U.S. Environmental Protection Agency
Office of Atmospheric Programs

EPA Analysis of The Climate Stewardship and Innovation Act of 2007

S. 280 in 110^{th} Congress

July 16, 2007

Request for EPA Analysis of S. 280

United States Senate
WASHINGTON, DC 20510

February 5, 2007

The Honorable Stephen L. Johnson
Administrator
Environmental Protection Agency
1200 Pennsylvania Avenue, NW
Washington, DC 20460

Dear Administrator Johnson:

We are writing to request that EPA estimate the economic impacts of S. 280, the Climate Stewardship and Innovation Act of 2007. A similar request is being forwarded to the Energy Information Administration.

We believe EPA's analysis of S. 280 would prove useful to us and other members of the Senate as we craft measures to combat global climate change.

We ask that EPA begin this process by meeting with our staff as soon as possible to discuss the parameters, methods, and duration of the analysis. Please call David McIntosh in Senator Lieberman's office at (202) 224-5016 or Floyd DesChamps in Senator McCain's office at (202) 224-5184.

Thank you for your assistance with this analysis.

Sincerely,

Joseph Lieberman
UNITED STATES SENATOR

John McCain
UNITED STATES SENATOR

- On February 5, 2007 Senators Lieberman and McCain requested that EPA estimate the economic impacts of S. 280, the Climate Stewardship and Innovation Act of 2007.

- This document covers the analysis of S.280 based on discussions with senate staff and internal EPA considerations.

- The analysis was conducted by EPA's Office of Atmospheric Programs.
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www.epa.gov/climatechange/economicanalyses.html

Key Results & Insights

S. 280 places a GHG emission cap on all GHGs in the Transportation, Electricity, Industrial, and Commercial sectors, establishes an auction and after-market for emission allowances, and allows for limited domestic offsets and international credits.

<u>Emissions Impacts</u>

- Under S. 280 total U.S. GHG emissions are approximately 25% lower than Reference Scenario emissions in 2030, and 44% lower in 2050.
- Purchasing international credits reduces non-U.S. emissions in 2030 by 588 $MMTCO_2e$, which is approximately six percent of U.S. Reference Scenario emissions in that year; and by 254 $MMTCO_2e$ in 2050, which is approximately two percent of U.S. Reference Scenario emissions in that year.
- Under S. 280 covered U.S. GHG emissions make up 79% of total U.S. GHG emissions in 2030, and 74% in 2050.

<u>Economic Impacts</u>

- In the Senate Scenario, modeled allowance prices range between $27 - 32 /tCO2e in 2030, and $70 - 85/tCO2e in 2050. In other scenarios that limit the availability of technology, modeled allowance prices range between $28 – 40 /tCO2e in 2030, and $55 – 105 /tCO2e in 2050.
- By 2030 GDP is projected to increase 112% from 2005 levels in the Reference Scenario, and by 2050 the projected increase in GDP from 2005 levels is 238%.
- Under S.280 GDP is modeled to be between 0.6% ($146 billion) and 1.6% ($419 billion) lower in 2030 and between 1.1% ($457 billion) and 3.2% ($1,332 billion) lower in 2050 than in the Reference Scenario.
- The average annual growth rate of consumption is ~ 0.04 percentage points lower. In 2030 per household average annual consumption is ~$550 lower and gasoline prices increase ~$0.26 per gallon. In 2050 per household average annual consumption is ~$1900 lower and gasoline prices increase ~$0.68 per gallon.
- Electricity prices are projected to increase 22% in 2030 and 25% in 2050, assuming the full cost of allowances are 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 lower in much of the country.
- In our modeling market outcomes are invariant to the auctioning of allowances given the assumption of lump sum transfers of auction revenues back to households. If the auction revenues were instead used to lower distortionary taxes, the costs of the policy would be lower. Other uses of auction revenues have the potential to increase the costs of the policy.
- The use of domestic offsets and international credits reduces allowance prices and total costs. Payments for international credits are approximately ~$12 billion in 2030 and ~$13 billion in 2050, given the assumption that international credits are purchased only after the supply of domestic offsets at the market clearing price is exhausted.
- The economic benefits of reducing emissions were not determined for this analysis.

Key Results & Insights (con't)

Sector Impacts

- The greatest emission abatement under S.280 occurs in CO_2 emissions from the electricity sector.
- The transportation sector provides a relatively small proportion of CO_2 emissions abatement. This result reflects the weak and indirect price signal an upstream cap and trade program sends to the transportation sector.
  - The price signal provided by S. 280 (~$0.26 increase in the price of gasoline in 2030, ~$0.68 increase in 2050), does not overcome the market barriers in the transportation sector that prevent larger reductions in GHG emissions.
  - This analysis did not estimate the reductions that could be achieved under a direct fuel and vehicle regulatory framework.

Enabling Technologies

- The enabling technologies in this analysis for electricity generation are Carbon Capture & Storage (CCS) and Nuclear Power.
- Detailed power sector modeling suggests most existing coal plants continue to operate but are less profitable in the near-term; and while economy-wide models indicate the near-term impact on coal may be greater than the impacts in the detailed power sector models, they show that coal usage rebounds after 2030 with the deployment of CCS technology based on assumption on costs and performance of CCS in this analysis.
- CCS is not yet proven on commercial scale but is the focus of considerable R&D funding. In this analysis, while CCS is available starting in 2015, carbon allowance prices rise to a high enough level to make CCS cost-competitive in ~2030 and it is rapidly deployed thereafter.
- If CCS is not deployed, in 2030 allowance prices increase by half and GDP effects are almost doubled from the Senate Scenario.
- In the Senate scenario nuclear power grows by ~150% by 2050. If the growth of nuclear power is constrained to ~ 75% by 2050, allowance prices increase by 5% and GDP effects are increased by 4% in both 2030 and 2050.
- If neither CCS nor nuclear are available at large scales at the cost used in this analysis then the allowance prices and the costs to the economy would increase significantly.

Key Results & Insights (con't)

Greenhouse Gas Concentration Impacts

- In the reference case, global CO_2 concentration rises from 380 ppm in 2005 to 718 ppm in 2095.
- Assuming that the U.S. adopts S. 280, Kyoto countries (excluding Russia) reduce emissions to 50% below 1990 levels by 2050, and all other countries adopt GHG emissions targets in 2025 and return emissions to 2000 levels by 2035, the global CO_2 concentration in 2095, while not stabilized, is lowered to 491 ppm.
- The incremental effect of S. 280 on lowering global CO_2 concentration is between 23 and 25 ppm.

Offsets Sensitivities

- If the 30% limit on the use of offsets is lifted, the allowance price falls by 35% in every year, the effects on GDP and consumption in are reduced by about one third in both 2030 and 2050.
- If offsets are not allowed, the allowance price increases by over 150% in all years.

International Climate Policy Sensitivity

- Relaxing the GHG emissions caps that other countries are assumed to adopt under the Senate Scenario reduces the global demand for abatement, and thus decreases the price of offsets domestically. This increases the quantity of international credits demanded in the U.S., but decreases the total value of international credits purchased by the U.S.
- Because of the 30% limit on the use of offsets in the U.S., reducing the offset price does not affect the marginal cost of abatement in the U.S. Consequently, the allowance price is unaffected.

Key Uncertainties

- There are many uncertainties that affect the economic impacts of S. 280.
- This analysis contains a set of scenarios that cover some of the most important uncertainties:
  - The extent and stringency of international actions to reduce GHG emissions by developed and developing countries.
  - The availability of domestic offsets and international credits.
  - The degree to which new nuclear power is technically, politically, and socially feasible.
  - Whether or not carbon capture and storage technology will be available at a large scale.

Contents

Legislative Assessment and Analytical Approach

S. 280 Bill Summary

- Economy-wide coverage:
  - Transportation (upstream on fuels)
  - Electricity, Industrial, and Commercial sectors (downstream on emissions)
- Extensive GHG coverage: CO_2, CH_4, N_2O, HFCs, PFCs, and SF_6
- GHG emission targets for covered sectors:

  2012: 2004 emission level, then adjusted for non-covered entities

  2020: 1990 emission level, then adjusted

  2050: 60% below 1990 emission level, then adjusted

- Establishes a market-driven system of tradable emission allowances
- Caps are placed on covered Entities that emit 10,000 tons CO_2e or more emissions per year
- Domestic offsets & international credits can be used to meet up to 30% of the emission cap level
  - S. 280 provides the EPA Administrator, in coordination with the Secretaries of Commerce, Energy, and Agriculture, discretion for setting standards for domestic and international mitigation activities

Analytical Scenarios

The first two scenarios consist of the EPA reference case, which is a business as usual scenario; and the S. 280 Senate Policy Scenario, which uses assumptions developed in consultation with Senate staff about the details of S. 280, and about other policies both domestic and international that affect the results of this analysis. The assumptions about other domestic and international policies that affect the results of this analysis do not necessarily reflect EPA's views on what is most likely to occur. Both of these scenarios were analyzed using the full suite of models used for this analysis.

1) EPA Reference Scenario

- Does not include any additional climate policies or measures to reduce international GHG emissions
- For domestic projections, benchmarked to AEO 2006
- For international projections, use CCSP Synthesis and Assessment Report 2.1 A MiniCAM Referece

2) S. 280 Senate Scenario

- Cap on covered sectors and entities, adjusted by EPA to account for emissions from exempted source categories and non-covered entities based on the U.S. GHG Inventory
- Domestic offsets and international credits constrained to 30%
- Auction / Allocation Split
  - Case 1: 30% of the 2012 allowances are auctioned, increasing at a constant annual rate to reach 90% in 20 years
  - Case 2: 70% of the 2012 allowances are auctioned, increasing at a constant annual rate to reach 90% in 20 years
- Substantial growth in nuclear power (nuclear power generation increases by ≈150% from 782 bill. kWh in 2005 to 1,982 bill. kWh in 2050) reflecting possible future policies to promote this technology in S. 280 and elsewhere
- Widespread international actions by developed and developing countries over the modeled time period. International policy assumptions are based on those used in the recent MIT report, "Assessment of U.S. Cap-and-Trade Proposals"
  - Group 1 countries (Kyoto group less Russia) follow an allowance path that is falling gradually from the simulated Kyoto emissions levels in 2012 to 50% below 1990 in 2050
  - Group 2 countries (rest of world) adopt a policy beginning in 2025 that returns and holds them at year 2015 emissions levels through 2034, and then returns and maintains them at 2000 emissions levels from 2035 to 2050

Analytical Scenarios (con't)

In the following additional scenarios, everything is the same as in the S. 280 Senate Scenario except for the specified differences. These scenarios provide important sensitivities on provisions of S. 280 and assumptions required for the analysis that have significant impacts on the cost of the policy. These scenarios were not all run by all of the models used for EPA reference scenario and the S. 280 Senate scenario due to resource and time constraints.

3) S. 280 Scenario with Low International Actions

- Developing countries do not take on GHG emissions targets over the period of the analysis
- Group 1 countries continue on a "Kyoto Forever" path

4) S. 280 Scenario Allowing Unlimited Offsets

- Removes the constraint in S. 280 that limits the usage of offsets to 30% of allowance submissions

5) S. 280 Scenario with No Offsets

- Assumes offsets are not allowed, and all reductions must come from covered entities within covered sectors

6) S. 280 Scenario with Lower Nuclear Power Generation

- Assumes less growth in nuclear power, although nuclear power still increases from reference
- Increase by ≈75% by 2050 (half of S. 280 Senate Scenario)

7) S. 280 Scenario with No Carbon, Capture & Storage Technology

- Assumes that carbon capture and storage technology is not available

EPA Models and Corresponding GHG Mitigation

S. 280 Sectors		Economy-wide Computable General Equilibrium (CGE) Models		Models Used to Provide Inputs to CGEs				Partial Equilibrium Model (Uses CGE Outputs)
		ADAGE	IGEM	NCGM	FASOM	GTM	MiniCAM	IPM
Domestic	Electricity Generation	All GHGs	All GHGs					CO_2
	Transportation	All GHGs	All GHGs					
	Industry	All GHGs	All GHGs	CH_4, N_20, F-gases				
	Commercial	All GHGs	All GHGs					
	Agriculture (& Forestry)	All GHGs	All GHGs		CO_2, CH_4, N_20			
	Residential	All GHGs	All GHGs	CH_4, N_20,				
International Credits*				CH_4, N_20, F-gases		CO_2	CO_2, CH_4, N_20, F-gases	

* International allowance and domestic offset markets were analyzed using EPA's spreadsheet tool which combines results from the NCGM, FASOM, GTM and MiniCAM models.

ADAGE	Applied Dynamic Analysis of the Global Economy (Ross, 2007)
IGEM	Intertemporal General Equilibrium Model (Jorgenson, 2007)
IPM	Integrated Planning Model (EPA, 2007)
NCGM	EPA's non-CO_2 GHG spreadsheet tools for estimating projections and mitigation of CH_4, N_2O, and F-gases (EPA, 2005)
FASOMGHG	Forest and Agriculture Sector Optimization Model, GHG version (EPA, 2005)
GTM	Global Timber Model (Sonhgen, 2006)
MiniCAM	Mini-Climate Assessment Model (Edmonds, 2005)

EPA Models Used for Different Analytical Scenarios

Table: Models Used for Different Scenarios

1) EPA Reference Scenario			
ADAGE	IGEM	MiniCAM	
2) S. 280 Senate Scenario			
ADAGE	IGEM	MiniCAM	NCGM/FASOM/GTM/MiniCAM Offset Spreadsheet Tool
3) S. 280 Scenario with Low International Actions			
	IGEM		NCGM/FASOM/GTM/MiniCAM Offset Spreadsheet Tool
4) S. 280 Scenario Allowing Unlimited Offsets			
	IGEM		NCGM/FASOM/GTM/MiniCAM Offset Spreadsheet Tool
5) S. 280 Scenario with No Offsets			
	IGEM		
6) S. 280 Scenario with Lower Nuclear Power Generation			
ADAGE			
7) S. 280 Scenario with No Carbon, Capture & Storage Technology			
ADAGE			

ADAGE Applied Dynamic Analysis of the Global Economy (Ross, 2007)
IGEM Intertemporal General Equilibrium Model (Jorgenson, 2007)
IPM Integrated Planning Model (EPA, 2007)
NCGM EPA's non-CO_2 GHG spreadsheet tools for estimating projections and mitigation of CH_4, N_2O, and F-gases (EPA, 2005)
FASOMGHG Forest and Agriculture Sector Optimization Model, GHG version (EPA, 2005)
GTM Global Timber Model (Sonhgen, 2006)
MiniCAM Mini-Climate Assessment Model (Edmonds, 2005)

Note: International allowance and domestic offset markets were analyzed using EPA's spreadsheet tool which combines results from the NCGM, FASOM, GTM and MiniCAM models.

Modeling Approach

- For the purpose of this analysis, we have chosen to use two separate computable general equilibrium (CGE) models: IGEM and ADAGE.
- CGE models are structural models.
  - They build up their representation of the whole economy through the interactions of multiple agents (e.g. households and firms), whose decisions are based upon optimizing economic behavior.
  - The models simulate a market economy, where in response to a new policy, prices and quantities adjust so that all markets clear.
- These models are best suited for capturing long-run equilibrium responses, and unique characteristics of specific sectors of the economy.
- The general equilibrium framework of these models allows us to examine both the direct and indirect economic effects of the proposed legislation, as well as the dynamics of how the economy adjusts in the long run in response to S. 280.
- The NCGM, FASOM, GTM, and MiniCAM models are used to provide information on abatement options that fall outside of the scope of the CGE models.
  - These models generate mitigation cost schedules for various abatement options.
- Additionally, the IPM model gives a detailed picture of the electricity sector in the short-run (through 2025), which complements the long-run (through 2050) equilibrium response represented in the CGE models.

Modeling Limitations

- The models used in this analysis do not formally represent uncertainty.
  - Confidence intervals cannot be presented for any of the results in this analysis.
  - Very few CGE models are capable of computing confidence intervals, so this limitation is currently shared with virtually all CGE models.
  - The use of two CGE models provides a range for many of the key results of this analysis; however, this range should not be interpreted as a confidence interval.
  - Alternate scenarios are presented to provided sensitivities on a few of the key determinants the modeled costs of S. 280.
- The CGE modeling approach generally does not allow for a detailed representation of technologies.
  - Since the electricity sector plays a vital role in the abatement of CO_2 emissions, we have supplemented the results from our CGE models with results from the Integrated Planning Model (IPM), which is bottom-up model of the electricity sector.
  - The CGE models do not explicitly model new developments in transportation technologies. These reductions occur as households alter their demand for motor gasoline and through broad representations of improvements in motor vehicle fuel efficiency.
- The time horizon of the CGE models, while long from an economic perspective, is short from a climate perspective.
- CGE models represent emissions of GHGs, but cannot capture the impact that changes in emissions have on global GHG concentrations.
  - In order to provide information on how S. 280 affects CO_2 concentrations throughout the 21st century, we have used the Mini-Climate Assessment Model (MiniCAM) to supplement our results.
- None of the models used in this analysis currently represent the benefits of GHG abatement.
  - While the models do not represent benefits, it can be said that as the abatement of GHG emissions increases over time, so do the benefits of the abatement.

Modeling Limitations (con't)

- The models used in this analysis do not incorporate benefit-side effects of reductions in conventional pollutants (SO_2, NOx, and Hg) , such as labor productivity improvements from gains in public health.
  - While this is an important limitation of the models, the impact on modeled costs of the policy is small because S. 280 does not impact overall emissions of conventional pollutants covered by existing cap and trade programs due to the existence of a cap.
- The costs of administering S. 280 (e.g. monitoring and enforcement) are not captured in this analysis.
- Household effects are not disaggregated.
- Both of the CGE models used in this analysis are full employment models.
  - The models do not represent effects on unemployment.
  - The models do represent the choice between labor and leisure, and thus labor supply changes are represented in the models.
- While ADAGE does include capital adjustment costs, capital in IGEM moves without cost.
- IGEM is a domestic model; ADAGE has the capability of representing regions outside of the U.S., which were used to incorporate interactions between the U.S. and Group 1 & 2 countries. For consistency across analyses, international abatement options were generated in the following fashion:
  - We used the MiniCAM model to generate the supply and demand of GHG emissions abatement internationally.
  - For Group 2 countries that are assumed to not have a cap on GHG emissions before 2025, and thus supply mitigation only through certified emissions reductions resulting from project activities, the potential energy related CO_2 mitigation supply is reduced by 90% though 2015, and by 75% between 2015 and 2025.
  - Combining the international demand for abatement from MiniCAM, the domestic demand for offsets determined by the 30% limit on offsets, and the mitigation cost schedules for the various sources of offsets generated by the NCGM, FASOM, GTM, and MiniCAM models, allows us to find market equilibrium price and quantity of offsets and international credits.

Modeling Limitations (con't)

- Since international abatement occurs outside of ADAGE and IGEM, the models do not capture emissions leakage* in this analysis. However, the potential for leakage under S. 280 is somewhat limited if the entire world adopts actions similar to that assumed in the S. 280 Senate Scenario. The potential for leakage under S. 280 is greater if there is less international action.
- The models do not represent bilateral trade, so it is not possible to determine the effect of S. 280 on trade with any particular country or region.
  - Since IGEM is a domestic model, world prices are not affected by climate policies in Group 1 and Group 2 countries. As a result of S. 280, the prices of U.S. exports rise relative to prices in the rest of the world, and export volumes fall. Since exports are price-elastic the volumes fall proportionally more than the price rises and thus the value of exports declines. Imports are reduced in part by the overall reduction in spending associated with the lower levels of consumption. Additionally, commodities directly effected by the emissions cap (e.g. oil) are reduced proportionally more than other imports due to the allowance prices embodied in their cost. Import substitution counterbalances the above two forces. U.S. prices of commodities not directly affected by the policy are relatively higher, which leads to substitution away from domestically produced goods and towards imported goods. To the extent that policies in Group 1 and Group 2 countries increase world prices of affected commodities, the relative price difference between goods produced in the U.S. and goods produced abroad will be lessened. This will reduce impact on exports, and reduce the import substitution effect, both of which are driven by the relative price differential.
  - Since ADAGE is a global model, the climate policies in Group 1 and Group 2 countries affect world prices. As a result the relative price differences between goods produced domestically and abroad are smaller than the differences in IGEM, and thus the relative price driven changes in imports and exports are smaller in ADAGE than in IGEM.

* Emissions leakage occurs when a domestic GHG policy causes a relative price differential between domestically produced goods and imported goods, which causes production of goods that domestically would have GHG allowance prices embodied in their cost to shift abroad, and thus causes an increase in GHG emissions in other countries.

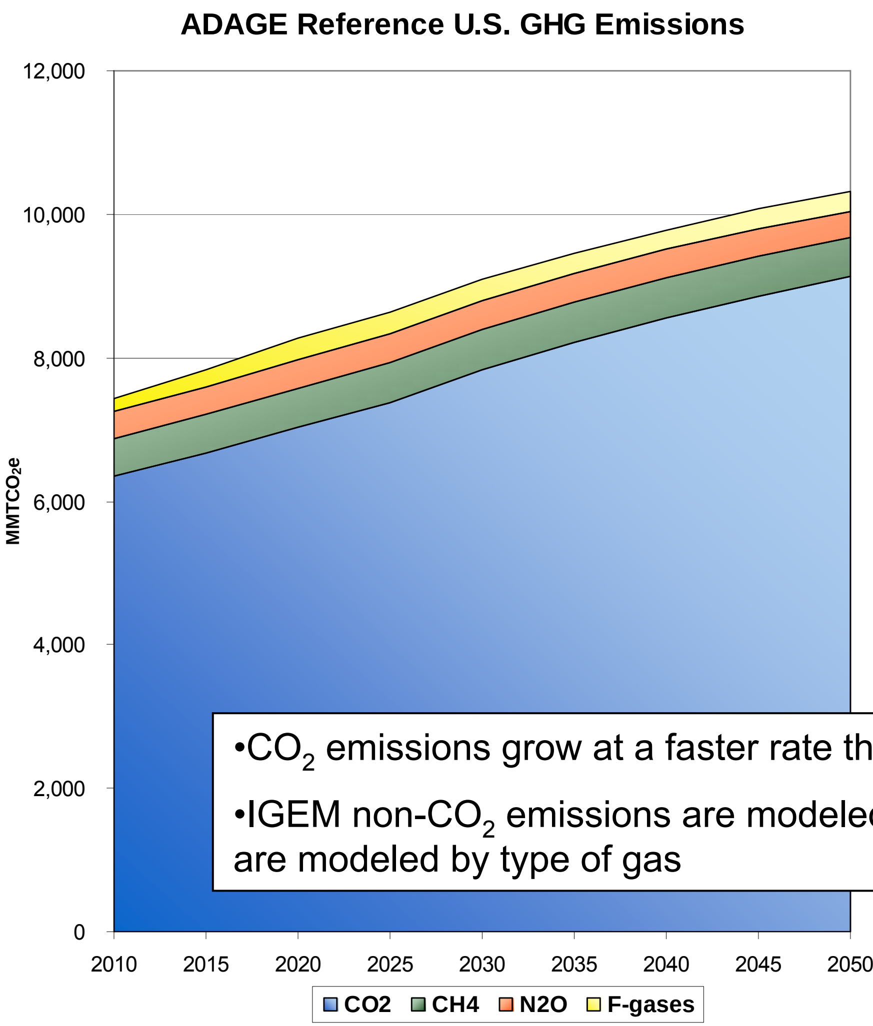
Domestic Offsets & International Credits Methodology Highlights

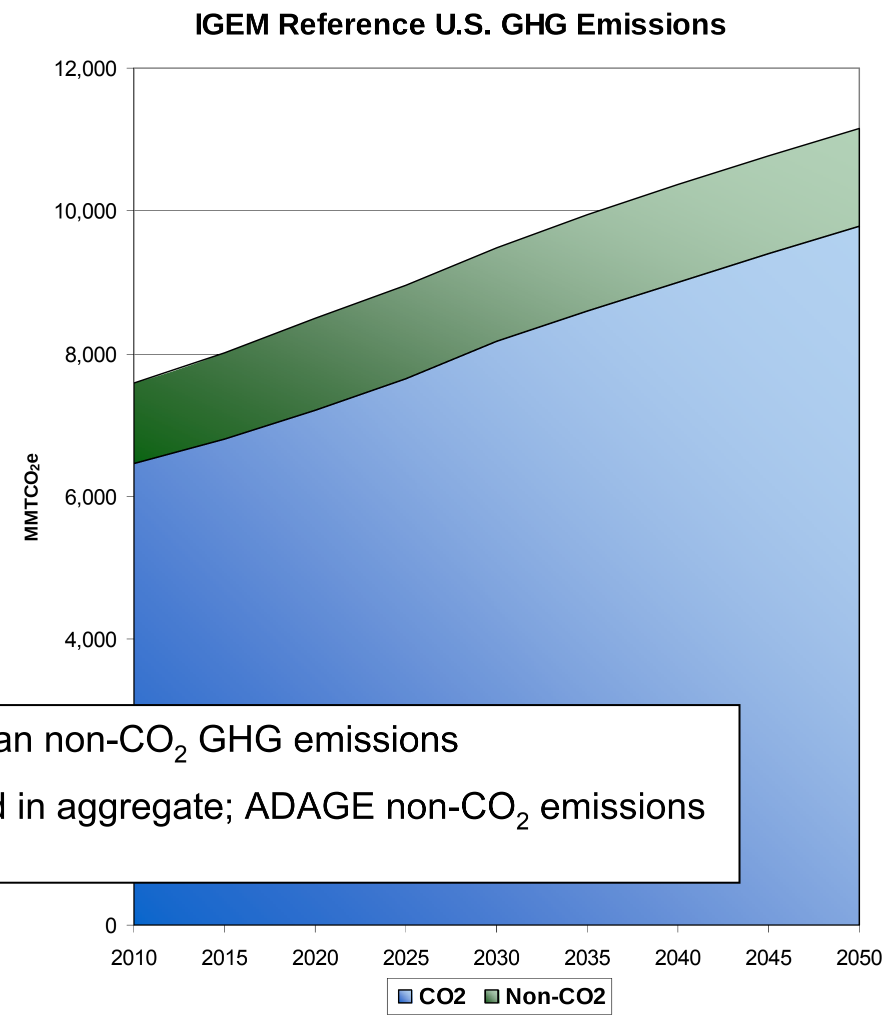
- EPA developed mitigation cost schedules for 24 offset mitigation categories, covering the following mitigation types:
  - Domestic non-CO_2 GHG emissions reductions
  - International non-CO_2 GHG emissions reductions
  - Domestic and international increases in terrestrial carbon sinks (soil and plant carbon stocks)
  - International energy-related CO_2 mitigation

- EPA evaluated individual mitigation options to determine potential eligibility and feasibility over time for a future mitigation program
  - Based on EPA's emissions inventory & mitigation program expertise
    - Considered a broad set of factors, including existing and emerging programs/protocols/tools, monitoring, measurement & verification (MMV), magnitude of potential, additionality, permanence, leakage, and co-effects
  - Options evaluated both domestically, internationally (by region group), and over time
  - Captured responses to rising carbon prices
    - Modeled rising carbon price pathways (vs. constant) to capture investment behavior
    - Applied in three mitigation categories: Domestic agriculture & forestry, international forestry, and international energy-related CO_2
  - Capped sector non-CO_2 and bio-energy emissions reductions are also modeled.

