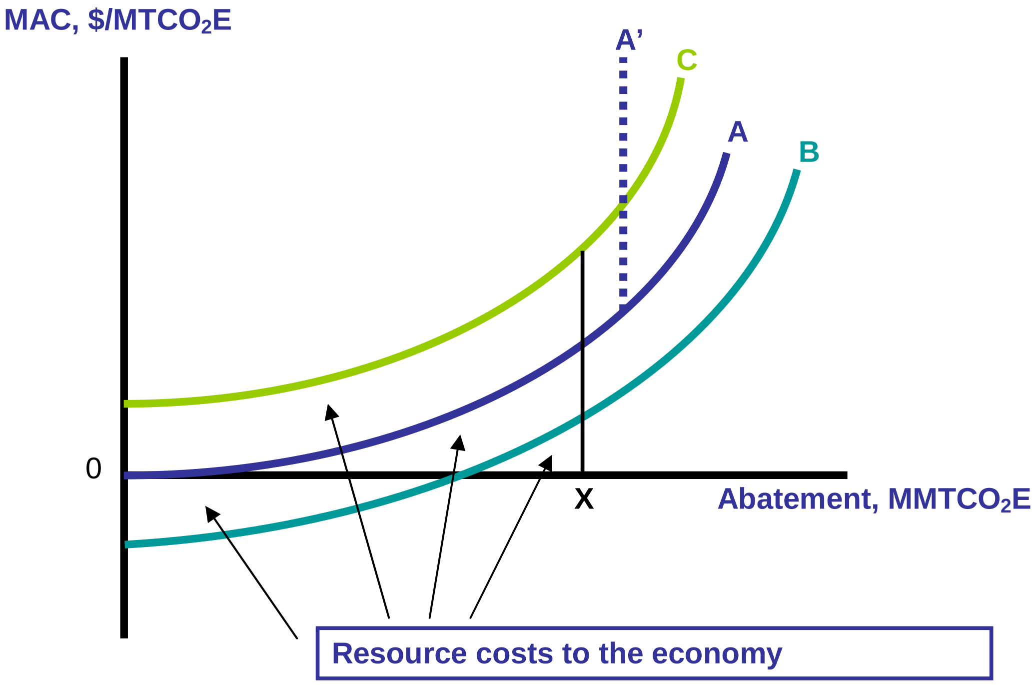
Chapter 4. Greenhouse gas emissions reduction and marginal abatement costs

4.1 Introduction

Central to the analysis of climate change policy is the concept of marginal abatement cost (MAC). This cost measures the sacrifice to the economy of diverting additional scarce resources to the elimination of an additional ton of emissions. Both theory and practice confirm that the marginal cost of abatement increases with the level of abatement. The relationship between costs and quantities for a given greenhouse gas (GHG) or a particular abatement source is summarized by a marginal abatement cost schedule.

Figure 4.1 illustrates common properties of the MAC schedules found in current mitigation assessments. Curve A is the typical representation. For zero abatement, the marginal cost of attainment also is zero. Significant abatement is available at comparatively low per unit cost. The MAC schedule rises but is initially relatively flat. However, as larger amounts of abatement are required or envisioned, the MAC curve becomes more steeply sloped.

Figure 4.1: Marginal Abatement Cost Schedules



Incremental emissions reductions become increasingly expensive in terms of their claims on the available resources. The vertical (dotted) line drawn from Curve A portrays a possible physical or regulatory limit on the availability of additional emissions reductions from a particular source; no additional abatement is to be had at any price.

Curve B shows some positive abatement occurring at a negative cost. This is an extreme representation of a “no regrets” region. It is indicative of abatement opportunities that currently are “profitable” in the sense of releasing resources to more productive uses while simultaneously achieving emissions reductions. These opportunities arise most frequently for informational reasons; buyers and-or sellers are simply unaware of the realizable net benefits from their actions. Eventually, Curve B exhibits more traditional behavior but not before the “no regrets” abatement takes place. Curve C depicts a MAC threshold. In this case, abatement from this source is not economically justified until the opportunity cost of abatement reaches some minimum. Only above this minimum is this source a competitive abatement alternative.

A principal benefit from a MAC schedule is that the cumulative area for an abatement level of a given quantity represents the opportunity cost to the economy of achieving that abatement. Equivalently, the area above less any below a marginal cost of zero measures the economic resources that must be diverted from other productive uses to attain the given emissions reduction. It is this feature that gives the MAC curve value both as an input to and an output from a particular methodology.

