Insights from Modeling Analyses of the Lieberman-Warner Climate Security Act (S. 2191)

Economic models establish a logical and consistent framework for considering the implications of different policies and have been extensively used to evaluate the consequences of different policy choices for addressing global climate change. Yet model results depend upon the assumptions, definitions, and structure of the model, as well as the data that are used for input into the model. For example, the flexibility of the economy in responding to change or the flexibility of the policy being modeled can both have significant implications for any assessment of the costs of a particular policy. Furthermore, there is enormous uncertainty in attempting to predict outcomes that occur in 50 years, both in terms of technologies that might be available and the costs of using those technologies. In the past, prior estimates of the costs of regulation were often many times more than the actual observed costs once a program is initiated.[1]

Models only provide a simplified view of our economy. In the case of the Lieberman-Warner Climate Security Act (S. 2191), models can capture many of the key policy elements (e.g., the impacts of targets, timing, and offsets) but cannot incorporate all of them. For example, the impact of the Carbon Market Efficiency Board, which can contain costs by adjusting the quantity of borrowed allowances and the trigger price that spurs this borrowing, is not included in any of the models. Furthermore many of the provisions designed to encourage higher deployment rates of energy efficient products and programs (e.g., allocation to states based on implementation of energy efficient building codes) are not specifically included. This does not mean that the modeling results are not useful but rather illustrates that model results represent an approximation of the bill and not the bill as a whole.

Few, if any, of the experts who work closely with models believe that specific model outputs regarding future energy costs or GDP impacts will actually materialize under any given policy. But the results are interesting for the broader insights they reveal. In the effort to craft and implement cost-effective, well-designed strategies for addressing the problem of climate change, it is critical that all who seek to understand and use modeling results share a realistic view of their proper role in the climate policy debate. (For a full discussion see the Pew Center's companion paper, "Insights Not Numbers."[2])

This *In Brief* examines some of the models that have been used to assess the economic impacts of the Lieberman-Warner Climate Security Act (as reported out of Committee in December 2007) and puts them in context for consumers of this modeling information. It is important to note that some of these modeling efforts were undertaken in advance of the new Energy Independence and Security Act of 2007 and the new forecast of baseline or "business as usual" (BAU) emissions through 2030. Because the more recent forecasts reflect lower baseline emissions than previously anticipated, the costs of the climate proposals based on earlier higher projections of baseline emissions are likely to be overestimated.

The underlying models have important structural and methodological differences that—along with key assumptions—impact their results. In addition, no model of S. 2191 is an integrated assessment that includes both costs and benefits of taking action (such as avoided impacts of sea-level rise and ancillary benefits of improved air quality or energy security). As such, the economic models profiled in this review present only one side of the story—the costs of policy, not the benefits of that policy.

The following section summarizes key policy insights that can be gleaned from these analyses of potential program costs of S. 2191. The economic modeling studies reviewed for this analysis are then briefly discussed, including key assumptions and results.

Modeling Insights

- **The availability of advanced, low-carbon technologies is crucial to minimizing the costs of achieving GHG reductions.** Models that constrain the use of potential technologies dramatically increase the costs of reducing emissions. For example, the ACCF/NAM model constrains the future deployment of nuclear energy so that less electricity is delivered from nuclear facilities in the High Cost Scenario than is projected under business as usual forecasts (developed by DOE's Energy Information Administration[3]). Similarly, the amount of electricity delivered by wind power is also constrained to an annual deployment level lower than was actually delivered in 2007. The ACCF/NAM model restricts additional wind capacity to 5 GW/year for the Low Cost Scenario and 3 GW/year in the High Cost Scenario. According to the American Wind Energy Association, there was an additional 5.244 GW of wind capacity added in 2007.[4] The result of these restrictions is that the costs from this model fall far outside the range of other modeling efforts. The central policy insight is that we need to take steps to ensure that advanced low carbon technologies are deployed (and not just developed). If by 2030 we do not have greater deployment of these and other low carbon technologies, the costs of meeting the climate policy goals will be quite high.
- **A combination of a price signal and complementary policies to promote end use efficiency can reduce the program costs by decreasing energy demand.** The models that attempt to simulate the bill's energy efficiency provisions (for example, EIA and CATF) anticipate lower allowance prices and consumer energy bills.
- **Flexibility in the timing of GHG reductions through approaches such as banking and borrowing keeps costs down over time.** Those modeling efforts that do not incorporate the banking and borrowing provisions provided for in S. 2191 (such as ACCF/NAM and CRA's no-banking analysis) result in higher overall impacts on GDP. Modeling efforts that do incorporate the banking provisions often show higher near-term allowance prices because firms hold additional allowances in anticipation of higher future prices; however, this ability to bank allowances reduces overall program costs in the longer term.
- **The more offsets included in a program, the lower the costs.** All of the models consistently demonstrate that one of the most important drivers of carbon allowance prices—in some modeling exercises, *the* most important driver—is the availability of offsets. The model scenarios that limit offsets below the total of 30% (international credits plus domestic offsets) provided for in S. 2191 show significantly higher costs. EPA's sensitivity analysis using IGEM found that if international credits were not allowed and domestic offsets were held at 15%, allowance prices increased by 34%. Further, when international credits and domestic offsets were not allowed at all, allowance prices in the model increased by 93% above estimates that included the full 30% offsets, as in the bill.
- **Some sectors will provide greater opportunities for reductions than others in the short term.** Across the models, the largest share of near-term emissions reductions come from the electric power sector (through efficiency improvements by industry and consumers and through fuel switching). Across most models, fuel switching in the near to medium term creates winners (natural gas and renewable generation) and losers (coal); however, in the longer term, the loss to the coal

sector is reduced if carbon capture and storage technology is available. As the cost of allowances rises over time, emissions reductions in the transportation sector are also anticipated (EPA's ADAGE).

- **In the medium to long term, CO_2 capture and storage (CCS) plays a potentially large role assuming adequate provisions are made for its use.** Analyses that assume a rapid deployment of CCS and/or improved capital costs over time (such as MIT's EPPA, EPA's ADAGE, and CATF's NEMS) typically result in more coal use over the longer term and a lower economic impact to the electric power generating sector and the broader economy. Those that restrict this deployment (such as EIA's High Cost and Limited Alternatives Cases[5] and ACCF/NAM) result in more fuel switching to natural gas, larger impacts on coal production and ultimately higher overall impacts on the economy.