GHG Emissions Results

Results: Reference Scenario

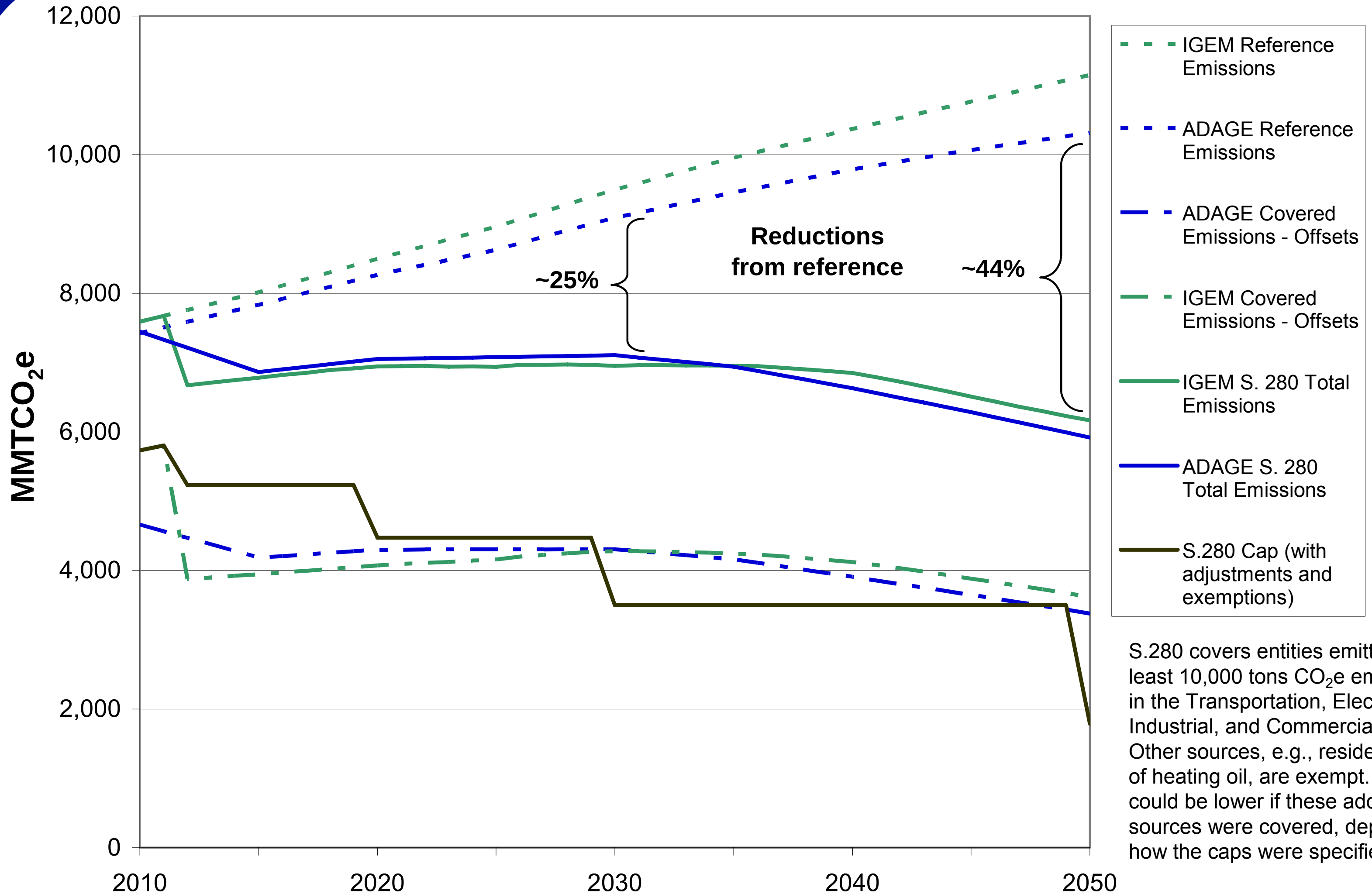




- CO_2 emissions grow at a faster rate than non-CO_2 GHG emissions
- IGEM non-CO_2 emissions are modeled in aggregate; ADAGE non-CO_2 emissions are modeled by type of gas

Results: S. 280 Senate Scenario

U.S. GHG Emissions



S.280 covers entities emitting at least 10,000 tons CO_2e emissions/yr in the Transportation, Electricity, Industrial, and Commercial sectors. Other sources, e.g., residential use of heating oil, are exempt. Costs could be lower if these additional sources were covered, depending on how the caps were specified.

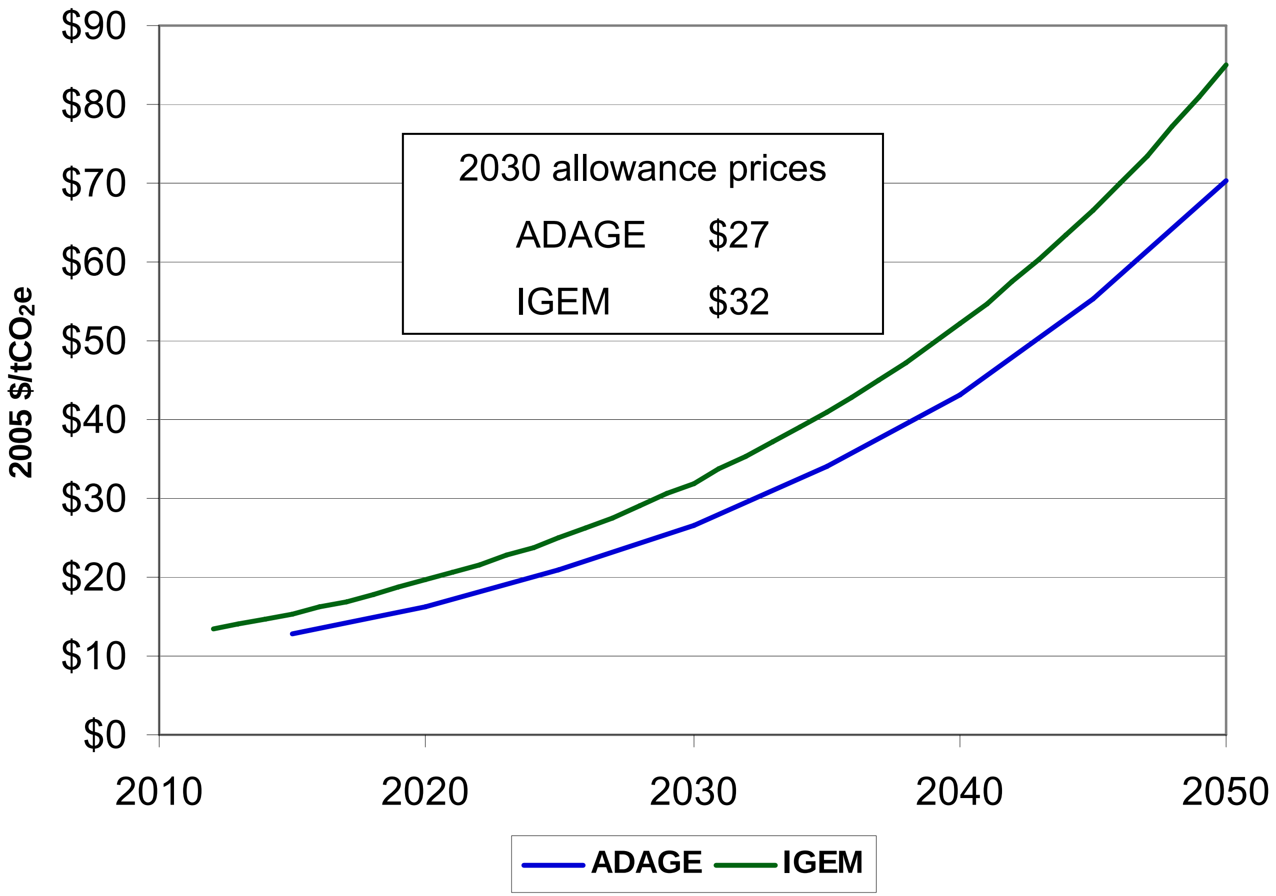
Results: S. 280 Senate Scenario

U.S. GHG Emissions

- The previous chart shows the emissions results of S. 280.
- The two dotted lines at the top are the Reference Scenario emissions of IGEM and ADAGE.
- At the bottom of the chart, the black "stair step" line is the cap on covered sector emissions (note that this cap level is lower than the quantities specified in the bill, as it has been adjusted for uncovered entities).
- The dashed blue and green lines show the emissions of covered sectors, taking into account purchases of offsets and international credits (note that these emissions are equivalent to the total emissions allowed under the cap, but the time path reflects the banking of allowances in the early years, as entities "over comply" to avoid higher allowance prices in later years).
- The solid blue and green lines show total U.S. emissions under S. 280. These levels include emissions from non-covered and exempt entities.
  - In 2030, total U.S. emissions under S. 280 are reduced in IGEM by 2,540 $MMTCO_2e$ from the Reference Scenario (27 percent reduction) and 1,983 $MMTCO_2e$ in ADAGE (22 percent reduction).
  - In 2030, total U.S. emissions under S. 280 are 3% below 2000 levels in IGEM, and 1% below 2000 levels in ADAGE.
  - In 2050, total U.S. emissions under S. 280 are 1% below 1990 levels in IGEM, and 5% below 1990 levels in ADAGE.
- S. 280 results in reductions of non-U.S. GHG emissions through U.S. purchases of international credits, so the bill actually reduces global GHG emissions by more than the solid blue and green lines indicate. The bill results in the purchase of 596 $MMTCO_2e$ of international credits in 2030, which is approximately six percent of the U.S. Reference Scenario emissions.

Results: S. 280 Senate Scenario

GHG Allowance Prices



- The $27 - 30 range of 2030 allowance prices only reflects differences in the models and does not reflect other scenarios or additional uncertainties discussed elsewhere.

Comparison with Other Analyses

- The recent MIT report, “Assessment of U.S. Cap-and-Trade Proposals” analyzed several scenarios, none of which directly corresponded to S. 280.
- For comparison, we ran one of the MIT scenarios (203 bmt) with the ADAGE model.
- For the 203 bmt scenario, the MIT analysis gave an allowance price of $41 in 2015 rising at 4%, while the ADAGE model gave a price of $40 in 2015 rising at 5%.

Results: S. 280 Senate Scenario

GHG Allowance Prices

- The previous chart shows the allowance prices from ADAGE and IGEM under S. 280.
- The allowance price is equal to the marginal cost of abatement in the U.S.
- S. 280 allows the banking of allowances, as a result the allowance prices in both models grow at the exogenously set 5% interest rate.
  - If instead the allowance price were rising faster than the interest rate, firms would have an incentive to increase abatement in order to hold onto their allowances, which would be earning a return better than the market interest rate. This would have the effect of increasing allowance prices in the present, and decreasing allowance prices in the future. Conversely, if the allowance price were rising slower than the interest rate, firms would have an incentive to draw down their bank of allowances, and use the money that would have been spent on abatement for alternative investments that earn the market rate of return. This behavior would decrease prices in the present and increase prices in the future. Because of these arbitrage opportunities, the allowance price is expected to rise at the interest rate.
- The terminal year for banking is assumed to be 2050 in this analysis. If later terminal year for banking was used instead, or if the terminal year for banking was endogenously determined, the allowance prices and costs of the policy would be higher, as a non-zero bank of emissions in 2050 would imply greater total emissions reductions.
  - A terminal ear for banking of 2050 ensures that the cumulative covered emissions less offsets over the time period from 2012 – 2050 are equal to the cumulative emissions allowed under the cap. An assumption about the terminal year for banking is required for the models used in this analysis, and the assumption of 2050 is consistent with the time horizon of the models. If the terminal year for banking were not fixed, we would expect an increase in the allowance price beginning in 2012, so that in whichever year the bank of allowances is exhausted, the allowance price would not have to increase more than the usual 5% in order to meet the cap. The 2050 terminal year for banking used in this analysis is consistent with the treatment of banking through 2050 in the recent MIT report, “Assessment of U.S. Cap-and-Trade Proposals”.
- IGEM runs in annual time steps, so the policy is implemented in 2012. ADAGE runs in 5 year time steps, so the policy is implemented in 2015.
- Note that the range of allowance price presented here simply represents the results of the two models and should not be interpreted as a confidence interval.

Scenario Comparison

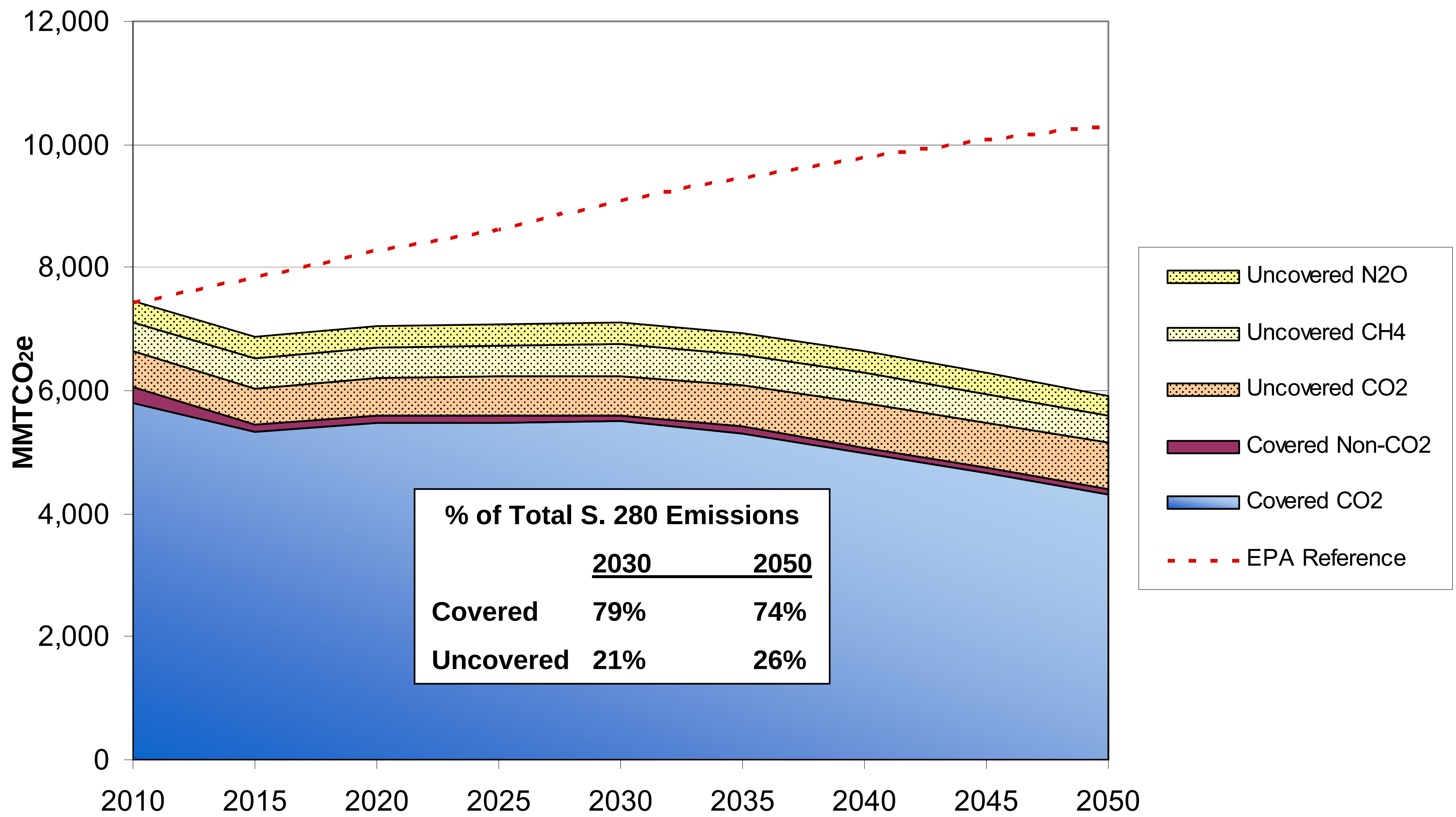
GHG Allowance Prices

Table: Allowance Price Comparisons (2005 $/tCO2e)

	2015	2020	2025	2030	2035	2040	2045	2050
2) S. 280 Senate Scenario								
ADAGE	$13	$16	$21	$27	$34	$43	$55	$70
IGEM	$15	$20	$25	$32	$41	$52	$67	$85
3) S. 280 Scenario with Low International Actions								
ADAGE	$13	$16	$21	$27	$34	$43	$55	$70
IGEM	$15	$20	$25	$32	$41	$52	$67	$85
4) S. 280 Scenario Allowing Unlimited Offsets								
ADAGE								
IGEM	$10	$13	$16	$21	$26	$34	$43	$55
5) S. 280 Scenario with No Offsets								
ADAGE								
IGEM	$40	$51	$65	$82	$105	$134	$171	$219
6) S. 280 Scenario with Lower Nuclear Power Generation								
ADAGE	$14	$17	$22	$28	$36	$46	$58	$74
IGEM								
7) S. 280 Scenario with No Carbon, Capture & Storage Technology								
ADAGE	$19	$25	$31	$40	$51	$65	$83	$105
IGEM								

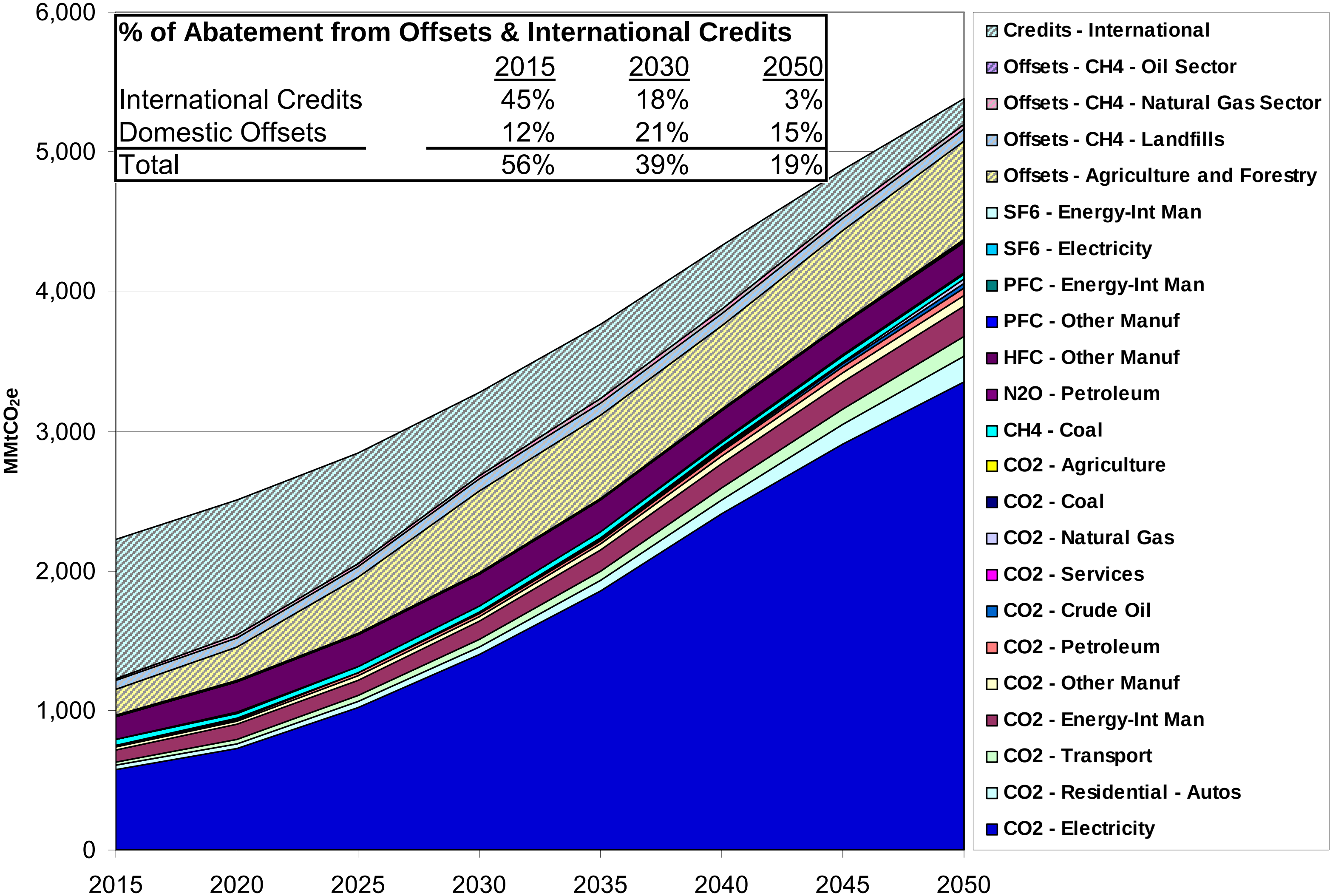
Results: S. 280 Senate Scenario

Total U.S. GHG Emissions (ADAGE)



Results: S. 280 Senate Scenario

Sources of GHG Abatement (ADAGE)



% of Abatement from Offsets & International Credits	2015	2030	2050
International Credits	45%	18%	3%
Domestic Offsets	12%	21%	15%
Total	56%	39%	19%

- S. 280 allows offsets and international credits to make up 30% of the total allowance submissions requirement.
- The quantity of offsets allowed decreases as allowance submissions decrease.
- Since the quantity of offsets allowed is decreasing over time and the quantity of abatement is increasing over time, offsets make up a large fraction of abatement in the early years of the policy, and there contribution to total abatement decreases over time.

Results: S. 280 Senate Scenario

Sources of GHG Abatement (ADAGE)

- The previous chart shows the sources by sector of GHG abatement under S. 280.
- CO_2 emissions from the electricity sector (the blue area at the bottom) represent the largest source of domestic reductions.
- The area toward the top of the chart shaded with hashed lines show emissions reductions from non-covered sectors (offsets) and international credits.
- International credits (the hashed area at the very top) are the largest source of abatement in 2012, but decrease in absolute and percent terms through time as the rising price of offsets increase the domestic supply of offsets, which displace the demand for international credits.
- Among domestic offsets, the agricultural and forestry sector (the yellow hashed area) supplies the most abatement, and this supply increases through time.
- Commercial transportation and personal vehicles (“residential autos”) are represented by the solid light blue and green areas above the electricity sector. Note that ADAGE does not explicitly model new developments in transportation technologies – these reductions occur in the model due to the price changes resulting from the imposition of the upstream cap on emissions from the petroleum sector.
- Since the electricity sector plays a key role in GHG abatement and the CGE models have a limited representation of technology, we used the IPM model to examine the electricity sector in more detail through 2025.

Detailed Near-Term Electricity Sector Modeling Results

Detailed Electricity Sector Modeling with IPM

Motivation for Using IPM:

- The CGE models used for this analysis do not have detailed technology representations; they are better suited for capturing long-run equilibrium responses than near-term responses.
- Since the electricity sector plays a key role in GHG mitigation, and the near-term response in the electricity sector is of particular interest, we have employed the Integrated Planning Model (IPM) model to shed further light on the near-term impact of S. 280 on the electricity sector as a complement to the broader picture presented by the CGE models.

Power Sector Modeling (IPM v3.01):

- IPM is a detailed, least-cost power plant dispatch and emissions forecasting model used by EPA. The model assumptions incorporate the best available information and undergo stakeholder comment.
- This version builds off recently released EPA Base Case v3.0 using IPM, w/ the following updates for purposes of modeling carbon policies:
  - Carbon capture and storage (for new and existing plants)
  - Biomass co-firing retrofit option
  - Constraints on new nuclear and renewable capacity builds

Modeling Approach:

For this analysis, EPA's Base Case v3.01 using IPM was used and incorporated two sets of data from the ADAGE model:

- CO_2 allowance price projections
- Percent change in electricity demand

Key Insights from IPM Results for the Near Term

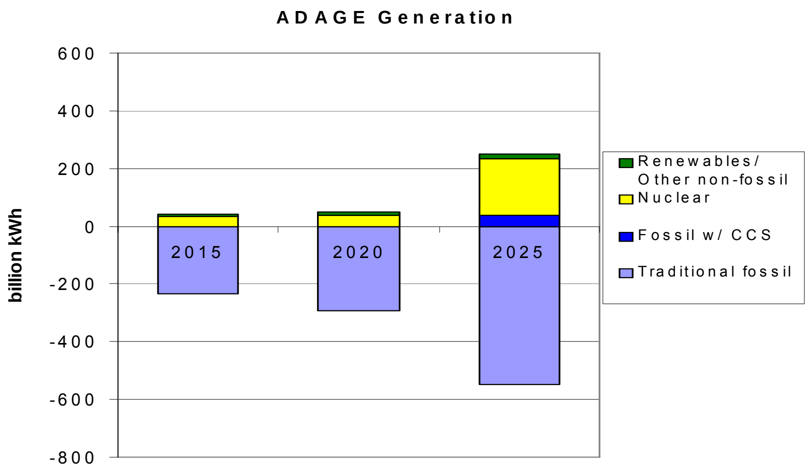
- The reduced demand levels provided by ADAGE produce the largest share of reductions in the early years.
- GHG allowance prices (at the projected levels of S. 280) will not be high enough to justify significant penetration of carbon capture and storage technology (CCS) in the near-term; however, the carbon price incurred by various emitting technologies (e.g., coal) makes new nuclear plants more economic to build.
- S. 280 does not impact overall emissions of conventional pollutants (SO_2, NOx, and Hg) covered by existing cap and trade programs (because of the existence of a cap), but can change the timing of emission reductions.
- Allowance allocation methodology can impact retail electricity prices (and thus the magnitude of demand-side response).
  - In 2025 electricity prices increase between 10 and 16 percent depending upon the allowance allocation methodology.
- In the near-term, most existing conventional coal plants continue to operate at the projected allowance prices of S. 280, although they will be less profitable and some less efficient plants do retire (about 2.2% of existing capacity).

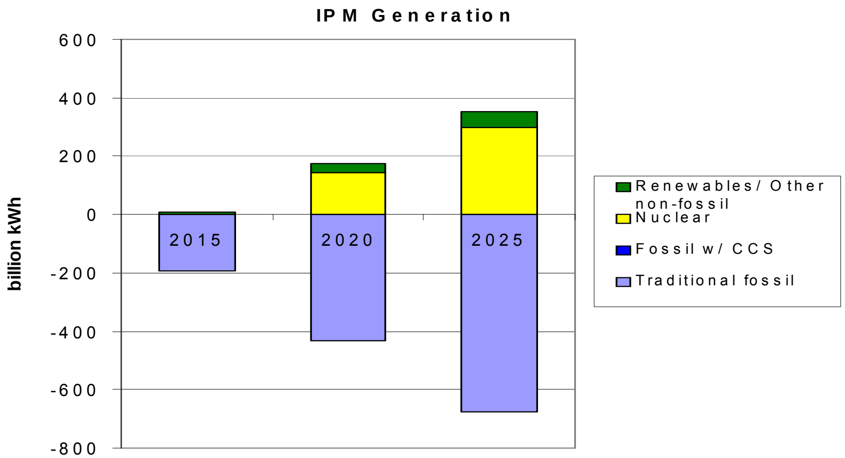
Change in generation in IPM and ADAGE is similar in 2015 through 2025

- In 2015 decreased demand in fossil fuel use compared to the reference case is consistent with the decrease in overall electricity demand.

