U.S. Environmental Protection Agency
Office of Atmospheric Programs

EPA Analysis of the American Power Act

in the 111th Congress

Appendix

6/14/10*

* This version was updated on 6/30/10 to present a corrected version of ADAGE "Scenario 5 – No International Offsets" that fixes a problem with the model code that overly limited nuclear power in this scenario. This version also corrects a reporting error in ADAGE reference case average annual household energy expenditures.

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The American Power Act

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*Note that all page number references on the following pages refer to "Discussion Draft" of the American Power Act that can be found at *kerry.senate.gov/americanpoweract/pdf/APAbill.pdf*

The American Power Act – Bill Summary
Coverage
(Title II, Subtitle A)

- In comparison with H.R. 2454 and S.1733:
  - Start year of program is 2013 in American Power Act rather than 2012 (CAA* Sec. 722, (a), p.324).
  - Direct emissions from refineries covered in 2013. Coverage for all other industrial stationary sources and natural gas local distribution companies (LDCs) begins in 2016 (CAA Sec. 722, (c)(1,2), p.331)
  - The American Power Act restricts exemptions from allowance holding requirements for electricity generating units (EGUs) to emissions resulting from the combustion of renewable biomass (and gas derived from biomass), (CAA Sec. 722, (b)(1), p.325). HR 2454 exempted EGU's emissions from the combustion of petroleum/coal-based fuels, natural gas liquids, renewable biomass (or gas derived from renewable biomass) and petroleum coke (or gas derived from petroleum coke) from allowance holding requirements.
  - Emissions allowance holding exemptions for industrial stationary sources other than refineries are limited to the combustion of renewable biomass (or gas derived from renewable biomass) and the use of any fluorinated gas that is a greenhouse gas purchased for use at the covered entity, except for nitrogen triflouride (CAA Sec. 722, (b)(6), p.327). The exemptions for industrial stationary sources eliminated from HR 2454 for The American Power Act are the same as those eliminated for EGU's.
  - The American Power Act allows the destruction of hydrochlorofluorocarbons (HCFCs) to earn credits applicable as an offset in the hydrofluorocarbon program (CAA Sec. 753, (b)(5), p.429 and CAA Sec. 619, (b)(9)(B)(i), p. 568). Otherwise, coverage of HFCs is identical to that in S. 1733.

* References to "CAA" are to the sections of the Clean Air Act that the current bill intends to create or amend.

The American Power Act
Bill Summary
(Title II, Subtitle A)

Cap Levels

- Cap targets are identical to H.R. 2454 (ie., 17% reduction in GHG emissions by 2020, 83% reduction by 2050, etc.). However, the new starting level, reflecting a later program start date in 2013, is 4.72 billion tons $C0_2e$ (CAA Sec. 721, (e)(1), p.311).
- Cap levels for hydrofluorocarbons (HFCs) are the same as in S.1733 (ie., 67% of base by 2020, 15% of base by 2033), (CAA Sec. 619, (b)(2), p.539).

Price Collar and Cost Containment Reserve

- Auction price floor of $12 in 2009 dollars, increasing at CPI+3% (Subtitle B, CAA Sec. 790, (d)(1,2), p.521).
- Price ceiling of $25 in 2009 dollars, increasing at CPI+5% (CAA Sec. 726, (b)(3)(A,B), p.349).
- One time per year, allowances from established reserve offered for sale at ceiling price prior to “true-up” period.
- Covered entities permitted to fulfill 15% of their annual compliance obligation from reserve allowances (CAA Sec. 726, (b)(5), p.350).
- Revenue from allowance sale used to purchase international REDD offsets, converted at a rate of 5:4 to reserve allowances (CAA Sec. 726, (c)(2)(A), p. 351).
- If REDD offsets not available, reserve replenishment may come from purchase of domestic offsets (CAA Sec. 726, (c)(2)(B), p.351).

The American Power Act – Bill Summary
Domestic and International Offsets
(Title II, Subtitle A, CAA Sec. 722, (d)(1), p. 331)

- Largely same as S. 1733.
- 2 billion tons of annual compliance obligations can be satisfied from offsets.
- Limit of 1.5 billion tons from domestic offsets and .5 billion tons from international offsets.
- If fewer than 1.5 billion tons equivalent of domestic offsets available in any given year, then the residual may be made up from the purchase of international offsets with an ultimate cap of 1 billion tons equivalent of international offset allowances. Whereas H.R. 2454 set an ultimate cap of 1.5 billion tons equivalent of international offsets annually, S. 1733 set this ultimate cap at 1.25 billion tons.
- International offsets convert to creditable allowances at a rate of 1:1 until the start of 2018 when they begin to convert at a 5:4 ratio.
- Offsets originate in activities in developing countries that reduce or avoid greenhouse gas emissions, or increase sequestration of greenhouse gases, including activities that reduce deforestation (CAA Sec. 753, (a)(1), p. 427). The Administrator or an international body may issue international offset credits for such projects (CAA Sec. 756, (b), p.447).

The American Power Act – Bill Summary

Uncapped Sources (Title I, Subtitle C, Part IV)

- Same as S.1733 – no New Source Performance Standards (NSPS) for significant sources of offset projects until 1/1/20 (CAA Sec. 801, (b)(2)(B), p. 174).

Stationary Source Performance Standards

- Same as S.1733 for new coal-fired units (CAA Sec. 801); EPA sets NSPS for existing EGU's.
- NSPS otherwise eliminated for capped sources.

Energy Efficiency Provisions (Title 1, Subtitle B)

- Permit allocation to states for energy efficiency and renewable energy of which up to $1 billion is dedicated to the rural utility savings program for low-interest loans for energy efficiency (CAA Sec. 781, (c)(5)(A,B), p.502).
- Of allowances dedicated to early action states, 2/3 of proceeds must go to state energy efficiency programs (CAA Sec. 788, (a,e(3)), pp.512-517).
- Up to $1.55 billion annually between 2013-2015 for industrial energy efficiency activities (CAA Sec. 781, (b)(2), p.498).
- Up to $50 million annually between 2013-2015 for manufacturing extension partnership activities (CAA Sec. 781, (b)(2)(B), p.499).
- Further details on the bill's energy efficiency provisions can be found in the appendix on energy efficiency.