- **Climate policies such as S. 2191 will still allow the economy to grow robustly.** It is important to note that projections of changes in Gross Domestic Product (GDP) across all of the models reflect a reduction in future expected growth—never an absolute reduction (see Table 1). For 2030, reductions from BAU forecasts of GDP vary across models from 0.3% to 2.7% but the ACCF/NAM analysis (which is not fully representative of the key policy elements of S. 2191) is a clear outlier. In all of these cases, including the most pessimistic, the economy is projected to grow significantly. Similarly, in 2050, estimates of reductions in future expected growth from BAU generally vary from 0.75% to 2.7%.

  The BAU or reference cases in the various models show that overall U.S. GDP doubles by 2030 and more than triples by 2050. Thus, decreases from future GDP are quite small compared to the overall economic growth over the time period considered. For example, in EIA's analysis, GDP grows 183% from 2005 to 2030 in the S. 2191 core (policy) scenario compared to 184% in the reference case. For context, this means that the economy would be less than 2 months behind BAU levels in 2030 with GHG caps.

- **Consideration of the range of uncertainty in the model is important for putting the potential cost impacts of a policy in perspective.** Uncertainty about the types of technology that will be available in 20, 30, or even 50 years is significant. Who would have predicted back in the 1950s the computing or communications capabilities we have today? Further, predicting how our economy will grow is also rife with uncertainty. In the six modeling exercises that we examined, the difference between reference case GDP (that is, future GDP in the absence of climate policy) in 2030 was almost 3 trillion dollars, representing a difference of more than 10 percent. Predicted impacts (for example, the 0.44% reduction in 2030 GDP from BAU suggested by the MIT model) in light of this large uncertainty seems insignificant.

Table 1

Summary of Key Modeling Results

Modeling Exercise	2020		2030		2050	
	Allowance Price (2005$)	GDP Impact (% change from BAU)	Allowance Price (2005$)	GDP Impact (% change from BAU)	Allowance Price (2005$)	GDP Impact (% change from BAU)
EIA–Core Scenario	$29	-0.27%	$59	-0.29%	—	—
CATF	$22	-0.5%	$48	-0.69%	—	—
ACCF/NAM–Low Cost	$52	-0.8%	$216	-2.60%	—	—
ACCF/NAM–High Cost	$61	-1.1%	$257	-2.70%	—	—
MIT–Offsets + CCS	$58	-0.8%	$86	-0.38%	$189	-0.75%
EPA (ADAGE)–Scenario 2	$37	-0.7%	$61	-0.90%	$159	-2.37%
EPA (ADAGE)–Scenario 10	$28	-0.5%	$46	-0.59%	$121	-1.76%
CRA–Scenario with Banking	$58	-1.5%	$84	-1.40%	$185	-2.70%

Energy Information Administration (EIA)

Modeling Background

The EIA analysis of S. 2191 uses the National Energy Modeling System (NEMS), which models U.S. energy markets out to 2030. NEMS explicitly represents the decisions involved in the production, conversion, and consumption of energy products. It consists of separate modules that represent various aspects of energy markets and macroeconomic activity: four supply sectors (oil and gas, natural gas transmission and distribution, coal, and renewable fuels); two conversion processes (electricity and petroleum refineries); four modules for end-use demand (residential, commercial, transportation, and industrial); one to simulate energy/economy interactions (macroeconomic activity); one module to simulate world oil markets (international energy activity); and an integrating module that provides the mechanism to achieve a general market equilibrium among all the other modules.[6] The analysis applies the version of NEMS used for the 2008 Annual Energy Outlook projections, which includes the impact of the Energy Independence and Security Act of 2007, as well as revised expectations about economic growth. EIA's reference case (called "BAU" here) includes current laws and legislation in addition to energy market changes over time, including compliance with future Corporate Average Fuel Economy (CAFE) and efficiency standards, and the continued penetration of more efficient energy technologies to meet new demand for appliances, vehicles, buildings, and other facilities, together with advances in energy production facilities.

The EIA analysis attempts to capture many provisions of S. 2191, including the following:[7]

- **Emissions from fossil fuel generation and combustion are covered, including coal-fired electrical and industrial boilers, petroleum use in transportation (upstream), and residential, commercial and industrial natural gas and petroleum use (upstream);**
- **Domestic and international offsets can each be used to meet up to 15% of the compliance obligation;**
- **There are no limits on the number of allowances that can be banked for future years.** For covered entities to be able to meet more stringent caps post-2030, EIA assumes that the bank will have a balance of 5 billion metric tons at the end of 2030. Although the bill has a borrowing provision, EIA assumes that covered entities comply without borrowing;
- **Both natural gas and coal would be eligible for the CCS credit and bonus allowance allocations from Title III of the bill;**
- **To simulate the energy efficiency provisions in the bill, EIA reduced the cost of energy-efficient appliances for end-users by half and tightened residential building codes by 30% in 2015 and 50% in 2025; and**
- **EIA also assumed that the 10% of allowances allocated to Load-Serving Entities (LSEs) and rural electric cooperatives were used to reduce electricity prices.**

The analysis does not include the separate caps for HFCs (Title X) or the Low Carbon Fuel Standard (LCFS) (Title XI). Allowance allocations to fossil fuel generators are also not covered in the model. For the S. 2191 core scenario, the bill is analyzed based on these assumptions. EIA also examines the effects of varying international offsets and the costs and availability of electricity generating technologies, through four alternative scenarios.[8] While EIA ran a number of scenarios for the sake of model comparison, the focus here is on cases representative of S. 2191.

Key Results

Due in part to a lower emissions reference case, more optimistic nuclear deployment assumptions, and inclusion of the allowance allocation and energy efficiency provisions of S. 2191, EIA forecasts that GHG caps will have limited impacts on the U.S. economy compared to other analyses discussed in this brief. The key results from the modeling analysis:

- **In the S. 2191 core scenario, total greenhouse gases (including offsets) are 7,003 $MtCO_2e$ in 2015 and decrease to 5,428 $MtCO_2e$ by 2030.**
- **Allowance prices are $20/$tCO_2e$ in 2015 and rise to $59/$tCO_2e$ by 2030 (2005$).**
- **GDP is 0.24% lower in the core scenario than the BAU scenario in 2015 and 0.3% lower in 2030.** Under S. 2191, GDP grows 183% from 2005 to 2030 compared to 184% in the reference case; this means that the economic growth would be less than 2 months behind BAU levels in 2030 with GHG caps.
- **Electricity prices increase by about 8% in 2030 from BAU levels in the core scenario (this includes the cost of allowances).** This is lower than projections from the other models, perhaps due to more optimistic assumptions about the benefit of allowance allocations to LSEs and electric cooperatives in reducing costs. Electricity demand is about 5% lower in 2030 from the reference case.
- **In terms of electricity generation, the analysis predicts that new coal builds without CCS are almost eliminated.** For the S. 2191 core scenario, 64 GW of new coal generation with CCS is built by 2030, and overall coal consumption is 74% lower than the reference case. The introduction of coal with CCS is largely driven by the bonus allowance provision which makes CCS more economically viable.
- **EIA uses optimistic assumptions about nuclear expansion.** Under the S. 2191 core scenario, nuclear generation expands rapidly, increasing by 266 GW from 2005 to 2030 (100 GW to 366 GW). Even with higher capital costs (S. 2191 High Cost Case), nuclear generation is expected to grow about 86% over the time period.
- **Renewable capacity more than doubles from 2005 to 2030 (an increase of more than 100 GW), mainly due to an expansion in wind generation, followed by biomass.** In the Limited Alternatives Case, where nuclear growth is constrained to BAU levels (17 GW over the time period), the increase in renewable capacity is much greater, above 300 GW.
- **Under the S. 2191 core scenario, natural gas generation is 17% lower than the reference case, due to a reduction in energy demand and increase in renewable and nuclear capacity.** Total natural gas consumption decreases over the time period of the analysis, and gas prices increase by about 35% from the BAU level in 2030 (this includes the cost of the carbon allowances). In the Limited Alternatives Case, which constrains both CCS and nuclear technologies, natural gas consumption is 12% above reference case levels in 2030, due to fuel switching and increased natural gas generation.
- **Offsets play a key role in reducing costs in the program.** In the core scenario, the 15% limit on offsets becomes binding in 2016 for international allowances and 2025 for domestic offsets. In an alternate scenario with no international credits, allowance prices are much higher than the other scenarios from 2012 to 2016, as covered entities rely on fuel switching and early investments in efficiency and carbon-neutral technologies. The analysis demonstrates that international offsets play an important role in mitigating costs in the early years of the program.

Clean Air Task Force (CATF)

Modeling Background

The CATF analysis of S. 2191 also uses the National Energy Modeling System (NEMS).[9] However, the CATF analysis uses data from EIA's Annual Energy Outlook 2007 but also includes the new Corporate Average Fuel Economy Standards enacted in December 2007. The CATF analysis captures the following provisions of the bill:

- **Emissions from the following sources are covered: coal-fired electrical and industrial boilers, petroleum use in transportation (upstream), and residential, commercial and industrial natural gas and petroleum use (upstream), all of which represent about 86% of total U.S. GHG emissions;**
- **Offsets can be used to meet up to 30% of the compliance obligation (the bill allows for 15% offsets and 15% from international allowance markets);**
- **There are no limits on the number of allowances that can be banked for future years;**
- **The various provisions for the use of auction revenues are included in the model via a production tax credit for CCS and a wind production tax credit to 2030; and**
- **To simulate the energy efficiency provisions in the bill, CATF uses EIA's Best Available Technology case, which assumes that consumers choose the highest efficiency equipment, regardless of cost.[10]**

The analysis does not consider the impact of the LCFS, the effects of the Carbon Market Efficiency Board, or the provisions which allow borrowing (included in the bill to contain costs). The CATF analysis uses the standard NEMS technology assumptions for the electricity market,[11] but limits the introduction of biomass power, due to competing uses for biomass from the transportation sector and the uncertain GHG benefits. There are no constraints on other technologies, including nuclear power.

Key Results

Due in part to more optimistic assumptions about improvements in energy efficiency, CATF generally forecasts lower costs than other models. The key results from the modeling analysis:

- **Total greenhouse gas emissions (including offsets) are 6,961 $MtCO_2e$ in 2015 and decrease to 6,348 $MtCO_2e$ by 2030.**
- **Allowance prices are \$17/tCO_2e in 2015 and rise to \$48/tCO_2e by 2030 (2005\$).**
- **With S. 2191, GDP is about 0.4% lower from the BAU scenario in 2015 and 0.7% lower in 2030.** GDP grows 102% from 2005 to 2030 compared to 104% in the reference case; the slower growth rate under S. 2191 means that the economy would be about 4 months behind BAU levels in 2030.
- **Electricity prices increase by 20% and natural gas prices by about 23% in 2030 from BAU levels (these price increases include the cost of allowances).** This is lower than projections from most of the other models, perhaps due to more optimistic assumptions about the rate of efficiency improvements and decrease in electricity demand.
- **The model predicts a considerable drop in energy use due to increases in both energy efficiency and the response to higher electricity prices.** This translates to a 20% decrease in electricity generation compared to the reference case in 2030. Thus, at the consumer level, monthly electric bills are on average lower relative to the reference case (although in three electricity regions price impacts are slightly higher than in the reference case).
- **In terms of the generation mix, the model shows no switching to natural gas as a "bridge fuel"—a combined effect of the production incentives for CCS along with the reduced energy use.** Coal generation drops by 14% from current levels, with a total 133 GW of IGCC with CCS built by 2030. The model also predicts new nuclear generation of about 104 GW by 2030, increasing total capacity to about 204 GW, and an expansion of renewable generation to 214 GW of total capacity.

American Council for Capital Formation (ACCF) and the National Association of Manufacturers (NAM)

Modeling Background

The analysis of S. 2191 conducted by Science Applications International Corporation (SAIC) on behalf of the ACCF and NAM uses the Energy Information Administration's (EIA) NEMS model.[12] This analysis incorporates many of the provisions in the bill in estimating both a Low and a High Cost Scenario,[13] but also includes several key constraining assumptions regarding the cost and availability of new energy technologies and other factors. In particular, banking is not included in the analysis, even though it is allowed in S. 2191. Furthermore, both the Low and the High Cost Scenarios involve limited availability of offsets.[14]

The ACCF/NAM's analysis contains the following assumptions about availability of technology:

- **The constraint on nuclear allows only 10-25 GW of additional capacity by 2030.**
- **Limited use of renewables: both scenarios limit new technology builds for both biomass and wind.** For example, the Low Cost Scenario assumes a maximum 5 GW/year of new wind power deployment, which is lower than the actual amount of wind power built in 2007 (5.244 GW).

Finally, the analysis does not explicitly model the CCS bonus allowance provision or the funds generated by the bill's auction/allocation, but does assume that the revenue from the sale of allowances is redistributed to the individual energy sectors.[15]

Key Results

The ACCF/NAM model shows relatively high allowance prices, in part due to limitations on offsets, constraints on technology, and the elimination of the banking provision contained in the bill.

