaucracy of credit programs, and the competition for them from foreign cap-and-trade programs. Until these features are resolved one can only speculate on how they will influence offset supply. We thus consider two offset paths:

(1) Full Offsets - we add 2 Gt to the total national allowances in each year, at a specified cost per ton CO_2-e.

(2) Medium Offsets - we impose a gradual path of offset use that builds up to 2 Gt by 2050, similarly at a specified cost.

The reasoning behind the latter path is that, even if the full level of offsets were available, the process of setting up a program to evaluate and approve them will be slow. Under these assumptions, cumulative emissions within the U.S. national cap are 239 Gt CO_2-e from 2012 to 2050 with full offsets and 203 Gt CO_2-e with medium offsets. These allowance-plus-offset paths are presented in **Figure C2**. To indicate the effect of the offset provision on the mitigation task, the allowed emissions path if there were no offsets is also shown in the figure.

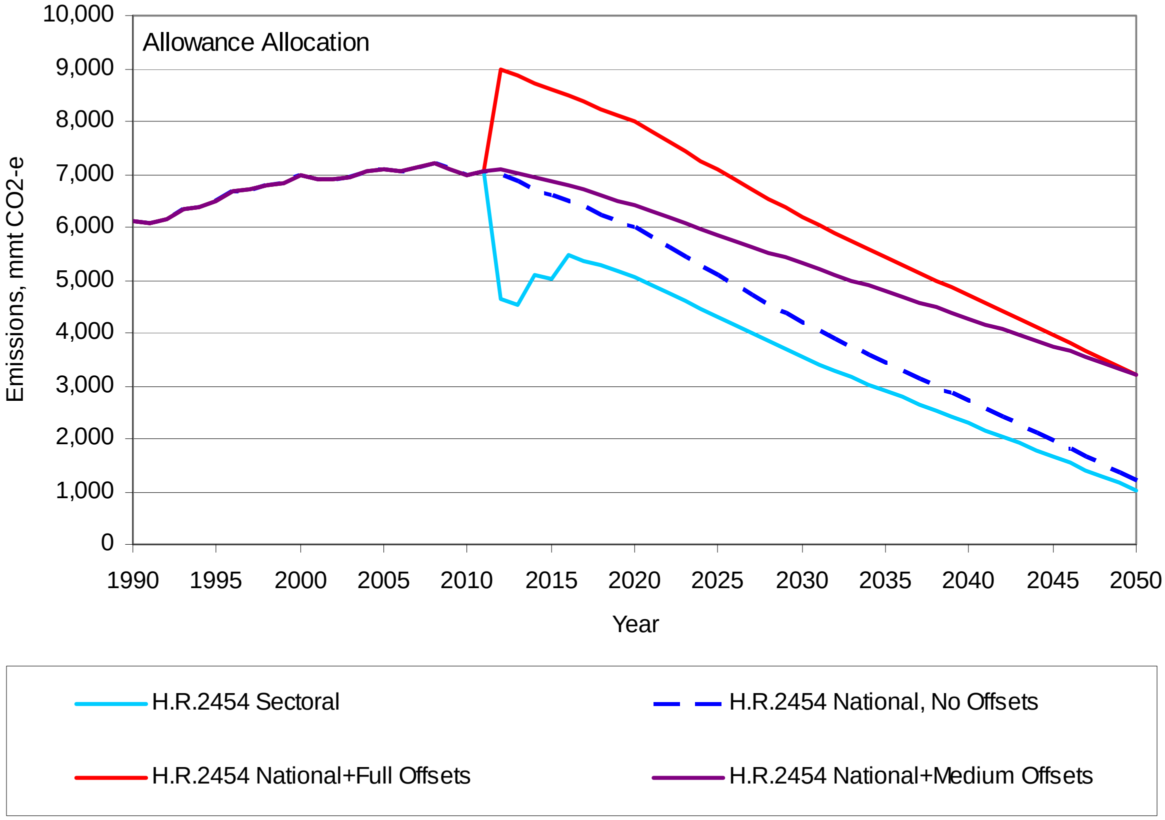

Figure C2. National Emissions Goals with Alternative Offset Paths.

We further assume offsets have a cost to the economy, and implement this assumption by transferring abroad the value of allowances purchased internationally. Our default assumption is that the average cost of these credits is $5 per effective ton of offsets CO_2-e in 2015, rising at 4% per year thereafter.[2] Later we provide the results with alternative assumptions about the cost of offsets: $15 per ton at the start and if available at no cost throughout.

Another cost containment provision is banking and borrowing. In the bill, banking of allowances is unlimited and a two-year compliance period allows unlimited borrowing from one

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[2] The bill specifies that 1.25 tons of foreign reductions are required to produce 1 ton of effective offsets. The $5/ton initial offset price means the actual payment per ton of foreign reduction is $4.

year ahead without penalty. Limited borrowing (15%) from two to five years ahead is also allowed, but with interest. We consider the allowance banking and borrowing provisions in our analysis. In general, we find no need for aggregate borrowing, and so there is no need to implement an explicit restriction on it. Also included in the bill is a strategic allowance reserve auction that sets aside a small percentage of allowances (1% in 2012-2019, 2% in 2020-2029, and 3% in 2030-2050) to be auctioned to contain short run allowance price spikes. The initial minimum price level for the auction would be set at $28 in 2012, and rise at 5% plus inflation for 2013 and 2014. Beginning in 2015, the reserve auction trigger price would be 60% above the rolling 36-month average of the market price of allowances. There are additional limits on the amount auctioned from the reserve each year and the amount each entity can purchase. The EPPA model simulates the economy on 5-year time steps and so it is not possible for us to consider the short-run dynamics under which this provision might be important. We assume all of this reserve is released to the market.

Title III also describes how allowances will be distributed, either through an auction or distribution at no cost. A large portion of allowances or auction revenues are distributed so as to return the value to lower and middle income households and to offset increases in energy costs. Emission allowances are also distributed to aid energy intensive, trade-vulnerable industries and domestic refiners and to support investment in clean technologies including carbon capture and storage (CCS), advanced vehicle technology, and energy R&D through various mechanisms including funding a State Energy and Environmental Development (SEED) program. These features of the bill are important in determining its distributional effects among income groups, but because EPPA has a single representative agent, they are not relevant to our analysis.

Renewables and Efficiency

Title I lays out a combined efficiency and renewable electricity standard which requires retail electric suppliers that sell more than 4 million megawatt hours of electricity to meet a growing percentage of their load with electricity generated from renewable resources and from electricity savings. The combined renewable electricity and electricity savings requirement begins at 6% in 2012 and gradually rises to 20% in 2020, where it stays until 2039. An interesting and potentially important aspect of the bill is the calculation of the base against which this percentage applies. In particular, the base is total electricity production minus: (1) electricity from non-qualified hydroelectric facilities, (2) electricity from nuclear generation built after the passage of this bill, (3) the proportion of electricity generated from fossil fuel plants that is equal to the proportion of GHGs those plants capture and geologically store, and (4) electricity from small utilities (those that sell less than 4 million MWh per year).[3] If RES requirement is not met there is an Alternative Compliance Payment of $25 per MWh (2.5 cents per kWh).

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[3] The characteristics of the base are crucial to the economics of this provision. For example, if the cap-and-trade policy led to complete phase out of fossil generation at some point, replaced by nuclear and fossil with CCS, the requirement would be 20% of a base of zero.