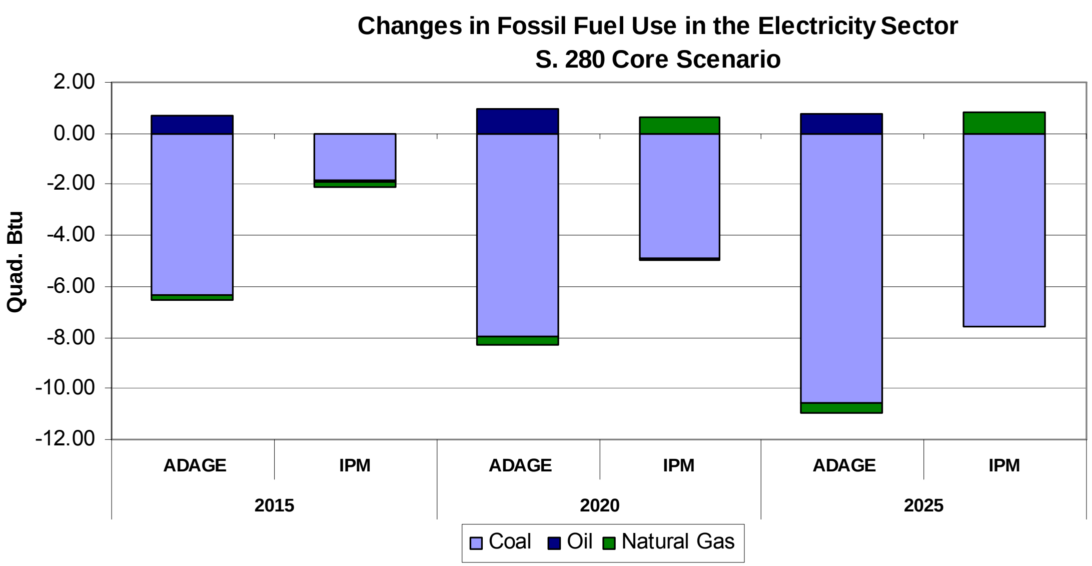
- In 2020, projected decreased fossil fuel use from the IPM run results from a combination of both decreased generation and increased non-fossil generation. In ADAGE, it is more because of decreases in overall generation.

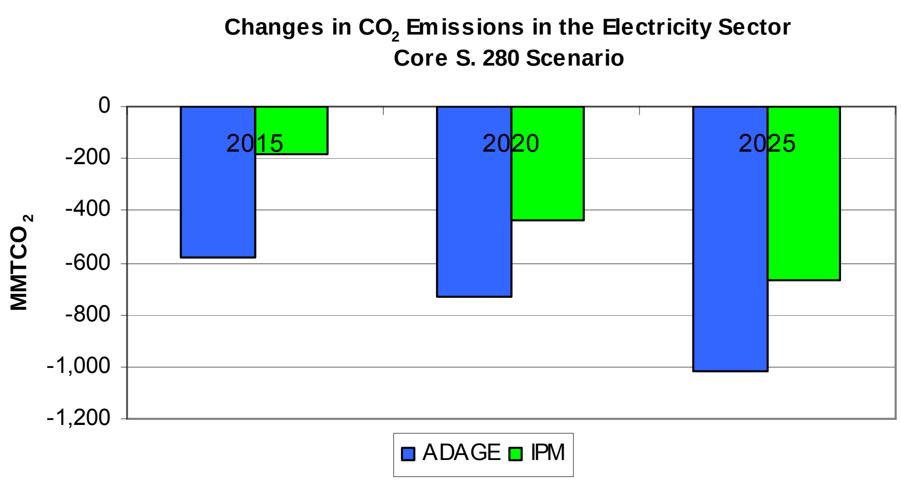
- By 2025, decreased demand in fossil fuel use is due to both decrease in overall electricity demand and increase in non-fossil generation.





Changes in Fossil Fuel Use and CO_2 Emissions



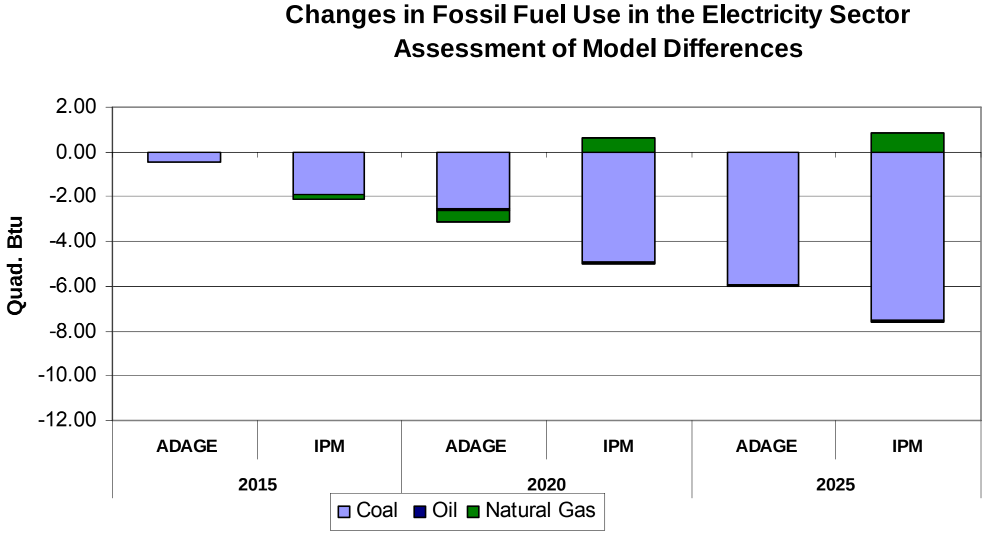


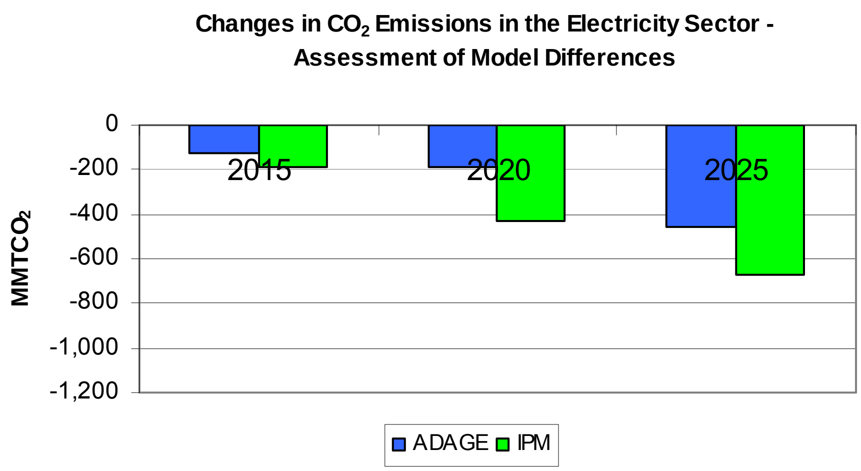
- While IPM has slightly greater reduction in fossil generation, it has less reduction in electricity sector fossil fuel use compared to ADAGE.
- This results in fewer CO_2 reductions in IPM than in the electricity sector in ADAGE.

Changes in Fossil Fuel Use and CO_2 Emissions

- CO_2 changes in ADAGE and IPM are not exact due to differences in:
  - Analysis time frame:
    - In IPM, the electricity sector responds to allowance prices out to 2030.
    - In ADAGE, the electricity sector responds with perfect foresight to allowance prices out to 2050.
  - Model detail, structure, and coverage:
    - IPM is a detailed bottom-up electricity sector model.
    - ADAGE is an economy-wide top-down model that does not model the electricity sector in detail.
  - Modeling technological change, including heat rate improvements:
    - IPM models details of the existing capital structure of the electricity sector, which inhibit quick fuel switching responses and capital turnover.
    - The modeling approach to the electricity sector in ADAGE is based on the MIT EPPA model. The elasticity that allows for efficiency improvements in ADAGE is slightly more flexible than MIT and less flexible than Charles River Associates MRN model.
- Since the IPM and ADAGE models show significantly different near-term CO_2 changes in the electricity sector, we evaluated the effect of this difference on the economy-wide impact of S. 280.

Assessment of Model Differences on Economic Impacts of S. 280



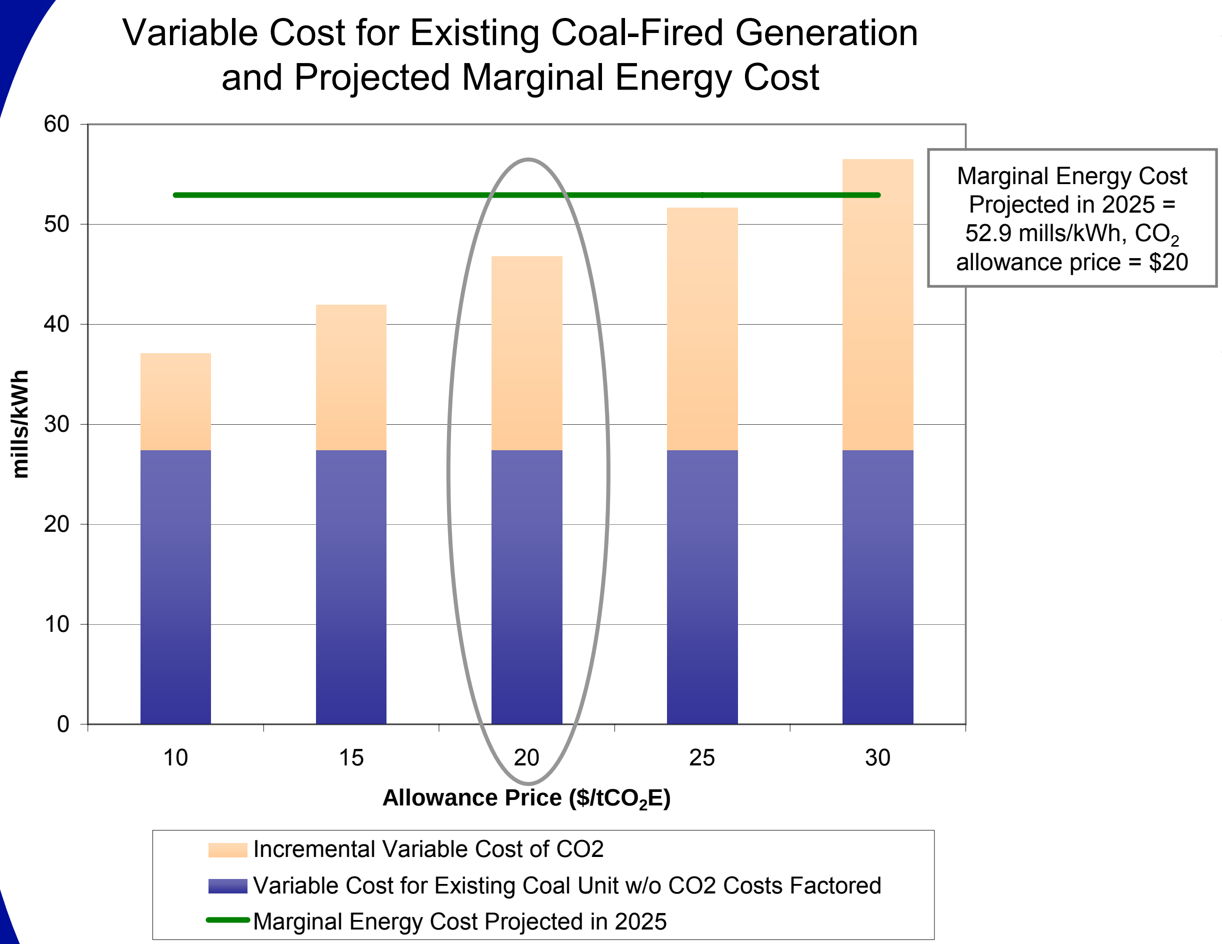


- This assessment provides an estimate of the effect of the differences between IPM and ADAGE on allowance prices.
- The most appropriate way to evaluate the impacts of the model differences, given the CGE structure of ADAGE, was to approximate the near-term IPM electricity sector CO_2 emission abatement in ADAGE.

<u>Results of Assessment</u>

- The resulting allowance price in 2015 was approximately \$1.50 higher than in the S. 280 Senate Scenario, and \$3 higher in 2030.
- In 2030 the GDP effect is 0.06 percentage points (\$16 billion) greater than in the S. 280 Senate Scenario.
- These differences are smaller than the differences between the results of the two CGE models in the S. 280 Senate Scenario.

Near-Term Coal Usage

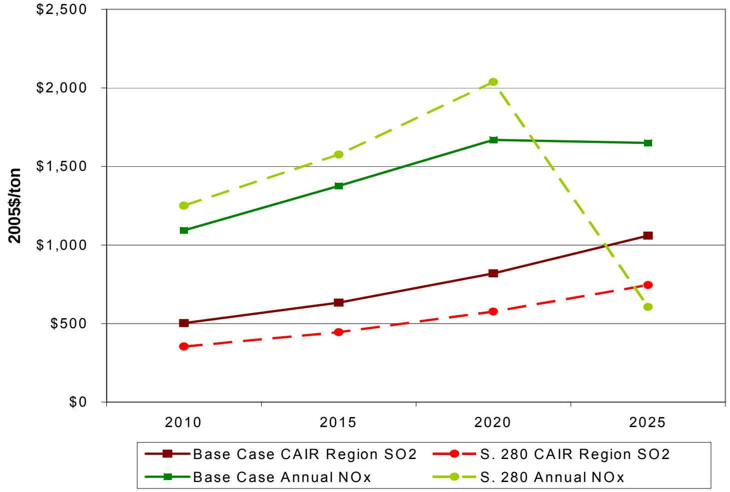


- To illustrate the economics of operating existing coal plants, the chart shows the incremental operating cost of a coal plant when the projected CO_2 allowance prices are included.
- Projected CO_2 allowance prices of roughly $20 ton in 2025 increase variable costs, but these costs are still below the marginal energy costs of producing electricity.
- Although cost of producing electricity form coal would significantly increase, most plants would not retire in the near-term since the variable cost of producing electricity is less than the marginal energy cost.*

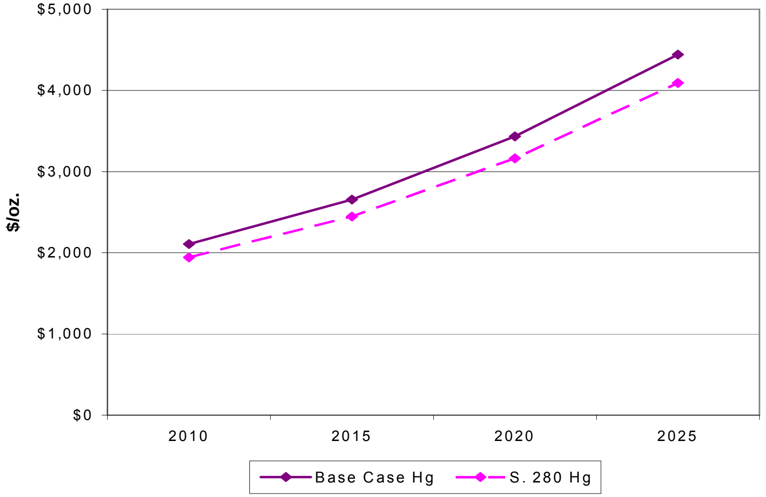
* For this illustrative calculation, EPA used a conservative efficiency metric (11,000 Btu/kWh), at which roughly 85% of existing coal plants currently operate or exceed, by capacity. EPA also assumed that the illustrative existing unit does not have advanced pollution controls for SO_2, NOx, or Hg removal (must purchase allowances), and the unit burns lower-sulfur coal. The marginal energy cost is defined as the cost of production of the most expensive unit operating in that hour. It includes the cost of fuel, variable O&M cost and the cost of environmental allowances.

CAIR and CAMR Allowance Prices Comparison

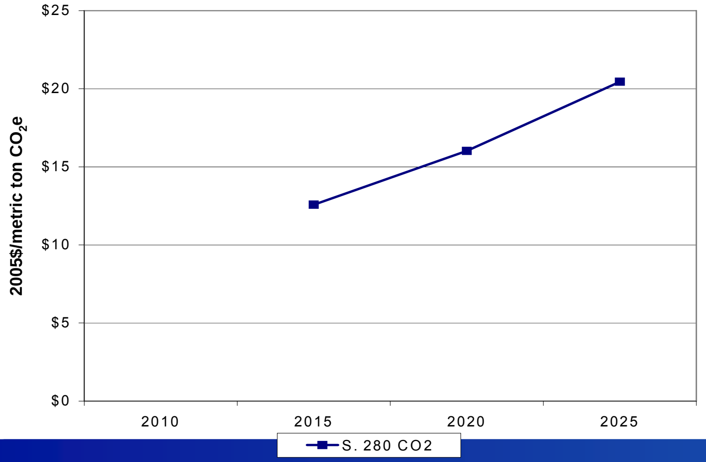
Projected Allowance Price of SO_2 and NOx under CAIR



Projected Allowance Price of Hg under CAMR



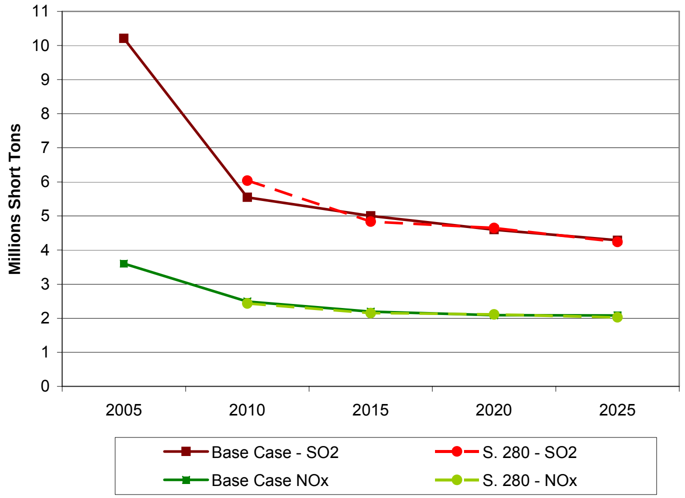
Projected Allowance Price of CO_2 (inputs to IPM)



Note: SO_2 allowance prices are for CAIR affected sources on a $/ton of emissions basis; Title IV allowance prices are not shown separately, but would be a fraction of this amount. The CO_2 allowance price is an input to IPM.

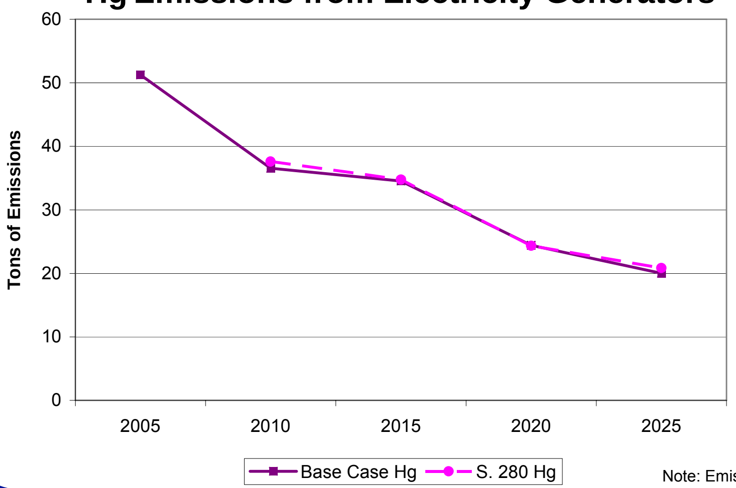
Power Sector Emissions

SO_2 and NOx Emissions from Electricity Generators

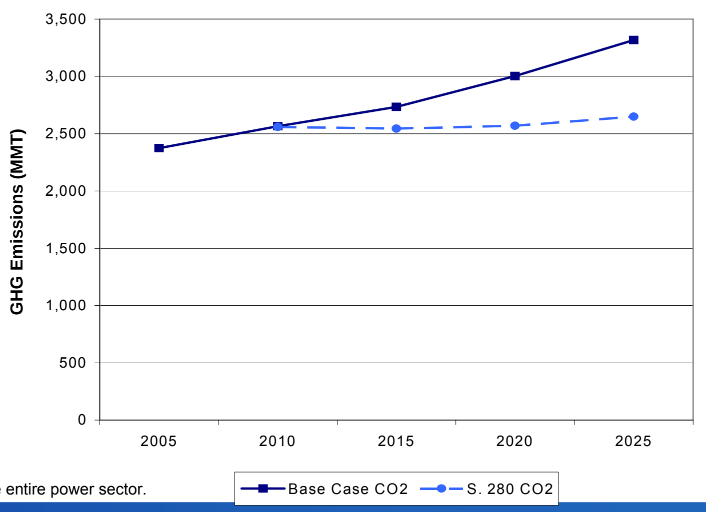


- CO_2 allowance prices projected in S. 280 influence the timing of SO_2 and Mercury emissions because of existing cap and trade programs and emission banking provisions of the CAIR and CAMR programs.

Hg Emissions from Electricity Generators

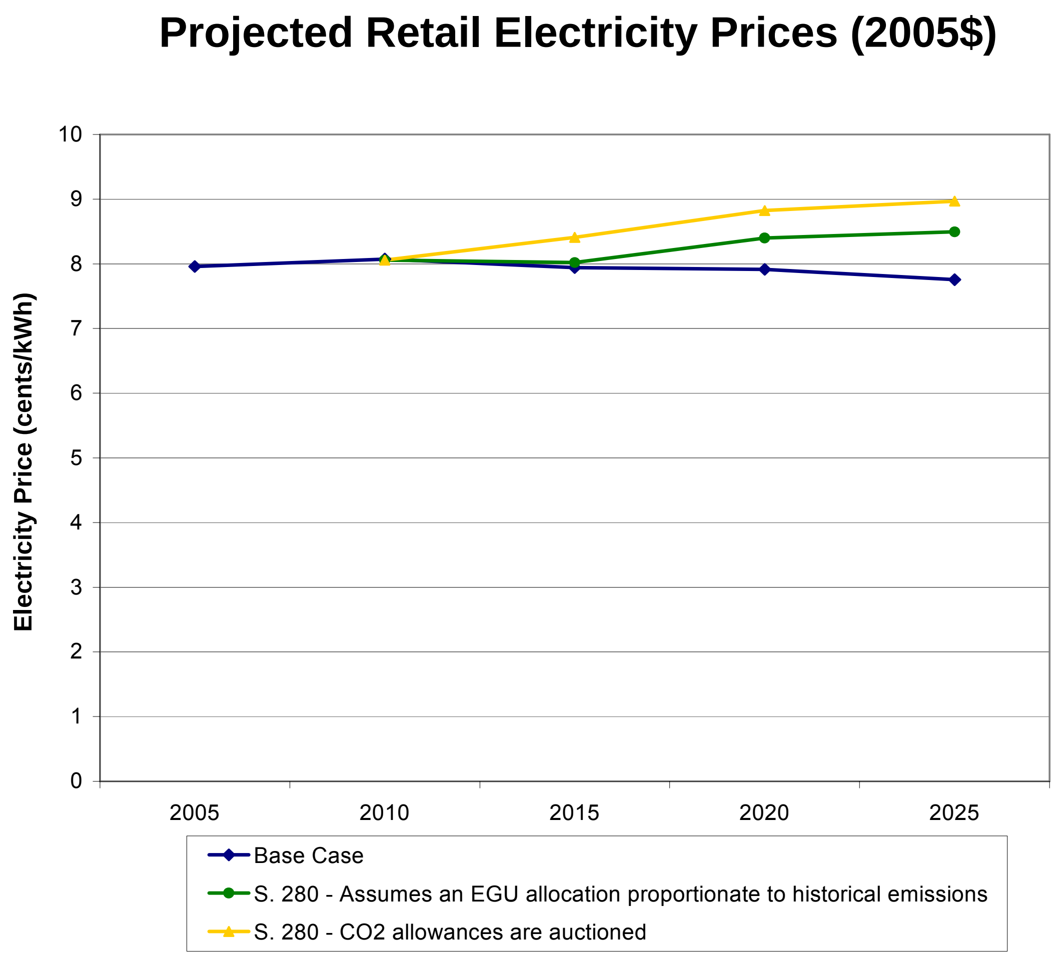


GHG Emissions from Electricity Generators



Note: Emission shown here are for the entire power sector.

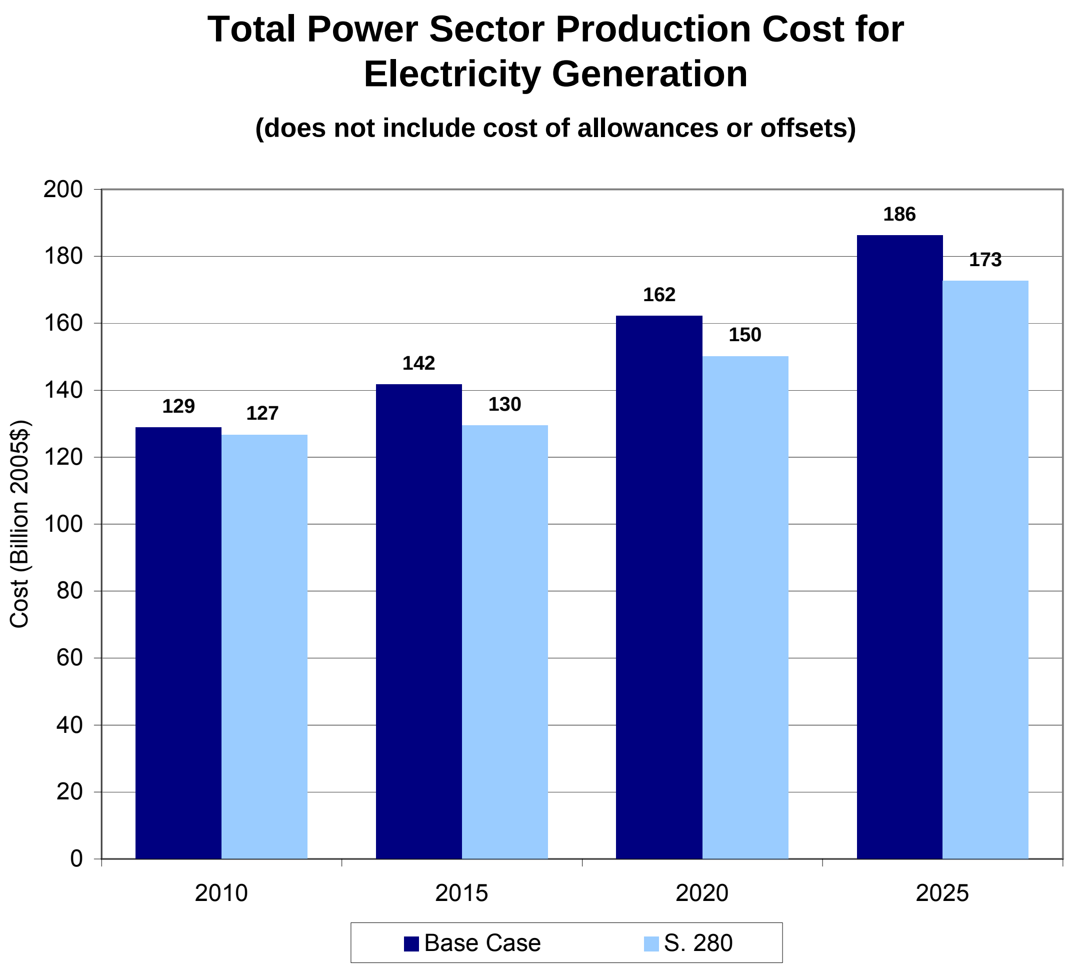
Projected Retail Electricity Prices



- This slide presents the average national impact. Regional impacts will vary.
- Because regulated utilities generally do not pass through cost of allowances that are allocated, the allocation methodology will have an impact on retail electricity price (and demand response).
- Regions with deregulated electricity markets (which represents about 1/3 of total generation) will see the similar price impacts which will be more similar to an auction, regardless of the allocation methodology.