The American Power Act – Bill Summary Transportation

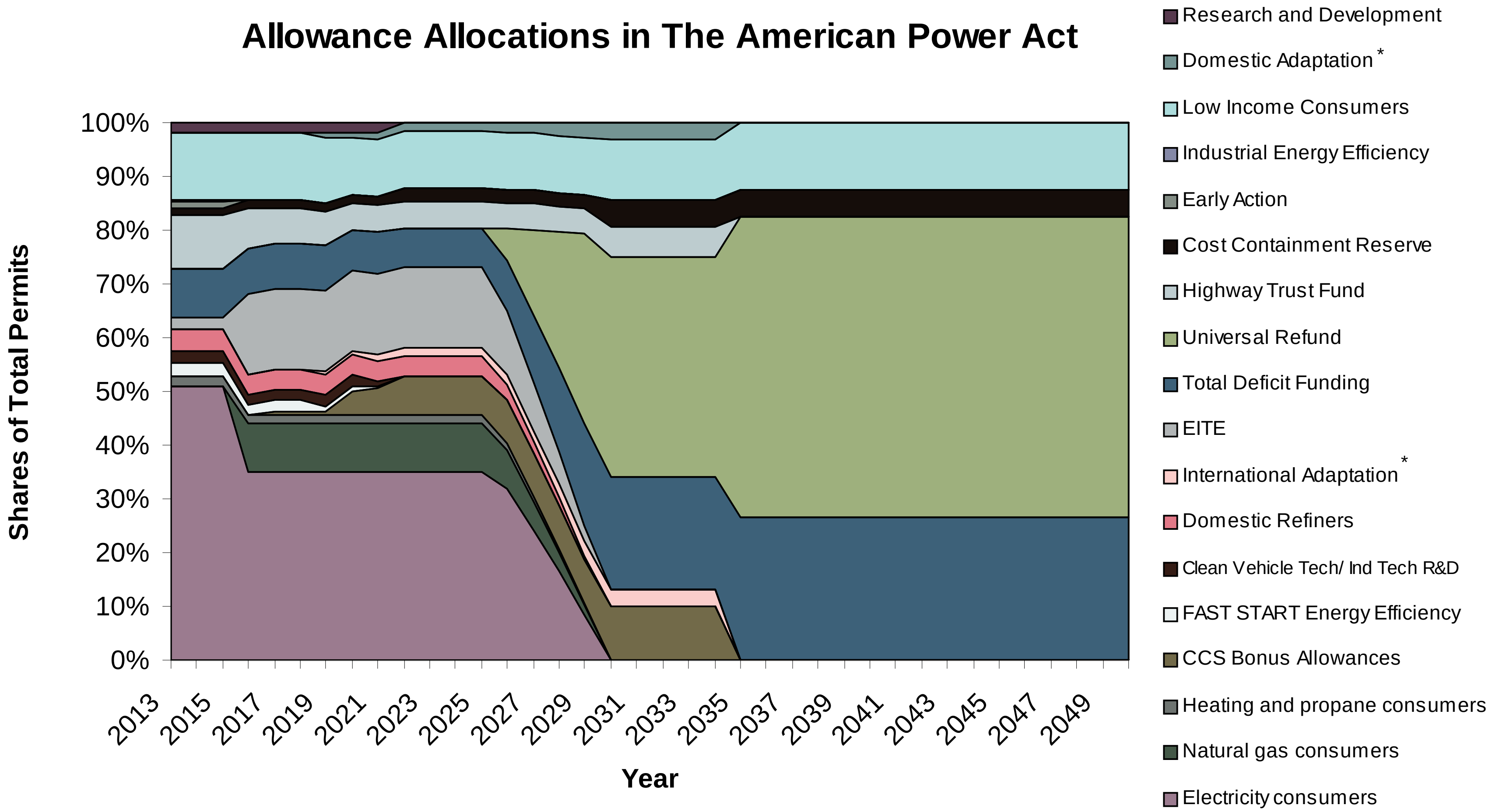
Transportation Fuels: The Alternative Compliance Program
(Title II, Subtitle A, CAA Sec. 729, p.361)

- Before start of each quarter, EPA sets aside from allowances to be auctioned the number of allowances projected to be needed for combustion of refined products in that quarter.
- Refined product sector purchases these allowances at the auction-clearing price for allowance vintages of that quarter for compliance in that quarter.
- If EPA did not set aside a sufficient number of allowances for a quarter, it draws down allowances available for auction in the following quarter.
- Allowances needed by sector based on quantity of fuel sold multiplied by EPA-determined emissions factor.
- Refined product providers include owners of fuels inside a fuel terminal, owners of fuels upon removal from a refinery, and importers.
- Excluded from the mandate: petroleum coke included in combustion at covered entities; distillate or residual fuel oil, if combusted in covered entities; distillate fuel or residual fuel oil used ot power ocean-going vessels; non-emissive feedstock; the renewable fuel component of a refined product; and otherwise refined product that is exported or sold for export.
- The system will be officially reassessed no later than January 1, 2033 and may be subsequently revised.

Transportation Policies
(Title IV, Subtitle B, Part II, CAA Sec. 804, p.871)

- Requires EPA to set standards for heavy-duty and non-road vehicles and engines .
- EPA and NHTSA to set GHG and CAFÉ standards for light-duty vehicles for model years after 2016, in consultation with California and representatives of the automobile industry (CAA Sec. 804, (e), p.877).
- Support for development of electric vehicle infrastructure, advanced vehicle technologies, and natural gas vehicles.

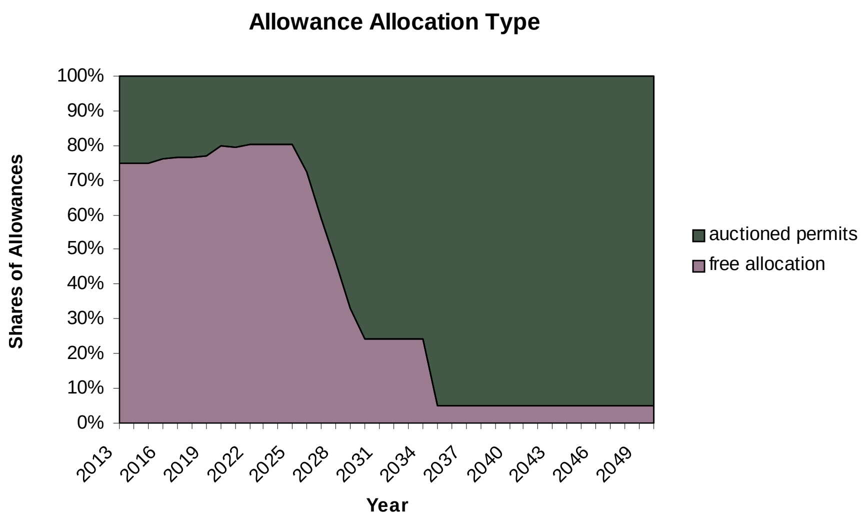
The American Power Act – Bill Summary
Allowance Allocations
(based on Title II, Subtitle B, p.492)

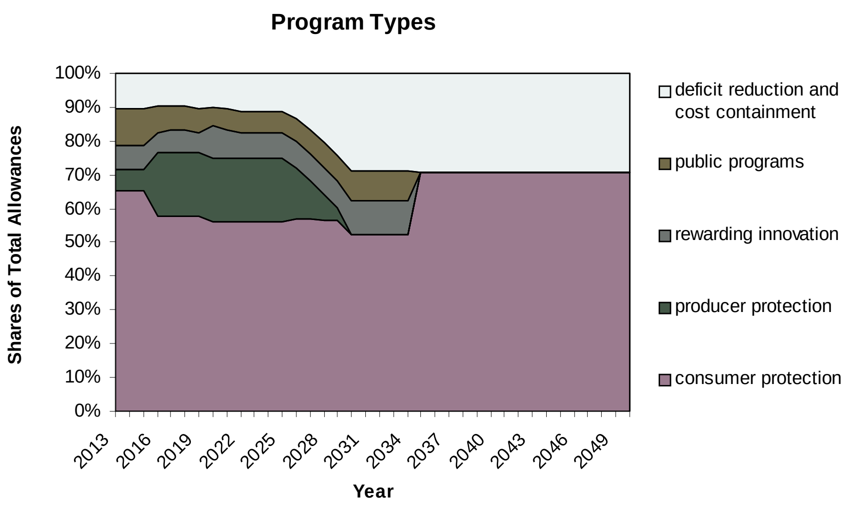


*The APA ultimately gives The President discretion to shift allocation amounts between international and domestic adaptation.

The American Power Act – Bill Summary

Other Characteristics of the Allocation (based on Title II, Subtitle B, p. 492)





Permits are initially distributed at no cost to most covered entities; however, after 20 years, most of the permits are auctioned. By 2036, the only allowances not being auctioned immediately are those saved in the cost containment reserve for possible future sale.

The largest share of allowance value is consistently used to protect consumers. Producers receive direct compensation during the program's first 20 years.

The American Power Act – Bill Summary

Allowances, Further Notes

- Two direct rebates (Title II, Subtitle B, CAA Sec. 781, (a)(4), p.494):
  - Working Families Relief for households whose annual income is between $1000 below 150% of the poverty level and $2000 below 250% of the poverty level (Title III, Subtitle C, IRC* Sec. 36D, (b,c), p.747); receives funding from allowance sales through 2029.
  - Energy Refund is for households whose gross income is at or below 150% of the poverty level (Sec. 2201, (c)(1), p.753); receives funding from allowance sales during the entire program duration.

- Electric LDC allocations are exclusively for rate-payer benefit (Title III, Subtitle A, CAA Sec. 782, (b)(5)(A), p.705); 20% of natural gas LDC allocations (which must all be used for rate-payer benefit) must be used for energy efficiency programs for natural gas consumers (Title III, Subtitle B, CAA Sec. 783, (4)(A), p.733).

- No special provisions for small LDCs.