With regard to the shares of renewables and efficiency improvement, the bill specifies that 75% of the requirement should be met by renewable energy while the remainder can come from reductions in electricity demand. The Federal Regulatory Commission can lower the renewables share to 60% upon petition from a state governor, but we do not consider this method of relaxing the target in our simulations. For purposes of simulating the renewable electricity standard (RES) in EPPA, the first simulation year is 2015, at which point the bill sets the RES at 9.5%, and this rises to 20% in 2020-2039. We further assume the target of 20% extends to 2050. In modeling the expansion of renewables required by the combined efficiency and renewables standard we take account of renewable supply that may already be in place in the baseline due to state RES programs and the American Recovery and Reinvestment Act of 2009 by implementing an estimate drawn from analysis by the Energy Information Administration (EIA, 2009).

The Bill does not specify a method for defining the contribution of electric demand reduction. It is possible to imagine its measurement, alternatively, in terms of the absolute reduction from the base-year level, as the reduction from a forecast baseline, or as the estimated savings from utility demand management programs. We model the contribution as the reduction from our projected, no-policy baseline. Reductions in excess of the contribution required to meet the efficiency component of RES can occur in our simulations simply because of the pass-through of higher generation costs in the electricity price. In these circumstances this 25% of the RES target is met through these electricity savings, at no additional cost.

Other Provisions

Sec. 782 of H.R. 2454 requires that a certain percentage of allowances in each year go toward the deployment of CCS technology. That percentage is 1.75% in 2015 and 5% in 2020-2050. To model this provision, we multiply the number of allowances going to CCS each year by the carbon price in that year and give the resulting amount of money to CCS technologies as a subsidy. We did not model additional bonus allowance provisions for CCS specified in the bill. We have modeled the performance standards for coal-fueled power plants as specified in Sec. 116 by ensuring that no new coal plants without CCS are built after 2025.

The bill has still other provisions that we do not consider. Other sections of Title I and Title II provide supports for energy efficiency and advanced technologies other than coal with CCS. Title I establishes State Energy and Environment Development (SEED) Accounts for energy efficiency and renewable energy deployment, and promotes clean energy investment, smart grid advancement and transmission planning and siting. Title II sets energy efficiency standards for buildings, lighting, appliances, and transportation and requires EPA to promulgate carbon emission standards for heavy-duty vehicles and off-road vehicles, such as construction equipment, trains, and large ships. These details are mostly below the level of detail of the EPPA model. Some of these features of the bill may be important for removing barriers to adoption of new technologies. Others may set standards that are redundant, given that the economy-wide cap will require substantial gains even without these standards. In general, the EPPA model assumes barriers will be overcome and so if these additional programs are an essential part of making that happen, any program costs associated with them are an additional macroeconomic cost beyond what we estimate in the model. If they go beyond what the cap would require, then they also would add to the cost by diverting abatement action to these more costly activities.

C2. ESTIMATES OF EMISSIONS PRICE AND COST UNDER H.R. 2454

We turn now to our estimates of the impacts of H.R. 2454 in terms of actual emissions reductions, CO_2-e prices, economy-wide welfare costs, and costs per average household. For a discussion of these and other cost concepts, see Appendix B of this report. Note that our analysis encompasses only the cost of emissions mitigation and so does not consider potential welfare improvements from ancillary benefits of emissions mitigation or from climate damages avoided. Our main results include the RES requirement and the cost of acquiring offsets. Because of the uncertainty about the offsets we show results for the two offset cases defined above. Later we with different assumptions about offset cost.

We present two views of the cost of the policy measures that would contribute to the achievement of the emissions target in H.R. 2454. A total cost measure includes the influence of other measures: the Energy Independence and Security Act of 2007 (EISA) which introduced biofuels and CAFE standards, the American Recovery and Reinvestment Act of 2009 (ARRA) which included subsidies to renewables, and state-level RES policies. This total cost is roughly consistent, assuming Medium Offsets, with the 203 bmt case in the main body of this report. The analysis of the cost implications of H.R. 2454 then treats the costs of these existing measures as sunk and considers only the incremental effort required to bring emissions down to the Bill's specified target. EISA and ARRA measures were implemented explicitly as fuels and technology requirements. As a result they impose a welfare cost on the economy but there is no explicit CO_2 price associated with these measures.

Emissions

Reference and policy emissions are presented in **Figure C3**. Estimates of the total cost of recently-imposed measures and H.R. 2454 are based on the Reference-No Policy baseline. The reduction effort required of H.R. 2454 then is defined in terms of a baseline that takes account of the reductions attributable to earlier measures, noted in the Figure as Reference+EISA+ARRA. Note that the banking of allowances over time leads to the emissions profiles that differ from the allowance paths in Figure C2. With banking and offsets the nominal national goal of 17% of 2005 emissions in 2050 (or 83% reduction) is not actually achieved. In the medium offsets case, emissions in 2050 are still about 68% of the 2005 level. In the full offset case, emissions by 2050 are about 87% of 2005 emissions. As long as the credits result in real reductions elsewhere, these different scenarios will have essentially the same effect on atmospheric concentrations, but they have different implications for what is required in terms of domestic changes in energy supply and use.

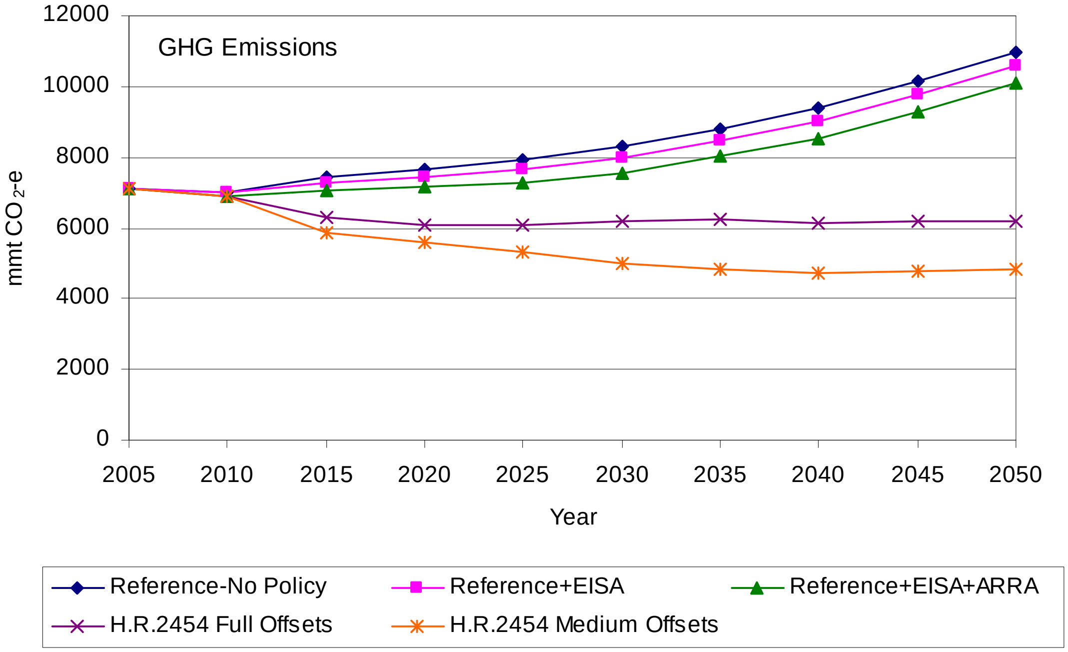

Figure C3. US GHG Emissions With and Without Policies.