Notes: 2005 data from EIA. For illustrative purposes, EPA made an assumption as to the allocation for the power sector to demonstrate the effect on retail electricity prices. S. 280 does not specify an allocation methodology.

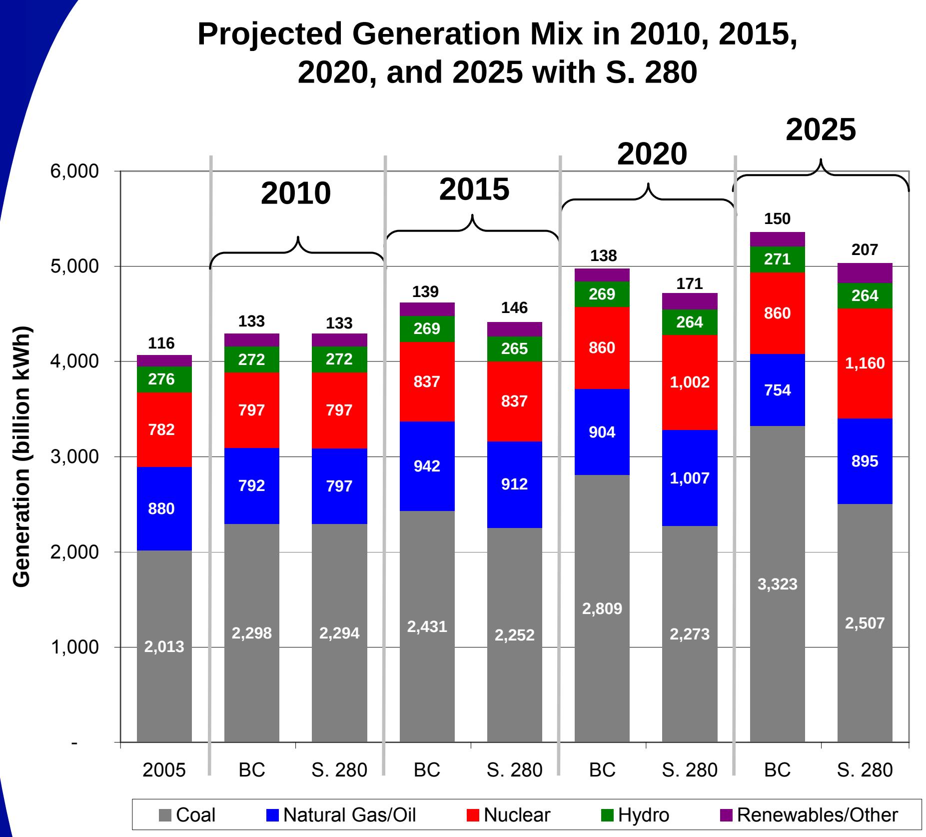
Generation Costs to Electricity Sector



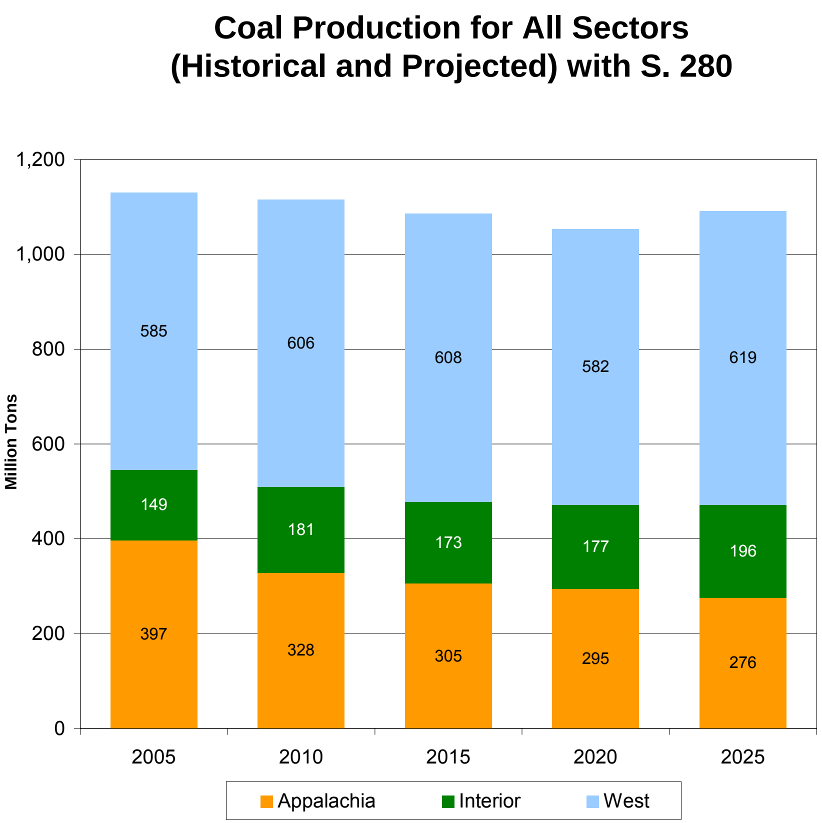
The production cost, as reported in IPM, is the cost of meeting electricity demand and includes the annualized capital costs of new investment decisions (includes control equipment costs and new plant costs), fuel costs, and the total variable and fixed operation and maintenance (O&M) costs of power plants.

- The graphic at left shows a comparison of generation costs for the electricity sector to meet lower demand using different electric generation mix in response to S. 280.
- There will be costs and savings in other segments of the economy that lower electric demand in various ways (e.g., purchase of more efficient appliances).
- There will be shifts in capital investment in generation capacity (e.g., movement from new coal capacity to nuclear).

Electricity Generation Mix and Coal Production

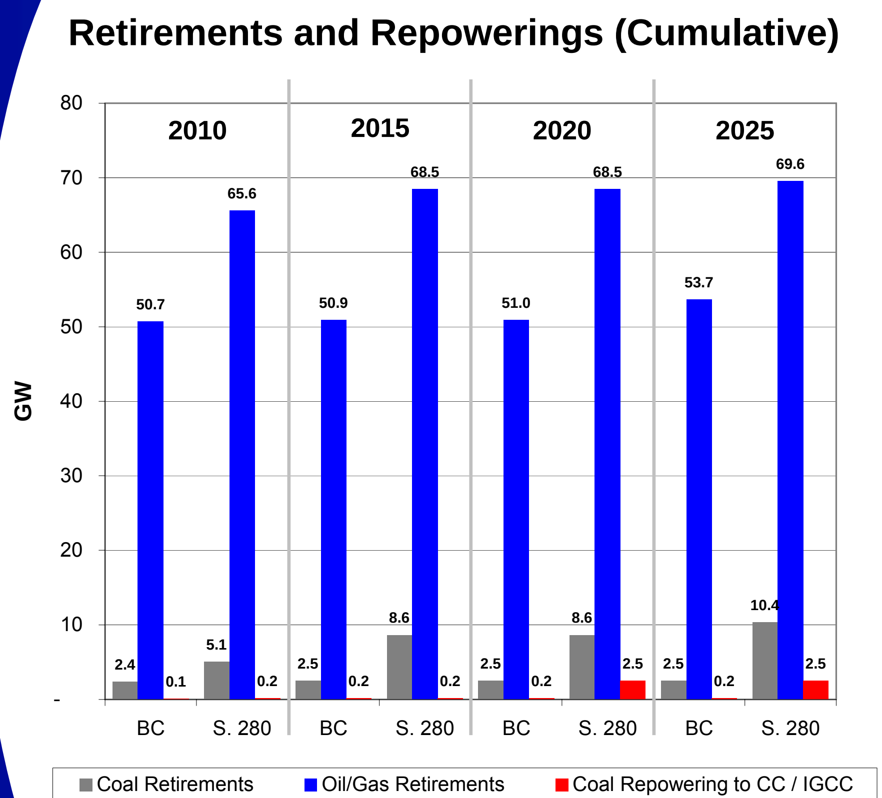


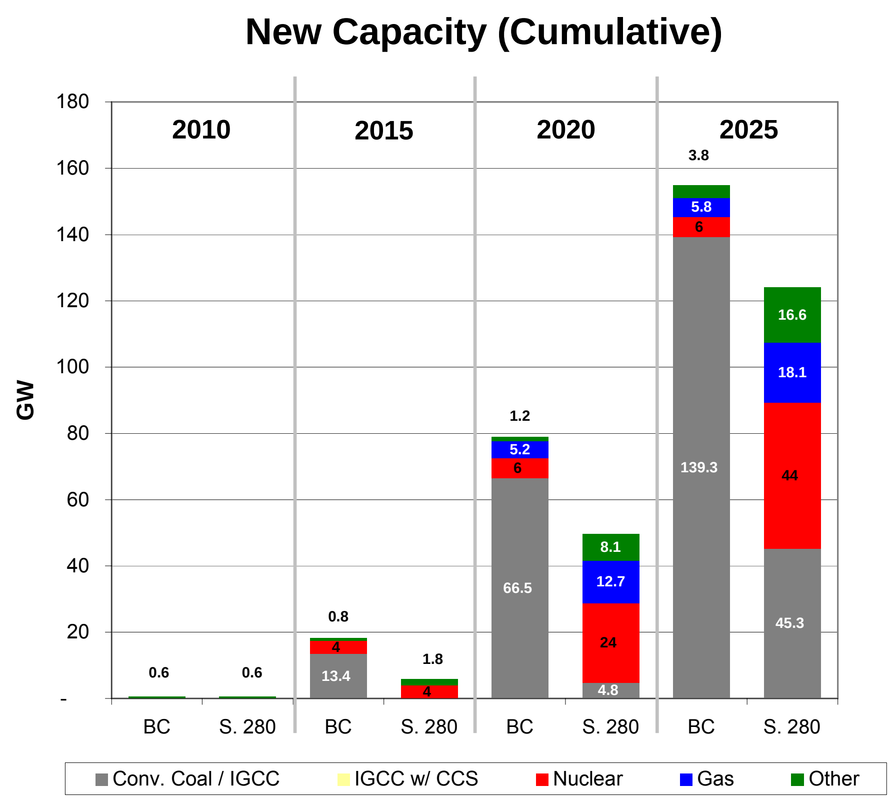
Note: 2005 data from EIA. Electricity demand is an input to IPM. Electricity demand for S. 280 was developed by taking the percent change in electricity demand from EPA's economy-wide model(s) and applying that change to the IPM base case electricity demand.



Note: 2005 data from EIA.

Retirements, Repowering, and New Capacity





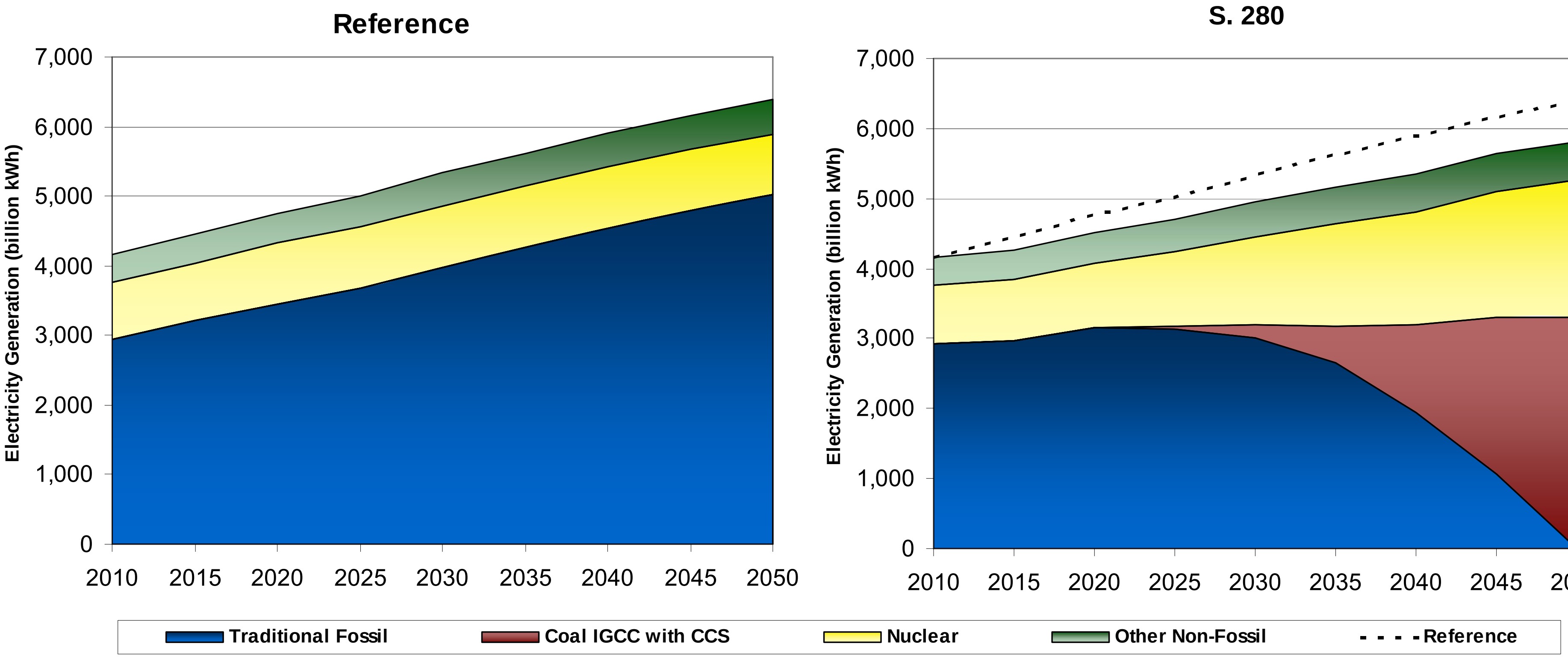
IPM Modeling Limitations

- IPM model timeframe only goes through 2025.
  - Model does not see longer term changes in electricity demand and CO_2 allowance prices (due to lowering of the cap post-2025).
  - This can affect projections for new capacity additions and retrofit decisions in later years.
- The “cost” of demand response as currently implemented is not captured by IPM.
- In this analysis, electricity demand was an input to IPM. Hence, the impacts of likely complementary state and federal policies on other sectors that could affect electricity demand are not modeled.
- EPA’s Base Case v3.01 does not incorporate several technological innovations that can become available over time (e.g., ultra-supercritical coal, advanced renewables).
- The recent labor/material shortfalls on future construction prices and the timing of power system adjustments have not been modeled.
- Geographic deployment, cost and performance of CCS is highly uncertain.
- Allowance allocation and auctioning are not fully accounted for in the modeling.
- While IPM endogenously builds new nuclear capacity, the model places an exogenous constraint on the total amount of new nuclear capacity builds. The assumed limitations on new nuclear capacity reflect the recent EPRI analysis “Electricity Technology in a Carbon-Constrained Future”.
  - There are non-economic considerations for significant expansion of nuclear power capacity which are not reflected in IPM.

Energy Sector Modeling Results

Results: S. 280 Senate Scenario

U.S. Electricity Generation, mid-term results (ADAGE)



Note: Other non-fossil includes hydro, geothermal, wind, solar, biomass and municipal solid waste.

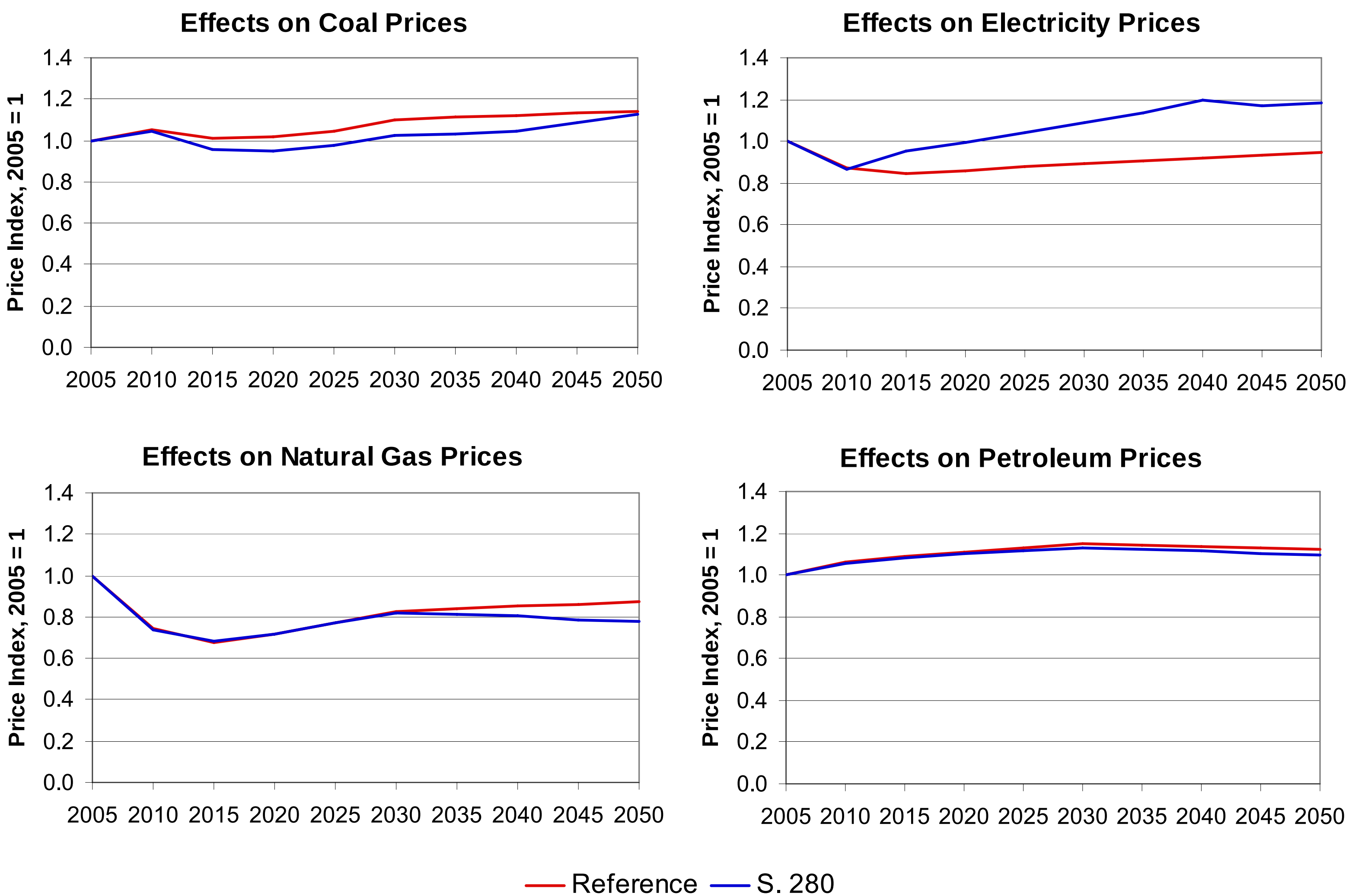
Results: S. 280 Senate Scenario

U.S. Electricity Generation, mid-term results (ADAGE)

- Electricity generation grows at a slower rate under S. 280 due to efficiency gains and reduced consumption.
- Generation technology mix shifts towards non-GHG-emitting technologies such as nuclear and CCS.
- By 2030 advanced coal with CCS begins to deploy and by 2050 CO_2 emissions from all fossil-fuel generated electricity are being captured and stored. This result is similar to the recent MIT report, "Assessment of U.S. Cap-and-Trade Proposals."
- Cost assumptions for transportation and storage of CO_2 are based on the Battelle 2006 report "Carbon Dioxide Capture and Geologic Storage." Capture costs are based on AEO 2006 assumptions.
- Nuclear generation increases by ~150% by 2050 based on exogenous assumptions from the U.S. CCSP Synthesis and Assessment Report 2.1a (MiniCAM Level 1 Scenario), which are consistent with the IPM nuclear assumptions.

Results: S. 280 Senate Scenario

Fuel Prices (ADAGE)



Results: S. 280 Senate Scenario

Fuel Prices (ADAGE)

- The S. 280 electricity price reflects the full allowance price the consumer would face.
- S. 280 electricity prices are 22% higher than in the Reference Scenario in 2030 and 25% higher in 2050, reflecting a shift in fuel mix from coal to gas in the earlier years, the adoption of carbon capture and storage technology in later years, and the increased prices the consumers of coal and gas face due to the price of allowances.
- For coal, natural gas, and petroleum, the price effect of S. 280 before adding in the allowance price is shown. This is the price producers of these fuels would face.
- Coal prices in the S. 280 Senate Scenario are lower than the Reference Scenario by 7% in 2030, reflecting decreased demand for coal in the earlier years as fuel switching to natural gas occurs in response to S. 280. As carbon capture and storage technology deploys from 2030 to 2050, coal prices rise back to the Reference Scenario levels in response to increased coal demand.
- Lower demand for fossil fuel drives petroleum and natural gas prices lower than in the Reference Scenario.

Results: S. 280 Senate Scenario

Fuel Price Adders

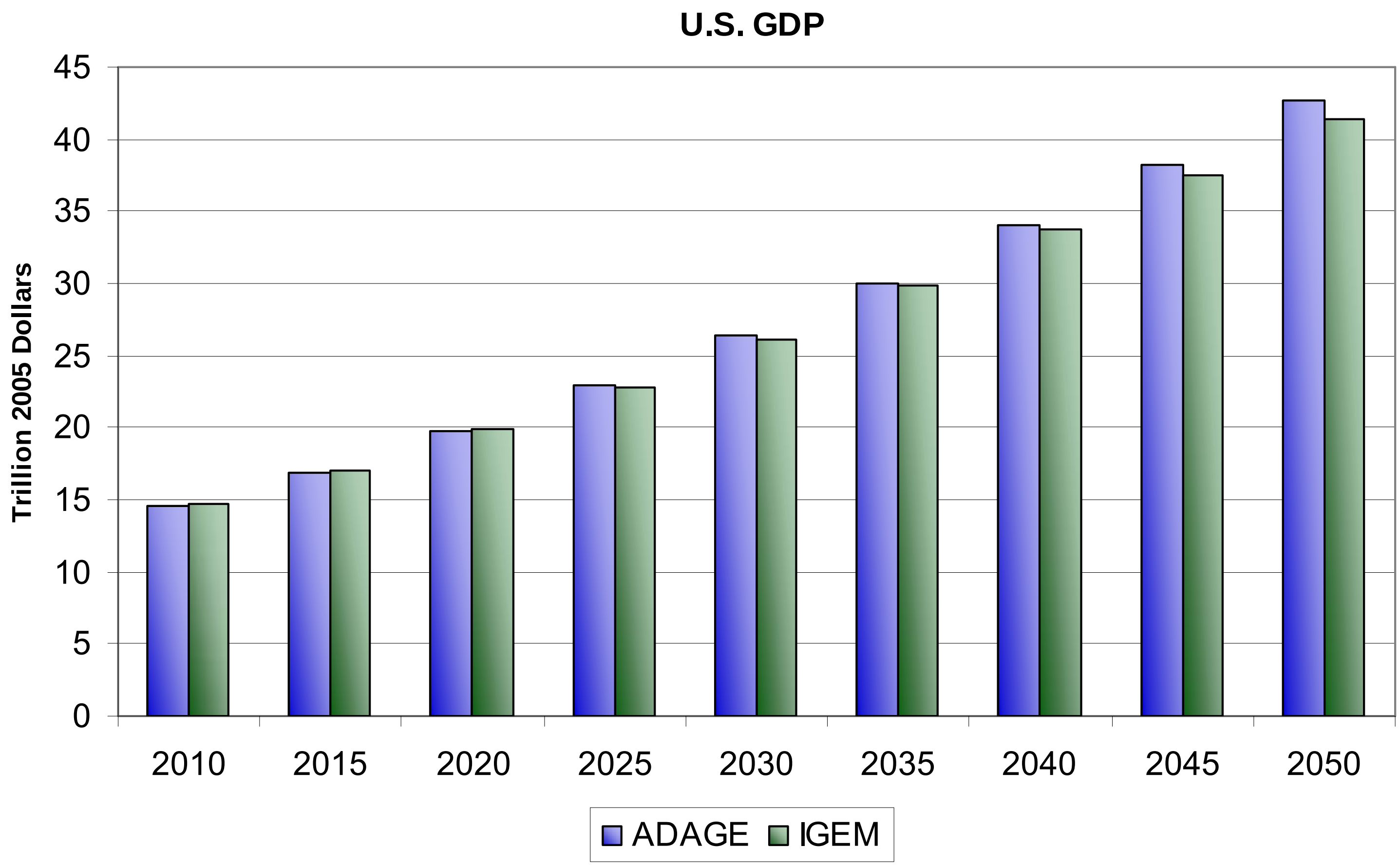
		2030		
	2005 Price	Producer Price	Cost of Carbon Content	End - User Price
Metric Ton of CO_2	n/a		$29.30 *	
Metric Ton of Carbon	n/a		$107.44	
Barrel of Oil	$50.28	$56.92	$12.54	$69.46
Gallon of Gasoline	$2.34	$2.65	$0.26	$2.91
Short Ton of Coal	$36.79	$37.70	$64.77	$102.47
Short Ton of Coal w/ CCS	$36.79	$37.70	$6.48	$44.18
tCf of Natural Gas	$7.51	$6.16	$1.59	$7.75

* Average of ADAGE and IGEM allowance prices

- The 2030 price is obtained by multiplying the 2030 index price in ADAGE by the 2005 price from EIA's 2006 Monthly Energy Review.
- The cost of carbon content is simply the product of the physical carbon content of the fuel and the allowance price.
- The consumer price is simply the sum of the price and the cost of carbon content.
- CCS technology for coal fired power generation captures and stores 90% of carbon emissions, which lowers the cost of carbon content by 90%, and lower the consumer price accordingly.
- The cost of the carbon content increases the price of gasoline by 9%, increases the price of oil by 20%, increases the price of natural gas by 23%, increases the price of coal by 156%, and increases the price of coal used with CCS by 16%.