- **Allowance prices are \$52/tCO_2e for the Low Cost Scenario and \$61 for the High Cost in 2020, and \$216/tCO_2e (Low) and \$257 (High) in 2030 (2005\$).**
- **GDP is projected to be 0.8% lower than BAU for the Low Cost Scenario and 1.1% lower for the High Cost case in 2020 and 2.6% and 2.7% lower for the two scenarios in 2030.** GDP grows by 183% under the S. 2191 scenarios versus 188% in the reference case; this correlates to about a 13-month lag in GDP from BAU levels.
- **Electricity prices are projected to increase by 28% and 33% by 2020, and 101% and 129% by 2030, for the Low and High Cost Scenarios, respectively.** These increases include the cost of carbon allowances.
- **Coal generation without CCS declines significantly by 2030 in both cases.** In the Low Cost case, there is about 50 GW of CCS capacity added by 2030 (93.5 GW for the High Cost case).
- **The analysis limits nuclear deployment in both cases.** By 2030, there is an additional 18 GW of nuclear capacity built in the Low Cost Scenario and only 9 GW for the High Cost Scenario. In comparison, EIA assumes that the business as usual growth in nuclear generation will add an additional 15 GW of capacity by 2030.[16]
- **With the constraints on nuclear and slower deployment of CCS, natural gas becomes the predominant fuel for electricity generation after 2025.** Natural gas prices increase by 108% and 146% from BAU levels in 2030, for the Low and the High Cost Scenarios, respectively. Natural gas consumption increases by more than 20% from 2015 to 2030 in both scenarios.
- **Renewable generation shows strong growth in both the Low and the High Cost Scenarios despite the limitations imposed on both wind and biomass of 5 GW (Low Cost) and 3 GW (High Cost) per year.** Renewable generation capacity nearly doubles by 2030 in both cases.
- **Gasoline prices increase \$0.43-\$1.46 per gallon in 2020 and \$1.78-\$3.35 per gallon in 2030.**

Massachusetts Institute of Technology (MIT)

Modeling Background

MIT researchers at the Joint Program on the Science and Policy of Global Change (Paltsev et al.) investigate the economic impacts of a range of policy proposals with the MIT Emissions Prediction and Policy Analysis (EPPA) model, a component of the larger MIT Integrated Global System Model (IGSM). EPPA is a multi-region, multi-sector recursive-dynamic representation of the global economy in which economic actors are modeled as having limited foresight ("myopic" expectations). The model includes the six major greenhouse gases.[17]

The MIT analysis of S. 2191 appears as an appendix to an assessment of cap-and-trade proposals that is not tied to any particular legislation (and which was first released before the bill was proposed).[18] The baseline used for the analysis is EIA's 2007 Annual Energy Outlook, which does not include estimated effects of emissions-reducing components of the Energy Independence and Security Act of 2007. Covered emissions include most energy sources, some non-CO_2 GHG emissions, and high GWP industrial gases. The analysis includes four scenarios that illustrate the impact of different provisions of the bill. The scenarios include ones with and without 15% offsets[19] and with and without the carbon capture and storage (CCS) bonus allowances to illustrate how these different provisions affect the results. The four scenarios analyzed are: the S. 2191 core scenario, core plus offsets, core plus CCS, and core plus offsets and CCS. All runs assume unlimited banking.

The analysis does not model international emissions trading (i.e., the 15% of international credits that could be obtained from foreign markets under S. 2191), because the impact on prices in the U.S. is dependent on assumptions about the stringency of policies abroad. The potential impact of international emissions trading is addressed in the main report for a scenario very close to S. 2191.[20] Also, other than the CCS bonus allowances, the auction revenues dedicated to efficiency and technology development are not modeled explicitly. If included, these may reduce the direct costs of the policy (i.e., the carbon price); however, there is also an opportunity cost to using the revenues for these types of programs, rather than distributing them directly to households or reducing distortionary taxes.

Key Results

- **The EPPA model estimates that S. 2191 caps cumulative U.S. emissions from 2012 to 2050 at 146 billion metric tons (bmt) CO_2e in covered sectors without offsets, or at 172 bmt with 15% offsets.** Adding the HFC allowances and non-covered sectors raises total U.S. emissions to 190 bmt without and 216 bmt with offsets.
- **Allowance prices are \$48/tCO_2e in 2015, \$86/ton in 2030, and reach \$189/tCO_2e in 2050 for the offsets + CCS scenario (2005\$); the S. 2191 base case with neither provision results in \$56, \$101, and \$222/tCO_2e in 2015, 2030, and 2050, respectively.** In MIT's analysis, offsets have a bigger impact on price than the CCS subsidy does.
- **GDP is estimated to be 0.57% lower in 2015, 0.38% lower in 2030, and 0.75% lower in 2050 than BAU for the offsets + CCS scenario; for 2050, this reduction in GDP means that the economy is only about three months behind projected growth without GHG caps.** In the scenario with neither offsets nor CCS included, GDP impacts are slightly higher, reaching 1.10% in 2050.

- **Electricity prices are projected to be 30.3% higher than BAU in 2015, but the impact decreases quickly to 13.8% in 2030 and stays mostly level out to 2050.** Total electricity production is 9.9% lower than BAU in 2050.
- **In terms of technology, this analysis predicts extensive deployment of CCS in all S. 2191 scenarios.** The CCS subsidy encourages earlier development and faster deployment of CCS; the 4% of total allowances allocated to CCS subsidies is dramatically below the modeled demand for them, and some method of rationing the bonus allowances will be necessary. However, even without subsidies, almost 75% of 2050 electricity generation in MIT's scenarios is from coal and gas with CCS.
- **Energy use from coal decreases in the 2015 to 2030 timeframe, with clear fuel switching to natural gas during this period, before coal use increases in the long term with full CCS deployment.** The adverse impact on the coal industry is reduced but not removed by the CCS subsidy. The model predicts that the CCS subsidy speeds deployment, with an approximate 3-fold increase in sequestered carbon in 2030 over the scenario without the CCS subsidy, but does not substantially increase CCS in 2050.
- **MIT assumes in their analysis that no additional nuclear reactors are built by 2050, and there is very little increase over BAU in other zero-emissions electricity production from hydro and other renewables.** In the offsets + CCS scenario, nuclear, hydro, and other renewables together show no change from baseline in 2015, are less than 5% higher in 2030, and are only 2% higher in 2050.
- **The separate cap for HFCs in S. 2191 produces low HFC allowance prices relative to the CO_2e market.** However, if trade were allowed between the two markets, lower price opportunities for HFC reductions would be available before some higher cost options for other gases, resulting in an overall reduction in the cost of the policy.
- **For all scenarios, the increasing stringency of the cap and increasing carbon price induce extensive banking early in the timetable and no borrowing.** This implies that emissions will be lower than the S. 2191 targets in early years, and higher in later years.