- EPA can require allowance recipients to auction allowances on consignment as needed in order to ensure availability of allowances for purchase by refined product providers and to ensure a robust auction market. Proceeds of such sales are earned by the original allowance recipient (Title II, Subtitle B, CAA Sec. 790, (f)(4)(B), p. 524).

- The Universal Refund (comprising 75% of the Universal Trust Fund allocation) is a transfer of permit auction revenue and available to all U.S. citizens (Title III, Subtitle C, IRC Sec 36E, (b), p.772).

* "IRC" refers to sections of the Internal Revenue Code of 1986 that the American Power Act would add or change.

The American Power Act – Bill Summary

Some Notes on Non-Allowance Support

- **Nuclear (Title I, Subtitle A, p.14)**:
  - 5-year accelerated depreciation period for new nuclear power plants.
  - Investment tax credit for nuclear power facilities.
  - Expansion of advanced energy project credit to include nuclear power facilities.
  - Modification of credit for production from advanced nuclear power facilities.
  - Allow tax-exempt bonds to be used for public-private partnerships for advanced nuclear power facilities.
  - Increased loan guarantees to $54 billion (from previous $18.5 billion), (Sec.1102, (a)(2), p.18).

- **Natural Gas Vehicles (Title IV, Subtitle B, Part II, Subpart B, p.850)**:
  - Extends and doubles for 10 years the alternative fuel credits for purchase of natural gas vehicles weighing more than 8500 pounds and are capable of operating on compressed or liquefied gas.
  - Extends and doubles credit for vehicles weighing less than 8500 pounds for commercial fleet vehicles of at least 10 cars and purchases of at least three natural gas vehicles.
  - Allows state and local government entities to issue tax credit bonds to finance natural gas vehicle projects, up to $3 billion nationally.
  - Allows 100% of the cost of a natural gas vehicle manufacturing facility placed in service before January 1, 2015 to be treated as a deduction in the taxable year that the facility was placed in service.

- **Carbon Capture and Storage Special Funding Program (Title I, Subtitle C, Part II, p.80)**:
  - $2-$2.1 billion annually for 10 years funded through fee on electric utilities on all fossil-fuel based electricity sold (Sec. 1415, (a), p.101);

The American Power Act – Bill Summary

Preventing Emissions Leakage to Other Countries

(Title IV, Subtitle A, CAA Part F, Subparts 1,2, p. 788-822)

- Trade-exposed industrial sectors receive allowance rebates to partially or fully cover emissions through 2025, officially phasing out between 2026 and 2030.

- The President establishes an international reserve program by January 1, 2020 if a comprehensive multilateral greenhouse gas reductions agreement has not yet entered into force. No later than June 30, 3023, subsequent to the establishment of the reserve program, the program will be activated for each industrial sector for which <u>less than</u> 70% of global production originates in a country that meets the following:
  - Products from countries that are party to an international emissions reduction agreement to which the United States is also a party, are party to a bilateral or multilateral emissions reduction agreement with the United States and from countries whose greenhouse gas intensity for the given sector is less than or equal to that in the corresponding sector in the United States.

- The reserve program may not be active if either <u>more than</u> 70 percent of a sector's product meets the above condition or if the domestic industrial sector is able to fully offset emissions reductions costs through continuing rebates.

- Upon the activation of the International Reserve Allowance program for a given trade-intensive sector, importers of goods from that sector are required to purchase International Reserve Allowances for emissions generated during foreign production, with the following exceptions:
  - Products from countries that the United Nations has identified as among the least developed of developing countries.
  - Products from any foreign country that the President has determined to be responsible for less than ½% of total global greenhouse gas emissions and less than 5% of global production of the good in question (CAA Sec. 777, (a)(4,5), p.820).

- Under the President's discretion, the rebate program may be used in place of the international reserve program for any industrial sector.

Allocations Treatment by ADAGE and IGEM

ADAGE and IGEM are models used in combination to estimate economic outcomes of climate change policy. Because each model's primary interest is slightly different from the other, they use somewhat different allowance allocation configurations. The following shows the allowance allocation framework of each model, with main differences highlighted in red. Either the allowance is modeled explicitly (flows to the intended recipient) or it is "not modeled" and assumed returned to consumers along with any other allowances intended to flow to consumers.

Allowance Allocation Treatment by IGEM and ADAGE

	Model Treatment	
Allowance Allocation (reference to Sec. 781 of the Clean Air Act)	IGEM	ADAGE
electricity consumers (a)(1)	explicitly	mixed
Local Distribution Companies	explicitly	explicitly
Merchant Coal	explicitly	lump-sum to households
Long-Term Contract Generators	explicitly	lump-sum to households
natural gas consumers (a)(2)	explicitly	explicitly
heating and propane consumers (a)(3)	explicitly	lump-sum to households
CCS Bonus Allowances (c)(1)	explicitly	explicitly
FAST START Energy Efficiency (c)(5)	lump-sum to households	explicitly
Rural Energy Savings (c)(5)(B)	lump-sum to households	explicitly
State EE (c)(5)(C)	lump-sum to households	explicitly
Early Action (e)	lump-sum to households	explicitly
Industrial Energy Efficiency (b)(2)	lump-sum to households	explicitly
Clean Vehicle Tech/ Ind Tech R&D (c)(2)(3)	explicitly	lump-sum to households
Clean Vehical Technology (c)(2)	explicitly	lump-sum to households
Industrial Tech R&D (c)(3)	explicitly	lump-sum to households
Domestic Refiners (b)(3)	explicitly	lump-sum to households
International Adaptation (d)	international transfer	international transfer
EITE (b)(1)	explicitly	explicitly
Total Deficit Funding (h)	explicitly	explicitly
Universal Refund (a)(5)	lump-sum to households	lump-sum to households
Transportation Infrastructure Efficiency	lump-sum to households	lump-sum to households
Highway Trust Fund (f)(1)	lump-sum to households	lump-sum to households
Tiger II (f)(2,3)	lump-sum to households	lump-sum to households
Clean TEA (f)(2,3)	lump-sum to households	lump-sum to households
Cost Containement Reserve (Sec.726)	explicitly	explicitly
Low Income Consumers (a)(4)	lump-sum to households	lump-sum to households
Energy Refund Program	lump-sum to households	lump-sum to households
Working Families Program	lump-sum to households	lump-sum to households
Domestic Adaptation (d)	lump-sum to households	lump-sum to households
Research and Development (b)(4)	lump-sum to households	lump-sum to households

Analytical Scenarios

Reference and Core Policy Scenarios

EPA analyzed 10 different scenarios in this report. The assumptions about other domestic and international policies that affect the results of this analysis do not necessarily reflect EPA's views on likely future actions.

Scenario 1 - EPA 2010 Reference

– This reference scenario is benchmarked to the AEO 2010 forecast and includes both EISA and ARRA.
  - Does not include any additional domestic or international climate policies or measures to reduce international GHG emissions
  - For international projections, uses the EMF-22 GCAM reference.

Scenario 2 – American Power Act (core policy scenario)

- This core policy scenario models the cap-and-trade program established in Title II of the American Power Act.
- Provisions explicitly modeled in this scenario:
  - CCS bonus allowances
  - EE provisions (allowance allocations and building energy efficiency codes*)
  - Output-based rebates
  - The price collar
  - Allocations to electricity local distribution companies (LDCs) (used to lower electricity prices)
- Widespread international actions by developed and developing countries over the modeled time period. International policy assumptions are consistent with the agreement among G8 leaders at the July 9, 2009 Major Economies Forum "to reduce their emissions 80% or more by 2050 as its share of a global goal to lower emissions 50% by 2050."
  - Group 1 countries (Kyoto group less Russia) follow an allowance path that is falling linearly from the simulated Kyoto emissions levels in 2012 to 83% below 2005 in 2050.
  - Group 2 countries (rest of world) adopt a policy beginning in 2025 that caps emissions at 2015 levels, and linearly reduces emissions to 26% below 2005 levels by 2050.
  - The combination of U.S., Group 1, and Group 2 actions caps 2050 emissions at 50% below 2005 levels.

* Building codes provision from S. 1462, Sec. 241, included per Senate specifications to EPA.