Economy-Wide and Sectoral Modeling Results

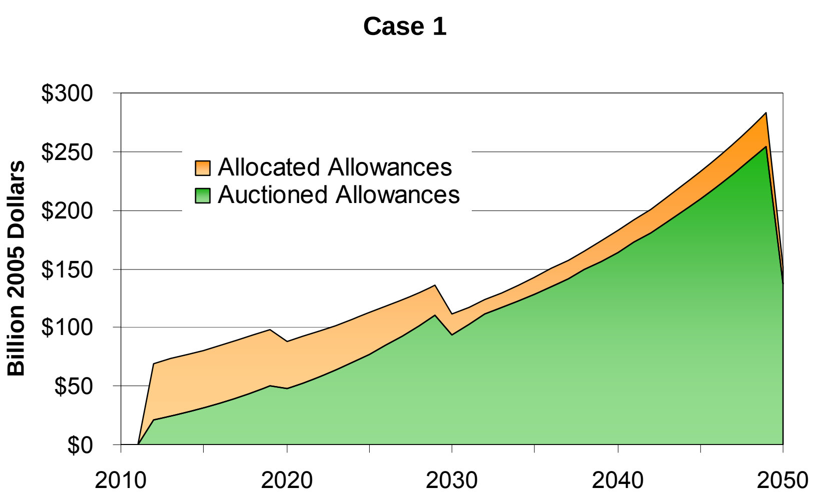
Results: Reference Scenario

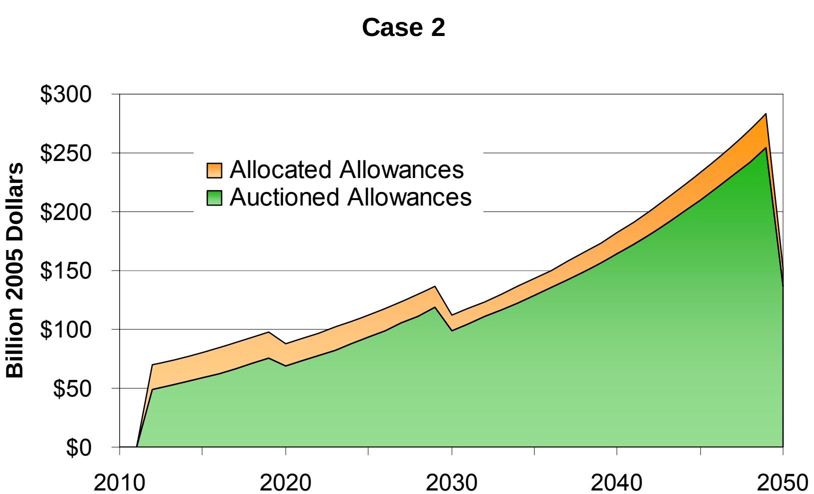


- GDP growth to 2030 is benchmarked to AEO2006
- Average annual GDP growth from 2010 to 2030 is ≈3%.
- Differences in GDP growth in the later years are due to differences in underlying model assumptions

Results: S. 280 Senate Scenario

Value of Allocated and Auctioned Allowances (IGEM)





- The share of allowances that are to be auctioned versus allocated is not specified in S. 280
- In consultation with Senate staff, EPA ran two cases:
  - Case 1 – the share of allowances that are auctioned starts at 30% in 2012 and increases linearly to 90% over 20 years
  - Case 2 – the share of allowances that are auctioned starts at 70% in 2012 and increases linearly to 90% over 20 years

Value of Allowances (Billion 2005 Dollars)

		2012	2030	2050
Case 1	Allocated	$49	$18	$15
	Auctioned	$21	$94	$137
Case 2	Allocated	$21	$13	$15
	Auctioned	$49	$99	$137

- In IGEM we assume that the policy is deficit and revenue neutral, which implies that the market outcomes are invariant to the auction / allocation spilt
  - Private sector revenues from allocated allowances accrue to employee-shareholder households, and the government adjusts taxes lump sum to maintain deficit and spending levels.
  - Allowance auction revenues flow to the U.S. government, and are redistributed to households lump sum to the extent that deficit and spending levels are maintained. If auction revenues were directed to special funds instead of returned directly to households as modeled, the impact on household annual consumption and GDP would be greater. If the auction revenues were instead used to lower distortionary taxes, the costs of the policy would be lower.
- In IPM the auction / allocation split affects market outcomes because regulated electric utilities, which are explicitly modeled, are allowed to pass on the cost of auctioned allowances to consumers, but are not allowed to pass on the cost of allocated allowances.

Results: S. 280 Senate Scenario

GDP

Table: Impact of S. 280 on U.S. GDP (Billion 2005 Dollars)

	2010	2020	2030	2040	2050	Average Annual Growth (2010 - 2050)
Reference						
ADAGE	$14,609	$19,821	$26,452	$33,979	$42,723	2.72%
IGEM	$14,733	$19,851	$26,173	$33,716	$41,372	2.61%
S.280						
ADAGE	$14,606	$19,749	$26,306	$33,750	$42,266	2.69%
IGEM	$14,678	$19,645	$25,754	$32,937	$40,040	2.54%
Absolute Change						
ADAGE	-$3	-$72	-$146	-$229	-$457	*-0.03 Percentage Points*
IGEM	-$55	-$206	-$419	-$779	-$1,332	*-0.07 Percentage Points*
% Change						
ADAGE	-0.02%	-0.36%	-0.55%	-0.67%	-1.07%	
IGEM	-0.37%	-1.04%	-1.60%	-2.31%	-3.22%	

Results: S. 280 Senate Scenario

Consumption

Table: **Impact of S. 280 on U.S. Consumption (Billion 2005 Dollars)**

	2010	2020	2030	2040	2050	Average Annual Growth (2010 - 2050)
Reference						
ADAGE	$10,791	$14,644	$19,722	$25,346	$31,878	2.75%
IGEM	$9,222	$12,346	$16,231	$20,921	$25,838	2.61%
S.280						
ADAGE	$10,834	$14,630	$19,647	$25,174	$31,571	2.71%
IGEM	$9,236	$12,315	$16,138	$20,725	$25,486	2.57%
Absolute Change						
ADAGE	$43	-$14	-$75	-$172	-$306	*-0.04 Percentage Points*
IGEM	$14	-$31	-$93	-$197	-$351	*-0.04 Percentage Points*
% Change						
ADAGE	0.40%	-0.10%	-0.38%	-0.68%	-0.96%	
IGEM	0.15%	-0.25%	-0.57%	-0.94%	-1.36%	
Annual Change per Household (2005 Dolllars)						
ADAGE	$331	-$100	-$489	-$1,067	-$1,822	
IGEM	$115	-$230	-$625	-$1,211	-$1,990	

Results: S. 280 Senate Scenario

2030 Selected Sectoral Results (IGEM)

Sector	2007	2030				
		Reference		S. 280		
	Output ($Billions)	Output ($Billions)	Percent Change from 2007	Output ($Billions)	Percent Change from 2007	Percent Change from Reference
Personal and business services	4304	8108	88%	8088	88%	0%
Finance, insurance and real estate	2642	6075	130%	6038	129%	-1%
Transportation and warehousing	681	1284	89%	1257	85%	-2%
Food and kindred products	565	1155	104%	1183	109%	2%
Motor vehicles	513	1095	114%	1063	107%	-3%
Electric utilities (services)	384	548	43%	499	30%	-9%
Petroleum refining	296	389	31%	344	16%	-11%
Gas utilities (services)	51	60	20%	56	11%	-8%
Coal mining	29	40	39%	25	-13%	-37%

- Detailed near-term electricity sector modeling in IPM indicates that the decrease in coal usage may be smaller than the decrease shown in the economy-wide models.
- The results for all 35 sectors and for 2050 are available in Appendix 2.

Results: S.280 Senate Scenario

2030 Selected Sectoral Results (IGEM)

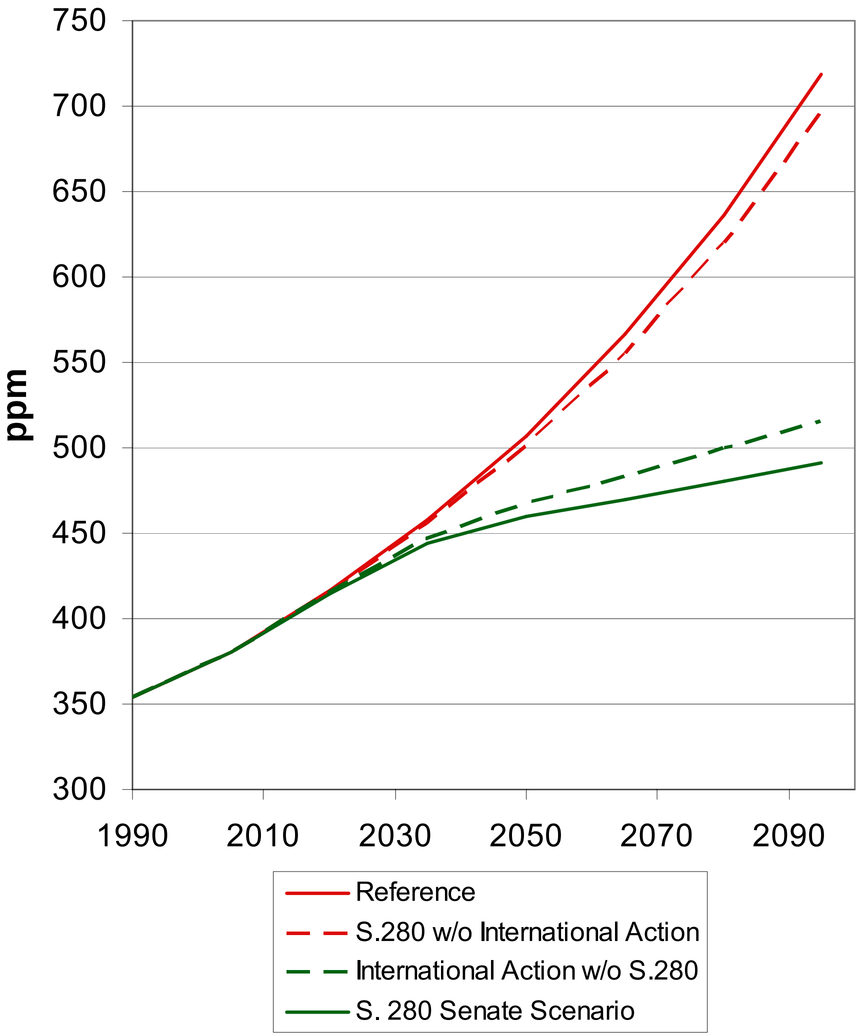
- The previous slide shows the impacts of S.280 on the value of output of nine of the 35 IGEM sectors. These sectors correspond roughly to the two digit NAICS classification. (Results for the remaining sectors are presented in the appendix).
- The largest sectors in IGEM (personal and business services and finance, insurance and real estate) account for some fourteen trillion dollars of economic activity in 2030 and are only modestly affected by the policy.
- Transportation (freight and warehousing) and motor vehicle manufacturing do experience reductions in the value of their output, as consumers and other sectors substitute away from energy consumption. The model does not explicitly represent technology, and does not show the possible impact of new transportation technologies.
- In response to S. 280, the food and kindred products sector is an example in IGEM of a sector which experiences a growth in demand, as consumers substitute away from other goods which may be more energy intensive.
- The energy production and transformation sectors experience reduction in output as other industries and consumers substitute capital, labor, and non-energy inputs.[1]

[1] Note that the coal industry shows large declines in output by 2030. Most domestic coal is consumed by the electricity sector, and IGEM does not explicitly represent generation technologies such as carbon capture and sequestration. The ADAGE model does represent generation technologies, and also shows that coal output decreases by 2030, but after 2030, all fossil generation is eventually replaced by coal fired integrated combined cycle and gasification plants with carbon capture and sequestration technologies, and coal output increases. See slide in Appendix on Primary Energy Use from ADAGE.

Global Results:
CO_2 Concentrations
and International GHG Market

Results: S. 280 Senate Scenario

Global CO_2 Concentration (MiniCAM)



S. 280 Senate Scenario

- USA adopts S. 280.
- Group 1 countries (Kyoto group less Russia) follow an allowance path that is falling gradually from the simulated Kyoto emissions levels in 2012 to 50% below 1990 in 2050.
- Group 2 countries (rest of world) adopt a policy beginning in 2025 that returns and holds them at year 2015 emissions levels through 2034, and then returns and maintains them at 2000 emissions levels from 2035 to 2050.
- After 2050, all countries hold emissions caps constant at 2050 levels.

CO_2 Concentration Results

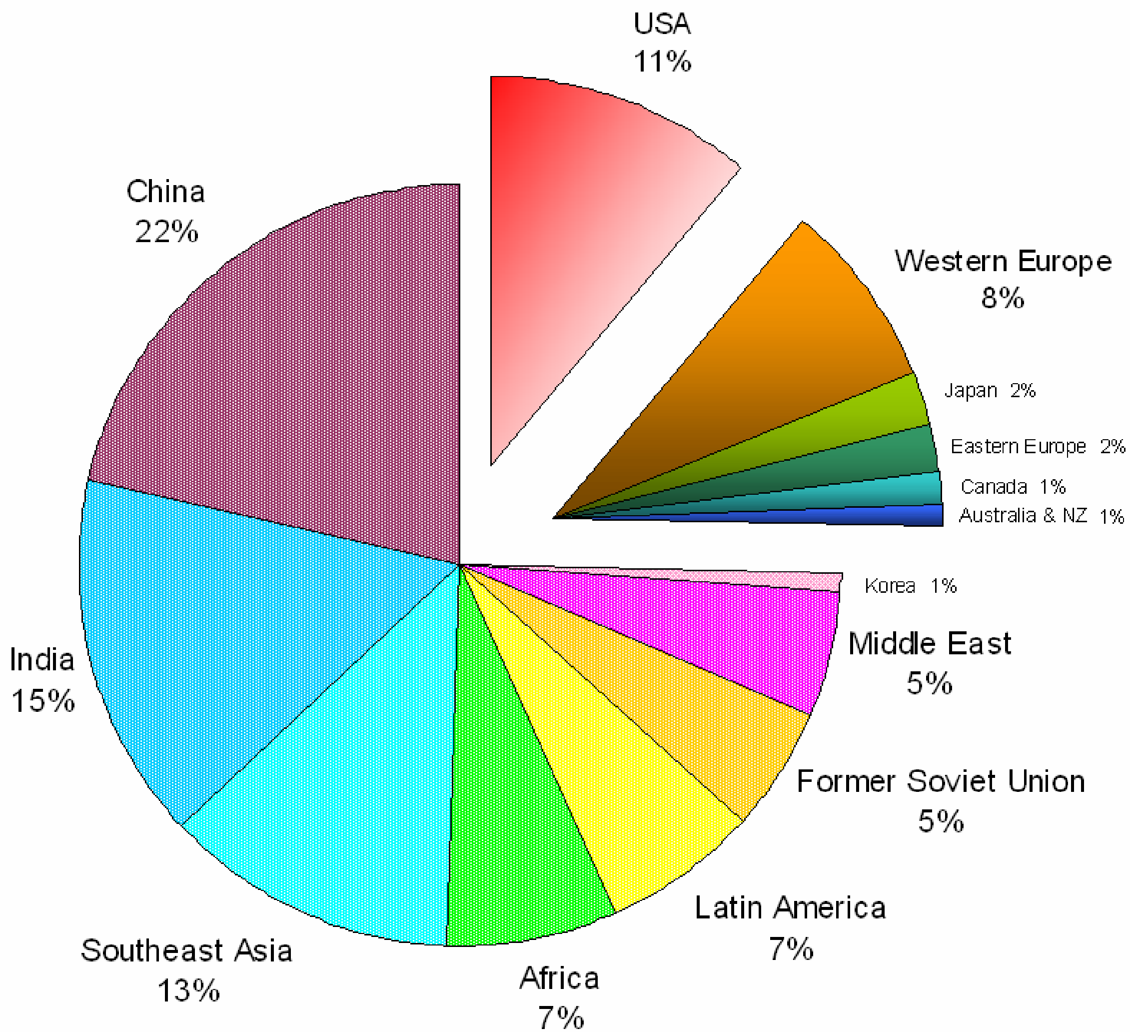
- In the reference scenario, Global CO_2 concentrations rise from historical levels of 354 parts per million (ppm) in 1990 to 718 ppm in 2095
- In the Senate scenario, CO_2 concentrations are 481 ppm in 2095.
- While CO_2 concentrations are significantly reduced in the Senate scenario, they are not on a stabilization trajectory.

Incremental Effect of S. 280

- If the U.S. adopts S. 280 and no other countries adopt emissions caps, then CO_2 concentrations in 2095 are 23 ppm lower than the reference scenario.
- If the U.S. does not cap emissions, and all other countries take on the targets from the Senate scenario, then CO_2 concentrations in 2095 are 25 ppm higher than the Senate scenario.
- The larger incremental effect when the U.S. acts alone is, in part, due to the fact that the U.S. is able to achieve more of its carbon-equivalent emissions reductions through non-CO_2 greenhouse gas abatement.
- This is counterbalanced by a smaller marginal effect on ocean uptake from the U.S. emissions reductions when the U.S. acts alone.

Results: S. 280 Senate Scenario

Share of Cumulative GHG Abatement in the 21st Century (MiniCAM)

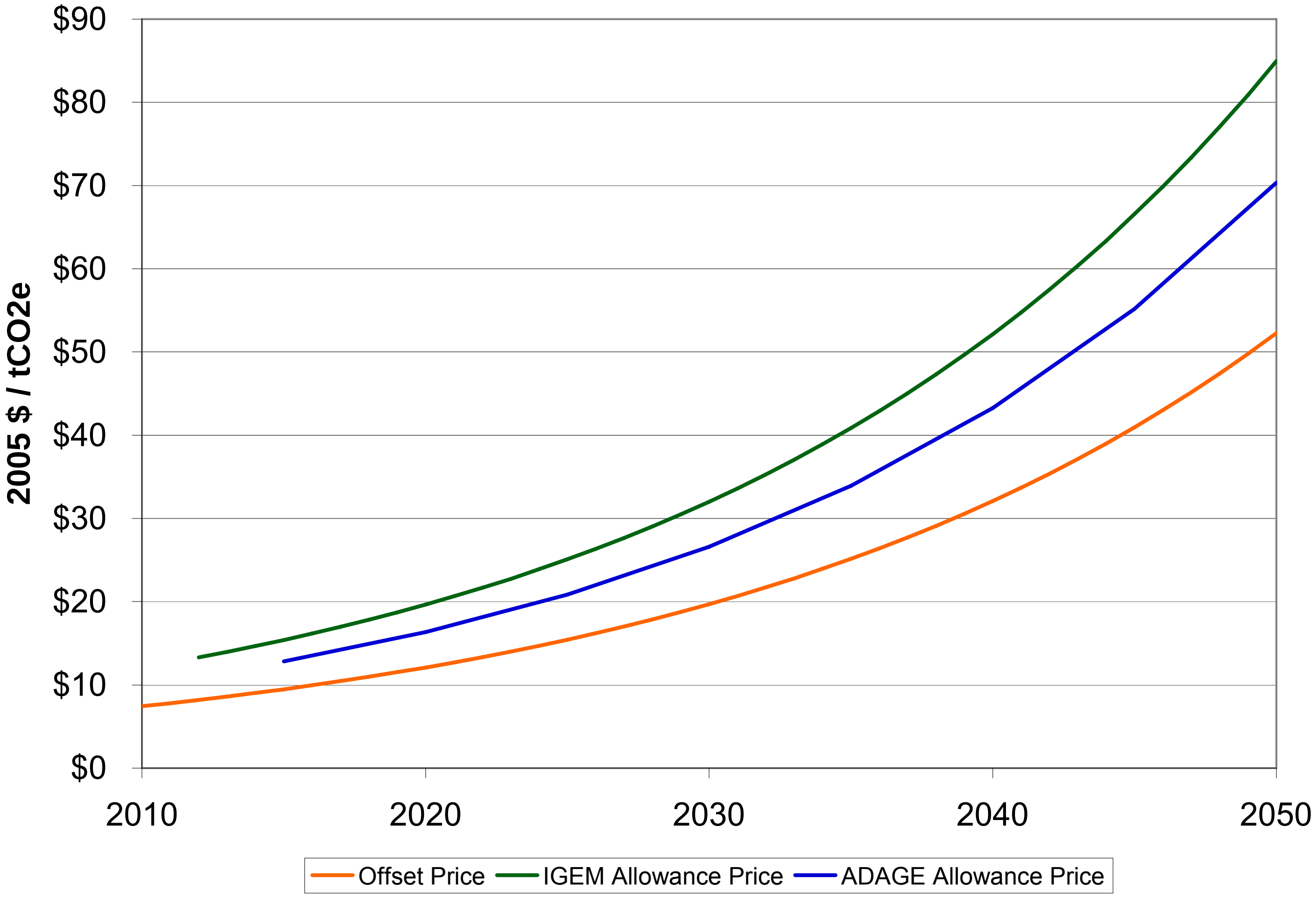


- Abatement is determined by the cap levels set in each country, so abatement associated with the purchase of international credits is attributed to the country that purchases the credits to meet its cap, not the country that sells the credits.
- US abatement from the implementation of S. 280 through the end of the century makes up 11% of global GHG emissions abatement.
- All Group 1 countries combined account for 14% of cumulative abatement over the century.
- Group 2 countries make up 75% of cumulative abatement.

Share of 21st Century Reference GHG Emissions	
USA	13%
Group 1	16%
Group 2	71%

Results: S. 280 Senate Scenario

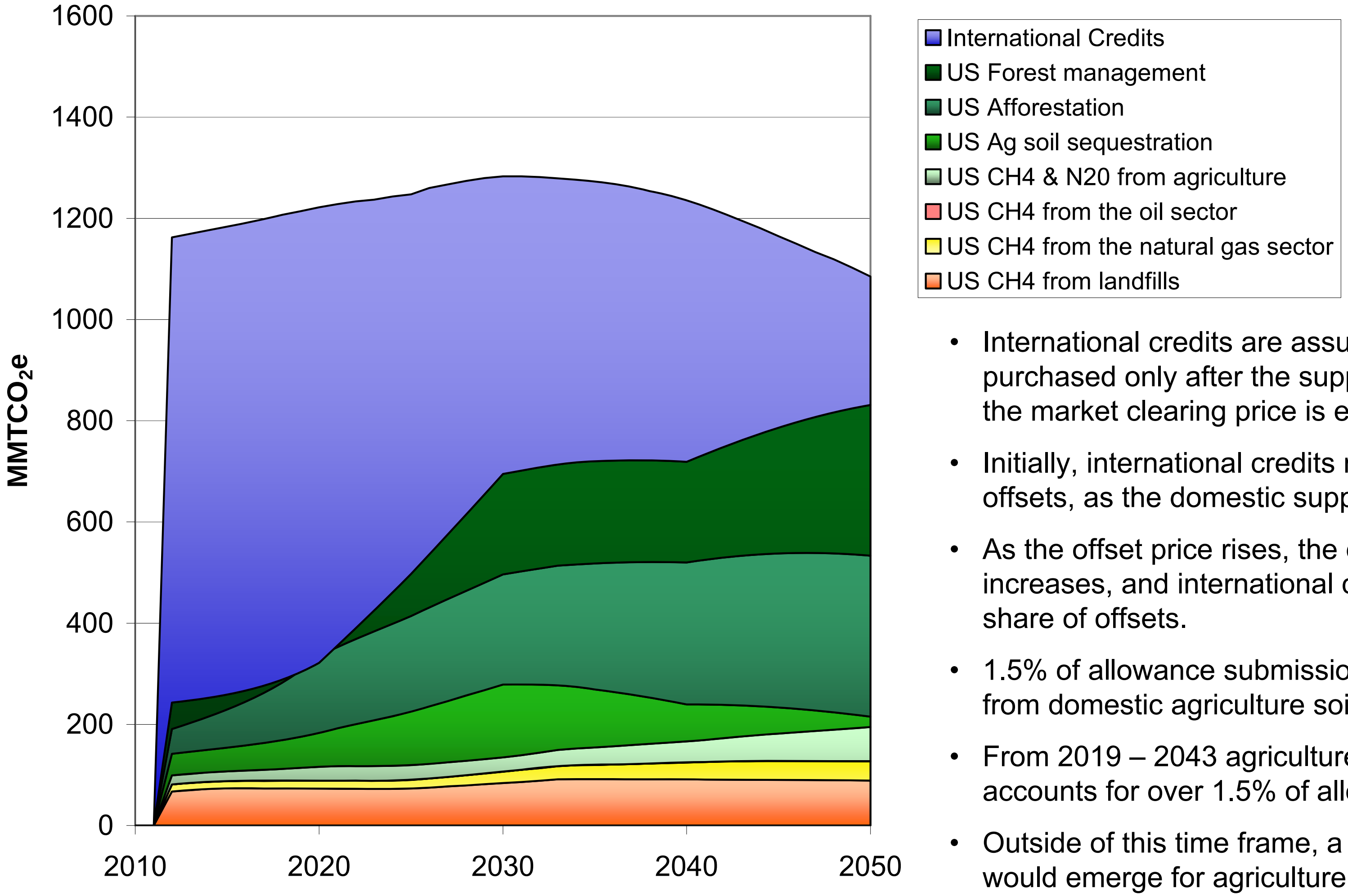
Market Clearing Offset / International Allowance Price



- Offset sources include:
  1. Tradable allowances from another nation's market in greenhouse gas emissions;
  2. A registered net increase in sequestration;
  3. Registered greenhouse gas emissions reductions by non-covered entities;
  4. Certified emissions reductions resulting from project activities in developing countries.
- Since offset sources include internationally traded allowances, there will be a single world price that clears the market for offsets and international credits.
- Since the offset price is always lower than the allowance price, the 30% limit on offsets is a binding constraint.

Results: S. 280 Senate Scenario

Sources of Offsets

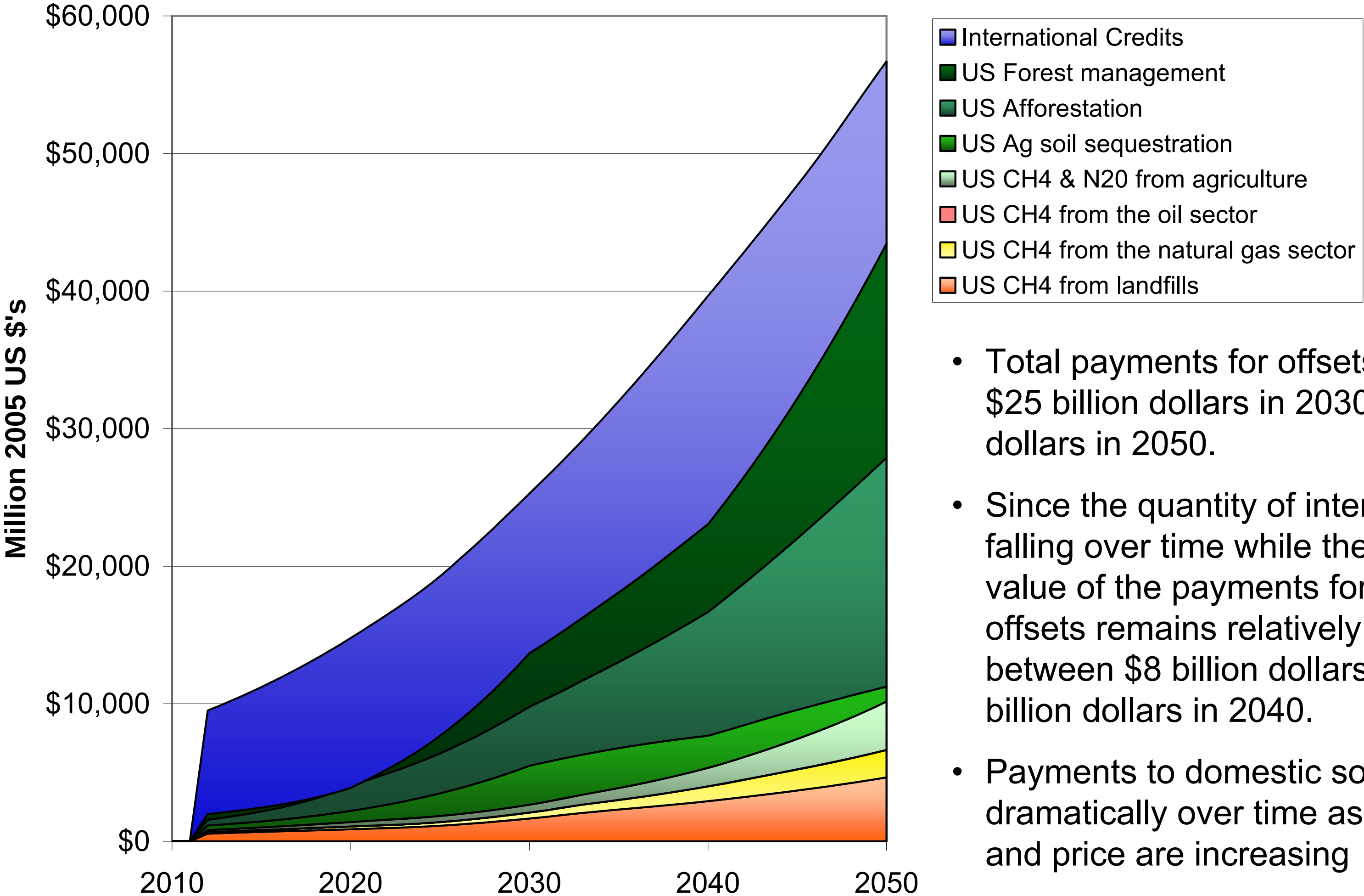


Note: CH_4 from coal mining and F-gases are capped.