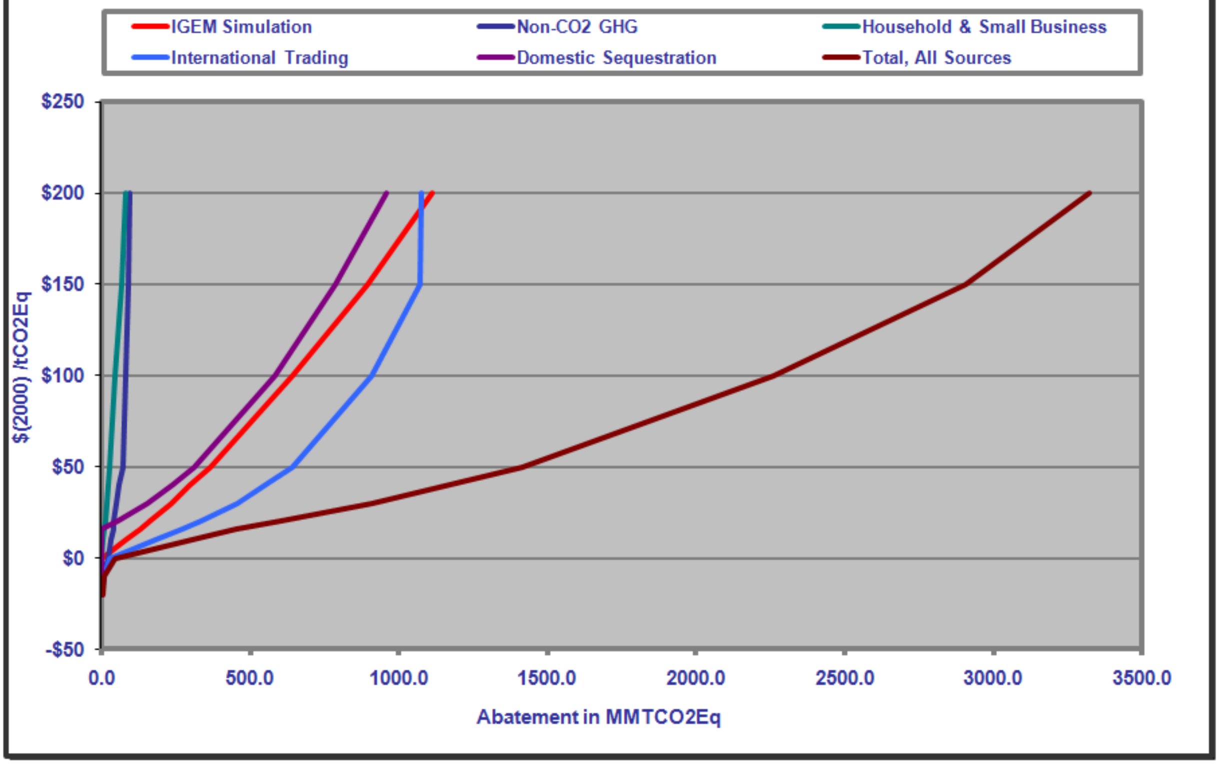
4.2 Achieving emissions reductions in IGEM

4.2.1 The climate change policy analysis of Chapter 5

If emissions intensities of output are unresponsive to market or policy-driven changes and all market and technological possibilities are fully represented within a model, there is no need for additional information. Marginal abatement cost schedules derived from model simulations will accurately characterize the economic costs associated with the substitutions and the market and technological changes that follow from implementation of a particular abatement strategy. To the extent that abatement possibilities above and beyond those included in a given model and their associated costs can be identified, this information can be incorporated into an analysis through MAC schedules. In the analysis of Chapter 5, we employ the following process to endogenize abatement opportunities external to IGEM:

1. For each GHG and each economic activity, mitigation possibilities are identified that are adequately represented in IGEM's response to a given policy initiative. These are considered to be internal to IGEM, as are the economic costs associated with their implementation. All other possibilities are external to IGEM and require external abatement cost schedules. Currently, foreseeable abatement opportunities related to carbon emissions are viewed as internal; that is, marginal abatement cost schedules derived from IGEM simulations accurately portray all the economic costs of their intermediate-term mitigation. The abatement opportunities related to residential and commercial mitigation strategies, non-CO_2 greenhouse gases, international greenhouse gas permit trading, and domestic sequestration are external to IGEM. The internal and external MAC schedules for the final model simulation are shown below in Figure 4.2.

Figure 4.2: Marginal Abatement Cost Schedules



2. First, IGEM is simulated to determine its response to the particular mitigation policy. This generates an initial marginal abatement cost (MAC) schedule that serves as the starting point of an iterative process. Typically, this step initial involves imposing an emissions constraint and observing the corresponding path of permit prices or introducing a path of permit prices and observing the corresponding abatement.
3. The marginal abatement cost schedule from step two (or step six below) is summed horizontally with those cost schedules external to IGEM to create an aggregate marginal abatement cost schedule.
4. The targeted or required level of abatement then calculated from this schedule and the allocation of abatement to each of the external and internal categories is determined. Since some abatement is provided from sources external to IGEM, the constraint in IGEM is relaxed or, equivalently, permit prices are reduced.
5. After determining the abatement benefits from external sources, it is also necessary to calculate and introduce their economic costs. These are determined by integrating the areas underneath the external MAC schedules in accordance with the amounts of abatement and introducing these costs into IGEM. International permit trading is treated as a factor payment and is substituted for a portion of the current account deficit that arises from international trade. The costs associated with domestic sequestration are assumed to be borne entirely by IGEM's agriculture, forestry and fisheries sector. All other costs are allocated to emissions-generating activities in proportion to their contributions to baseline GHG emissions. In addition, all costs other than those associated with international permit trading are introduced as Hicks-neutral changes in productivity.
6. IGEM is then simulated again with less internal abatement or lower permit prices and more external abatement, as represented in the external abatement cost schedules. This yields a new schedule of marginal abatement costs from IGEM.
7. Steps three through six are repeated until IGEM's internal marginal abatement cost schedule no longer changes from one iteration to another; this requires anywhere from one to six iterations for the abatement possibilities considered in Chapter 5.