Analytical Scenarios

Sensitivity Scenarios

In the following scenarios all assumptions are identical to scenario 2 unless specified.

International action sensitivities:

- **Scenario 3 – Early developing country action scenario**
  - Explores the impact of earlier action by developing countries, with a 2050 target that is consistent with the G8 agreement:
  - Group 1 countries (Kyoto group less Russia) follow an allowance path that is falling linearly from the simulated Kyoto emissions levels in 2012 to 83% below 2005 in 2050.
  - Group 2 countries (rest of world) adopt a policy beginning in 2020 that caps emissions 15% below BAU levels, and linearly reduces emissions to 26% below 2005 levels by 2050.
  - The combination of U.S., Group 1, and Group 2 actions cap 2050 emissions at 50% below 2005 levels.

- **Scenario 4 – No developing country action**
  - Explores the impact of developing countries not taking any action, resulting in a failure to achieve the G8 2050 goals:
  - Group 1 countries (Kyoto group less Russia) follow an allowance path that is falling linearly from the simulated Kyoto emissions levels in 2012 to 83% below 2005 in 2050.
  - Group 2 countries (rest of world) do not cap GHG emissions.

Analytical Scenarios

Sensitivity Scenarios

In the following scenarios all assumptions are identical to scenario 2 unless specified.

Technology and offset sensitivities requested by Senator Voinovich

- **Scenario 5 – V – No Int'l Offsets**
  - International offsets are not allowed or available.

- **Scenario 6 – V – Reference Nuclear & Biomass / Delayed CCS**
  - No nuclear or bioelectricity capacity additions above what is allowed in the reference case.
  - CCS technology is not available until after 2030.

- **Scenario 7 – V – Reference Nuclear & Biomass / Delayed CCS – No Int'l Offsets**
  - No nuclear or bioelectricity capacity additions above what is allowed in the reference case.
  - CCS technology is not available until after 2030.
  - International offsets are not allowed or available.

- **Scenario 8 – V – IPM electricity sector reductions imposed on ADAGE**
  - The ADAGE model is constrained so that emissions reductions in the electricity sector match the emissions reductions projected by IPM.

- **Scenario 9 – No CCS Bonus Allowances**
  - CCS technology is available, but not subsidized through CCS bonus allowances or wire charges.

Analytical Scenarios

Sensitivity Scenarios

Scenario for comparing the American Power Act with H.R. 2454. EPA's January 29, 2010 supplemental analysis of H.R. 2454 is not directly comparable to this anlaysis of the American Power Act becuase of different assumptions about the reference case both domestically and internationally. Therefore, we have reanalyzed H.R. 2454 using a set of assumptions consistent with those used in this analysis. This is the appropriate scenario to use to compare the two bills.

- **Scenario 10 – H.R. 2454**
  - Models the cap-and-trade program established in Title III of H.R. 2454.
  - Provisions explicitly modeled in this scenario:
    - CCS bonus allowances
    - EE provisions (allowance allocations, building energy efficiency codes, and energy efficiency standard component of CERES)
    - Output-based rebates
    - Strategic allowance reserve
    - Allocations to electricity local distribution companies (LDCs) (used to lower electricity prices)
  - Widespread international actions by developed and developing countries over the modeled time period. International policy assumptions are consistent with the agreement among G8 leaders at the July 9, 2009 Major Economies Forum "to reduce their emissions 80% or more by 2050 as its share of a global goal to lower emissions 50% by 2050."
    - Group 1 countries (Kyoto group less Russia) follow an allowance path that is falling linearly from the simulated Kyoto emissions levels in 2012 to 83% below 2005 in 2050.
    - Group 2 countries (rest of world) adopt a policy beginning in 2025 that caps emissions at 2015 levels, and linearly reduces emissions to 26% below 2005 levels by 2050.
    - The combination of U.S., Group 1, and Group 2 actions caps 2050 emissions at 50% below 2005 levels.

Analytical Scenarios

Sensitivity Scenarios

In the following scenarios all assumptions are identical to scenario 2 unless specified. These scenarios were run with the reduced form IGEM model, which only provides a limited set of outputs.

Additional sensitivities using the reduced form IGEM model:

- **Scenario 2a – Slower International Reference Emissions Growth (CCSP Reference)**
  - For the purpose of analyzing the international offset market, international reference emissions are based on the CCSP SAP 2.1a GCAM reference scenario, instead of the GCAM Energy Modeling Forum 22 reference scenario used in other scenarios in this analysis.
- **Scenario 2b – Less International CO_2 Abatement Potential (CCSP MACs)**
  - For the purpose of analyzing the international offset market, international energy related CO_2 marginal abatement cost curves are generated by the CCSP SAP 2.1a era GCAM model, instead of the Energy Modeling Forum 22 era GCAM model used to generate the international energy related CO_2 MAC curves used for other scenarios in this analysis.
- **Scenario 2c – Slower International Reference Emissions Growth & Less International CO_2 Abatement Potential (CCSP Reference & MACs)**
  - For the purpose of analyzing the international offset market, international reference emissions are based on the CCSP SAP 2.1a GCAM reference scenario, instead of the GCAM Energy Modeling Forum 22 reference scenario used in other scenarios in this analysis.
  - For the purpose of analyzing the international offset market, international energy related CO_2 marginal abatement cost curves are generated by the CCSP SAP 2.1a era GCAM model, instead of the Energy Modeling Forum 22 era GCAM model used to generate the international energy related CO_2 MAC curves used for other scenarios in this analysis.
- **Scenario 2d – Strategic Reserve Carve Out**
  - The cap is reduced by the amount of strategic reserve allowances that are specified in the bill. The strategic reserve allowances are not released back into the system.
- **Scenario 2e – Terminal Bank**
  - All countries are required to hold a terminal bank of allowances in 2050, in order to represent the effect of post-2050 GHG emissions caps.

Analytical Scenarios

Sensitivity Scenarios

In the following scenarios all assumptions are identical to scenario 2 unless specified. These scenarios were run with the reduced form IGEM model, which only provides a limited set of outputs.

Offset sensitivities:

- **Scenario 5a –No International REDD Offsets**
  - No reduced emissions from deforestation and degradation (REDD) offsets for the U.S. or for any other country.
- **Scenario 5b –International Offsets Delayed 10 Years**
  - U.S. covered entities are not allowed to purchase international offsets for the first 10 years.
- **Scenario 5c –International Offsets Delayed 20 Years**
  - U.S. covered entities are not allowed to purchase international offsets for the first 20 years.
- **Scenario 5d –No International or Domestic Offsets**
  - U.S. covered entities are not allowed to use domestic or international offsets.
- **Scenario 5e –No Domestic Offsets**
  - U.S. covered entities are not allowed to use domestic offsets.
- **Scenario 5f – Low Domestic Offsets**
  - Domestic offset potential is reduced by 50%.
- **Scenario 5g – High Domestic Offsets**
  - Domestic offset potential is increased by 50%.

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 representations of the whole economy through the interactions of multiple agents (households, firms, government, and countries, for example), whose decisions are based upon optimizing economic behavior in the context of a given policy environment.
  - The models simulate a market economy, where in response to a new policy, prices and quantities adjust so that all markets clear (i.e., economic equilibrium).
- These models are especially well-suited for capturing long-run equilibrium responses, and the 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 climate change policies.
- The NCGM, FASOM, GTM, and MiniCAM models are used to provide information on abatement options that fall outside of the scope of the IGEM and ADAGE 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), complementing the long-run (through 2050) equilibrium response represented in the CGE models.

Modeling Approach

Reference Calibration and Composition of GDP (IGEM)

- In IGEM's AEO 2010 Reference Case, the composition of GDP arises as follows. First, there is an important accounting distinction. The Jorgenson-IGEM accounts treat consumer durables like housing differently than they are treated in the U.S. National Income Accounts (NIA). Specifically, expenditures on these appear as part of investment, not consumption as in the NIA, while their capital services flows are added both to consumption and GDP. This accounting treatment lowers consumption's share of GDP and raises investment's share of GDP in comparison to pure NIA-based ratios.