Prices and Welfare

CO_2-e price and welfare effects are presented in **Figures C4 and C5** and in **Table C1.** For H.R. 2454 with medium offsets the initial price is \$21/tCO_2-e in 2015 and it rises to around \$84 per tCO_2-e by 2050. Carbon prices are lower than in the closest scenario in the main body of the report (203 bmt), where the price is projected to rise from \$39 to \$155. (H.R. 2454 with medium offsets and the 203 bmt scenario coincidentally results in the same cumulative emissions over 2012-2050.) A scenario with the full amount of offsets decreases the 2015 carbon price to \$7 with a price in 2050 of around \$29 per ton CO_2-e. The welfare costs of H.R. 2454 with medium offsets rise from 0.1% in 2015 to 1.45% in 2050, while the total cost of climate policy including EISA and ARRA is 0.3% in 2015 rising to 1.73% in 2050, again similar to the 203 bmt scenario, where they increase from 0.1% in 2015 to 1.75% in 2050.

The costs are higher and carbon prices are lower than the 203 bmt case due to several reasons: (1) Energy Independence and Security Act of 2007 and American Recovery and Reinvestment Act of 2009 introduce biofuels, CAFÉ standards and subsidies to renewables that reduce GHG emissions. As a result, they cover a part of the cost of reaching targets specified in H.R. 2454; (2) subsidies to CCS and the RES requirements in H.R. 2454 reduce the carbon price but increase the welfare cost of the policy (for more discussion of the interaction of renewable electricity requirement with a cap-and-trade system, see Morris, 2009); (3) our estimate of U.S. natural gas resources has also increased while our estimate of the cost of producing electricity from natural gas combined-cycle generation is lower reflecting recent evidence on resources availability and generation costs.

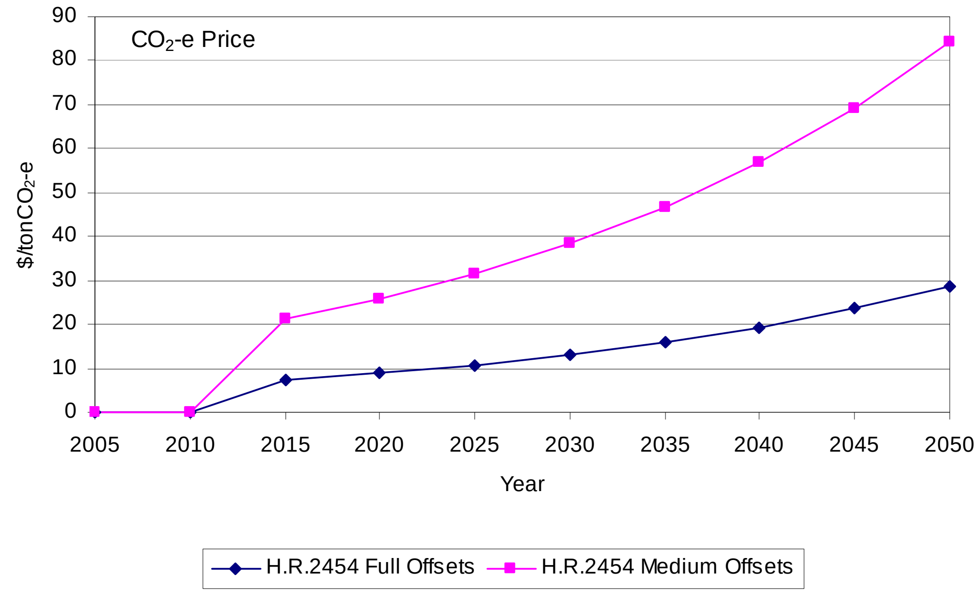

Figure C4. Carbon Prices in H.R. 2454 with Different Offsets.

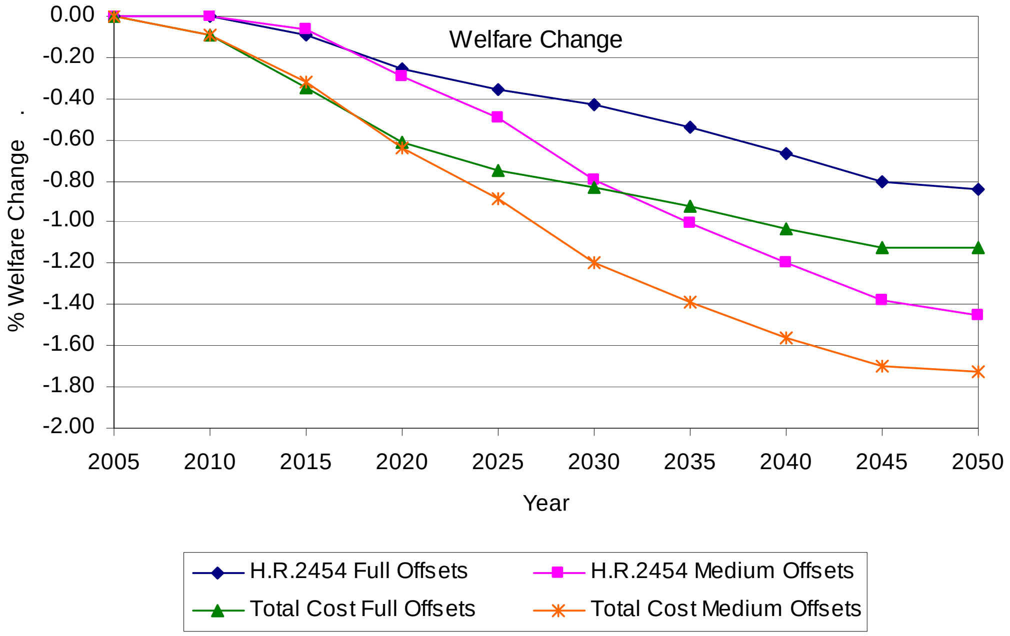

Figure C5. Welfare Change in H.R. 2454 with Different Offsets.

By the end of the analysis period our different offset assumptions affect the estimates of cost substantially. Our estimates of the cost of H.R. 2454 with full offsets leads to 0.8% welfare loss in 2050 while a scenario with medium offsets results in 1.45%. A similar difference appears in welfare costs by 2050 when the total cost of climate policy is considered: – 1.12% in the full offsets scenario and 1.73% with medium offsets. More detailed results for the total cost of climate policy are provided at the end of this note.

Table C1. CO_2-e Price and Welfare Cost with Different Offsets.

	H.R. 2454				Total Cost	
	Price, \$/ton CO_2-e		Welfare Cost, %		Welfare Cost, %	
	Med Offsets	Full Offsets	Med Offsets	Full Offsets	Med Offsets	Full Offsets
2010	0.00	0.00	0.00	0.00	-0.09	-0.09
2015	21.31	7.27	-0.07	-0.10	-0.32	-0.35
2020	25.92	8.85	-0.29	-0.26	-0.64	-0.61
2025	31.54	10.76	-0.50	-0.35	-0.89	-0.75
2030	38.37	13.09	-0.79	-0.43	-1.19	-0.83
2035	46.68	15.93	-1.00	-0.54	-1.39	-0.93
2040	56.80	19.38	-1.19	-0.67	-1.56	-1.04
2045	69.10	23.58	-1.38	-0.80	-1.70	-1.12
2050	84.07	28.69	-1.45	-0.84	-1.73	-1.12

Cost per Household

Recent analyses have reported economic cost as a dollar cost per household. We construct this estimate by monetizing the welfare loss and dividing it by the number of households. **Table C2** provides our calculation for this cost of H.R. 2454, using the U.S. 2005 average of 2.57 persons per household, and a population of 296 million. We assume the household size stays the same over time, with the number of households increasing as population grows. The cost per household in 2015 for the medium offsets case is \$68 (\$97 in the full offset case[4]). This rises to just over \$300 (about \$280 in the full offset case) in 2020, and to about \$2700 (\$1560 in the full offset case) per household by 2050.[5] On average for the 2012-2050 period, the cost per household is between \$720 and \$1200 depending on the offsets assumption.