The procedure outlined above is conceptually identical to that implemented in the Emissions Prediction and Policy Analysis (EPPA) Model of MIT's Joint Program on the Science and Policy of Climate Change (Hyman, et al., 2003). The iterative process sacrifices the computational efficiency of the MIT approach to gain fuller use of the information represented in the external MAC schedules, specifically, areas of "no regrets," the precise curvature of the schedules, and the points at which they become inelastic. Both approaches endogenize market and technological abatement opportunities and their costs that are outside the boundaries of the model's substitution possibilities.

4.2.2 The new approach to abatement in IGEM

Among the many features of current climate change initiatives are the allowance of permit banking and borrowing, intricate rules governing the use of offsets, and an increasingly rich technological array of domestic and international abatement opportunities. Permit banking is the use of permits for earlier periods in qualifying for abatement in later periods, while borrowing is the reverse. Examples of trading rules are time-varying constraints related to the use of domestic and international offsets and the discounting of future credits for these offsets. There are currently no markets for new technologies, so that the substitution possibilities lie outside the data sample used in setting parameters for IGEM.

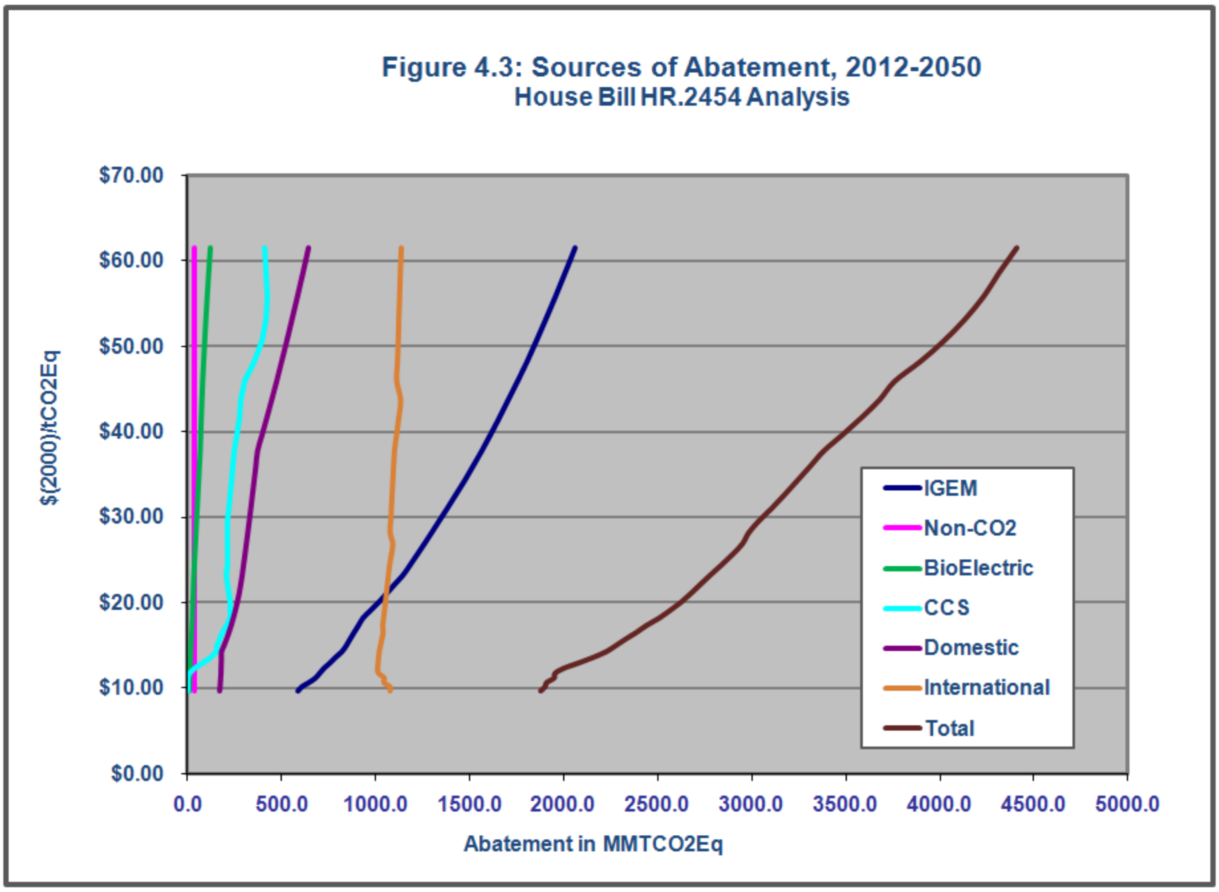
Banking and borrowing, complex trading rules, and external technological offsets pose problems for models of climate policy. Banking and borrowing involve the addition of inter-temporal trade-offs. Sophisticated trading rules also pose a problem in that they often vary over the life of the policy, are triggered endogenously, and require re-programming for each new policy initiative. Finally, external abatement opportunities pose a problem in that their integration into our model system can be achieved only through the iterative scheme described in Section 4.2.1.