- Second, government purchases are endogenous and result from combining an exogenous deficit with endogenous tax receipts, tax rates being exogenous. Model closure requires that government debt eventually stabilizes which implies the government deficit is zero in steady state. Reference case assumptions regarding annual deficits and tax rates are based on Congressional Budget Office (CBO) projections that are several years old, vintage 2003-04, with the government deficit projected to vanish by 2037 at a rate slower than the CBO forecast.

- Third, exports are driven by exogenous export demands combined with endogenous relative prices, U.S. versus rest-of-world. Imports are driven purely by relative price effects, import prices being exogenous. Model closure requires that rest-of-world debt also eventually stabilizes which implies the exogenous current account deficit is zero in steady state. Aside from oil and gas import prices which are scaled to reflect the Energy Information Administration's (EIA's) AEO 2010 Reference Case pricing, the trends in export demands and import prices also are of the 2003-04 vintage and reflect the CBO forecasts and their underlying data; here, the current account deficit vanishes also more slowly but by 2025. In simulation, the exchange rate adjusts so that relative prices, U.S. versus rest-of-world, yield export and import patterns aligned to the current account deficit.

- In developing IGEM's AEO 2010 Reference Case, the model is calibrated using industry and aggregate productivity adjustments to match closely the levels and growth in real GDP and coal, petroleum, gas and electricity consumption of EIA's AEO 2010 Reference Case. In examining IGEM's simulated share composition of GDP, it is important to note that all shares are consistent with their respective long-run historical averages and, thus, offers a reasonable basis against which to frame APA policy outcomes. Nevertheless, it is worthwhile to consider what likely would occur were the government and trade assumptions brought more up-to-date. For government, the deficits would be larger and the tax rates lower, combining to yield a lower government share than forecasted by the model. For trade, rest-of-world demands would grow more rapidly, import prices, except for oil and gas, would be slightly lower and current account deficits would be larger. With an endogenous exchange rate, these would combine primarily to yield a larger import share and slightly larger consumption and investment shares as net foreign saving (i.e., investment in U.S. assets) is presumed to be larger.

- In that the overall scale of the economy and energy consumption and greenhouse gas emissions patterns are very close across the ADAGE, IGEM and NEMS reference cases, does it matter that their compositions of GDP slightly differ? The following point cannot be emphasized too strongly. *While it is tempting to focus on levels, it is the absolute and relative changes and their underlying causes that matter most once a common scale among variables of interest and across methodologies has been achieved.* Indeed, a common scale only becomes necessary to the extent that overall model outcomes arise from dominant non-constant elasticities and response surfaces somewhere in their functional representations. Also, model outcomes to policy changes are more than likely to be qualitatively very robust and relatively insensitive across small compositional differences within a methodology and a common scale; in short, model differences matter much more than do starting points.

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, a limitation shared by nearly 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.
  - Sensitivity analyses on a few of the key determinants of the APA costs are provided in the form of differing modeling scenarios.
- The CGE modeling approach generally does not allow for a detailed representation of technologies.
  - While ADAGE does represent different electricity generation technologies within the electricity sector, it does not represent peak and base load generation requirements.
  - 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), a detailed 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 motor vehicle fuel efficiency improvements.
  - The CGE models do not explicitly represent end-use efficiency technologies.
- The 50-year time horizon of the CGE models, while long from an economic perspective, is short from a climate perspective.
- The CGE models represent GHG emissions, but do not capture the impact that such changes have on global GHG concentrations.
  - In this analysis, EPA has used the GCAM and MAGICC models to supplement to provide information on how APA and the G8 agreement affect CO_2 concentrations throughout the 21^{st} century.
- The models used in this analysis currently <u>do not</u> represent the benefits of GHG abatement.
  - It is thus important to realize that the model's results show only the monetary costs of the policy without "netting out" from these costs the economic benefits represented by GHG emissions reductions.
  - Equivalently, the reference scenario does not include the no-policy costs of the impacts of climate change.
- Using sectoral models to construct offset curves limits the ability to estimate all leakage effects.

Modeling Limitations (continued)

- The models used in this analysis do not incorporate the effects of changes in conventional pollutants (SO_2, NOx, and Hg) on labor productivity and public health.
  - While this is an important limitation of the models, the impact on modeled costs of the policy is small because H.R. 2454 does not necessarily reduce overall emissions of conventional pollutants covered by existing cap and trade programs. Instead, allowance prices for conventional pollutants would fall.
- The federal government costs of administering the APA (e.g. monitoring and enforcement) are not captured in this analysis.
- Household effects are not disaggregated by demographic characteristics (e.g. income class).
- 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 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 (continued)

- IGEM does not capture emissions leakage because it does not model international emissions.*
  - Since IGEM is a domestic model, world prices are not affected by climate policies in Group 1 and 2 countries. As a result of this modeling limitation, the APA leads to rises in the prices of U.S. exports relative to prices in the rest of the world, and export volumes subsequently fall. Since exports are price-elastic the volumes fall proportionally more than the increase in price, the value of exports thus declining.
  - Without modeling world price changes, imports would be expected to decline, in part by the overall reduction in spending associated with the lower levels of consumption. Additionally, imported commodities directly affected by the emissions cap (e.g. oil) are negatively impacted proportionally more than other imports due to the allowance prices embodied in their production cost.
  - Import substitution would counter the decline in imports described in the previous paragraph. 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 2 countries increase world prices of affected commodities (not modeled by IGEM), the relative price difference between goods produced in the U.S. and goods produced abroad will be lessened. This will reduce the negative impact on exports and reduce the import substitution effect, both of which are driven by the relative price differential.

- ADAGE is a global model that does represent the emissions leakage associated with the APA.
  - The assumed climate policies in Group 1 and Group 2 impact world prices. As a result, the relative price differences between goods produced domestically and abroad are smaller than the differences in IGEM. Changes in import and export amounts are thus also smaller than those in IGEM.

* Emissions leakage occurs when a domestic GHG policy causes a relative price differential between domestically produced and imported goods. This causes domestic production, embodying the GHG allowance price, to shift abroad. Subsequently, the level of GHG emissions increases in other countries, counteracting the reductions intended by the domestic policy. Additionally, emissions leakage not associated with trade effects may occur when a GHG policy reduces domestic consumption of oil, lowering its world demand and thus price. The lower price would induce an increase in oil consumption, and thus GHG emissions, in countries without an emissions reduction policy.

Modeling Limitations

Specified Uses of Auctioned / Allocated Allowances

- The use of the revenue generated by auctioning permits can affect the cost of the policy.
- Compared to returning auction revenues to consumers in a lump sum fashion that maintains deficit neutrality, other uses of auction revenues can positively or negatively impact the cost of the policy.
  - Using auction revenues to lower distortionary taxes can lower the cost of the policy.
    - This possibility is known as the "double dividend" and has been widely discussed in the economics literature (e.g. Goulder et al. 1999, Parry et al. 1999, Parry and Oates 2000, and Parry and Bento 2000, CBO 2007).
    - One study (Parry and Bento 2000) finds that different methods of revenue recycling under a cap-and-trade system that reduces emissions by 10 percent can lead to economy-wide costs that differ by a factor of three.
  - Directing auction revenues to special funds or creating subsidies to specific technologies can raise the overall costs of a policy due to the need to finance these policies with increases in distortionary taxes (the converse of the "double dividend" benefit of reducing distortionary taxes discussed above).
    - Note that substantial cost savings could be achieved by combining direct emissions policies (e.g. cap-and-trade or carbon tax) with technology push policies (e.g. technology and R&D incentives) that correct for the market failure associated with the fact that the inventor of a new technology cannot appropriate all of the associated social benefits (Fischer and Newell 2005; Schneider and Goulder 1997). However, the value of the subsidy needed to fully correct the market failure is not known.
- In IGEM we assume that the policy is deficit neutral, implying that the market outcomes are invariant to the auction/allocation split.
  - 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 reduction in household annual consumption and GDP would likely be greater. If the auction revenues were instead used to lower distortionary taxes, the costs of the policy would be lower.
  - Private sector revenues from allocated allowances accrue to employee-shareholder households, and the government adjusts taxes lump sum to maintain deficit and spending levels.