The RES requirement increases the household cost in the first decade of the policy when the renewable share must increase rapidly. The rapid phase-in of the RES—from about 7% to 15% in just 5 years creates further adjustment costs. The affect of the RES is moderated in later years, partly because the constraint is less binding and partly because the cap-and-trade costs continue to rise as the target tightens, while the RES requirement remains unchanged. However, larger overall losses in early years due to the RES depress the level of saving and investment, and the reduction in investment continues to affect the level of the economy in later years even when the RES is not binding.

Also shown is the total household cost of the H.R. 2454 targets when the effects of the Energy Independence and Security Act (EISA) and American Recovery and Reinvestment Act (ARRA)

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[4] The cost per household is higher in the full offset case in early years but lower over the whole period specified in the bill because in early years the payment for the full amount of offsets must be made, while in the medium offsets case these offsets are not available and not paid for. As overall emissions reduction is bigger when full offsets are not available, the medium offsets case is getting more expensive over time. The exact reduction profile is also affected by allowance banking behavior.

[5] To provide a context for these annual costs, the average per-family consumption under the growth scenario imposed here, for the medium offsets case, is \$90,000 in 2020 and \$150,000 in 2050. Naturally, these costs do not fall evenly on all families. Indeed, the allowance allocation in H.R. 2454 is designed to lower the price impact on low- and middle-income consumers.

are considered. On average for the 2012-2050 period, the total cost per household is between $1200 and $1700.

To the extent the policy represents a long term commitment it is useful to calculate an average annual cost per household over the horizon of the policy. To do this, we discount costs to 2010 at 4% to arrive at a net present value of the cost in each year, and then take the average for the 2015 to 2050 period. In the medium offsets case, this leads to an average net present value cost of H.R. 2454 of about $250 in the full offset case to just over $400 per household in the medium offsets case. The corresponding numbers for the total cost of climate policy are about $450 per household when full offsets are available and about $600 per household in the scenario with medium offsets (for more discussion on the different cost measures, see Section 6 of Appendix B to this report).

Table C2. Cost per Household (in dollars) of H.R. 2454 with Different Offsets, Annual and Discounted to 2010 at 4%.

	H.R. 2454				Total Cost			
	Med Offsets		Full Offsets		Med Offsets		Full Offsets	
	Annual	Discount to 2010	Annual	Discount to 2010	Annual	Discount to 2010	Annual	Discount to 2010
2010	0	0	0	0	81	81	81	81
2015	68	56	97	80	326	268	355	292
2020	319	215	283	191	704	475	668	451
2025	588	326	419	232	1058	587	889	494
2030	1036	473	556	254	1563	713	1083	494
2035	1433	538	771	289	1994	748	1332	500
2040	1867	576	1043	322	2449	755	1625	501
2045	2354	597	1366	346	2907	737	1918	486
2050	2695	561	1562	325	3225	672	2091	436
Average	**1223**	**404**	**720**	**247**	**1701**	**607**	**1198**	**451**

Electricity Generation

Electricity generation by source for the medium offsets case is presented in **Figure C6**. The reference case, as in the main report, relies heavily on coal. We find that the main response of the electricity sector to the emissions constraint is to shift heavily to natural gas generation. In the 203 bmt scenario, presented in Figure 4c of the main report, new nuclear played a large role. A change in the EPPA model parameters to reflect an increase in domestic natural gas resources and lower NGCC costs contributes to this difference in results between the main report and this appendix. The policy also leads to a substantial reduction in electricity use compared to the reference case without EISA and ARRA measures, more than enough to contribute the 25% of the RES allowed for electricity savings. According to our estimates, EISA and ARRA lead to renewables that almost meet the RES requirements in H.R. 2454. In early years (2020-2035) an additional 1-3% of the requirement must still be met with H.R.2454 measures. We did not consider the scenario in which state governors petition to meet 40% of the RES requirement through efficiency savings, which would make the requirement non-binding in all years.

The bill prohibits new coal plants unless they are far more efficient than existing plants. With high enough CO_2 prices there would be no economic incentive to build new coal plants. We find, however, that with the EISA, ARRA, and offsets there was considerable new investment in conventional coal. We thus implemented in EPPA limits on new investment in coal plants without CCS. Figure C6 reflects those limits, and hence coal generation drops as old plants are retired.

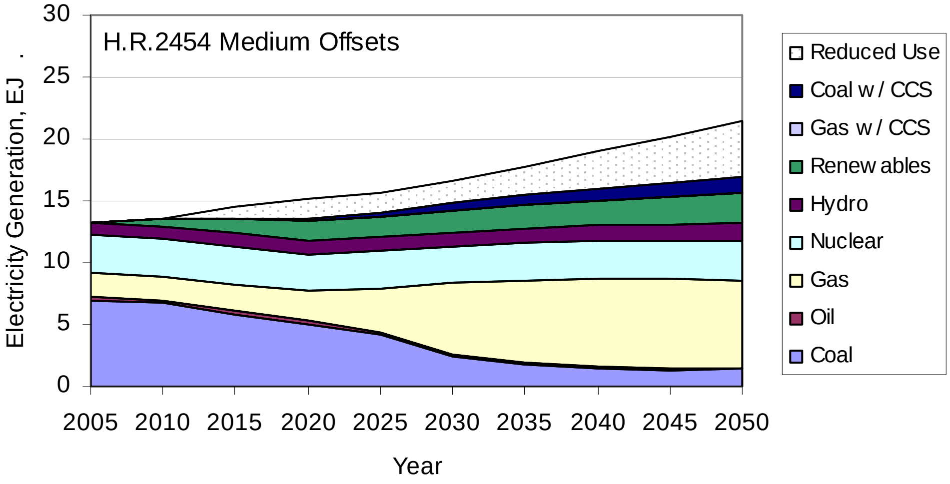

Figure C6. Electricity Generation in H.R. 2454 with Medium Offsets.

Primary Energy

Primary energy by source in the medium offsets case is presented in **Figure C7**. While the share of natural gas increases in the electricity sector substantially as a result of the policy, the overall share of natural gas is not increasing as dramatically in the economy as a whole. Thus the more important factor behind the increase in gas in electricity generation is the lower cost of NGCC which leads to diversion of gas from other sectors.

Petroleum products remain an important energy source for transportation because other alternatives (e.g., biofuels) do not increase by enough to meet increasing demand, and hence oil consumption remains roughly level, but less than in the reference case[6]. Reduced energy use, shown in Figure C7 and calculated as the difference in total primary energy between the reference (without EISA and ARRA) and policy case is a major contributor to meeting the policy target. In the reference, primary energy use increased from about 100 EJ to 140 EJ in 2050 while in this policy case total use in 2050 remains at about 100 EJ.

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[6] In a scenario (not shown here) when restrictions on imported biofuels are eliminated and domestic biofuels costs are reduced, starting in 2030 most of oil is replaced with biofuels.