A reduced-form approach solves these problems, while minimizing the time required to complete a given policy scenario. This approach integrates simulated model outcomes with external marginal abatement cost schedules related to new technologies and abatement opportunities. It also allows a speedy determination of optimal allowance prices with or without banking or borrowing and under complex trading rules and subsidy schemes. The approach solves for the endogenous time-path of allowance prices, the optimal abatement from IGEM and other sources, and the cumulative costs for these sources. The abatement amounts from external sources serve to relax the constraint on the required abatement from IGEM.

Permit prices and the costs associated with external abatement are represented as Hicks-neutral productivity changes. These changes are introduced into IGEM to obtain the detailed results. This algorithm can be re-programmed to conform to the unique design of each new policy initiative. The reduced-form approach has proven to be extremely useful in the conduct of policy analyses. It has the additional benefit of allowing a broader range of IGEM policy scenarios for which the time path of allowance prices and the details of abatement are the only analytical objectives.

To illustrate the results of the reduced-form approach, Figure 4.3 compares shows the mix of abatement options for the American Clean Energy and Security Act of 2009 (House Bill HR.2454). Figure 4.2 shows simulation inputs whereas Figure 4.3 shows simulation outputs. In each case, the MACs external to IGEM are themselves aggregations of more detailed MACs. In Figure 4.3, the non-CO_2 MACs include N_2O from acidic and nitric acid production, SF_6 from electric power systems, magnesium production and semiconductor manufacturing, PFC from semiconductor and aluminum production and HFC-23 from HCFC-22 production.

While the domestic offset MACs cover a broad range of abatement opportunities in agriculture and forestry; they exclude CH_4 from the coal, oil and gas sectors and from landfills that are options under some policies. The international MACs are aggregates of the net allowances available for purchase by the U.S. from all trading nations and a wide variety of CO_2 and non-CO_2 abatement options in agriculture and manufacturing. Finally, the reduced-form approach allows for the explicit consideration of new technologies and technology vintages. In the HR.2454 analysis, there are MACs representing the potential build rates for coal-based carbon capture-and-storage (CCS) and current and emerging technologies for electricity from biofuels (BioElectric).



4.3 Marginal abatement costs in IGEM

The IGEM inputs to the algorithm of Section 4.2.2 are obtained by simulating the effects of an allowance price that is constant relative to the price of GDP. The permits associated with this price are assumed to be government-auctioned with revenue and deficit neutrality achieved through lump-sum redistributions. With multiple simulations conducted over a wide range of permit prices, we measure IGEM's abatement as functions of price and time. The IGEM MACs generated in this fashion are unique to each base case and not to each policy scenario. This has a significant advantage in that IGEM's MACs hold for any policy initiative that is to be compared to a particular base case.

It is important to note that the MACs generated from IGEM are *ex post* general equilibrium outcomes rather the more traditional *ex ante* partial equilibrium cost schedules. Whereas the latter can be used to measure the direct costs to the economy (i.e., their underlying areas) of a given level of abatement, the costs from IGEM MACs are net of the cumulative substitution, restructuring and productivity effects associated with achieving that level of abatement. While these internal and external MACs can be combined to solve for an integrated time path of allowance prices, their respective measures of economic sacrifice are neither directly comparable nor meaningfully additive.

The impetus for creating a new base case is provided by new releases of EPA's *Inventory of U.S. Greenhouse Gas Emissions and Sinks (Inventory)* and EIA's *Annual Energy Outlook (AEO)* and from changes in the emissions coverage from one policy initiative to another. The EPA's *Inventory* alters the starting points and trends in IGEM's emissions coefficients while the EIA's *AEO* projections drive the trends in energy demand and the overall economy to which IGEM must be calibrated.

Examining the marginal abatement cost schedules from IGEM for a range of recent base cases and policy initiatives provides insights into the changing nature of these schedules. As important, this examination reveals behavioral characteristics that are unique to IGEM and that have real-world implications for policy designs and outcomes. Table 4.1 summarizes the relevant ingredients for four distinct base case-policy initiative combinations. The base cases are those for the Climate Stewardship and Innovation Act of 2007 (S.280), the American Climate Security Act of 2007 (S.2191), the Lieberman-Warner Climate Security Act of 2008 (S.3036), and the American Clean Energy and Security Act of 2009 (HR.2454).