Near Term Incidence Analysis

The Incidence Model and Linkages to ADAGE

- The incidence model is a partial equilibrium structure that captures the direct effect of energy good price increases on households and the indirect effects of increased energy prices on other final goods, assuming full pass through of the allowance price onto consumers. The incidence model does not draw the price changes of goods and total consumption changes directly from ADAGE with the exception of the change in electricity price.

- Generally, the budget shares assumed in the incidence model for 2016, absent the American Power Act, are assumed to be the same as actual household budget shares in the 2004 through 2008 Consumer Expenditure Survey (CE).
  - This analysis focuses on the near term incidence, of the policy, in part because the CE is used to characterize the baseline consumption of households. Consumption patterns may be quite different in the future without the American Power Act.

- The CE is also used to estimate representative household budget shares for each income decile. The boundaries of the income deciles provided are based on the incomes of the respondents to the survey.

- Because the incidence model is not fully linked to ADAGE inputs and outputs including the share of energy inputs in production, forecast changes in prices and the demand for goods differ between the two models. ADAGE is a general equilibrium model that captures competition amongst markets for production inputs and capital and labor markets, which the incidence model (generally speaking) does not. Had the general equilibrium price changes been used in the incidence model, the budget shares of goods would differ from what is implied in this analysis.
  - However, the relative effects of the American Power Act across the income deciles would likely not change significantly if all price changes were drawn from ADAGE because, in the near term, the changes in the bundles of goods consumed are not dramatic.
  - The forecast sectoral-level price changes from ADAGE could not be used in the incidence model in time for this analysis.

- The average abatement cost per household is similar between ADAGE and the incidence model because the abatement costs in each sector in the incidence model are calibrated to the total abatement costs from ADAGE.
  - See Appendix 6 for discussion about the calculation of abatement costs in ADAGE using an approximate marginal abatement cost curve.

Near Term Incidence Analysis

Incidence Model and Modeling Caveats

- When modeling the Energy Refund provision of the American Power Act, the loss in purchasing power for the household at 150% of the poverty level is calculated without accounting for the lump sum rebates to households that proxy for the incidence effects of the research and development and transportation programs.

- The analysis assumes that all households that are eligible for a particular program, such as the Working Families Relief program, enroll in it.

- The incidence model does not capture the effect of programs that are automatically indexed to inflation. For example, social security payments will rise as the carbon price raises the overall price level. This automatic adjustment to social security payments will mitigate the effect of the policy on some households.

- The adapted incidence model used in this analysis differs from the one described in Burtraw et al. (2009) in a limited number of ways:
  - The model used in this analysis uses ADAGE to represent changes in the electricity market. The model used in Burtraw et al. (2009) has competition amongst markets for inputs and capital in the electricity sector using the Haiku electricity market model.
  - It assumes that 100% of domestic capital is owned by households in the U.S. to be consistent with ADAGE, whereas the Burtraw et al. (2009) model assumes that 10% of domestic capital is owned by non-U.S. households.
  - It does not withhold allowance value for the energy price increases faced by government. In the Burtraw et al. (2009) analysis 14 percent of allowance value is withheld to pay for increased federal and state government expenditures due to higher costs of energy goods.
  - It captures the earning of profits by sellers of domestic offsets and the payment by demanders of domestic offsets differently than the Burtraw et al. (2009) model. This incidence analysis assumes that the profits that flow to suppliers of offsets accrue to owners of shareholder equity.

Peer Review

- Over the past three years, EPA performed multiple analyses of GHG cap & trade bills at the request of Members of Congress, including analyses of: S. 280 (McCain-Lieberman), S. 1766 (Bingaman-Specter), S. 2191 (Lieberman-Warner), the Waxman-Markey discussion draft, and H.R. 2454 (Waxman-Markey).
- EPA's approach to these analyses has been to use multiple models, each with different strengths. These models include economy-wide computable general equilibrium (CGE) models (IGEM, ADAGE), and detailed sector-specific models (IPM, FASOMGHG).
- Each of EPA's analyses (including this analysis) has undergone extensive internal EPA peer review and external inter-agency review by economists and other experts within the federal government.

- IGEM
  - IGEM stands for Inter-temporal General Equilibrium Model. IGEM is formerly known as the Jorgenson-Wilcoxen model and the Jorgenson-Wilcoxen-Ho model, after its developers.
  - The model is described and results presented in a number of publications, including:
    - Jorgenson, Dale and Goettle, Richard, et al., *U.S. Market Consequences of Climate Change.* Prepared for the Pew Center on Global Climate Change. April 2004.
    - Jorgenson, Dale and Goettle, Richard, et al., *The Role of Substitution in Understanding the Costs of Climate Change Policy.* Prepared for the Pew Center on Global Climate Change. September 2000.
    - Jorgenson, Dale and Goettle, Richard, et al., *Carbon Mitigation, Permit Trading and Revenue Recycling.* Prepared for U.S. Environmental Protection Agency. 1998.
    - Jorgenson, Dale, *Econometric General Equilibrium Modeling (Growth, Volume 1)*, Cambridge, The MIT Press, 1998.
    - Jorgenson, Dale, *Energy, the Environment, and Economic Growth (Growth, Volume 2)*, Cambridge, The MIT Press, 1998.
    - *The Benefits and Costs of the Clean Air Act, 1970 to 1990.* Washington, DC: Prepared for the U.S. Congress by the U.S. Environmental Protection Agency, October 1997.
    - *The Clean Air Act and the U.S. Economy.* Cambridge, MA: Prepared for the U.S. Environmental Protection Agency by Dale W. Jorgenson Associates, August 1993.
  - IGEM underwent a peer review through the EPA Scientific Advisory Board as part of the Clean Air Act Amendments of 1990 Section 812 process that produced *The Benefits and Costs of the Clean Air Act, 1970 to 1990.* The peer review of the 812 approach was completed October 1996.
  - EPA has completed a peer review by a panel of outside experts of IGEM and ADAGE. The peer-review findings are available at http://cfpub.epa.gov/crem/knowledge_base/crem_report.cfm?deid=198005. The following is exerpted from the peer review report:

    "On balance, these are two excellent models that provide useful information to EPA as it goes about its work of evaluating climate policies. While we may have issues with elements of the models, in general we find these to be first-rate and state-of-the-art. These models are essential tools for the analysis of environmental policy in general and climate policy in particular. "

Peer Review (continued)

- ADAGE
  - ADAGE stands for Applied Dynamic Analysis of the Global Economy. It is a dynamic computable general equilibrium (CGE) model capable of investigating economic policies at the international, national, U.S. regional, and U.S. state levels.
  - Peer-reviewed articles based on ADAGE modeling include an article in *B.E. Journal of Economic Analysis* and an article in a 2009 special issue of *Energy Economics*.
  - The core model of ADAGE is based on the MIT Emissions Predictions and Policy Analysis (EPPA) model, also a multi-sector, multi-region CGE model of the world economy. EPPA analyses have been published in multiple peer-reviewed academic energy, economic, and environmental journals.
  - EPA has completed peer review by a panel of outside experts of IGEM and ADAGE. The peer-review findings are available at http://cfpub.epa.gov/crem/knowledge_base/crem_report.cfm?deid=198000 The following is exerpted from the peer review report:

    "On balance, these are two excellent models that provide useful information to EPA as it goes about its work of evaluating climate policies. While we may have issues with elements of the models, in general we find these to be first-rate and state-of-the-art. These models are essential tools for the analysis of environmental policy in general and climate policy in particular."