Environmental Protection Agency (EPA)

Modeling Background

EPA's analysis of S. 2191 uses two computable general equilibrium (CGE) models, both of which optimize the decisions of households and firms to develop a model of the whole economy. The first is the Intertemporal General Equilibrium Model (IGEM) developed and run by Dale Jorgenson Associates, and the second is the Applied Dynamic Analysis of the Global Economy (ADAGE) developed and run by RTI International. In utilizing both models, EPA assumes the following regarding the structure of S. 2191:

- **Upstream coverage for petroleum, natural gas, and manufacturers of F-gases and N_2O; downstream on coal facilities using over 5,000 tons of coal per year;**
- **Domestic offsets and international credits can each be used to meet 15% of the compliance obligation;**
- **Set asides for agriculture and forestry sequestration and landfill and coal mine methane are available; and**
- **Bonus allowances for CCS.**

The analysis compares the results between the two models for a set of 10 scenarios: 2 BAU reference scenarios and 8 bill scenarios. The core policy scenario (Scenario 2) assumes substantial growth in nuclear power (150% increase from 2005-2050) and widespread international actions by developed and developing countries. Other scenarios include limits on international actions, unlimited offsets, no offsets, and a series of three scenarios requested by Senators Inhofe, Voinovich, and Barrasso combining constraints on nuclear, biomass, CCS, and international action as well as the emergence of a natural gas cartel. In order to approximate emissions reductions associated with the recently passed Energy Independence and Security Act of 2007 (not currently in the "baseline"), EPA also developed a "high technology reference scenario" (Scenario 9) and applied the provisions of S. 2191 as well as the core scenario's assumptions of substantial growth in nuclear and widespread international action (Scenario 10). EPA's scenarios are based on EIA's AEO 2006 (Reference or High Technology), both of which have higher baseline emissions than the recently released AEO 2008 which includes the EISA. This will result in higher allowance prices and macroeconomic effects than if the lower AEO 2008 projections had been available as a starting point for the analysis.

Key Results

In general, the use of offsets and international credits has a larger impact on allowance prices than any constraints placed on technology. Because ADAGE more fully represents international markets, the key results for Scenarios 2 and 10 using the ADAGE model are presented below.

- **Under Scenario 2 in ADAGE, total U.S. GHG emissions (including offsets and international credits) in 2030 are estimated to be 5,867 $MtCO_2e$, dropping to 5,279 $MtCO_2e$ by 2050.** Using ADAGE Scenario 10, emissions are 5,953 $MtCO_2e$ in 2030 and 5,263 $MtCO_2e$ in 2050.
- **For the core policy case (Scenario 2), allowance prices in 2015 are \$29/tCO_2e, increasing to \$61/tCO_2e in 2030 and \$159/tCO_2e in 2050.**[21] Using the high technology scenario (Scenario 10), allowance prices are slightly lower: \$22/tCO_2e in 2015, \$46/tCO_2e in 2030, and \$121/tCO_2e in 2050.

- **The ADAGE model projects that in 2030, GDP is 0.9% lower than BAU for Scenario 2 (0.6% for Scenario 10).** In 2050, GDP is 2.37% lower under Scenario 2 and 1.76% under Scenario 10; in both scenarios GDP grows by more than 335% from 2005 to 2050 compared to 344% in the BAU case. The economy would be about 11 months behind BAU levels under Scenario 2 and about 8 months under Scenario 10.
- **Electricity prices are projected to increase 44% in 2030 and 27% in 2050 under Scenario 2 in ADAGE.**[22]
- **Modeling of regional impacts indicates a switch from coal to natural gas and CCS in 2030.** Natural gas consumption increases in both Scenarios 2 and 10 until 2020, after which it decreases by more than 25% from 2005 levels by 2050.
- **Coal generation with CCS picks up after 2015 with roughly 175 GW of coal capacity with CCS built by 2030.** All coal without CCS is retired by 2035 and total CCS capacity increases to 323 GW in 2035, then decreases slightly to 299 GW by 2050.
- **The electricity sector provides the vast majority of the GHG reductions in the early years.** Even after 2035, the electricity sector still provides most of the GHG abatement, although transportation and energy intensive manufacturing begin to contribute more to emissions reductions. Nuclear and renewable generation capacity increases steadily, more than doubling from 2005 to 2050.
- **In Scenario 2 of ADAGE, gasoline prices increase $0.53 per gallon in 2030 and $1.40 per gallon in 2050 due to the cost of the carbon content.** The higher gas price, due to the increased cost of carbon allowances in the later years of the analysis spurs GHG reductions from the transportation sector.
- **To better understand the bill's offset provisions, EPA also estimated two alternative scenarios in IGEM: one that allowed for unlimited use of offsets (Scenario 4) and one in which no offsets were allowed (Scenario 5).** All other assumptions remained the same as Scenario 2. For Scenario 4, allowance prices were 71% lower than the core policy scenario in 2050; for Scenario 5, they were 93% higher.
- **To test the sensitivity to various technology assumptions, EPA included a modeling run that limited nuclear and biomass power to BAU levels and assumed that CCS is not available before 2030 (ADAGE Scenario 7).** In this case, allowance prices in 2050 were 82% higher than the core policy scenario.

CRA International

Modeling Background

CRA International uses an integrated version of two models: the Multi-Region National (MRN) Model and the North American Electricity and Environment Model (NEEM), both developed in-house, for its analysis of the Lieberman-Warner bill. MRN is a top-down, computable general equilibrium (CGE) model that examines the net economic impact from reducing carbon emissions. NEEM is a linear programming model for the U.S. electricity market. For the analysis of S. 2191, MRN-NEEM was run using the following assumptions:[23]

- **A cap which covers all U.S. emission sources excluding landfill, coal mine, and agricultural methane, non-energy CO_2, and agricultural and mobile source N_2O. CRA excludes high-GWP gases and does not model the separate HFC cap;**
- **The banking and borrowing provisions in the bill;**
- **Domestic offsets used to meet 15% of the compliance obligation;**
- **The bonus allowances for CCS;**
- **Sector and region-specific allowance allocations;[24] and**
- **The low-carbon fuel standard (LCFS), which requires a reduction in carbon intensity of the transportation fuel pool of 5% by 2015 and 10% by 2020.[25]**

CRA's analysis is the only one considered here that includes the proposed LCFS. CRA assumes that the Carbon Market Efficiency Board's ability to alter borrowing does not affect allowance prices and therefore CRA does not include it in the model. The S. 2191 scenario omits the provision that allows 15% of the compliance obligation to come from international allowances because CRA assumes that countries with "mandatory caps" of "comparable stringency" would have similar allowance prices as the U.S. program. The energy efficiency programs (Title V) and HFC provisions (Title X) of the bill are also not included.