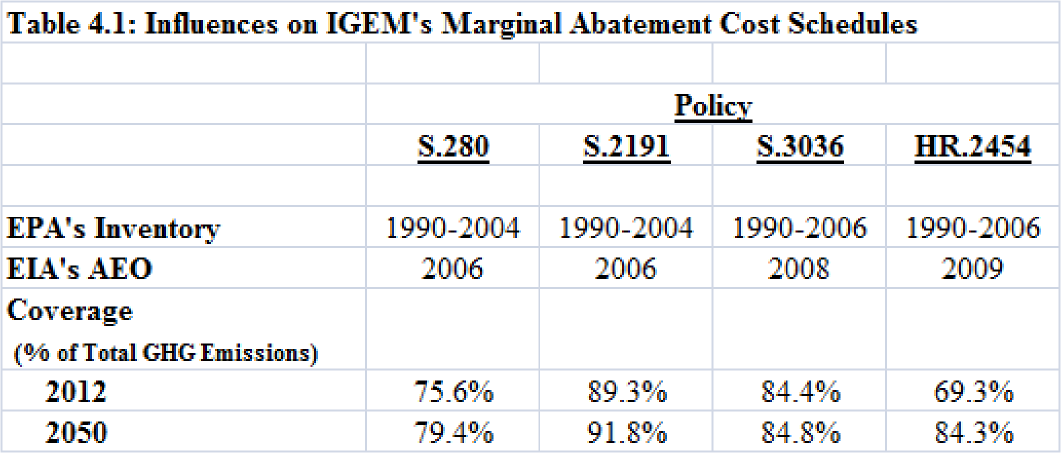
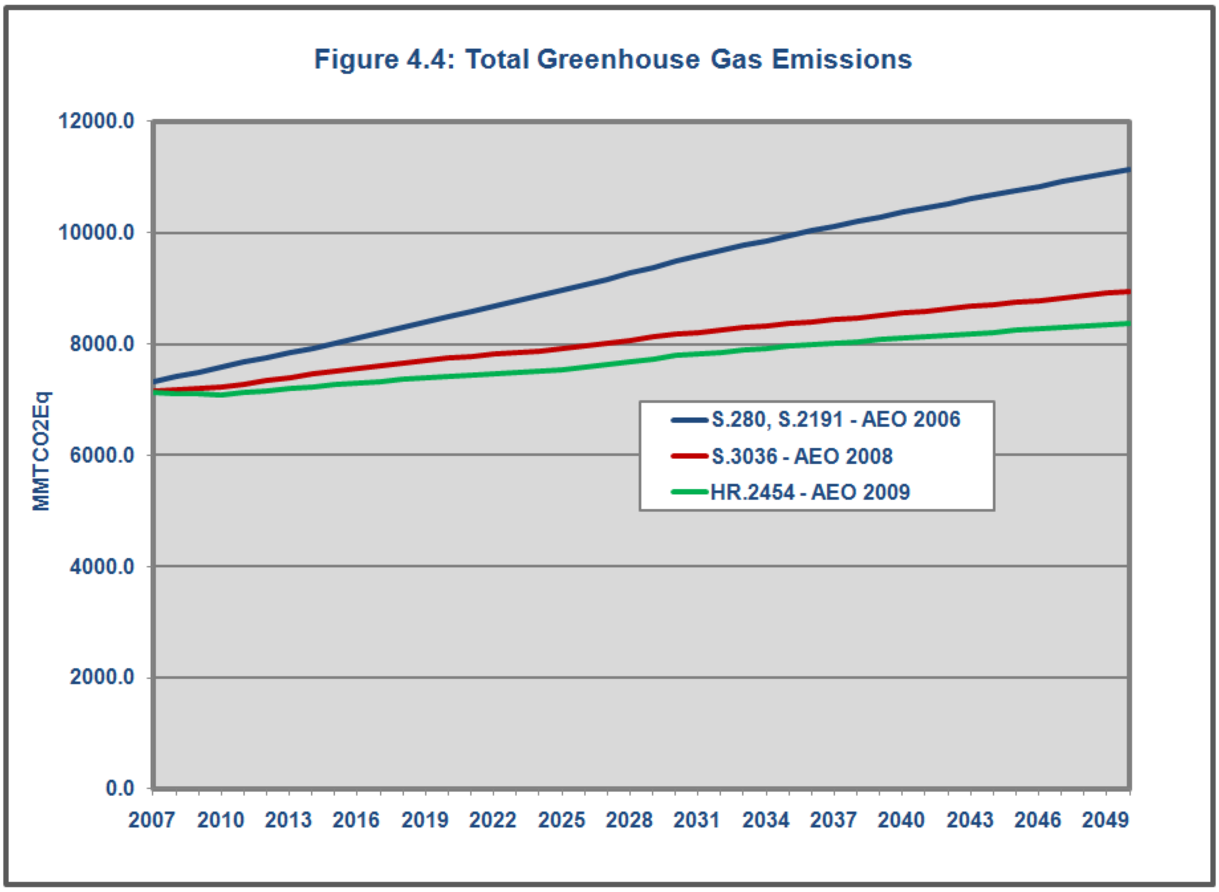


Table 4.1: Influences on IGEM's Marginal Abatement Cost Schedules

	Policy			
	S.280	**S.2191**	**S.3036**	**HR.2454**
EPA's Inventory	1990-2004	1990-2004	1990-2006	1990-2006
EIA's AEO	2006	2006	2008	2009
Coverage (% of Total GHG Emissions)				
2012	75.6%	89.3%	84.4%	69.3%
2050	79.4%	91.8%	84.8%	84.3%

The base cases for S.280 and S.2191 rely on the same EPA Inventory (1990-2004) and EIA AEO (2006). The only differences lie in emissions-generating activities that are considered covered by policy and those that are not. Coverage in S.280 is less than coverage in S.2191, so that the emissions reductions expected from a given allowance price should be less as greater substitutions toward uncovered activities occur. The base cases for S.3036 and HR.2454 differ in additional respects. They share the updated Inventory (1990-2006) but not the AEO assumptions. The base case for S.3036 is calibrated to AEO 2008 and that for HR.2454 to AEO 2009. The eventual coverage for S.3036 and HR.2454 is approximately the same but the latter is more generous in the very early years.