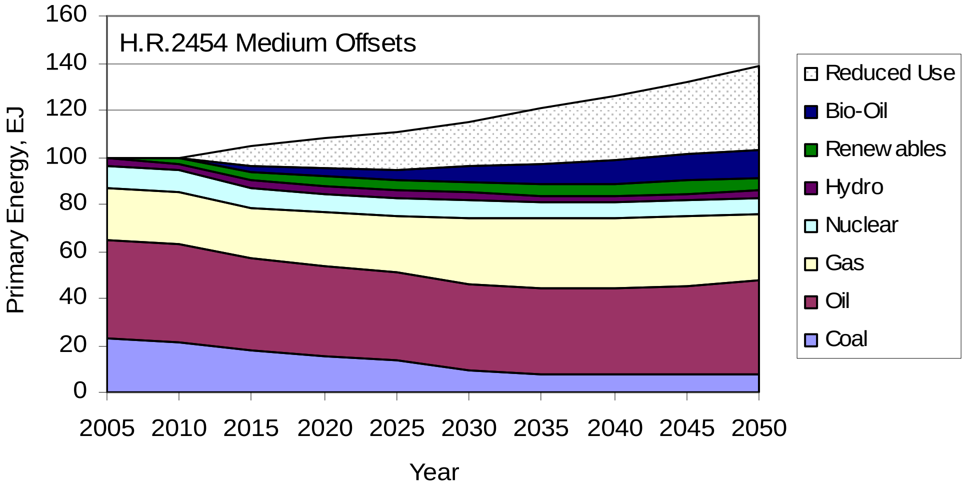

Figure C7. Primary Energy Use in H.R. 2454 with Medium Offsets.

Energy Prices

Energy prices are presented in **Figure C8**, where reference (no climate policy) prices and the impact of the CO_2 charge on producer and consumer prices for fuels are shown. The electricity price includes any CO_2 charge on fossil fuels still being used and added costs for generation to meet the CO_2 and RES requirement.

Producer prices for fuels tend to fall as demand falls, while consumer prices rise because of the embedded CO_2 charge. Coal prices inclusive of the CO_2 charge grow to about $200 per short ton by 2050 from the current prices of just over $30. The producer price falls very little because there is little rent in coal resources. Most of the adjustment occurs in the quantity produced. The reference case shows a substantial increase in natural gas prices, which grow to about $20 per thousand cubic feet (tcf) by 2050. Non-electric sector users reduce gas use in response to the CO_2 policy, while in the electric sector gas increases as it substitutes for coal, leaving little net change in total national use. As a result, the producer prices for gas in H.R. 2454 are not very different from the reference level. Consumer prices for gas are higher ($27 per tcf in 2050). Oil prices also rise in the no policy case so that by 2050 we estimate prices at $160/barrel. Inclusive of the CO_2 price, the cost of using oil rises to around $180, while reduced demand leads to a producer price that is about $20 per barrel less in 2050 than in the reference. The impacts on electricity prices are also substantial and lead to $0.20 per kWh price in the policy scenario compared to $0.13 per kWh in the reference case.

The bill distributes allowances to local gas and electricity distribution companies. The value of these allowances would likely go to rate payers. Whether this would lead to a lower electricity and natural gas rates or be distributed in a lump-sum or some other manner is unclear. In our study all allowance value is distributed in a lump-sum manner to households, consistent with the intent of the legislation to direct allowance value to consumers. If local distribution companies choose to use the allowances to lower the rates, the electricity and natural gas prices would be lower that we report here. However, failure to fully reflect carbon cost in rates would reduce the efficiency of the program and increase the overall cost of the policy.

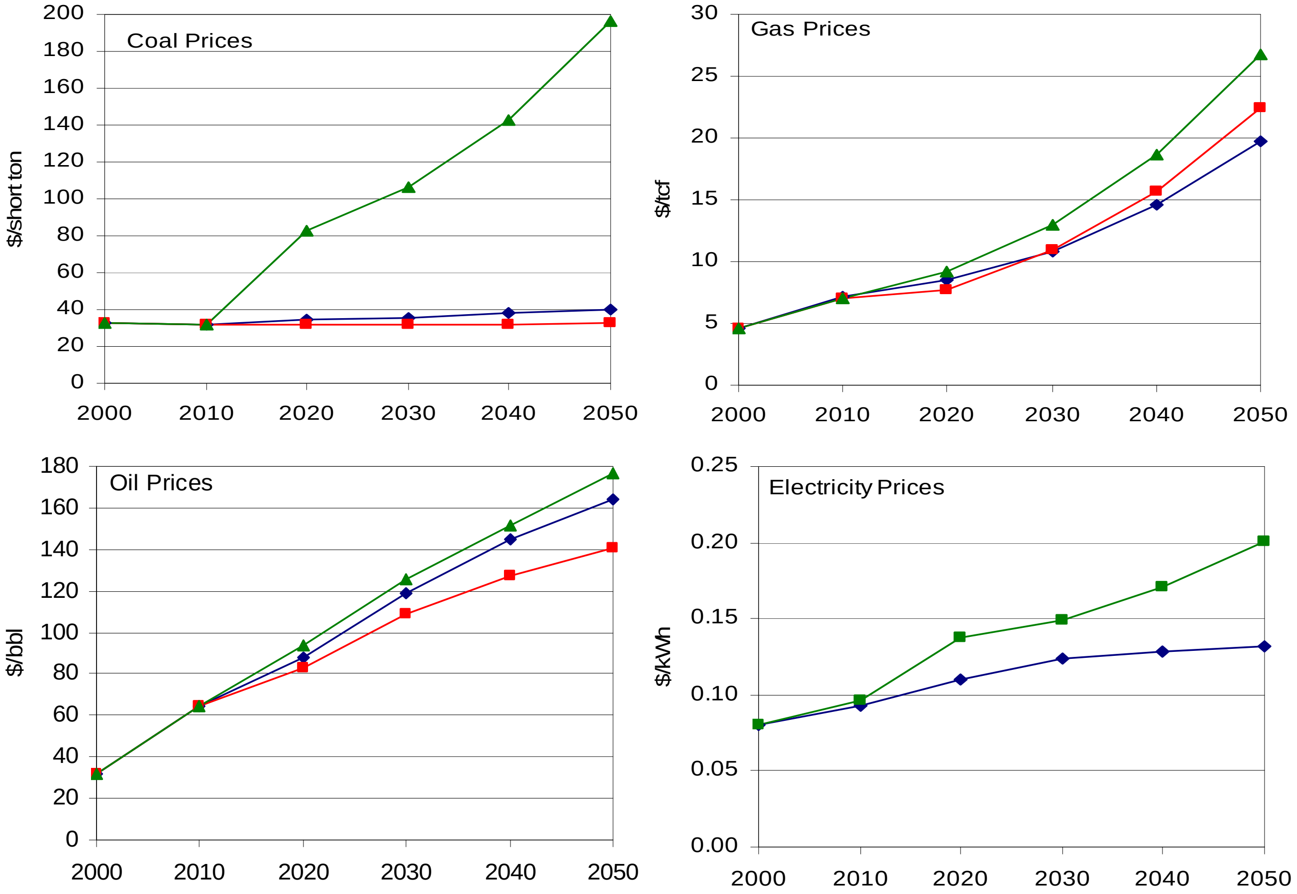

Figure C8. Energy Prices in H.R. 2454 with Medium Offsets (reference prices in blue, consumer prices in green, and producer prices in red).

C3. RESULTS WITH DIFFERENT OFFSET COSTS

The offset costs are a key uncertainty. Lacking a definition of what would qualify as an offset and the potential competition from cap-and-trade systems abroad, little can be done in the way of analysis to evaluate the cost of offset supply to the U.S. market. Here we attest the sensitivity of our results in two scenarios, one where the costs of offsets start at 15$ per tCO_2-e in 2015 and rise at 4% and another where there is no cost to offsets. Results for cost per household are presented in **Table C3**.