- International credits are assumed in this analysis to be purchased only after the supply of domestic offsets at the market clearing price is exhausted.
- Initially, international credits make up the majority of offsets, as the domestic supply is limited.
- As the offset price rises, the domestic supply of offsets increases, and international credits make up a smaller share of offsets.
- 1.5% of allowance submissions are required to come from domestic agriculture soil sequestration.
- From 2019 – 2043 agriculture soil sequestration accounts for over 1.5% of allowance submissions.
- Outside of this time frame, a separate and higher price would emerge for agriculture soil sequestration in order to meet the 1.5% requirement.

Results: S. 280 Senate Scenario

Offset Payments



Note: CH_4 from coal mining and F-gases are capped.

- Total payments for offsets are approximately \$25 billion dollars in 2030, and \$57 billion dollars in 2050.
- Since the quantity of international credits is falling over time while the price is rising, the value of the payments for international offsets remains relatively constant, ranging between \$8 billion dollars in 2012 and \$16 billion dollars in 2040.
- Payments to domestic sources of offsets rise dramatically over time as both the quantity and price are increasing

Results: S. 280 Senate Scenario

Total Abatement Costs

Table: Abatement Cost Calculations

	2015	2020	2025	2030	2035	2040	2045	2050
Domestic Covered Abatement (MMTCO2e)								
ADAGE	969	1,217	1,553	1,986	2,514	3,156	3,776	4,369
IGEM	971	1,230	1,524	1,845	2,282	2,802	3,460	4,150
Domestic Offset Abatement (MMTCO2e)								
ADAGE	259	322	498	695	720	719	796	832
IGEM	259	322	498	695	720	719	796	832
International Credits (MMTCO2e)								
ADAGE	996	968	793	596	528	453	298	182
IGEM	924	900	749	588	553	517	369	253
Allowance Price ($/tCO2e)								
ADAGE	$13	$16	$21	$27	$34	$43	$55	$70
IGEM	$15	$20	$25	$32	$41	$52	$67	$85
Offset Price ($/tCO2e)								
ADAGE	$9	$12	$15	$20	$25	$32	$41	$52
IGEM	$9	$12	$15	$20	$25	$32	$41	$52
Domestic Covered Abatement Cost (Billion 2005 Dollars)								
ADAGE	$6	$10	$16	$26	$43	$68	$104	$154
IGEM	$7	$12	$19	$30	$47	$73	$115	$176
Domestic Offset Abatement Cost (Billion 2005 Dollars)								
ADAGE	$1	$2	$4	$7	$9	$12	$16	$22
IGEM	$1	$2	$4	$7	$9	$12	$16	$22
International Credit Payments (Billion 2005 Dollars)								
ADAGE	$9	$12	$12	$12	$13	$15	$12	$10
IGEM	$9	$11	$12	$12	$14	$17	$15	$13
Total Abatement Cost (Billion 2005 Dollars)								
ADAGE	$17	$24	$32	$45	$65	$94	$133	$185
IGEM	$17	$25	$35	$48	$70	$101	$147	$211

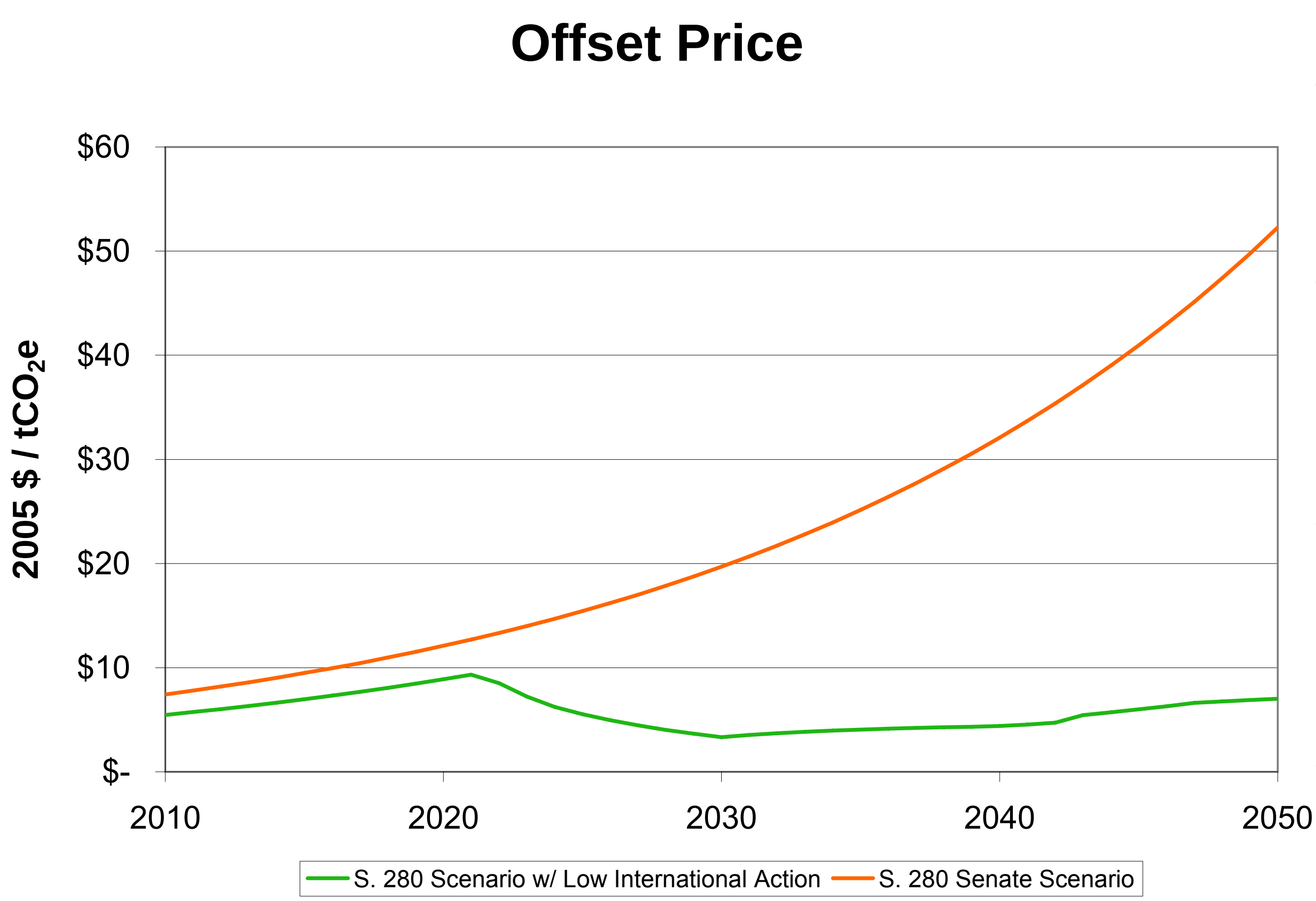
Results: S. 280 Senate Scenario

Total Abatement Costs

- The allowance price is equal to the marginal cost of abatement by covered entities in covered sectors in the U.S.
- The offset price is the marginal cost of abatement internationally and for uncovered sectors and entities in the U.S.
- Domestic covered abatement cost is approximated for each model as the product of domestic covered GHG emissions abatement and the allowance price divided by two.
    - Division by 2 is assumed to represent the fact that most reduction measures are not implemented at the S. 280 marginal allowance price but at lower prices. In most cases, the relationship between emission reduction and the marginal price is a concave curve – which implies a value larger than 2. The value of 2, used here for simplicity leads to an overestimation of abatement costs.
- Domestic offset abatement cost is approximated for each model as the product of domestic offset abatement and the offset price divided by two.
- International credit payments are calculated for each model as the product of the amount of international credits purchased and the offset price (which is equal to the price of international allowances).
    - Unlike the abatement costs associated with domestic covered abatement and domestic offsets, there is no need for dividing by two when calculating the costs of international credits as all international credits are purchased at the full price of international allowances and those payments are sent abroad.
- Total abatement cost is simply the sum of domestic covered abatement cost, domestic offset abatement cost, and payments for international credits.

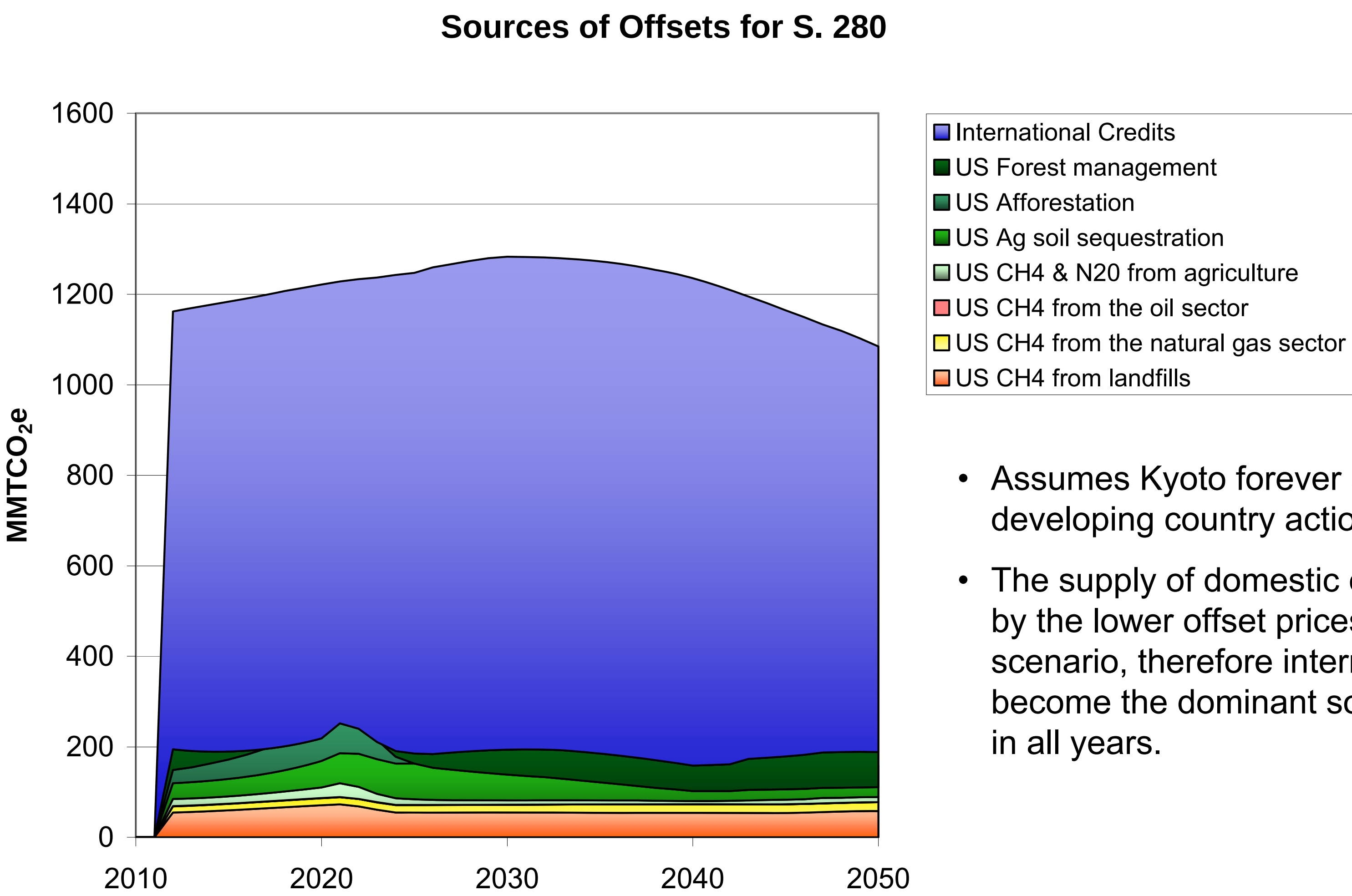
Appendix 1: Additional Scenarios

Results: Additional Scenarios (3) Low International Action



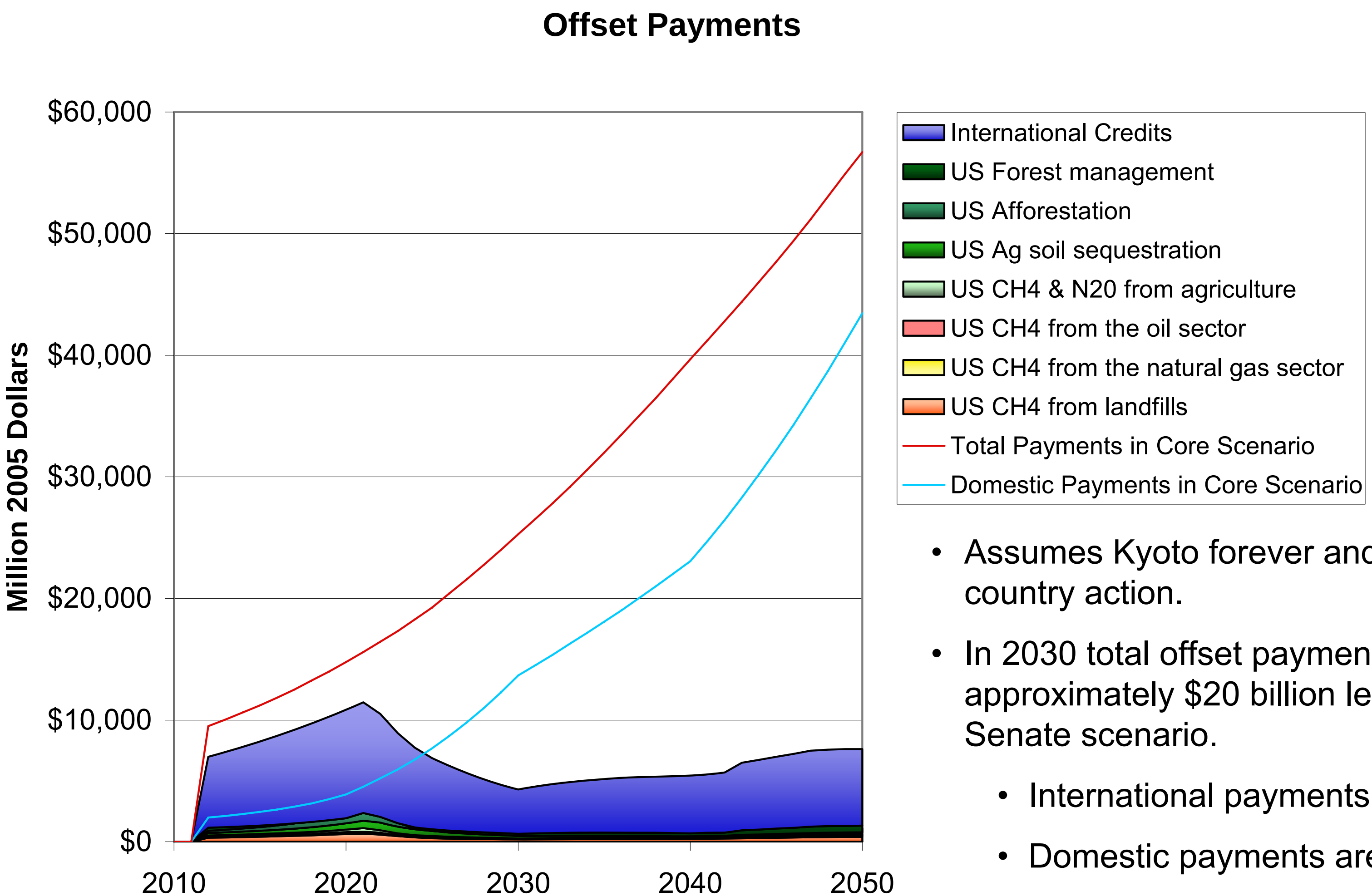
- Assumes Kyoto forever and no developing country action.
- Since the international demand for abatement is so much lower, the price of offsets is much lower.
- The price does not rise at the 5% interest rate over the entire time frame because while banking is allowed, borrowing is not.
- Since the 30% limit on offsets still applies, the marginal price of abatement remains the same, and thus the allowance price is unaffected.
- The GDP impact will be slightly smaller than in the Senate scenario due to the lower cost of offsets and international credits.

Results: Additional Scenarios (3) Low International Action



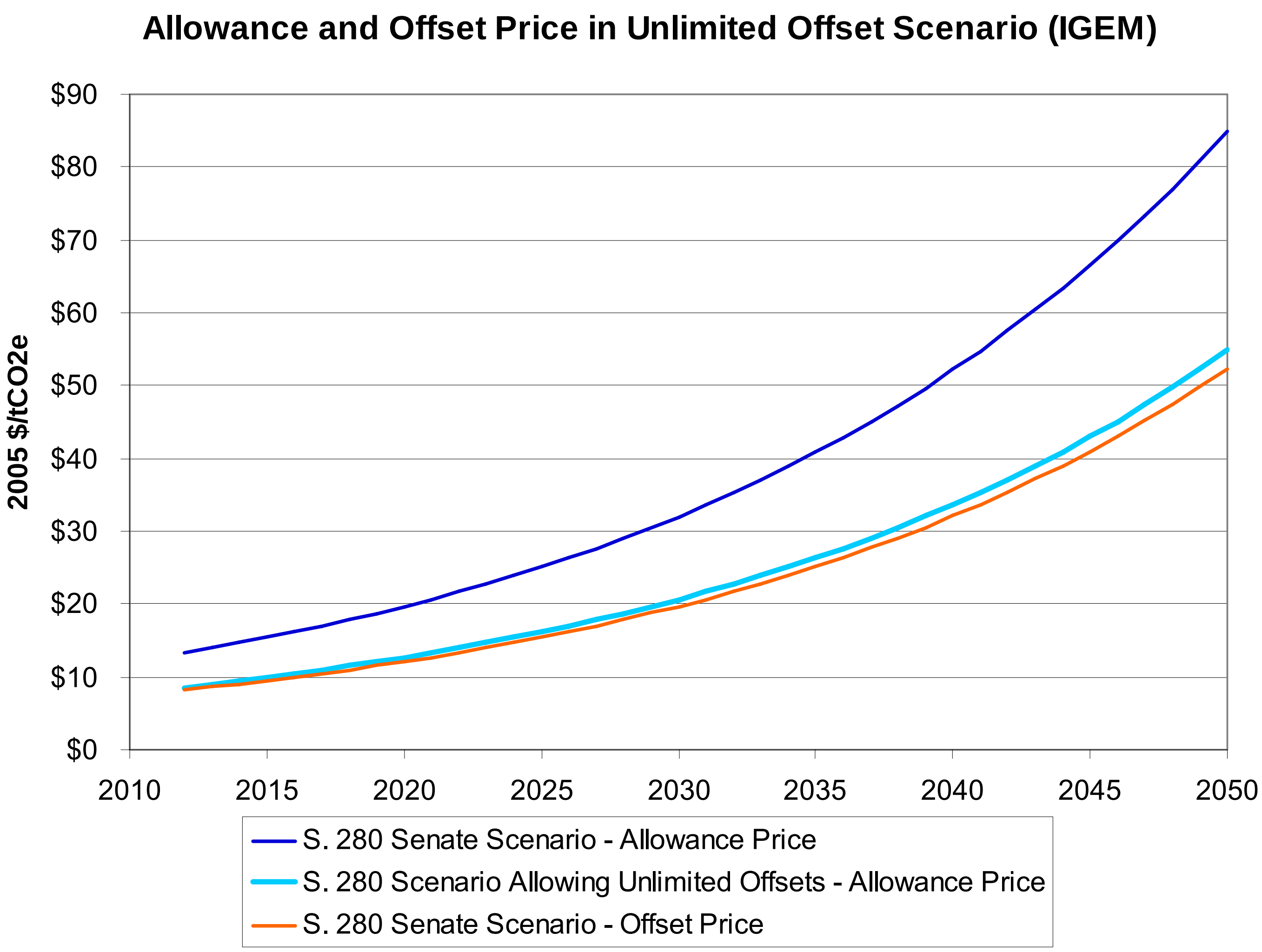
- Assumes Kyoto forever and no developing country action.
- The supply of domestic offsets is limited by the lower offset prices in this scenario, therefore international credits become the dominant source of offsets in all years.

Results: Additional Scenarios (3) Low International Action



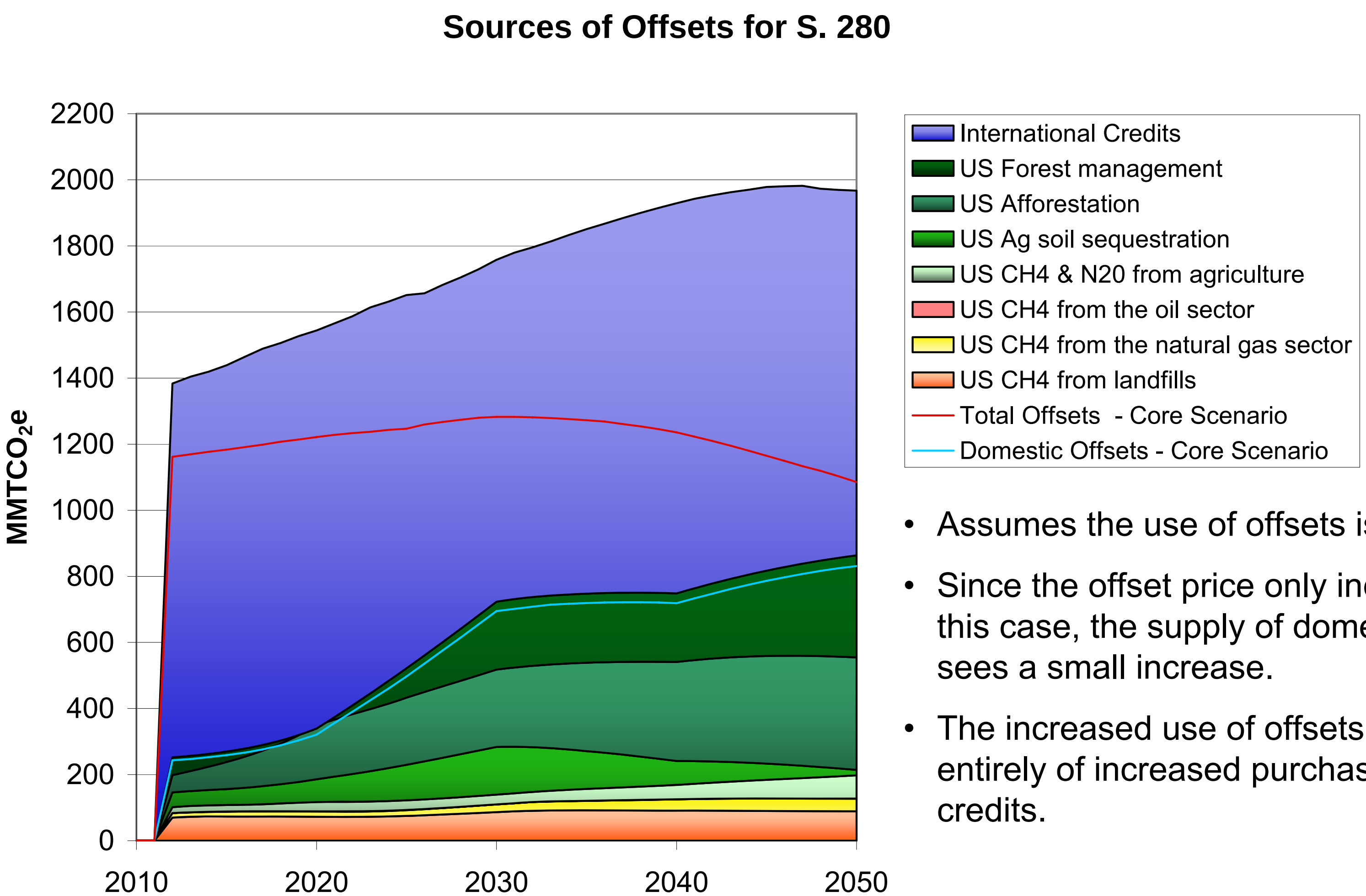
- Assumes Kyoto forever and no developing country action.
- In 2030 total offset payments are approximately $20 billion less than in the Senate scenario.
  - International payments are $8 billion less.
  - Domestic payments are $12 billion less.