For the levels of abatement achievable from a given allowance price the baseline emissions levels are critical. These depend on the alignments to the AEO projections. Figure 4.4 shows the time paths of total greenhouse gas emissions under the assumptions of Table 4.1. The shift from one EPA Inventory to another results in slightly lower expected emissions in 2007 and somewhat slower emissions growth. More dramatic are the effects of calibrating to AEO 2008 from AEO 2006 and to AEO 2009 from AEO 2008. These baseline reductions are driven primarily by the slower economic growth and the price- and policy-induced changes in energy demand in the successive AEO forecasts. The receding baselines have extremely important implications for climate change initiatives in that emissions targets are achieved more easily with lower economic costs when the required abatement is lessened.



Figures 4.5 through 4.8 show selected IGEM MACs for the four initiatives of Table 4.1. Figure 4.9 shows the cost schedules for 2050, the terminal policy year in each case. Abatement possibilities across these figures are shown on a common scale to make the following conclusions more obvious. First, the extent of policy coverage matters. For a given price, the abatement secured is greater when the policy coverage is greater. This is evidenced by the fact that the S.2191 family of MACs is everywhere greater than their S.280 counterparts for identical base cases (Figure 4.6 versus 4.5 and Figure 4.9). It also is evidenced by the wider spread between the 2010 and 2020 MACs from the HR.2454 analysis (Figure 4.8 versus 4.5, 4.6 and 4.7). Here, policy coverage is initially very low but rises within four years to its higher terminal range.

The abatement achievable from a given allowance price diminishes as baseline emissions diminish, as shown in Figure 4.9. IGEM is unique in that it is constructed from econometrically estimated models of producer and purchaser behavior. In examining the progression from S.280

and S.2191 (Figures 4.5 and 4.6) to S.3036 (Figure 4.7) and on to HR.2454 (Figure 4.8), it is clear that IGEM responds to price less elastically as energy use is calibrated to lower and lower levels. The families of cost schedules shift leftward with lower abatement and narrowing gaps at each price in the moves from AEO 2006 to AEO 2008 and from AEO 2008 to AEO 2009 (again, Figure 4.9). Indeed, the inter-decade gaps shrink so much in transition that the MACs in the HR.2454 analysis for 2040 and 2050 are virtually identical.