Assuming that offsets would come at no cost reduces the cost per household in 2020 (discounted to 2010 at 4%) to $127 with Full Offsets and around $202 with Medium Offsets (compared to $191 and $215 in the scenario presented in Table C2). The higher cost of offsets increases the burden. The corresponding 2020 numbers for the scenario with offsets starting at $15 are $223 and $241. For different assumptions about the availability and cost of offsets, the cost per household ranges from as low as $180 if all the offsets allowed are available at no cost to about $470 if a medium number of offsets are available at a higher price. As the economy meets the same target, the results for CO_2 prices and energy composition do not change with different costs of offsets[7].

Table C3. Cost per Household (in dollars, discounted to 2010 at 4%) of H.R. 2454 with Offsets at Zero Cost or Starting a $15 per ton and increasing at 4%, Annual and Discounted to 2010 at 4%.

	Annual				**Discounted to 2010**			
	Zero Cost		**Starting at $15**		**Zero Cost**		**Starting at $15**	
	Full Offsets	**Medium Offsets**	**Full Offsets**	**Medium Offsets**	**Full Offsets**	**Medium Offsets**	**Full Offsets**	**Medium Offsets**
2015	24	58	111	87	20	48	91	72
2020	187	299	330	357	127	202	223	241
2025	299	546	575	672	166	303	319	373
2030	408	962	1056	1185	186	439	482	541
2035	591	1324	1495	1650	222	497	561	619
2040	819	1726	1945	2171	253	532	600	669
2045	1093	2148	2492	2768	277	544	632	701
2050	1239	2420	2899	3245	258	504	604	676
Average	**549**	**1122**	**1283**	**1428**	**182**	**371**	**424**	**469**

C4. THE POLICY HORIZON AND OTHER UNCERTAINTIES

H.R. 2454 specifies a policy through 2050. We assume full banking through 2050 but we assume no foresight beyond 2050. Hence, the allowance bank at 2050 is zero. As we showed in the main report, depending on how economic agents look forward, or not, the near term results are affected. We should also point out, however, that if the policy is adhered to through 2050 it seems likely it will be extended beyond that horizon, which could lead to a positive bank in 2050 as agents see the extension coming. If so, that would then require greater reductions and higher costs through 2050. Here the role of future technology is critical. As shown in Gurgel *et al.* (2007) the existence of a known backstop in a forward looking model can lead to a lower near term cost. Agents looking ahead realize that in NPV terms abatement will be less expensive, and so they delay abatement. An important aspect of these scenarios is that some near-backstop technologies such as nuclear (electricity) and biofuels (transportation) have not yet entered, and so they remain an unexploited abatement option as of 2050. However, for these options to lead to lower near terms costs, there would have to be the ability to borrow, and that is restricted in H.R. 2454, requiring a substantial interest payment that would tend to offset any economic

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[7] Emissions, energy mix and carbon prices are different if the offsets cost is higher than the cost of abatement within covered sectors. Depending on relative costs, there will be a decreased (or zero) usage of offsets. In the scenario with full offsets starting at $15, the full amount of offsets is available but not used to the full degree.

advantage of borrowing. Thus, without consideration of the post-2050 period it is hard to say whether expectations of continuation of the policy would raise costs or leave them unchanged.

While it should be obvious, it is useful to emphasize that there are many uncertainties in estimates of this kind. We have already noted the importance of the supply of offsets. Technology costs themselves are uncertain as is the rate of economic and emissions growth in the baseline. Additionally, though we believe their influence on costs is small, there are other provisions of the bill that we have not been able to include in the analysis.

C5. COMPARISON TO OTHER ANALYSES OF H.R. 2454

The Congressional Budget Office (CBO, 2009), the Energy Information Administration (EIA, 2009) and the Environmental Protection Agency (EPA, 2009) also have conducted analyses of H.R. 2454. The CBO focused on estimating the average household costs and reported numbers for 2020; the EIA applied its NEMS model to the task, and EPA utilized two different economic models. We could compare many different aspects of these model results, but since they all report an average household cost and carbon price, these provide a convenient basis for comparison. While average household cost is seemingly a well defined concept, there are some subtle differences in reported estimates.

The Congressional Budget Office (CBO, 2009) reported a household cost just for 2020 and estimated it to be $175. EIA calculates an undiscounted 2020 cost per household of $142 for the basic case and a range of $32 to $382 across all cases. The EPA 2020 undiscounted cost per household is $84 in one model and $105 in the other. Our estimate is $319 per household in 2020. We and the EPA analysis report costs in 2005 dollars and the EIA original estimate is in 2007 dollars which we have converted to 2005 dollars. The CBO reported in 2010 dollars, undiscounted but reduced to reflect real GDP growth.[8] The rationale for the CBO approach apparently was that households today would compare the expense to their income today, failing to realize that incomes were projected to grow. This convention essentially discounts the 2020 estimate by the rate of growth of GDP. We reported costs, discounted to 2010 by 4%, and our estimate for 2020 in those terms is $215. EPA reports a net present value average annual household cost, as we do, which summarizes costs over the full horizon of the bill. Their estimate is $80 in one model and $111 in the other (EPA used a discount rate of 5%). The similar estimate from our EPPA model is about $400 ($250 in the scenario when the full amount of offsets is utilized).

We can also compare CO_2 prices over time in the EPA and EIA analyses. EIA simulates the policy only to 2030, but assume a positive bank of allowances is held at the end of 2030 on expectation that the policy continue and costs would rise faster than their assumed discount rate. EIA's CO_2-e prices, converted from 2007 to 2005 dollars, are $34/ton$CO_2$-e in 2020 and $69/ton$CO_2$-e in 2030 for its basic case, and across all cases they range from $21 to $99 in 2020 and $44 to $203 in 2030. In the EPA's base analysis allowance costs start at $13 in 2015 and rise

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[8] We do not have CBO's estimate of 2010 inflation and so could not convert these to 2005 dollars.

to \$70 in 2050, and they report an alternative scenario with different technology assumptions that increases the allowance price by 15%, and an alternative offset scenario that increases prices by 89% relative to their base analysis. CBO reports a carbon price of \$28 in 2020. EPPA's prices for the H.R. 2454 medium offsets case are \$26 in 2020 and \$38 in 2030.

C6. CONCLUSIONS

H.R. 2454 would be an important step toward reducing U.S. greenhouse gas emissions. We attempted to include several of the most important features of the bill including the Renewable Electricity Standard (RES) and provisions affecting CCS and coal generation. We also explain the lower cost of H.R. 2454 compared to similar reductions in the main report as a result of the Energy Independence and Security Act of 2007 and the American Recovery and Reinvestment Act of 2009. These two pieces of legislation included measures that would already reduce greenhouse gas emissions, thereby lowering our estimate of the cost of H.R. 2454, but the total costs of climate policy is similar to those described in the main body of the MIT Joint Program report 173.

An uncertainty in cost estimates of H.R. 2454 is the availability and price of offsets. In our case with medium offsets, the CO_2-e price starts at \$21 per ton in 2015 and rises to \$84 in 2050. The welfare cost rises to 1.45 percent in 2050, from about 0.1 percent in 2015. The average cost per household in this case is about \$70 in 2015, around \$300 in 2020, and rises to \$2700 in 2050. The net present value average annual cost for the period of 2012-2050, the horizon over which the policy is specified, is about \$400. For different assumptions about the availability and cost of offsets, the cost per household ranges from as low as \$180 if all the offsets allowed are available at no cost to about \$470 if a medium number of offsets are available at a higher price.