Results: Additional Scenarios (4) Unlimited Offsets



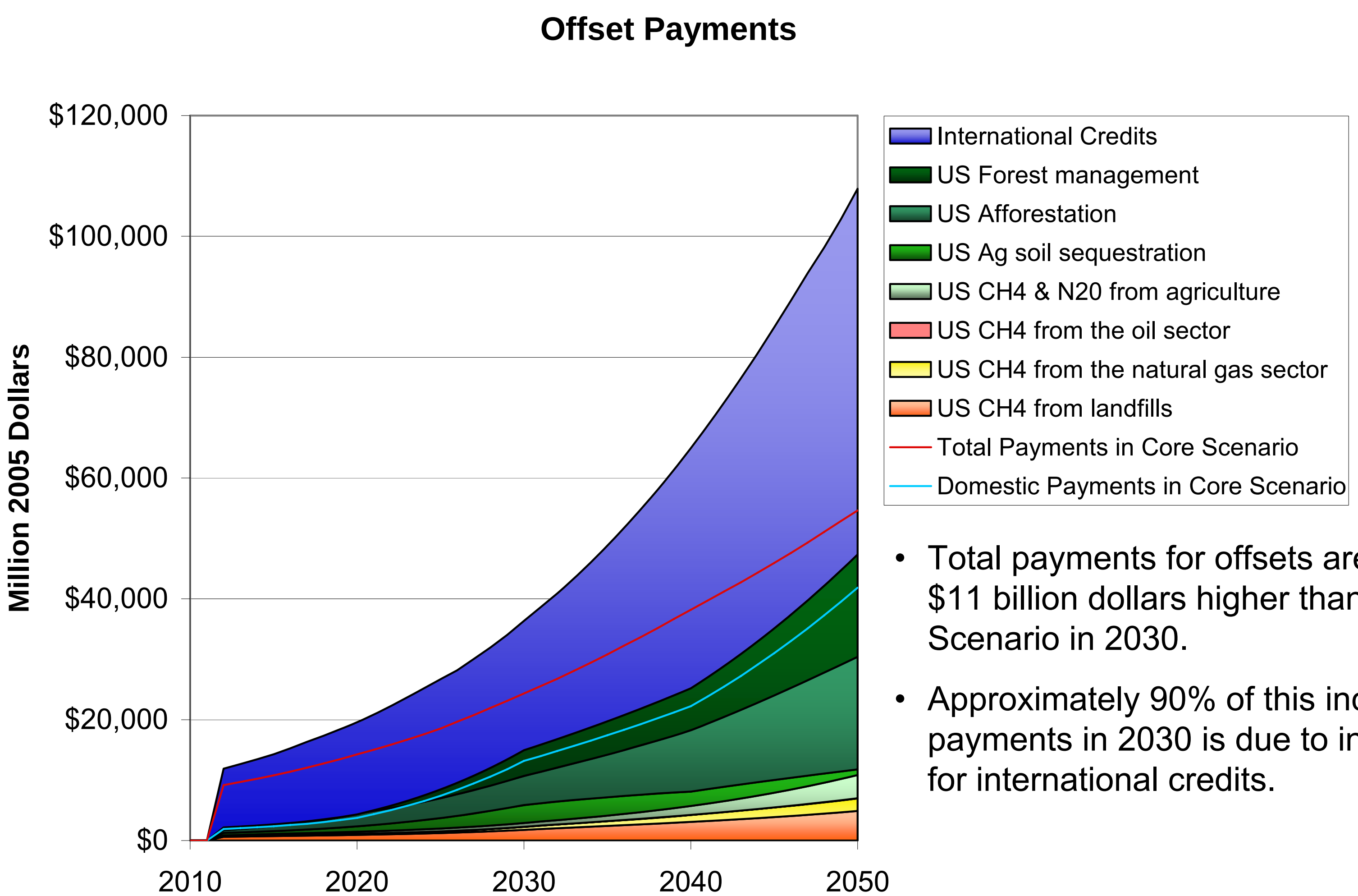
- Assumes no limits are placed on the usage of domestic offsets and international credits.
- Instead of separate allowance and offset prices as we saw in the Senate scenario, there is a single world price.
- The small increase in world demand for abatement associated with the increased demand from the U.S. results in a small increase in the world price.
- Domestically, allowing unlimited offsets reduces the allowance price by 35%.

Results: Additional Scenarios (4) Unlimited Offsets



- Assumes the use of offsets is unrestricted.
- Since the offset price only increase slightly in this case, the supply of domestic offsets only sees a small increase.
- The increased use of offsets is made up almost entirely of increased purchases of international credits.

Results: Additional Scenarios (4) Unlimited Offsets



- Total payments for offsets are approximately \$11 billion dollars higher than in the Senate Scenario in 2030.
- Approximately 90% of this increase in offset payments in 2030 is due to increased payments for international credits.

Results: Additional Scenarios (4) Unlimited Offsets

Table: **IGEM - Impact of S. 280 on U.S. GDP (Billion 2005 Dollars)**

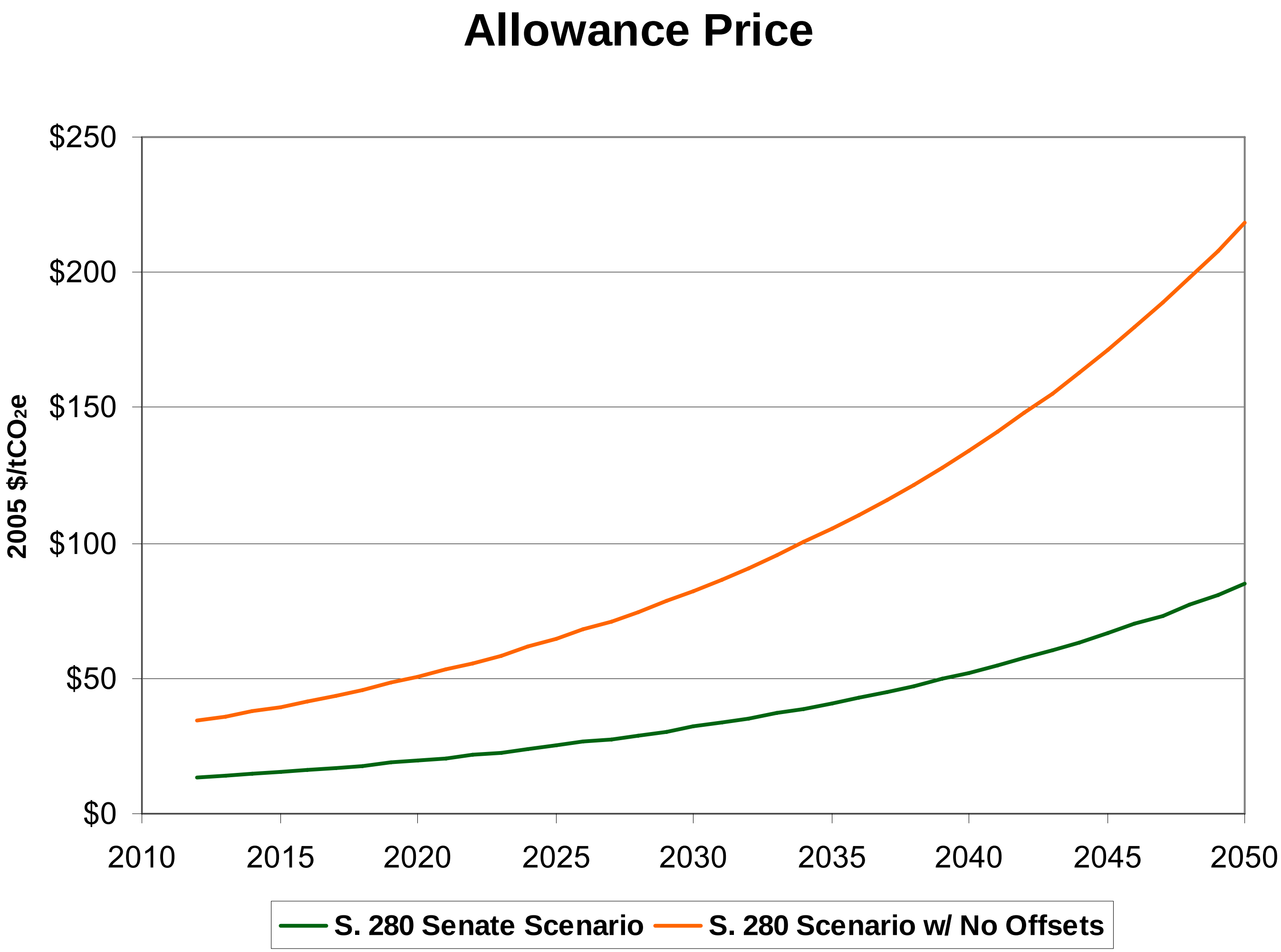
	2010	2020	2030	2040	2050	Average Annual Growth (2010 - 2050)
Reference						
	$14,733	$19,851	$26,173	$33,716	$41,372	2.61%
S.280						
Core	$14,678	$19,645	$25,754	$32,937	$40,040	2.54%
Unlimited Offsets	$14,696	$19,710	$25,893	$33,183	$40,441	2.56%
Absolute Change						
Core	-$55	-$206	-$419	-$779	-$1,332	*-0.07 Percentage Points*
Unlimited Offsets	-$37	-$141	-$280	-$533	-$931	*-0.05 Percentage Points*
% Change						
Core	-0.37%	-1.04%	-1.60%	-2.31%	-3.22%	
Unlimited Offsets	-0.25%	-0.71%	-1.07%	-1.58%	-2.25%	

Table: **IGEM - Impact of S. 280 on U.S. Consumption (Billion 2005 Dollars)**

	2010	2020	2030	2040	2050	Average Annual Growth (2010 - 2050)
Reference						
	$9,222	$12,346	$16,231	$20,921	$25,838	2.61%
S.280						
Core	$9,236	$12,315	$16,138	$20,725	$25,486	2.57%
Unlimited Offsets	$9,233	$12,328	$16,169	$20,787	$25,600	2.58%
Absolute Change						
Core	$14	-$31	-$93	-$197	-$351	*-0.04 Percentage Points*
Unlimited Offsets	$10	-$19	-$62	-$134	-$238	*-0.03 Percentage Points*
% Change						
Core	0.15%	-0.25%	-0.57%	-0.94%	-1.36%	
Unlimited Offsets	0.11%	-0.15%	-0.38%	-0.64%	-0.92%	
Change per Household (2005 Dolllars)						
Core	$115	-$230	-$625	-$1,211	-$1,990	
Unlimited Offsets	$84	-$138	-$416	-$825	-$1,346	

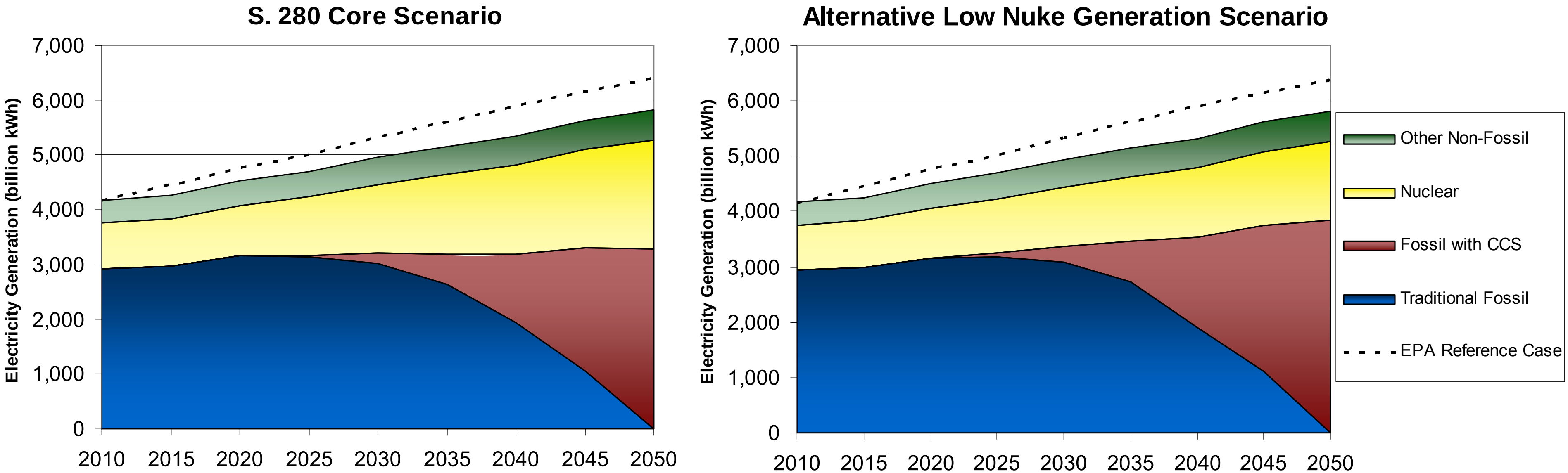
- Assumes no limits are placed on the usage of domestic offsets and international credits.
- In 2030, removing the restriction on the amount of offsets that may be used reduces the impact on both GDP and household consumption by approximately one third.

Results: Additional Scenarios
(5) No Offsets



- Assumes that no offsets or international credits are allowed.
- In 2030, the allowance price is approximately $82, which is 157% higher than in the allowance price in the Senate Scenario.

Results: Additional Scenarios (6) Lower Nuclear Power Generation (ADAGE)

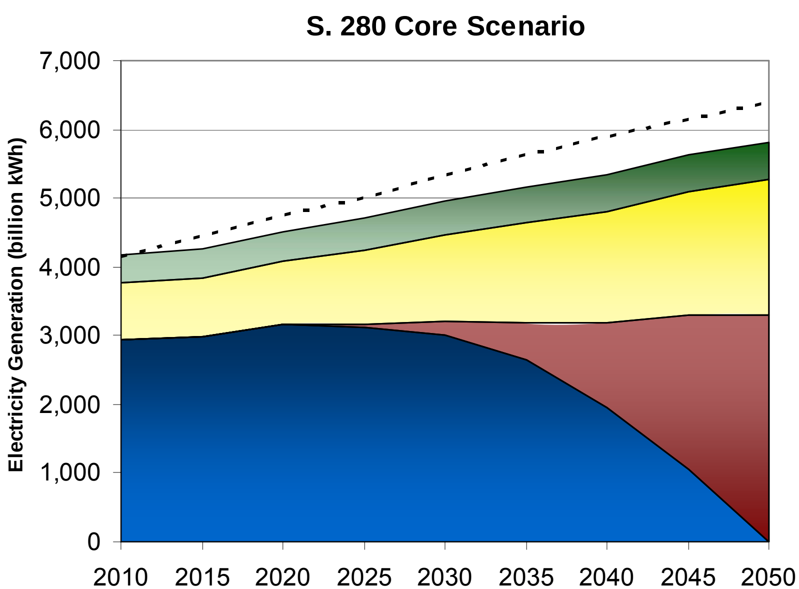


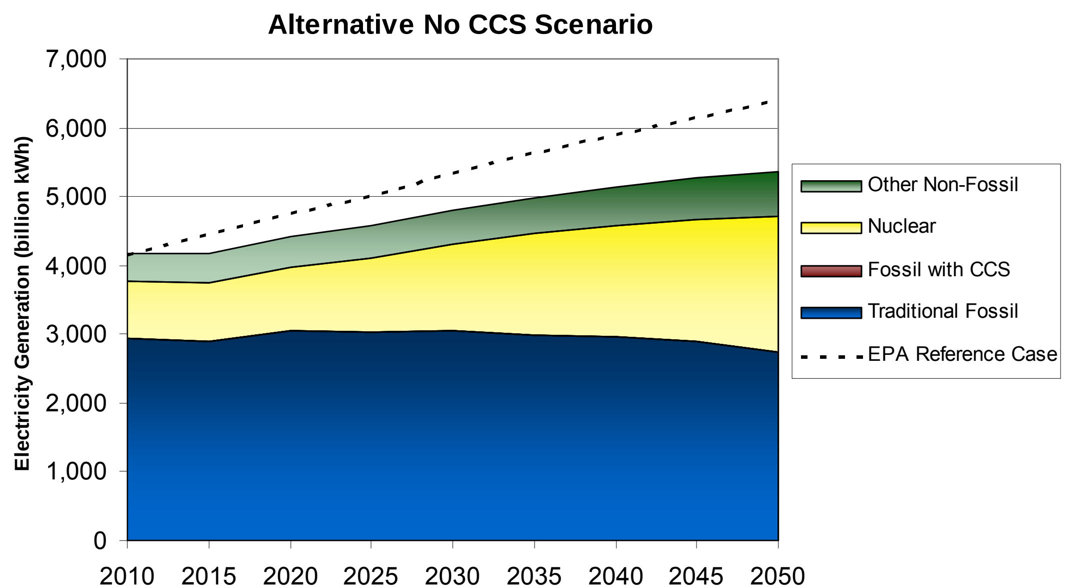
	2030		2050	
	S. 280 Senate Scenario	S. 280 Low Nuke Scenario	S. 280 Senate Scenario	S. 280 Low Nuke Scenario
GDP (% change from BAU)	-0.55%	-0.58%	-1.07%	-1.11%
Allowance Price (2005 $/tCO$_2$e)	$26.59	$28.00	$70.33	$74.03

- Assumes nuclear power generation increase by ≈75% by 2050 (half of Senate Scenario)
- Compensating increases in fossil with CCS generation reduce the economic impact of the lower nuclear capacity

Note: Other non-fossil includes nuclear, hydro, geothermal, wind, solar, biomass and municipal solid waste.

Results: Additional Scenarios
(7) No CCS Technology (ADAGE)





	2030		2050	
	S. 280 Senate Scenario	S. 280 No CCS Scenario	S. 280 Senate Scenario	S. 280 No CCS Scenario
GDP (% change from BAU)	-0.55%	-0.97%	-1.07%	-1.82%
Allowance Price (2005 $/t$CO_2$e)	$26.59	$39.90	$70.33	$105.23

- Assumes no CCS technology is available
- Results in 50% higher allowance prices
- Results in reduced electricity generation

Note: Other non-fossil includes nuclear, hydro, geothermal, wind, solar, biomass and municipal solid waste.

Scenario Comparison

GHG Allowance Prices

Table: Allowance Price Comparisons (2005 $/tCO2e)

	2015	2020	2025	2030	2035	2040	2045	2050
2) S. 280 Senate Scenario								
ADAGE	$13	$16	$21	$27	$34	$43	$55	$70
IGEM	$15	$20	$25	$32	$41	$52	$67	$85
3) S. 280 Scenario with Low International Actions								
ADAGE	$13	$16	$21	$27	$34	$43	$55	$70
IGEM	$15	$20	$25	$32	$41	$52	$67	$85
4) S. 280 Scenario Allowing Unlimited Offsets								
ADAGE								
IGEM	$10	$13	$16	$21	$26	$34	$43	$55
5) S. 280 Scenario with No Offsets								
ADAGE								
IGEM	$40	$51	$65	$82	$105	$134	$171	$219
6) S. 280 Scenario with Lower Nuclear Power Generation								
ADAGE	$14	$17	$22	$28	$36	$46	$58	$74
IGEM								
7) S. 280 Scenario with No Carbon, Capture & Storage Technology								
ADAGE	$19	$25	$31	$40	$51	$65	$83	$105
IGEM								

Scenario Comparison

Offset Prices

Table: Offset Price Comparisons (2005 $/tCO2e)

	2015	2020	2025	2030	2035	2040	2045	2050
2) S. 280 Senate Scenario								
	$9	$12	$15	$20	$25	$32	$41	$52
3) S. 280 Scenario with Low International Actions								
	$7	$9	$6	$3	$4	$4	$6	$7
4) S. 280 Scenario Allowing Unlimited Offsets								
	$10	$13	$16	$21	$26	$34	$43	$55
5) S. 280 Scenario with No Offsets								
	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a
6) S. 280 Scenario with Lower Nuclear Power Generation								
	$9	$12	$15	$20	$25	$32	$41	$52
7) S. 280 Scenario with No Carbon, Capture & Storage Technology								
	$9	$12	$15	$20	$25	$32	$41	$52

Scenario Comparison

GDP Impacts (Percentage Change)

Table: GDP Comparisons (% Change from Reference)

	2015	2020	2025	2030	2035	2040	2045	2050
2) S. 280 Senate Scenario								
ADAGE	-0.22%	-0.36%	-0.40%	-0.55%	-0.61%	-0.67%	-0.69%	-1.07%
IGEM	-0.79%	-1.04%	-1.32%	-1.60%	-1.94%	-2.30%	-2.73%	-3.21%
3) S. 280 Scenario with Low International Actions								
ADAGE								
IGEM	-0.79%	-1.05%	-1.31%	-1.60%	-1.94%	-2.30%	-2.73%	-3.19%
4) S. 280 Scenario Allowing Unlimited Offsets								
ADAGE								
IGEM	-0.54%	-0.71%	-0.89%	-1.07%	-1.31%	-1.58%	-1.88%	-2.25%
5) S. 280 Scenario with No Offsets								
ADAGE								
IGEM	-1.76%	-2.26%	-2.78%	-3.31%	-3.93%	-4.58%	-5.30%	-6.08%
6) S. 280 Scenario with Lower Nuclear Power Generation								
ADAGE	-0.23%	-0.38%	-0.42%	-0.58%	-0.63%	-0.70%	-0.72%	-1.11%
IGEM								
7) S. 280 Scenario with No Carbon, Capture & Storage Technology								
ADAGE	-0.57%	-0.70%	-0.83%	-0.97%	-1.14%	-1.34%	-1.58%	-1.82%
IGEM								

Scenario Comparison

GDP Impacts (Absolute Change)

Table: GDP Comparisons (Billion 2005 $ Change from Referene)

	2015	2020	2025	2030	2035	2040	2045	2050
2) S. 280 Senate Scenario								
ADAGE	-$37	-$72	-$92	-$146	-$183	-$229	-$263	-$457
IGEM	-$134	-$206	-$301	-$419	-$580	-$776	-$1,025	-$1,328
3) S. 280 Scenario with Low International Actions								
ADAGE								
IGEM	-$135	-$208	-$299	-$419	-$579	-$774	-$1,024	-$1,321
4) S. 280 Scenario Allowing Unlimited Offsets								
ADAGE								
IGEM	-$91	-$141	-$202	-$280	-$392	-$531	-$705	-$931
5) S. 280 Scenario with No Offsets								
ADAGE								
IGEM	-$300	-$449	-$634	-$867	-$1,173	-$1,544	-$1,986	-$2,516
6) S. 280 Scenario with Lower Nuclear Power Generation								
ADAGE	-$40	-$75	-$96	-$152	-$191	-$239	-$276	-$473
IGEM								
7) S. 280 Scenario with No Carbon, Capture & Storage Technology								
ADAGE	-$97	-$138	-$189	-$257	-$342	-$456	-$602	-$776
IGEM								

Scenario Comparison

Consumption Impacts (Percentage Change)

Table: Consumption Comparisons (% Change from Reference)

	2015	2020	2025	2030	2035	2040	2045	2050
2) S. 280 Senate Scenario								
ADAGE	0.02%	-0.10%	-0.23%	-0.38%	-0.53%	-0.68%	-0.79%	-0.96%
IGEM	-0.05%	-0.25%	-0.41%	-0.57%	-0.75%	-0.94%	-1.13%	-1.36%
3) S. 280 Scenario with Low International Actions								
ADAGE								
IGEM	-0.05%	-0.24%	-0.40%	-0.55%	-0.73%	-0.90%	-1.08%	-1.31%
4) S. 280 Scenario Allowing Unlimited Offsets								
ADAGE								
IGEM	-0.02%	-0.15%	-0.27%	-0.38%	-0.51%	-0.64%	-0.77%	-0.92%
5) S. 280 Scenario with No Offsets								
ADAGE								
IGEM	-0.15%	-0.58%	-0.93%	-1.27%	-1.64%	-2.01%	-2.40%	-2.84%
6) S. 280 Scenario with Lower Nuclear Power Generation								
ADAGE	0.00%	-0.12%	-0.26%	-0.42%	-0.57%	-0.73%	-0.84%	-1.00%
IGEM								
7) S. 280 Scenario with No Carbon, Capture & Storage Technology								
ADAGE	-0.08%	-0.24%	-0.41%	-0.62%	-0.82%	-1.03%	-1.32%	-1.62%
IGEM								

Scenario Comparison

Consumption Impacts (Absolute Change)

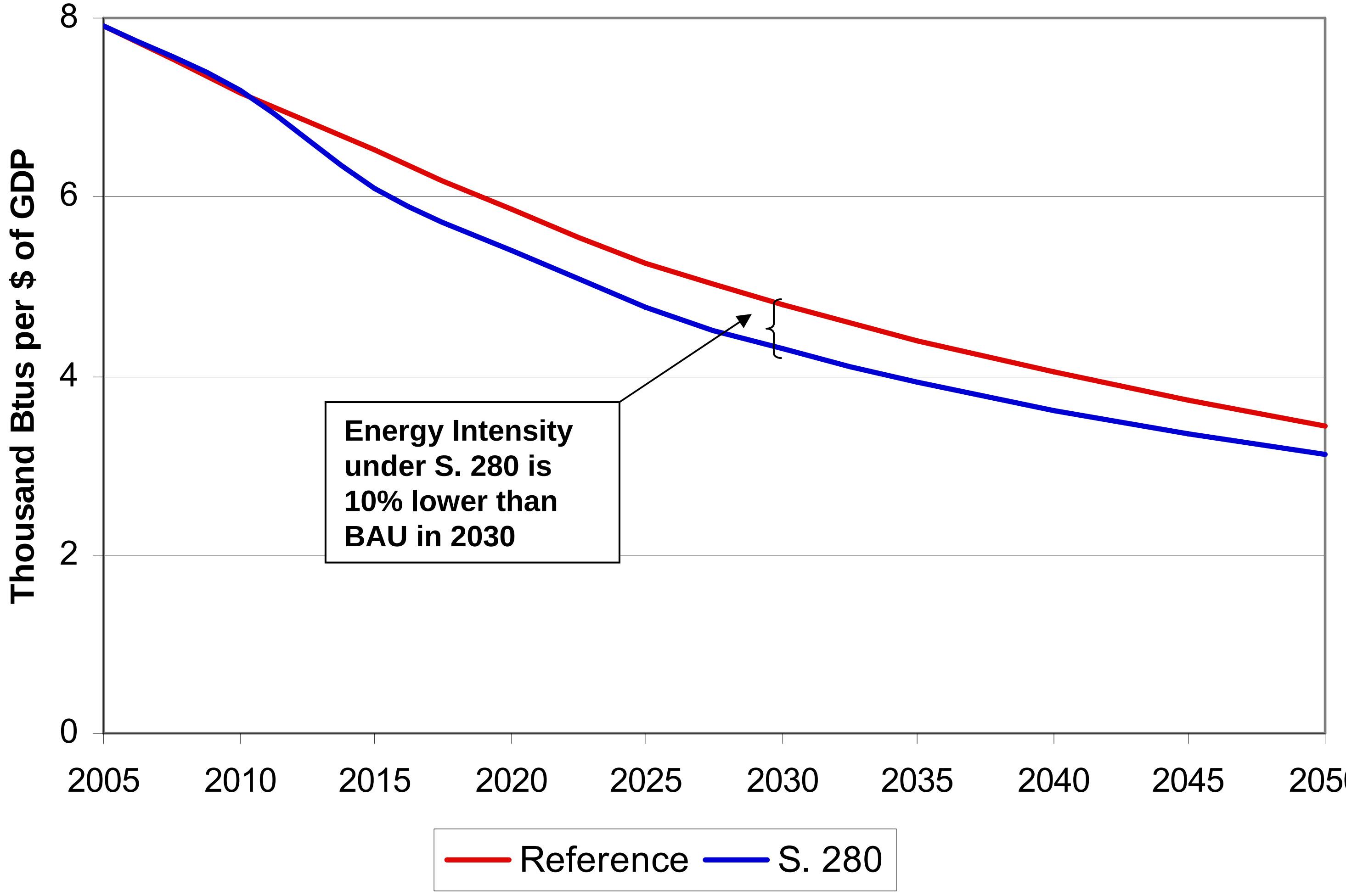
Table: Consumption Comparisons (Billion 2005 $ Change from Referene)