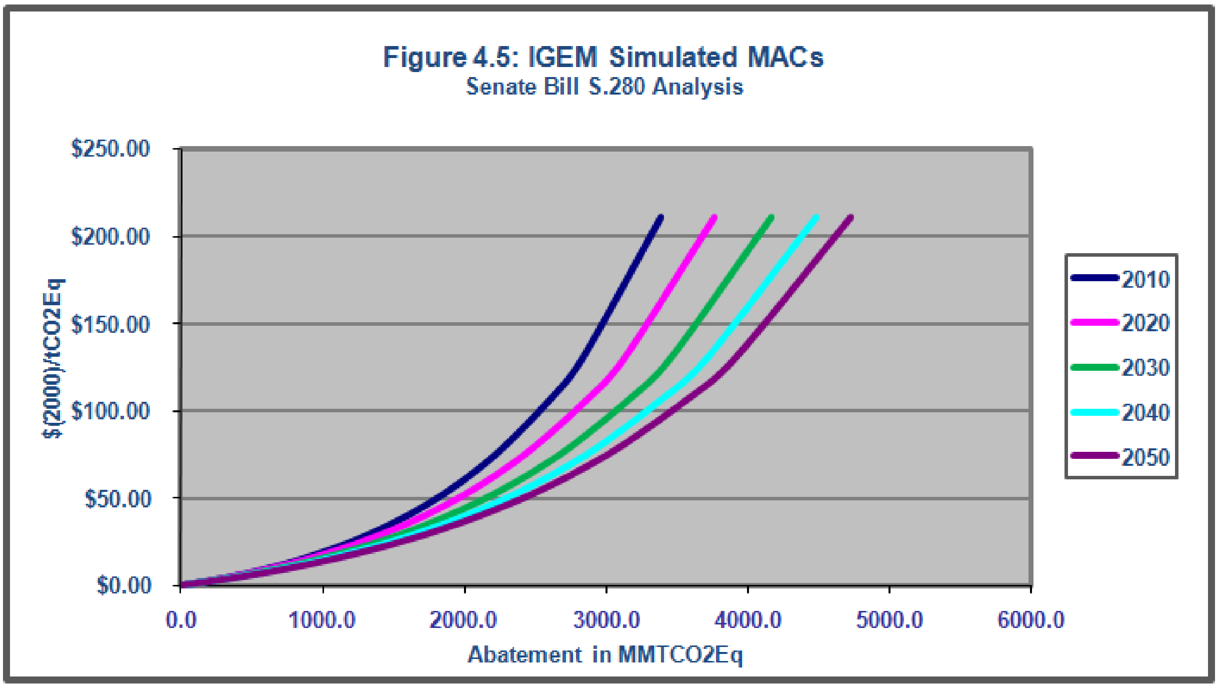


Figure 4.5: IGEM Simulated MACs
Senate Bill S.280 Analysis

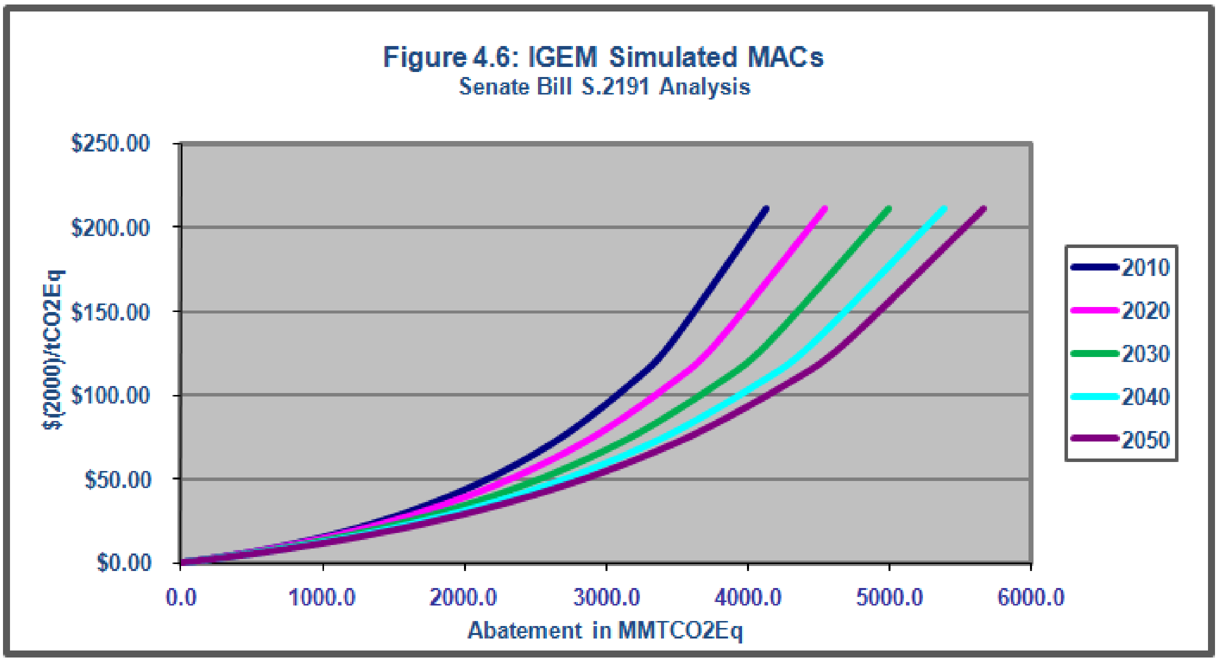


Figure 4.6: IGEM Simulated MACs
Senate Bill S.2191 Analysis

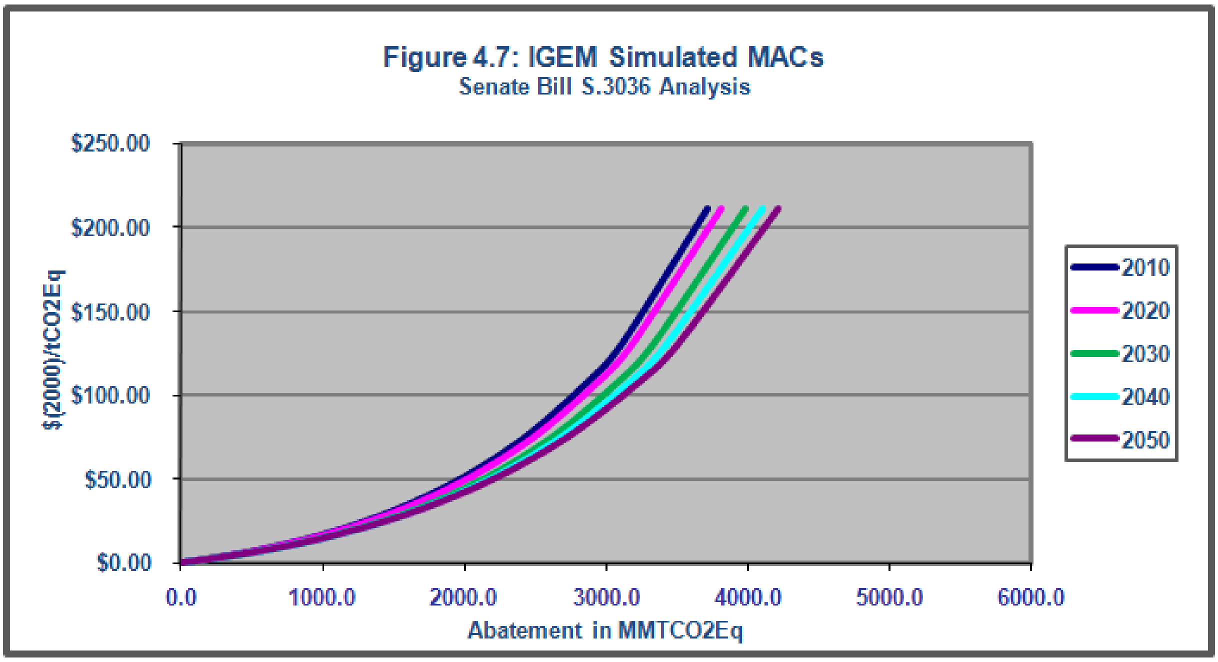