We find that nuclear, carbon capture and storage, and biofuels are less likely to make a major contribution to abatement over this period than we had estimated in previous studies of U.S. abatement costs. Nuclear and CCS costs have risen substantially as plans to actually build plants have progressed. As in the main report, we believe producing electricity with these technologies would cost 70 to 80% more than building a pulverized coal plant—the least expensive alternative if CO_2 were not a concern. Biofuel and biomass energy also appears less likely to be a good low CO_2 alternative. Recent analyses have highlighted the fact that a full life cycle accounting of greenhouse gas implications of even advanced cellulosic technologies may lead to greater emissions than fossil fuels at least in the near term. We have reflected this fact by raising substantially the cost of biofuels, and so it does not play a substantial role.

Another important consideration in estimating the cost of H.R. 2454 is that under the U.S. Supreme Court ruling in *Massachusetts vs. EPA* CO_2 was found to be a pollutant, and therefore could require EPA regulation under the Clean Air Act. H.R. 2454 would supersede such EPA regulations. At this point it is unknown what EPA would require under this ruling but such regulations could be a costly way to reduce emissions. An argument can therefore be made that H.R. 2454 should be compared against such an EPA regulatory approach, and the bill could be a more efficient way to achieve the emission reduction target.

The climate impacts of H.R. 2454 are difficult to assess as they depend on the efforts of the rest of the world, particularly, China and India. Our previous analyses show that failure to take any action, or failure to substantially involve the developing countries would lead to very substantial warming over the century (for the climate impacts of the scenarios with different participation by developed and developing countries, see Paltsev *et al.*, 2007), but engaging developing countries might require large financial transfers (Jacoby *et al.*, 2008).

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Table C4. Reference + EISA + ARRA

	2005	2010	2015	2020	2025	2030	2035	2040	2045	2050
ECONOMY WIDE INDICATORS										
Population (million)	296	310	326	341	357	374	390	406	422	439
GDP (billion 2005\$)	12614	13486	15696	17743	20056	22911	26192	29792	33810	38349
% Change GDP from Reference	0.00	-0.11	-0.31	-0.40	-0.45	-0.46	-0.44	-0.42	-0.37	-0.33
Market Consumption (billion 2005\$)	8653	9192	10736	12006	13493	15384	17564	19959	22638	25665
% Change Consumption from Reference	0.00	-0.11	-0.33	-0.44	-0.50	-0.52	-0.50	-0.48	-0.42	-0.37
Welfare (billion 2005\$)	10168	10813	12858	14524	16506	18957	21710	24690	28020	31795
% Change Welfare from Reference (EV)	0.00	-0.09	-0.25	-0.35	-0.39	-0.40	-0.39	-0.37	-0.32	-0.28
CO_2-E Price (2005\$/tCO_2-e)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
***PRICES** (index, 2005=1.00)*										
Petroleum Product (exclusive of carbon charge)	1.00	1.10	1.23	1.38	1.56	1.77	1.95	2.11	2.23	2.36
Natural Gas (exclusive of carbon charge)	1.00	1.04	1.13	1.24	1.37	1.56	1.81	2.09	2.46	2.82
Coal (exclusive of carbon charge)	1.00	1.00	1.02	1.04	1.07	1.09	1.12	1.15	1.18	1.22
Electricity (inclusive of carbon charge)	1.00	1.09	1.28	1.33	1.40	1.46	1.49	1.50	1.52	1.54
***GHG EMISSIONS** (mmt CO_2-e)*										
GHG Emissions	7109.1	6895.5	7052.8	7141.0	7266.1	7567.4	8017.9	8551.4	9288.3	10075.3
CO_2 Emissions	5992.3	5841.5	5977.4	6060.8	6160.1	6425.5	6838.4	7328.3	8012.8	8733.1
CH_4 Emissions	588.9	546.8	549.3	545.1	541.8	547.0	550.9	557.4	565.3	577.0
N_2O Emissions	388.3	353.2	339.6	324.3	311.9	305.6	306.1	308.7	317.4	333.4
Fluorinated Gases Emissions	140.6	155.0	187.4	211.7	253.4	290.3	323.6	358.2	393.9	433.0
***PRIMARY ENERGY USE** (EJ)*										
Coal	22.8	21.6	22.0	22.1	22.9	24.7	27.1	29.6	32.4	35.3
Petroleum Products	41.7	41.4	42.1	42.9	43.1	44.3	47.1	49.8	53.3	57.1
Natural Gas	22.4	22.1	23.2	23.6	23.9	24.4	24.5	24.3	23.7	23.3
Nuclear (primary energy eq)	9.3	9.1	8.8	8.6	8.3	8.1	8.0	7.9	7.8	7.7
Hydro (primary energy eq)	2.9	3.0	3.1	3.0	2.9	2.9	2.9	2.9	3.0	3.1
Renewable Elec. (primary energy eq)	0.0	2.1	3.4	3.8	4.2	4.4	4.6	4.9	5.1	5.4
Biomass Liquids	0.0	0.0	2.1	2.6	3.6	4.2	4.1	4.3	4.2	4.2
Total Primary Energy Use	99.3	99.3	104.7	106.5	108.9	112.9	118.3	123.7	129.5	136.0
Reduced Use from Reference	0.0	-0.2	0.1	1.2	1.6	2.0	2.4	2.7	2.8	2.9
***ELECTRICITY PRODUCTION** (EJ)*										
Coal w/o CCS	6.9	6.7	6.9	7.1	7.6	8.3	9.3	10.3	11.4	12.5
Oil w/o CCS	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.4	0.4
Gas w/o CCS	2.1	1.9	1.9	1.9	1.9	1.9	1.9	1.9	1.9	1.9
Nuclear	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0
Hydro	0.9	1.0	1.0	1.0	1.0	1.1	1.1	1.1	1.2	1.2
Renewables	0.0	0.7	1.1	1.3	1.5	1.6	1.7	1.9	2.0	2.1
Gas with CCS	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Coal with CCS	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Total Electricity Production	13.2	13.6	14.3	14.6	15.3	16.2	17.3	18.5	19.8	21.1