	2015	2020	2025	2030	2035	2040	2045	2050
2) S. 280 Senate Scenario								
ADAGE	$2	-$14	-$39	-$75	-$119	-$172	-$225	-$306
IGEM	-$5	-$30	-$58	-$93	-$138	-$196	-$264	-$350
3) S. 280 Scenario with Low International Actions								
ADAGE								
IGEM	-$5	-$30	-$56	-$89	-$135	-$189	-$252	-$338
4) S. 280 Scenario Allowing Unlimited Offsets								
ADAGE								
IGEM	-$2	-$19	-$38	-$62	-$95	-$133	-$181	-$238
5) S. 280 Scenario with No Offsets								
ADAGE								
IGEM	-$16	-$71	-$132	-$207	-$304	-$420	-$561	-$735
6) S. 280 Scenario with Lower Nuclear Power Generation								
ADAGE	$0	-$18	-$44	-$82	-$128	-$185	-$238	-$320
IGEM								
7) S. 280 Scenario with No Carbon, Capture & Storage Technology								
ADAGE	-$10	-$35	-$71	-$122	-$184	-$262	-$375	-$515
IGEM								

Appendix 2: Additional Information

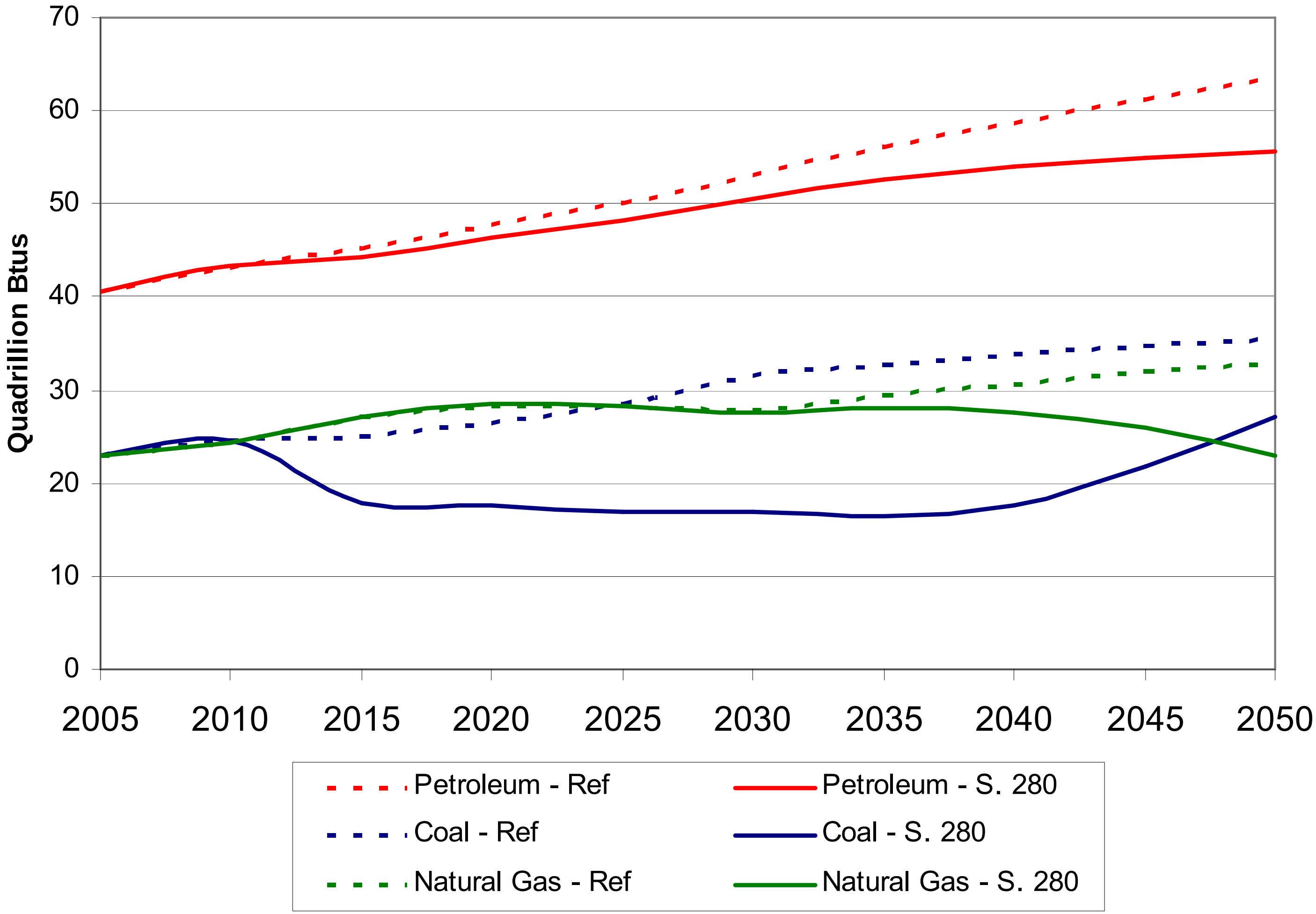
Results: S. 280 Senate Scenario

Energy Intensity (ADAGE)



Results: S. 280 Senate Scenario

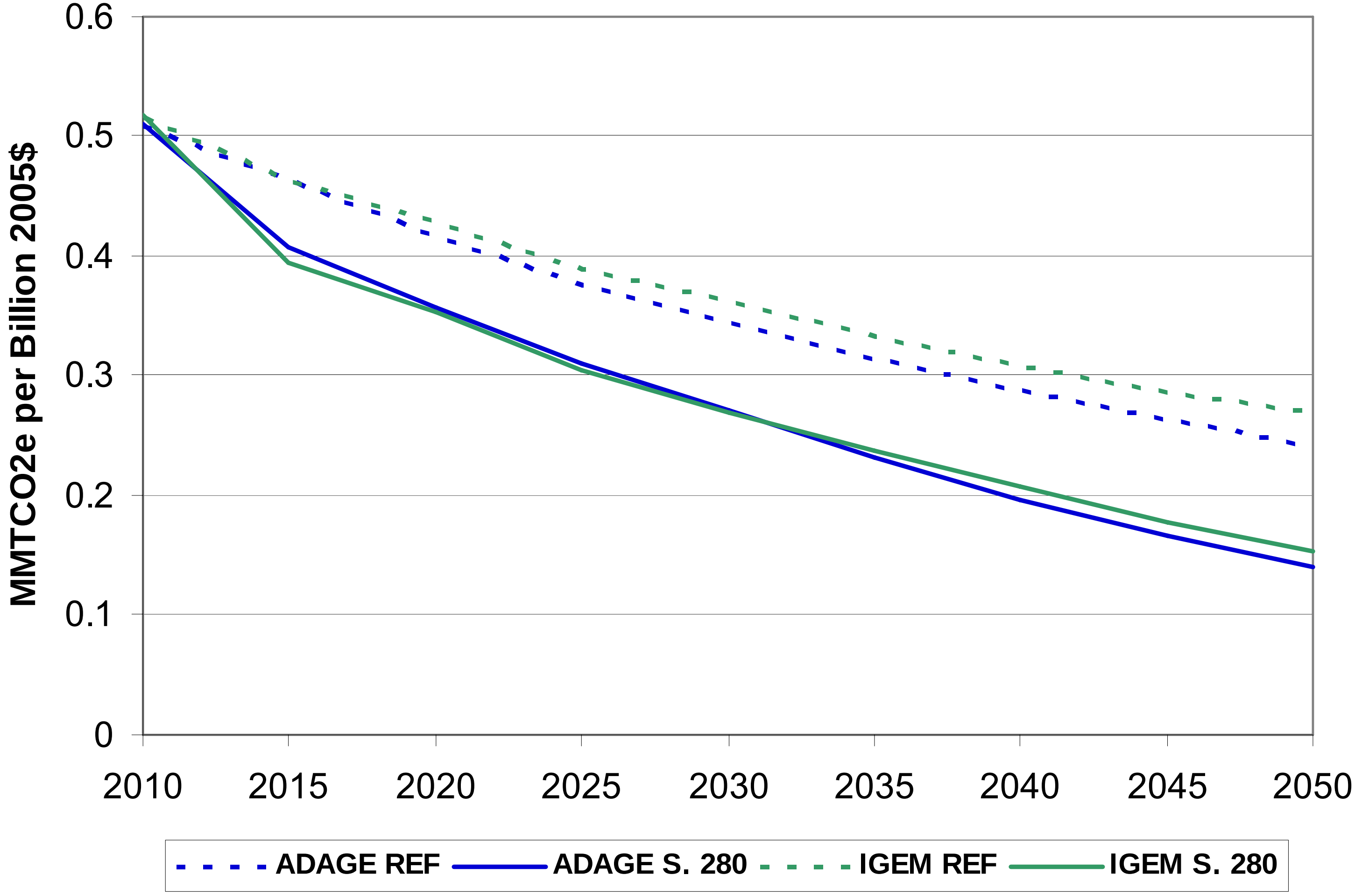
Primary Energy Use (ADAGE)



- Growth in petroleum use is less under S. 280 than in the Reference Scenario.
- Coal use falls as S. 280 is implemented and fuel-switching to natural gas occurs, then rises again in the later years as coal-fired gasification plants with CCS are deployed.
  - Note that the IPM analysis shows a much smaller impact on near-term coal usage.
- The natural gas use trend follows an opposite path to the coal use trend. Natural gas use increases in the earlier years as fuel-switching occurs, and then falls in the later years as CCS is deployed.

Results: S. 280 Senate Scenario

GHG Intensity



Results: S. 280 Senate Scenario

Fuel Price Adders for 2050

	2005 Price	2050 Producer Price	2050 Cost of Carbon Content	2050 End - User Price
Metric Ton of CO_2	n/a		$77.63 *	
Metric Ton of Carbon	n/a		$284.65	
Barrel of Oil	$50.28	$55.08	$33.23	$88.31
Gallon of Gasoline	$2.34	$2.56	$0.68	$3.25
Short Ton of Coal	$36.79	$41.35	$171.61	$212.96
Short Ton of Coal w/ CCS	$36.79	$41.35	$17.16	$58.51
tCf of Natural Gas	$7.51	$5.86	$4.22	$10.08

* Average of ADAGE and IGEM allowance prices

- The 2050 price is obtained by multiplying the 2050 index price in ADAGE by the 2005 price from EIA's 2006 Monthly Energy Review.
- The cost of carbon content is simply the product of the physical carbon content of the fuel and the allowance price.
- The consumer price is simply the sum of the price and the cost of carbon content.
- CCS technology for coal fired power generation captures and stores 90% of carbon emissions, which lowers the cost of carbon content by 90%, and lower the consumer price accordingly.

Results: S. 280 Senate Scenario

2030 Sectoral Results (Sectors 1 - 18) (IGEM)

Sector	2007	2030				
		Reference		S. 280		
	Output ($Billions)	Output ($Billions)	Percent Change from 2007	Output ($Billions)	Percent Change from 2007	Percent Change from Reference
Agriculture, forestry, fisheries	492	991	101%	987	101%	0%
Metal mining	80	158	98%	152	91%	-4%
Coal mining	29	40	39%	25	-13%	-37%
Crude oil and gas extraction	159	232	46%	220	39%	-5%
Non-metallic mineral mining	16	14	-11%	14	-15%	-5%
Construction	1151	1578	37%	1544	34%	-2%
Food and kindred products	565	1155	104%	1183	109%	2%
Tobacco manufactures	32	58	79%	60	86%	4%
Textile mill products	83	230	178%	225	173%	-2%
Apparel and other textile products	78	218	180%	215	177%	-1%
Lumber and wood products	148	331	124%	321	118%	-3%
Furniture and fixtures	100	225	125%	219	119%	-3%
Paper and allied products	217	555	156%	540	149%	-3%
Printing and publishing	243	440	81%	435	78%	-1%
Chemicals and allied products	515	1400	172%	1335	159%	-5%
Petroleum refining	296	389	31%	344	16%	-11%
Rubber and plastic products	218	550	152%	536	146%	-2%
Leather and leather products	13	34	167%	33	162%	-2%

Results: S. 280 Senate Scenario

2030 Sectoral Results (Sectors 19 - 35) (IGEM)

Sector	2007	2030				
		Reference		S. 280		
	Output ($Billions)	Output ($Billions)	Percent Change from 2007	Output ($Billions)	Percent Change from 2007	Percent Change from Reference
Stone, clay and glass products	116	249	114%	241	107%	-3%
Primary metals	205	448	119%	424	107%	-5%
Fabricated metal products	317	625	97%	604	91%	-3%
Non-electrical machinery	631	2387	278%	2310	266%	-3%
Electrical machinery	448	3276	631%	3177	609%	-3%
Motor vehicles	513	1095	114%	1063	107%	-3%
Other transportation equipment	219	420	92%	412	89%	-2%
Instruments	252	566	125%	555	121%	-2%
Miscellaneous manufacturing	66	176	166%	172	161%	-2%
Transportation and warehousing	681	1284	89%	1257	85%	-2%
Communications	517	1137	120%	1135	119%	0%
Electric utilities (services)	384	548	43%	499	30%	-9%
Gas utilities (services)	51	60	20%	56	11%	-8%
Wholesale and retail trade	2495	4703	89%	4606	85%	-2%
Finance, insurance and real estate	2642	6075	130%	6038	129%	-1%
Personal and business services	4304	8108	88%	8088	88%	0%
Government enterprises	449	842	87%	832	85%	-1%

Results: S. 280 Senate Scenario

2050 Sectoral Results (Sectors 1 - 18) (IGEM)

Sector	2007	2050				
		Reference		S. 280		
	Output ($Billions)	Output ($Billions)	Percent Change from 2007	Output ($Billions)	Percent Change from 2007	Percent Change from Reference
Agriculture, forestry, fisheries	492	1459	197%	1438	192%	-1%
Metal mining	80	246	208%	228	186%	-7%
Coal mining	29	51	77%	22	-25%	-58%
Crude oil and gas extraction	159	313	97%	275	73%	-12%
Non-metallic mineral mining	16	18	15%	17	7%	-7%
Construction	1151	2189	90%	2106	83%	-4%
Food and kindred products	565	1788	216%	1903	237%	6%
Tobacco manufactures	32	91	183%	102	214%	11%
Textile mill products	83	394	377%	382	363%	-3%
Apparel and other textile products	78	397	411%	387	398%	-3%
Lumber and wood products	148	609	313%	576	290%	-5%
Furniture and fixtures	100	339	239%	322	222%	-5%
Paper and allied products	217	973	348%	921	325%	-5%
Printing and publishing	243	686	182%	667	174%	-3%
Chemicals and allied products	515	2530	391%	2316	349%	-8%
Petroleum refining	296	460	55%	348	17%	-24%
Rubber and plastic products	218	868	298%	826	279%	-5%
Leather and leather products	13	60	367%	57	349%	-4%

Results: S. 280 Senate Scenario

2050 Sectoral Results (Sectors 19 - 35) (IGEM)

Sector	2007	2050				
		Reference		S. 280		
	Output ($Billions)	Output ($Billions)	Percent Change from 2007	Output ($Billions)	Percent Change from 2007	Percent Change from Reference
Stone, clay and glass products	116	451	287%	434	273%	-4%
Primary metals	205	739	261%	664	224%	-10%
Fabricated metal products	317	985	211%	924	192%	-6%
Non-electrical machinery	631	4465	608%	4200	566%	-6%
Electrical machinery	448	7466	1567%	7040	1472%	-6%
Motor vehicles	513	1818	255%	1723	236%	-5%
Other transportation equipment	219	677	210%	655	200%	-3%
Instruments	252	861	242%	833	231%	-3%
Miscellaneous manufacturing	66	317	379%	306	362%	-4%
Transportation and warehousing	681	1932	184%	1851	172%	-4%
Communications	517	1849	258%	1844	257%	0%
Electric utilities (services)	384	704	83%	575	50%	-18%
Gas utilities (services)	51	64	27%	53	4%	-18%
Wholesale and retail trade	2495	7024	182%	6752	171%	-4%
Finance, insurance and real estate	2642	9879	274%	9777	270%	-1%
Personal and business services	4304	12226	184%	12184	183%	0%
Government enterprises	449	1249	178%	1219	171%	-2%

Appendix 3: Model Descriptions

Intertemporal General Equilibrium Model (IGEM)

- IGEM is a model of the U.S. economy with an emphasis on the energy and environmental aspects.
- It is a dynamic model, which depicts growth of the economy due to capital accumulation, technical change and population change.
- It is a detailed multi-sector model covering 35 industries.
- It also depicts changes in consumption patterns due to demographic changes, price and income effects.
- The model is designed to simulate the effects of policy changes, external shocks and demographic changes on the prices, production and consumption of energy, and the emissions of pollutants.
- The main driver of economic growth in this model is capital accumulation and technological change. It also includes official projections of the population, giving us activity levels in both level and per-capita terms.
- Capital accumulation arises from savings of a household that is modeled as an economic actor with “perfect foresight.”

- This model is implemented econometrically which means that the parameters governing the behavior of producers and consumers are statistically estimated over a time series dataset that is constructed specifically for this purpose.
- This is in contrast to many other multi-sector models that are calibrated to the economy of one particular year.
- These data are based on a system of national accounts developed by Jorgenson (1980) that integrates the capital accounts with the National Income Accounts.
- These capital accounts include an equation linking the price of investment goods to the stream of future rental flows, a link that is essential to modeling the dynamics of growth.

- The model is developed and run by Dale Jorgenson Associates for EPA.
- Model Homepage: http://post.economics.harvard.edu/faculty/jorgenson/papers/papers.html

Applied Dynamic Analysis of the Global Economy (ADAGE)

- ADAGE is a dynamic computable general equilibrium (CGE) model capable of examining many types of economic, energy, environmental, climate-change mitigation, and trade policies at the international, national, U.S. regional, and U.S. state levels.
- To investigate policy effects, the CGE model combines a consistent theoretical structure with economic data covering all interactions among businesses and households.
- A classical Arrow-Debreu general equilibrium framework is used to describe economic behaviors of these agents.

- ADAGE has three distinct modules: International, U.S. Regional, and Single Country.
- Each module relies on different data sources and has a different geographic scope, but all have the same theoretical structure.
- This internally consistent, integrated framework allows its components to use relevant policy findings from other modules with broader geographic coverage, thus obtaining detailed regional and state-level results that incorporate international impacts of policies.
- Economic data in ADAGE come from the GTAP and IMPLAN databases, and energy data and various growth forecasts come from the International Energy Agency and Energy Information Administration of the U.S. Department of Energy.
- Emissions estimates and associated abatement costs for six types of greenhouse gases (GHGs) are also included in the model.

- The model is developed and run by RTI International for EPA.
- Model Homepage: http://www.rti.org/adage

Non-CO_2 GHG Models

- EPA develops and houses projections and economic analyses of emission abatement through the use of extensive bottom-up, spreadsheet models.
- These are engineering–economic models capturing the relevant cost and performance data on over 15 sectors emitting the non-CO_2 GHGs.
- For the emissions inventory and projections, all anthropogenic sources are covered. For mitigation of methane, the sources evaluated include coal mining, natural gas systems, oil production, and solid waste management.
- For mitigation of HFC, PFC, and SF6, the sources evaluated include over 12 industrial sectors.
- For mitigation of nitrous oxide, sources evaluated include adipic and nitric acid production.
- Only currently available or close-to-commercial technologies are evaluated.
- The estimated reductions and costs are assembled into marginal abatement curves (MACs).
- MACs are straightforward, informative tools in policy analyses for evaluating economic impacts of GHG mitigation. A MAC illustrates the amount of reductions possible at various values for a unit reduction of GHG emissions and is derived by rank ordering individual opportunities by cost per unit of emission reduction. Any point along a MAC represents the marginal cost of abating an additional amount of a GHG.
- The total cost of meeting an absolute emission reduction target can be estimated by taking the integral of a MAC curve from the origin to the target.
- Global mitigation estimates are available aggregated into nine major regions of the world including the U.S. and are reported for the years 2010, 20015 and 2020.
- The data used in the report are from *Global Mitigation of Non-CO_2 Greenhouse Gases* (EPA Report 430-R-06-005). www.epa.gov/nonco2/econ-inv/international.html

Forest and Agriculture Sector Optimization Model-GHG

- FASOM-GHG simulates land management and land allocation decisions over time to competing activities in both the forest and agricultural sectors. In doing this, it simulates the resultant consequences for the commodity markets supplied by these lands and, importantly for policy purposes, the net greenhouse gas (GHG) emissions.
- The model was developed to evaluate the welfare and market impacts of public policies and environmental changes affecting agriculture and forestry. To date, FASOMGHG and its predecessor models FASOM and ASM have been used to examine the effects of GHG mitigation policy, climate change impacts, public timber harvest policy, federal farm program policy, biofuel prospects, and pulpwood production by agriculture among other policies and environmental changes.
- FASOMGHG is a multiperiod, intertemporal, price-endogenous, mathematical programming model depicting land transfers and other resource allocations between and within the agricultural and forest sectors in the US. The model solution portrays simultaneous market equilibrium over an extended time, typically 70 to 100 years on a ten year time step basis.
- The results from FASOMGHG yield a dynamic simulation of prices, production, management, consumption, GHG effects, and other environmental and economic indicators within these two sectors, under the scenario depicted in the model data.
- The principal model developer is Dr. Bruce McCarl, Department of Agricultural Economics, Texas A&M University.
- The data used in the report are from *Greenhouse Gas Mitigation Potential in U.S. Forestry and Agriculture* (EPA Report 430-R-05-006). http://www.epa.gov/sequestration/greenhouse_gas.html.
- Model Homepage: http://agecon2.tamu.edu/people.faculty/mccarl-bruce/FASOM.html

Global Timber Model (GTM)

- GTM is an economic model capable of examining global forestry land-use, management, and trade responses to policies. In responding to a policy, the model captures afforestation, forest management, and avoided deforestation behavior.
- The model estimates harvests in industrial forests and inaccessible forests, timberland management intensity, and plantation establishment, all important components of both future timber supply and carbon flux. The model also captures global market interactions.
- The model is a partial equilibrium intertemporally optimizing model that maximizes welfare in timber markets over time across approximately 250 world timber supply regions by managing forest stand ages, compositions, and acreage given production and land rental costs. The model equates supply and demand in each period, and predicts supply responses to current and future prices. The 250 supply regions are delineated by ecosystem and timber management classes, as well as geo-political regional boundaries. The model runs on 10-year time steps.
- The model has been used to explore a variety of climate change mitigation policies, including carbon prices, stabilization, and optimal mitigation policies.
- The principal model developer is Brent Sohngen, Department of Agricultural, Environmental, and Development Economics, Ohio State University. Other key developers and collaborators over the life of the model include Robert Mendelsohn, Roger Sedjo, and Kenneth Lyon. For this analysis, the model was run by Dr. Sohngen for EPA.
- Website for GTM papers and input datasets: http://aede.osu.edu/people/sohngen.1/forests/ccforest.htm#gfmod

Mini-Climate Assessment Model (MiniCAM)

- The MiniCAM is a highly aggregated integrated assessment model that focuses on the world's energy and agriculture systems, atmospheric concentrations of greenhouse gases (CO_2 and non-CO_2) and sulfur dioxide, and consequences regarding climate change and sea level rise.
- It has been updated many times since the early eighties to include additional technology options. MiniCAM is capable of incorporating carbon taxes and carbon constraints in conjunction with the numerous technology options including carbon capture and sequestration.
- The model has been exercised extensively to explore how the technology gap can be filled between a business-as-usual emissions future and an atmospheric stabilization scenario.
- The MiniCAM model is designed to assess various climate change policies and technology strategies for the globe over long time scales. It is configured as a partial equilibrium model that balances supply and demand for commodities such as oil, gas, coal, biomass and agricultural products.
- The model runs in 15-year time steps from 1990 to 2095 and includes 14 geographic regions.
- The model is developed and run at the Joint Global Change Research Institute, University of Maryland. Model Homepage: http://www.globalchange.umd.edu

The Integrated Planning Model (IPM)

- EPA uses the Integrated Planning Model (IPM) to analyze the projected impact of environmental policies on the electric power sector in the 48 contiguous states and the District of Columbia.
- IPM is a multi-regional, dynamic, deterministic linear programming model of the U.S. electric power sector.
- The model provides forecasts of least-cost capacity expansion, electricity dispatch, and emission control strategies for meeting energy demand and environmental, transmission, dispatch, and reliability constraints.
- IPM can be used to evaluate the cost and emissions impacts of proposed policies to limit emissions of sulfur dioxide (SO_2), nitrogen oxides (NOx), carbon dioxide (CO_2), and mercury (Hg) from the electric power sector.
- The IPM was a key analytical tool in developing the Clean Air Interstate Regulation (CAIR) and the Clean Air Mercury Rule (CAMR).
- IPM provides both a broad and detailed analysis of control options for major emissions from the power sector, such as power generation adjustments, pollution control actions, air emissions changes (national, regional/state, and local), major fuel use changes, and economic impacts (costs, wholesale electricity prices, closures, allowance values, etc.).
- The model was developed by ICF Resources and is applied by EPA for its Base Case. IPM® is a registered trademark of ICF Resources, Inc.
- EPA’s application of IPM Homepage: http://www.epa.gov/airmarkets/progsregs/epa-ipm/index.html

National Energy Modeling System (NEMS)

- When Senators Lieberman and McCain requested that EPA analyze S. 280, they sent a similar request to the Energy Information Administration (EIA).
- EIA is using NEMS for its analysis of S. 280.
- NEMS is also used to produce the Annual Energy Outlook (AEO).
- NEMS represents domestic energy markets by explicitly representing the economic decision making involved in the production, conversion, and consumption of energy products.
- Where possible, NEMS includes explicit representation of energy technologies and their characteristics.
- NEMS is organized and implemented as a modular system.
  - For each fuel and consuming sector, NEMS balances the energy supply and demand, accounting for the economic competition between the various energy fuels and sources.
  - The modules represent each of the fuel supply markets, conversion sectors, and end-use consumption sectors of the energy system.
  - NEMS also includes a macroeconomic and an international module.
  - For purposes of S.280 analysis, NEMS is augmented with a representation of greenhouse gas emissions outside of the energy sector and uses marginal abatement curves to represent opportunities to reduce them.
- NEMS includes regional detail (nine Census divisions).
- NEMS runs in annual time steps through 2030.

Differences between NEMS and IGEM / ADAGE

- Analysis Time Frame
  - ADAGE and IGEM report through 2050
  - NEMS reports through 2030
- Technology Detail
  - ADAGE and IGEM are top-down models with limited technology detail
  - NEMS is a bottom-up model with extensive technology detail
- Macroeconomic Effects
  - NEMS Macroeconomic Activity Module is based on the Global Insight Model of the U.S. Economy, which is a macroeconomic forecasting model.
    - Based on estimated relationships at an aggregate level, using adaptive rather than rational expectations.
    - Forecasts effects at the aggregate level, such as how GDP and unemployment, are affected by changes in inflation or fiscal and monetary policies.
    - These types of models can capture short- and medium-term disequilibrium adjustments in response to exogenous shocks. They can address short and medium-term transition costs of energy policies as the economy transitions to a long-run growth path. They have more detailed government sectors and a well-defined set of fiscal policies. In addition, they can incorporate accommodating monetary policies.
  - IGEM and ADAGE are Computable General Equilibrium models
    - Structural models based on microeconomic foundations.
    - They build up their representation of the whole economy through the interactions of multiple agents (e.g. households and firms), whose decisions are based upon optimization.
    - These models are best suited for capturing long-run equilibrium responses, and unique characteristics of specific sectors of the economy.