In terms of electricity-generating technology, this implementation of MRN-NEEM includes constraints on the rate of new capacity deployment for IGCC with CCS, nuclear, wind, and biomass. Only the limit on nuclear power becomes binding (40 GW of additional capacity by 2030 and 100 GW by 2050). For capital costs, CRA revises previous estimates to include recent, higher construction costs. The business as usual scenario is a combination of EIA's 2008 Annual Energy Outlook (early release) and CRA's estimate of the impacts of the Energy Independence and Security Act of 2007.

Key Results

Due to limits on offsets, higher capital costs for technology, and constraints on nuclear generation, the CRA analysis finds higher economic impacts than most other models in this analysis. In the early years, the LCFS also plays a role.

- **Total emissions including offsets, minus tons of biosequestration, are 6,299 $MtCO_2e$ in 2015 and decrease to 3,784 $MtCO_2e$ by 2050.**
- **For the core policy scenario, allowance prices start at about \$48/tCO_2e in 2015, rise to \$84/tCO_2e in 2030 and to \$185/tCO_2e in 2050 (2005\$).** For the scenario that removes the banking provision, allowance prices start lower, \$36/tCO_2e in 2015 and \$64/tCO_2e in 2030, but rise quickly after 2035, increasing to \$334/tCO_2e in 2050.

- **The model predicts widely different results for the scenarios with and without banking.** For the core policy case, GDP is lower than BAU levels in 2015 by 2.1%, in 2030 by 1.4% and by 2.7% in 2050. In the case without banking, GDP impacts are smaller in the early years—only 1.0% in 2030—but substantially higher in 2050, about 3.5%.
- **Under S. 2191, electricity demand remains nearly constant through 2050.** Electricity prices, including the cost of allowances, are projected to increase by 42% in 2030 and 52% by 2050.
- **In terms of the generation mix, almost all coal without CCS is eliminated by 2040.** CCS is introduced starting in 2015 with 2 GW of capacity and increases to 129 GW by 2050.
- **Natural gas generation must increase significantly before 2030 as a way of replacing coal, but then declines because its emissions are too high to meet long-term targets.** According to CRA, there is no additional natural gas capacity added after 2040, and total natural gas generation is halved from 2005 (18%) to 2050 (8%).
- **Renewable generation makes up about one-third of total capacity, with 257 GW of total renewable capacity in 2050.**
- **CRA's costs vary over time due to specific assumptions and bill provisions.** CRA finds relatively higher costs in the early years of the program, due to the costs of complying with the LCFS. After 2025, impacts are lower because of the emission reduction benefits of the Energy Independence and Security Act of 2007. Impacts grow in the long term as more low carbon technologies are added to meet the cap. Overall, both the electricity and transportation sectors are 90% decarbonized by 2050 under S. 2191.
- **The impacts of the LCFS are mixed.** The LCFS increases the cost of the program in 2015. Program costs decrease as lower and zero carbon fuels become available in 2020. In the short term, corn-based ethanol is most likely the only available alternative fuel. To achieve the targeted reductions in the LCFS for 2015, ethanol production would have to increase to an infeasible share of total fuel consumption, since it provides a carbon reduction of only 25% relative to gasoline. Instead, CRA's model pushes gasoline prices up to decrease demand. As gasoline consumption falls, the available quantities of ethanol are sufficient to meet the 5% carbon intensity reduction required by the LCFS. Furthermore, higher gasoline prices lead to reductions in vehicle miles traveled and increased demand for fuel economy (the model projects fuel economy levels above the CAFE standard in 2015).

Table 2

Modeling results

2015	EIA Core Case	CATF	ACCF/NAM Low Cost	ACCF/NAM High Cost	MIT Offsets + CCS	EPA ADAGE Scenario 2	EPA ADAGE Scenario 10	CRA Scenario w/ Banking
S. 2191 Cap[1] ($MtCO_2e$)	5,489	5,489	5,456	5,456	5,456	5,456	5,456	5,456
Total GHG Emissions[2] ($MtCO_2e$)	7,003	6,961	5,703	5,572	6,813	6,362	6,347	6,299[3]
Allowance Price ($/t$CO_2e$, 2005$)	$ 20.27	$17	$35[4]	$36	$48	$29	$22	$48
GDP Impact (% chg from BAU)	-0.24%	-0.4%	-0.8%	-1.6%	-0.6%	-0.7%	-0.5%	-2.1%
Consumption Impact (% chg from BAU)	-0.37%	-0.70%	-1.00%	-2.80%	-0.31%	-0.30%	-0.15%	-2.8%
Consumption Impact per household (2005$)	$ (283.9)	$ (648)	$ (959)	$ (2,638)	$ (292)[5]	$ (270)	$ (136)	$ (2,155)
Coal Prices (% change)[6, 7]	110%	90%	197%	213%	338%	175%	136%	149%
Electricity Prices (% change)[6, 8]	2%	2%	13%	14%	30%	28%	22%	20%
Natural Gas Prices (% change)[6, 9]	14%	5%	18%	21%	10%	22%	16%	30%
Total CCS (GW)	0.0	0.5	1.4	1.2	11.2	0.0	0.0	2.0
Total Nuclear (GW)	102.1	106.3	101.9	101.9	109.2	118.3	117.3	107.0
Total Renewables (GW)	131.0	146.5	115.3	118.9	95.6	122.3	121.9	57.0
Total Natural Gas Consumption (Quads)	23.0	23.8	23.7	22.9	22.6	26.2	25.3	25.0