- IPM
  - Periodic formal peer review of IPM includes separate expert panels on the model itself, and on EPA's key modeling input assumptions. For example, within the past six years separate panels of independent experts have been convened to review IPM's coal supply and transportation assumptions, natural gas assumptions, and model formulation.
  - Rulemaking process provides opportunity for expert review and comment by
    - Operators of the electricity sector that is represented in IPM
    - Stakeholders affected by the policies being modeled
    - Developers of other models of the U.S. electricity sector
    - This feedback provides a highly detailed reality check of
      - Input assumptions
      - Model representation
      - Model results
    - EPA is required to respond to every significant comment submitted
    - Comments on IPM have been solicited in most of the major air regulations that EPA has promulgated in the last 15 years
  - IPM has been used by states (e.g., for RGGI, WRAP, OTAG), other Federal agencies (e.g., FERC, GAO), environmental groups (including the Clean Air Task Force), and industry (e.g., TVA, SoCAL), all of whom subject the model to their own review procedures
  - Extensive review by energy and environmental modeling experts from states, industry, and other groups during the 2 years of the OTAG process in 1997-1998,
  - Science Advisory Board review of IPM as part of the CAAA Section 812 prospective study 1997-1999

Peer Review (continued)

- FASOMGHG
  - The FASOMGHG model has been vetted through an extensive refereeing process in numerous academic publications including: *Science, Nature, American Journal of Agricultural Economics, Environmental and Resource Economics, Climatic Change, Ecological Economics, Land Economics, Forest Ecology and Management, Journal of Soil and Water Conservation*, and more.
  - FASOMGHG and its predecessors have been used for assessments on ozone impacts (Adams et al., 1984), acid rain (Adams et al., 1993), soil conservation policy (Chang et al., 1994), global climate change impacts (Reilly et al., 2000), and GHG mitigation (USEPA, 2005, USEPA, 2007), among many others.

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  - EPA, in collaboration with USDA, has initiated peer review of FASOM to be conducted by outside experts.

Appendix 2: Additional Qualitative Considerations

Allowance Allocation & Revenue

Recycling in ADAGE and IGEM

- In the models used for this analysis, households are represented by a single representative consumer. Since the model assumes that the behavior of employee-shareholders does not vary by industry, variations in the initial allocation of allowances to different industries would not affect estimated model outcomes so long as those allocations are undertaken in a lump-sum, non-distortionary manner.

- We also assume that the policy is deficit neutral, implying that the market outcomes are invariant to the split between auctioned and allocated allowances.
  - Private sector revenues from allocated allowances accrue to employee-shareholder households, the government adjusting taxes lump-sum to maintain current 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 instead modeled to be directed to special funds, the resulting reduction in household annual consumption and in GDP would be greater. If the auction revenues were instead modeled to be used to lower distortionary taxes, the resulting costs of the policy would be lower.

Revenue Recycling Issues

- As implied by the discussion on the previous page, the manner of spending the revenue generated by auctioning allowances can affect the cost of the policy.

- Compared to returning auction revenues to consumers in a lump-sum fashion that maintains deficit neutrality, other uses of auction revenue can positively or negatively impact policy cost.
  - Using auction revenues to lower distortionary taxes can lower the cost of the policy.
    - This possibility is known as the "double dividend" and has been widely discussed in the economics literature (e.g., Goulder et al. 1999, Parry et al. 1999, Parry and Oates 2000, and Parry and Bento 2000, CBO 2007).
    - One study (Parry and Bento 2000) finds that different methods of revenue recycling under a cap-and-trade system that reduces emissions by 10 percent can lead to economy-wide costs that differ by a factor of three.
  - Directing auction revenues to special funds or creating subsidies to specific technologies may raise the overall costs of a policy due to the need to finance these policies with increases in distortionary taxes (the converse of the "double dividend" benefit of reducing distortionary taxes).
    - However, substantial cost savings could be achieved by combining direct emissions policies (e.g. cap-and-trade or carbon tax) with technology push policies (e.g. technology and R&D incentives) that correct for the market failure associated with the fact that the inventor of a new technology cannot appropriate all of the associated social benefits (Fischer and Newell 2005; Schneider and Goulder 1997).

Allowance Allocation Issues

- It is worth noting that since emissions allowances are valuable assets, differing allowance allocation schemes can have equity implications that are not shown by a single representative household model.

- Equity considerations can justify allocating allowances to (or directing allowance auction revenue to) those who are expected to ultimately bear the cost of abatement.

- Who bears the ultimate burden of the costs of abatement is not necessarily determined by who is required to hold allowances (or by who performs the abatement), but by the complex interaction of markets.
  - (Harberger 1962 provides the first general equilibrium model of tax incidence, Kotlikoff and Summers 1987 provides a useful review of the subsequent literature, CBO 2007 discusses the issue in the context of a cap-and-trade program).

- Freely allocating allowances to the entities required to hold allowances may create a windfall gain for such entities as they receive a valuable asset and can choose to pass the costs associated with abatement downstream to consumers. Windfall gains may also accrue to firms who are in the position to sell their acquired allowances.
  - Bovenberg and Goulder 2001 examines the degree to which freely allocated allowances maintain or increase profits.

- Similar to creating subsidies, allocating allowances in a non lump-sum fashion may, in some cases, raise costs.
  - For example, allocating allowances based on the average number of production employees at a facility acts as a distortionary subsidy for labor.

Allowance Allocation Issues

(continued)

- Allocation policy interactions with previously existing distortionary taxes, for example a tax on labor, may enhance the distortion and indirectly reduce the labor supply. (See Murray, Thurman, and Keeler, 2000)

  – Burtraw et al (2001) discuss three alternative allocation mechanisms and their resulting distributional impacts on consumers and producers. They demonstrate that, compared with allocations through auction sales, an allocation based on a generation performance standard acts as a subsidy to generation, increasing the overall costs of the emissions reduction policy.

  – Fischer, Kerr, and Toman (1998) discuss the types of risk associated with different allocation systems. They note that "external" risk (e.g. changes in caps due to international agreements or improved climate science) should be borne by the emitter while "internal" risk (e.g. political or revenue based motivations for changing caps) should be eliminated to the extent possible. They also address tax effects of different allocation systems and note that there are tax distortion effects in both grandfathering and auction systems (encouraging too much and too little banking, respectively) and that eliminating these effects would require a broad overhaul of the capital gains tax system.

  – Neuhoff, Grubb, and Keats (2005) demonstrate that the potential for future updating of the emissions allocation baseline in Europe creates distortionary incentives in operation and investment.

  – Burtraw, Kahn, and Palmer (2005) examine the proposed Regional Greenhouse Gas Initiative effort by nine NE/mid-Atlantic states and discuss the implications for individual firms' profits. They find that the choice of allocation mechanism impacts the price of electricity, level of consumption, and mix of production technologies. Additionally, they show that the regional nature of the system will allow for leakage, creating profits for firms outside the region.

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Appendix 3: Additional Information on Offsets and the International Market for GHG Abatement

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.
  - For the individual mitigation options that were determined to be eligible, no further discounting was assumed.
  - EPA did not estimate transaction costs associated with the use of offsets in this analysis.
  - Because international and domestic land use offsets are not analyzed within a single model, the potential for emissions leakage to other countries or sectors if offsets programs are limited or unavailable is not reflected in our analysis.

Modeling of Domestic Offsets

- Forest and agricultural lands in the United States currently comprise a net carbon sink of over 940 million metric tons of CO_2 equivalent per year (U.S. GHG inventory, EPA 2010).

- For this analysis, EPA has used estimates of domestic agriculture and forestry offset supply based on analyses performed in March 2009. This makes the underlying domestic offset supply potential consistent with the April 20th analysis of the Waxman Markey Discussion Draft, the June 23rd analysis of H.R. 2454, the October 23rd analysis of S.1733, and the January 2010 supplemental analysis of H.R. 2454.

- While this analysis does not distinguish between different domestic offset types, the models underlying the domestic offset marginal abatement cost curves include the Forestry and Agricultural Sector Optimization Model (FASOM) model for agriculture and forestry offsets, and 2006 U.S. EPA report, "Global Mitigation of Non-CO_2 Greenhouse Gases," provides marginal abatement cost curves for the various sources of non-CO2 abatement including landfill and coal mine CH_4 offsets.

- Modeling efforts focus on GHG mitigation and *potential* offset supply. We have included many of the most significant mitigation and sequestration activities in the agriculture and forestry sectors including afforestation, conservation tillage, no-till, and animal waste systems. We were unable to model some other practices specified in the bill such as specific practices on organic soils, changes in fertilizer application, and changes to other programs such as the Conservation Reserve program. To address these remaining issues, we have included "scenario 5f – Low domestic offsets" and "scenario 5g – high domestic offsets" that explore various levels of domestic offset availability.