Figure 4.7: IGEM Simulated MACs
Senate Bill S.3036 Analysis

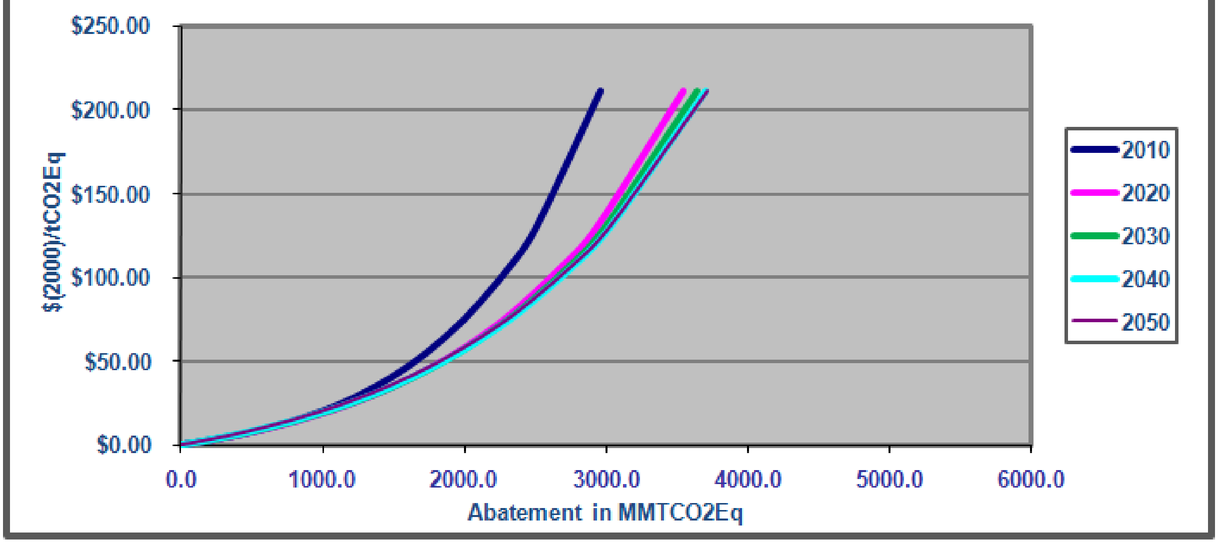


Figure 4.8: IGEM Simulated MACs
House Bill HR.2454 Analysis

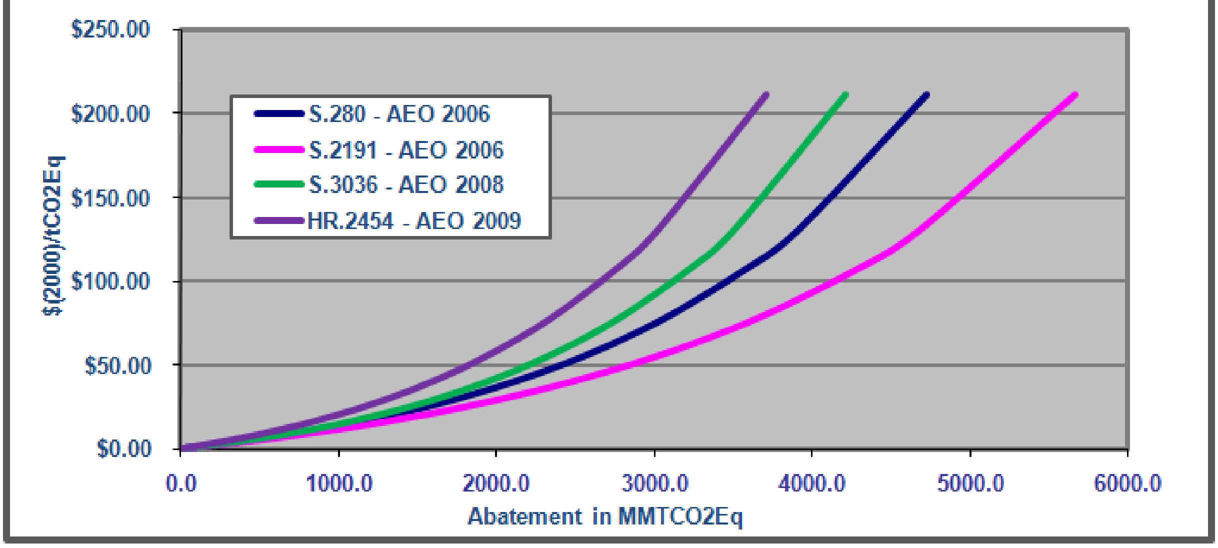


Figure 4.9: IGEM Simulated MACs, 2050