2020	EIA Core Case	CATF	ACCF/NAM Low Cost	ACCF/NAM High Cost	MIT Offsets + CCS	EPA ADAGE Scenario 2	EPA ADAGE Scenario 10	CRA Scenario w/ Banking
S. 2191 Cap ($MtCO_2e$)	4,992	4,968	4,992	4,992	4,924	4,924	4,924	4,924
Total GHG Emissions ($MtCO_2e$)	6,770	6,910	5,593	5,385	6,325	6,388	6,256	5,748[3]
Allowance Price ($/t$CO_2e$, 2005$)	$ 28.96	$22	$52	$61	$58	$37	$28	$58
GDP Impact (% chg from BAU)	-0.27%	-0.5%	-0.8%	-1.1%	-0.8%	-0.7%	-0.5%	-1.5%
Consumption Impact (% chg from BAU)	-0.41%	-0.7%	-0.7%	-2.6%	-0.7%	-0.4%	-0.2%	-2.5%
Consumption Impact per household (2005$)	$ (316.9)	$ (743)	$ (701)	$ (2,778)	$ (747)	$ (446)	$ (239)	$ (1,940)
Coal Prices (% change)	163%	118%	322%	389%	402%	224%	188%	200%
Electricity Prices (% change)	3%	5%	28%	33%	30%	32%	26%	32%
Natural Gas Prices (% change)	18%	8%	26%	36%	14%	25%	19%	43%
Total CCS (GW)	18.5	8.0	12.7	22.0	37.3	25.0	25.0	17.0
Total Nuclear (GW)	126.3	119.7	102.7	102.7	109.2	126.2	125.2	119.0
Total Renewables (GW)	178.5	188.4	140.3	134.0	137.3	138.1	138.1	83.0
Total Natural Gas Consumption (Quads)	21.8	23.8	24.3	24.2	26.4	26.5	25.5	25.5

CALCULATIONS

For MIT data, we have adjusted the prices to include their reported allowance prices, according to the following formulas:

Price (coal or natural gas) under S.2191 = Price Index relative to 2005 * Price in 2005 + Carbon Content * Allowance Price in $MtCO_2e$

Price in Reference Case = Price Index relative to 2005 * Price in 2005

Thus: Percent change in price from BAU = (Price under S.2191 / Price in Reference) – 1

Coal Price in 2005 ($ per short ton of coal) $26.70
Natural Gas Price in 2005 ($ per tCf).....................................$11.05
Carbon Content of Coal ($MtCO_2e$ per short ton)......................2.048
Carbon Content of Gas ($MtCO_2e$ per tCf)...............................0.055

For comparison purposes, we converted electricity generation reported in the MIT analysis (exajoules) to electricity capacity (gigawatts).
Capacity in GW = Generation in EJ * (1/1.055056 Btu per EJ) * (1000/3.412 Watts per Btu) * 1000/(8760 Hours per year * Capacity conversion factor)

Capacity Conversion Factors:
Nuclear: 90% CCS: 85% Biomass: 83% Hydro: 40% Wind/Solar: 38%

2030	EIA Core Case	CATF	ACCF/NAM Low Cost	ACCF/NAM High Cost	MIT Offsets + CCS	EPA ADAGE Scenario 2	EPA ADAGE Scenario 10	CRA Scenario w/ Banking
S. 2191 Cap ($MtCO_2e$)	3,856	3,927	3,856	3,856	3,860	3,860	3,860	3,860
Total GHG Emissions ($MtCO_2e$)	5,429	6,348	4,581	4,419	4,889	5,867	5,953	4,674[3]
Allowance Price ($/t$CO_2e$, 2005$)	$ 59.14	$48	$216	$257	$86	$61	$46	$84
GDP Impact (% chg from BAU)	-0.29%	-0.7%	-2.6%	-2.7%	-0.4%	-0.9%	-0.6%	-1.4%
Consumption Impact (% chg from BAU)	-0.48%	-0.9%	-2.9%	-4.9%	-1.5%	-0.9%	-0.6%	-1.8%
Consumption Impact per household (2005$)	$ (391.0)	$ (1,121)	$ (3,818)	$ (6,409)	$ (1,890)	$ (1,176)	$ (768)	$ (1,358)
Coal Prices (% change)	299%	240%	1322%	1635%	560%	340%	254%	333%
Electricity Prices (% change)	8%	20%	101%	129%	14%	44%	35%	42%
Natural Gas Prices (% change)	34%	23%	108%	146%	6%	33%	24%	55%
Total CCS (GW)	64.0	132.9	49.5	93.5	253.7	175.0	94.0	61.0
Total Nuclear (GW)	366.1	204.0	118.0	109.0	109.2	175.9	174.4	149.0
Total Renewables (GW)	196.9	214.1	200.8	181.9	128.9	167.8	170.3	132.0
Total Natural Gas Consumption (Quads)	18.8	22.7	28.4	28.8	23.8	21.6	23.1	23.1

2050	EIA Core Case	CATF	ACCF/NAM Low Cost	ACCF/NAM High Cost	MIT Offsets + CCS	EPA ADAGE Scenario 2	EPA ADAGE Scenario 10	CRA Scenario w/ Banking
S. 2191 Cap ($MtCO_2e$)	—	—	—	—	1,732	1,732	1,732	1,732
Total GHG Emissions ($MtCO_2e$)	—	—	—	—	3,760	5,279	5,263	3,784[3]
Allowance Price ($/t$CO_2e$, 2005$)	—	—	—	—	$189	$159	$121	$185
GDP Impact (% chg from BAU)	—	—	—	—	-0.8%	-2.4%	-1.8%	-2.7%
Consumption Impact (% chg from BAU)	—	—	—	—	-2.0%	-2.1%	-1.7%	-2.4%
Consumption Impact per household (2005$)	—	—	—	—	$ (3,897)	$ (3,984)	$ (3,222)	$ (1,862)
Coal Prices (% change)	—	—	—	—	1086%	877%	661%	789%
Electricity Prices (% change)	—	—	—	—	14%	27%	28%	52%
Natural Gas Prices (% change)	—	—	—	—	-23%	96%	74%	84%
Total CCS (GW)	—	—	—	—	693.9	299.0	254.0	129.0
Total Nuclear (GW)	—	—	—	—	109.2	268.6	266.8	209.0
Total Renewables (GW)	—	—	—	—	153.1	261.7	265.1	257.0
Total Natural Gas Consumption (Quads)	—	—	—	—	15.2	16.9	17.1	21.5

NOTES:

[1] *Covered sectors only.*

[2] *Total emissions including offsets.*

[3] *Total emissions including offsets minus biosequestration.*

[4] *All values in the 2015 section for the ACCF/NAM analysis are actually 2014 forecasts, as identified in their report.*

[5] *We obtained the number of households by dividing the population by an average household size of 2.6, and then the difference in aggregate consumption by that number.*

[6] *Includes the cost of allowances.*

[7] *Average delivered price.*

[8] *Residential electricity price.*

[9] *The changes in natural gas prices are calculated using average delivered price (including allowance prices) for EIA, EPA, CATF, and CRA, and using residential price for ACCF/NAM and MIT, with MIT adjusted to include the price of allowances (see calculation on previous page).*

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[1]Harrington, Winston, Richard D. Morgenstern, and Peter Nelson. "On the Accuracy of Regulatory Cost Estimates." Washington, DC: RFF Discussion Paper 99-18, January 1999.