Table C5. Climate Policy including H.R. 2454 with Medium Offsets										
	2005	***2010***	***2015***	***2020***	***2025***	***2030***	***2035***	***2040***	***2045***	***2050***
ECONOMY WIDE INDICATORS										
Population (million)	296	310	326	341	357	374	390	406	422	439
GDP (billion 2005\$)	12614	13486	15648	17646	19909	22679	25861	29348	33233	37648
% Change GDP from Reference	0.00	-0.11	-0.62	-0.94	-1.17	-1.47	-1.70	-1.91	-2.07	-2.15
Market Consumption (billion 2005\$)	8653	9192	10715	11950	13396	15220	17325	19637	22224	25175
% Change Consumption from Reference	0.00	-0.11	-0.52	-0.91	-1.21	-1.58	-1.86	-2.08	-2.24	-2.27
Welfare (billion 2005\$)	10168	10812	12849	14481	16425	18806	21492	24395	27634	31334
% Change Welfare from Reference (EV)	0.00	-0.09	-0.32	-0.64	-0.89	-1.19	-1.39	-1.56	-1.70	-1.73
CO_2-E Price (2005\$/tCO_2-e)	0.00	0.00	21.31	25.92	31.54	38.37	46.68	56.80	69.10	84.07
PRICES *(index, 2005=1.00)*										
Petroleum Product (exclusive of carbon charge)	1.00	1.10	1.22	1.35	1.51	1.70	1.85	1.95	2.04	2.14
Natural Gas (exclusive of carbon charge)	1.00	1.04	1.06	1.14	1.29	1.61	1.92	2.30	2.77	3.29
Coal (exclusive of carbon charge)	1.00	1.00	1.00	0.99	1.00	0.98	0.98	0.99	0.99	1.00
Electricity (inclusive of carbon charge)	1.00	1.09	1.46	1.55	1.62	1.68	1.80	1.93	2.09	2.26
GHG EMISSIONS *(mmt CO_2-e)*										
GHG Emissions	7109.1	6897.0	5866.3	5575.1	5322.7	4994.5	4819.8	4746.8	4784.4	4843.7
CO_2 Emissions	5992.3	5842.9	5295.2	5033.0	4803.7	4502.4	4342.2	4275.9	4310.3	4360.8
CH_4 Emissions	588.9	546.8	335.2	325.7	313.6	296.1	286.8	282.1	282.2	285.3
N_2O Emissions	388.3	353.2	225.2	206.3	195.6	186.7	181.8	180.2	183.7	189.9
Fluorinated Gases Emissions	140.6	155.0	11.2	10.6	10.3	9.9	9.5	9.1	8.6	8.2
PRIMARY ENERGY USE *(EJ)*										
Coal	22.8	21.6	18.0	15.5	13.3	9.1	7.8	7.5	7.6	8.0
Petroleum Products	41.7	41.4	38.6	38.4	37.6	36.9	36.3	36.4	37.8	39.2
Natural Gas	22.4	22.1	22.0	22.4	24.3	28.3	29.5	29.8	29.4	28.2
Nuclear (primary energy eq)	9.3	9.1	8.6	8.2	7.8	7.7	7.3	7.0	6.9	7.1
Hydro (primary energy eq)	2.9	3.0	3.1	3.0	2.9	2.9	2.9	2.9	3.0	3.0
Renewable Elec. (primary energy eq)	0.0	2.1	3.4	4.4	4.3	4.4	4.4	4.6	5.1	5.4
Biomass Liquids	0.0	0.0	2.3	3.2	4.7	6.3	8.6	10.5	11.4	12.1
Total Primary Energy Use	99.3	99.3	96.0	95.2	94.8	95.8	96.8	98.8	101.1	103.1
Reduced Use from Reference	0.0	-0.2	8.7	12.5	15.7	19.2	23.8	27.5	31.2	35.9
ELECTRICITY PRODUCTION *(EJ)*										
Coal w/o CCS	6.9	6.7	5.9	5.1	4.3	2.4	1.8	1.5	1.3	1.4
Oil w/o CCS	0.3	0.3	0.2	0.2	0.2	0.1	0.1	0.1	0.1	0.1
Gas w/o CCS	2.1	1.9	2.2	2.4	3.5	5.8	6.7	7.2	7.4	7.1
Nuclear	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.2
Hydro	0.9	1.0	1.1	1.1	1.1	1.1	1.2	1.2	1.3	1.4
Renewables	0.0	0.7	1.2	1.6	1.7	1.7	1.8	2.0	2.2	2.4
Gas with CCS	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Coal with CCS	0.0	0.0	0.0	0.2	0.4	0.6	0.8	1.0	1.2	1.3
Total Electricity Production	13.2	13.6	13.5	13.6	14.1	14.8	15.5	16.0	16.5	16.9

Table C6. Climate Policy including H.R. 2454 with Full Offsets

	2005	2010	2015	2020	2025	2030	2035	2040	2045	2050
ECONOMY WIDE INDICATORS										
Population (million)	296	310	326	341	357	374	390	406	422	439
GDP (billion 2005$)	12614	13486	15679	17692	19985	22813	26045	29581	33518	37983
% Change GDP from Reference	0.00	-0.11	-0.42	-0.69	-0.80	-0.88	-1.00	-1.13	-1.23	-1.28
Market Consumption (billion 2005$)	8653	9192	10720	11965	13432	15301	17443	19789	22414	25400
% Change Consumption from Reference	0.00	-0.11	-0.47	-0.79	-0.95	-1.06	-1.19	-1.32	-1.40	-1.39
Welfare (billion 2005$)	10168	10812	12846	14486	16448	18876	21593	24526	27796	31528
% Change Welfare from Reference (EV)	0.00	-0.09	-0.35	-0.61	-0.75	-0.83	-0.93	-1.04	-1.12	-1.12
CO_2-E Price (2005\$/tCO_2-e)	0.00	0.00	7.27	8.85	10.76	13.09	15.93	19.38	23.58	28.69
***PRICES** (index, 2005=1.00)*										
Petroleum Product (exclusive of carbon charge)	1.00	1.10	1.22	1.36	1.52	1.72	1.88	1.98	2.08	2.18
Natural Gas (exclusive of carbon charge)	1.00	1.04	1.10	1.19	1.34	1.53	1.85	2.29	2.80	3.51
Coal (exclusive of carbon charge)	1.00	1.00	1.01	1.01	1.02	1.03	1.03	1.03	1.03	1.04
Electricity (inclusive of carbon charge)	1.00	1.09	1.35	1.45	1.49	1.57	1.67	1.79	1.92	2.11
***GHG EMISSIONS** (mmt CO_2-e)*										
GHG Emissions	7109.1	6897.0	6293.9	6094.1	6073.1	6167.7	6160.0	6031.6	6137.4	6093.2
CO_2 Emissions	5992.3	5842.9	5684.6	5511.2	5505.9	5607.9	5612.7	5494.8	5597.4	5550.5
CH_4 Emissions	588.9	546.8	360.8	353.2	346.7	345.7	336.6	328.2	327.2	324.0
N_2O Emissions	388.3	353.2	236.5	217.9	208.7	202.5	199.0	197.3	202.1	208.6
Fluorinated Gases Emissions	140.6	155.0	12.6	12.3	12.2	12.1	12.1	11.7	11.2	10.6
***PRIMARY ENERGY USE** (EJ)*										
Coal	22.8	21.6	20.0	17.8	17.1	17.0	15.1	13.3	13.0	12.3
Petroleum Products	41.7	41.4	41.0	41.1	41.4	42.7	44.6	45.0	48.3	49.9
Natural Gas	22.4	22.1	23.1	23.5	24.7	25.7	27.7	29.0	29.1	29.0
Nuclear (primary energy eq)	9.3	9.1	8.7	8.4	8.0	7.6	7.3	6.9	6.6	6.2
Hydro (primary energy eq)	2.9	3.0	3.1	3.0	2.9	2.8	2.8	2.8	2.8	2.8
Renewable Elec. (primary energy eq)	0.0	2.1	3.3	4.8	4.7	4.8	4.8	4.6	4.5	4.4
Biomass Liquids	0.0	0.0	2.1	3.1	3.9	4.3	4.7	7.2	7.0	8.5
Total Primary Energy Use	99.3	99.3	101.2	101.6	102.7	104.9	107.0	108.8	111.3	113.2
Reduced Use from Reference	0.0	-0.2	3.5	6.1	7.9	10.1	13.7	17.5	21.0	25.7
***ELECTRICITY PRODUCTION** (EJ)*										
Coal w/o CCS	6.9	6.7	6.4	5.8	5.7	5.8	5.0	4.3	3.8	3.2
Oil w/o CCS	0.3	0.3	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.1
Gas w/o CCS	2.1	1.9	2.1	2.2	2.8	3.3	4.5	5.7	6.2	6.8
Nuclear	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0
Hydro	0.9	1.0	1.1	1.1	1.1	1.1	1.2	1.2	1.3	1.3
Renewables	0.0	0.7	1.1	1.7	1.8	1.9	2.0	2.0	2.1	2.1
Gas with CCS	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Coal with CCS	0.0	0.0	0.0	0.0	0.1	0.2	0.4	0.6	1.0	1.4
Total Electricity Production	13.2	13.6	14.0	14.1	14.8	15.5	16.3	17.0	17.6	18.0

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