[2]Peace, Janet and John Weyant. "Insights Not Numbers: The Appropriate Use of Economic Models." Arlington, VA: Pew Center on Global Climate Change, April 2008.

[3]EIA's Annual Energy Outlook 2007 predicted an additional 12.6 GW of new capacity by 2030, without any changes in current policy, which is higher than the nuclear power constraint in ACCF/NAM's High Cost Scenario (110 GW by 2030). See EIA, AEO 2007: Electricity Forecast, http://www.eia.doe.gov/oiaf/archive/ aeo07/electricity.html

[4]AWEA 2007 Market Report, January 2008. Retrieved from http://www.awea.org/Market_Report_Jan08.pdf

[5]The "Limited Alternatives" case was requested by Senators Inhofe, Voinovich and Barrasso. Other cases, such as "No International Offsets" and "High Cost" cases were presented to demonstrate the sensitivity to some highly uncertain assumptions.

[6]Energy Information Administration, Department of Energy (DOE). The National Energy Modeling System: An Overview 2003. Retrieved May 5, 2008, from http://www.eia.doe.gov/oiaf/aeo/overview/overview.html

[7]Energy Information Administration, Office of Integrated Analysis and Forecasting, U.S. Department of Energy. Energy Market and Economic Impacts of S. 2191, the Lieberman-Warner Climate Security Act of 2007. Washington, DC: April 2008. Retrieved April 29, 2008, from http://www.eia.doe.gov/oiaf/servicerpt/s2191/index.html

[8]EIA ran several alternative scenarios: S. 2191 High Cost case (costs for nuclear, biomass, and CCS are 50% higher); S. 2191 Limited Alternatives Scenarios (CCS not available until 2030, new nuclear and biomass capacity restricted to reference case growth levels, and LNG imports restricted to reference levels); No International Offsets (the bill's provision that specifies 15% international offsets is assumed to be unavailable); and a S. 2191 Limited Alternatives Scenario/No International Scenario.

[9]Banks, Jonathan. The Lieberman-Warner Climate Security Act—S. 2191: A Summary of Modeling Results from the National Energy Modeling System. Clean Air Task Force, February 2008. Retrieved March 18, 2008, from http://www.catf.us/publications/presentations/CATF_LWCSA_Short_Hill_Briefing_with_CAFE.pdf

[10]Energy Information Administration. DOE. Assumptions to the Annual Energy Outlook 2007: Residential Demand Module. April 2007. Retrieved March 18, 2008, from http://www.eia.doe.gov/oiaf/aeo/ assumption/residential.html

[11]Energy Information Administration. DOE. The National Energy Modeling System: Documentation. Retrieved March 18, 2008, from http://tonto.eia.doe.gov/reports/reports_kindD.asp?type=model%20documentation

[12]Analysis of the Lieberman-Warner Climate Security Act (S. 2191) using the National Energy Modeling System (NEMS/ACCF/NAM). A Report by the American Council for Capital Formation and the National Association of Manufacturers. Analysis Conducted by Science Applications International Corporation (SAIC), March 2008. Retrieved March 26, 2008, from http://www.eenews.net/features/documents/2008/03/13/document_pm_03.pdf

[13]Both scenarios assume the same capital costs for technology but differ in their constraints on technology deployment.

[14]SAIC employed the NEMS offset curves that EIA established for their original analysis of S. 280 (McCain-Lieberman bill). In the case of the offsets: the High Cost Scenario accounted for an aggregate average offsets purchase of 14% of the capped CO_2 emissions between 2012 and 2030. The Low Cost Scenario accounted for an aggregate average offsets purchase of 17% of the capped CO_2 emissions between 2012 and 2030. (Source: Thorning, Margo. Private Communication. May 5, 2008).

[15]The ACCF cases were run on the basis of a "Market for Allowance Permits with Emissions Offsets." The market approach was taken because of the complexity of the allowance distributions provided by the proposed legislation and the likelihood that these would be traded within energy sectors. Allowance permits are assumed transferable within the country, but are not banked. The distribution of emissions permits per year, equal to legislated annual emissions limits, is assumed to take place. As a result, the revenue from the sale of allowances is assumed to be redistributed back to the individual energy sectors. (Source: Thorning, Margo. Private Communication. May 5, 2008).

[16]Energy Information Administration. Annual Energy Outlook 2008 (Revised Early Release). Report #: DOE/EIA-0383(2008), Released Date: March 2008 (Revised).

[17]For more information on the EPPA model, see Paltsev, S., et al. "Assessment of U.S. Cap-and-Trade Proposals." MIT Global Change Joint Program, April 2007. Retrieved March 26, 2008, from http://web.mit.edu/globalchange/www/reports.html#r146

[18]Paltsev, Sergey, et al. "Appendix D: Analysis of the Cap and Trade Features of the Lieberman-Warner Climate Security Act (S. 2191)." Feb 2008.

[19]In the MIT analysis, offsets are assumed to be free, i.e., the model does not explicitly include the supply/costs of offsets. Thus, the offsets provision is equivalent to a relaxation of the cap by 17.65%.

[20]The "International emissions trading: 203 bmt" scenario in the main report could be compared to the "Core scenario: 203 bmt" to isolate the impact of international emissions trading in the context of a cap-and-trade environment with similar stringency.

[21]In comparison, for IGEM, prices start at \$40/tCO_2e in 2015 and increase to \$83/tCO_2e by 2030 and \$220/tCO_2e by 2050 for scenario 2.

[22]Electricity price reflects the full allowance price the consumer would face. Assumes the cost of allowances can partially be passed on to consumers (as is the case in a full auction). If allowances are given directly to power companies, the cost of those allowances would not be passed on to consumers in regulated electricity markets, so electricity price increases would be smaller in much of the country.

[23]Montgomery, David, and Anne E. Smith. Economic Analysis of the Lieberman-Warner Climate Security Act of 2007: Using CRA's MRN-NEEM Model Summary of Findings. CRA, International, April 2008. Retrieved May 9, 2008, from http://www.nma.org/pdf/040808_crai_presentation.pdf

[24]CRA assumes that these allowances are used to lower the household impacts of higher energy prices.

[25]CRA uses three "stock" low carbon fuels—a corn-based ethanol (25% lifecycle emissions reduction relative to gasoline), a low carbon biofuel that achieves an 80% reduction and a zero-carbon fuel, relative to gasoline.

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