- As with any modeling exercise, it is important to remember that models are useful for gauging the responsiveness of complex economic systems. EPA has found the FASOM model the best tool available for analyzing policies that affect both domestic forestry and agricultural producers. Even with the best modeling efforts, precise predictions of conditions thirty years hence is impossible. EPA is committed to supporting the legislative process by providing analysis that identifies policies and opportunities that can benefit agriculture and forestry producers while reducing greenhouse gas emissions. A more detailed description of the FASOM model can be found in the Appendix to EPA's June 23rd analysis of H.R. 2454.

- EPA is working with USDA and the FASOM modeling team to continue improving the analytical tools that are used to assess how different climate policies would affect agriculture. An external peer review of the updated FASOM model will be completed in 2010.

APA Offsets Provisions

Title II, Subtitle A, CAA Sec. 722, (d)(1)

- 2 billion tons of annual compliance obligations can be satisfied from offsets.
- While H.R. 2454 attempts to place a limit of 2 billion tons on total offset usage, and specifies provisions for pro rata sharing of offsets among covered entities that violates the 2 billion ton limit, the American Power Act corrects this problem by establishing the entity level limit on offsets as the product of 2 billion tons and that entity's share of covered emissions from the previous year.
- Limit of 1.5 billion tons from domestic offsets and .5 billion tons from international offsets.
- If fewer than 1.5 billion tons equivalent of domestic offsets available in any given year, then the residual may be made up from the purchase of international offsets with an ultimate cap of 1 billion tons equivalent of international offset allowances. Whereas H.R. 2454 set an ultimate cap of 1.5 billion tons equivalent of international offsets annually, S. 1733 set this ultimate cap at 1.25 billion tons.
- International offsets convert to creditable allowances at a rate of 1:1 until the start of 2018 when they begin to convert at a 5:4 ratio.
- Offsets originate in activities in developing countries that reduce or avoid greenhouse gas emissions, or increase sequestration of greenhouse gases, including activities that reduce deforestation (CAA Sec. 753, (a)(1), p. 427). The Administrator or an international body may issue international offset credits for such projects (CAA Sec. 756, (b), p.447).

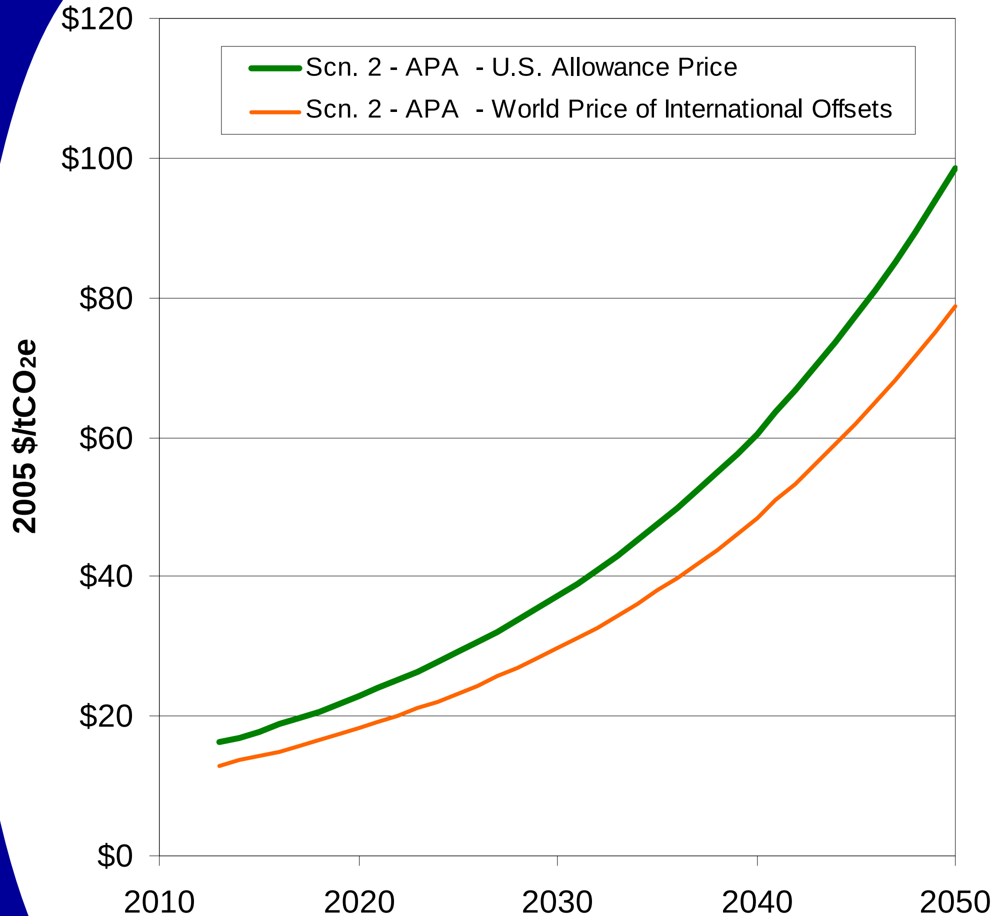
H.R. 2454 Offsets Provisions

H.R. 2454 Sec. 722 (d) (1)

- H.R. 2454 Sec 722 (d) (1) (A) allows covered entities to collectively use offset credits to demonstrate compliance for up to a maximum of 2 billion tons of GHG emissions annually.
- This section also attempts to share the 2 billion tons of offsets allowed pro rata among covered entities. However, the formula specified for pro rata sharing among covered entities does not result in 2 billion tons of offsets in total.
  - Covered entities are allowed to satisfy a specified percentage of the number of allowances required to be held for compliance with offsets credits.
  - H.R. 2454 Sec 722 (d) (1) (B) shows that for each year, the specified percentage is calculated by dividing two billion by the sum of two billion and the annual tonnage limit for that year. For example, in 2012, when the cap level is 4.627 GtCO2e, the percentage would be 30.20%; and in 2050, when the cap level is 1.035 GtCO2e the percentage would be 65.90%.
  - The number of allowances required to be held for compliance is equal to the amount of covered emissions, so for any given firm the amount of offsets they are allowed to use is equal to the product of their covered emissions and the percentage specified above.
  - The total amount of offsets allowed is equal to the product of the total amount of covered emissions and the specified percentage. In order for this to be equal to the 2 billion ton limit on offsets specified above, total covered GHG emissions would have to be equal to the cap level plus 2 billion tons. There are several reasons why this is unlikely to be the case.
    - First, even if covered emissions remain at reference levels, in the early years of the policy they will not be 2 billion tons over the cap level.
    - Second, if firms bank allowances, their covered GHG emissions will be reduced, which will reduce the amount of offsets they are allowed to use.
    - Third, in the later years when firms are drawing down their bank of allowances, it is possible for covered GHG emissions to be more than 2 billion tons above the cap, which means that the pro rata sharing formula can be in conflict with the overall 2 GtCO2e limit on offsets usage. However, if the domestic limit is non-binding, then the pro-rata sharing would allow for the international limit to exceed 1 GtCO2e, so long as the sum of domestic and international offsets were still below 2 GtCO2e.
- H.R. 2454 Sec 722 (d) (1) (C) modifies the pro rata sharing to allow more international offsets if fewer than 0.9 GtCO2e are expected to be used.
  - In years when this provision triggers, an additional amount of international offsets are allowed equal to the lesser of: 1 GtCO2e less the actual amount of domestic offsets used; or 0.5 GtCO2e.
  - This has the potential in later years to allow more than 2 GtCO2e of offsets into the system, so our interpretation is that the actual amount of extra international offsets allowed would be equal to the lesser of the amount calculated above, or 2 GtCO2e less the sum of the international offsets limit and the actual usage of domestic offsets.
  - Because the pro-rata sharing limits domestic offsets in the early years to well below 0.9 GtCO2e, this provision will automatically trigger, even if the actual limit on domestic offsets were binding.

Offset and Allowance Prices

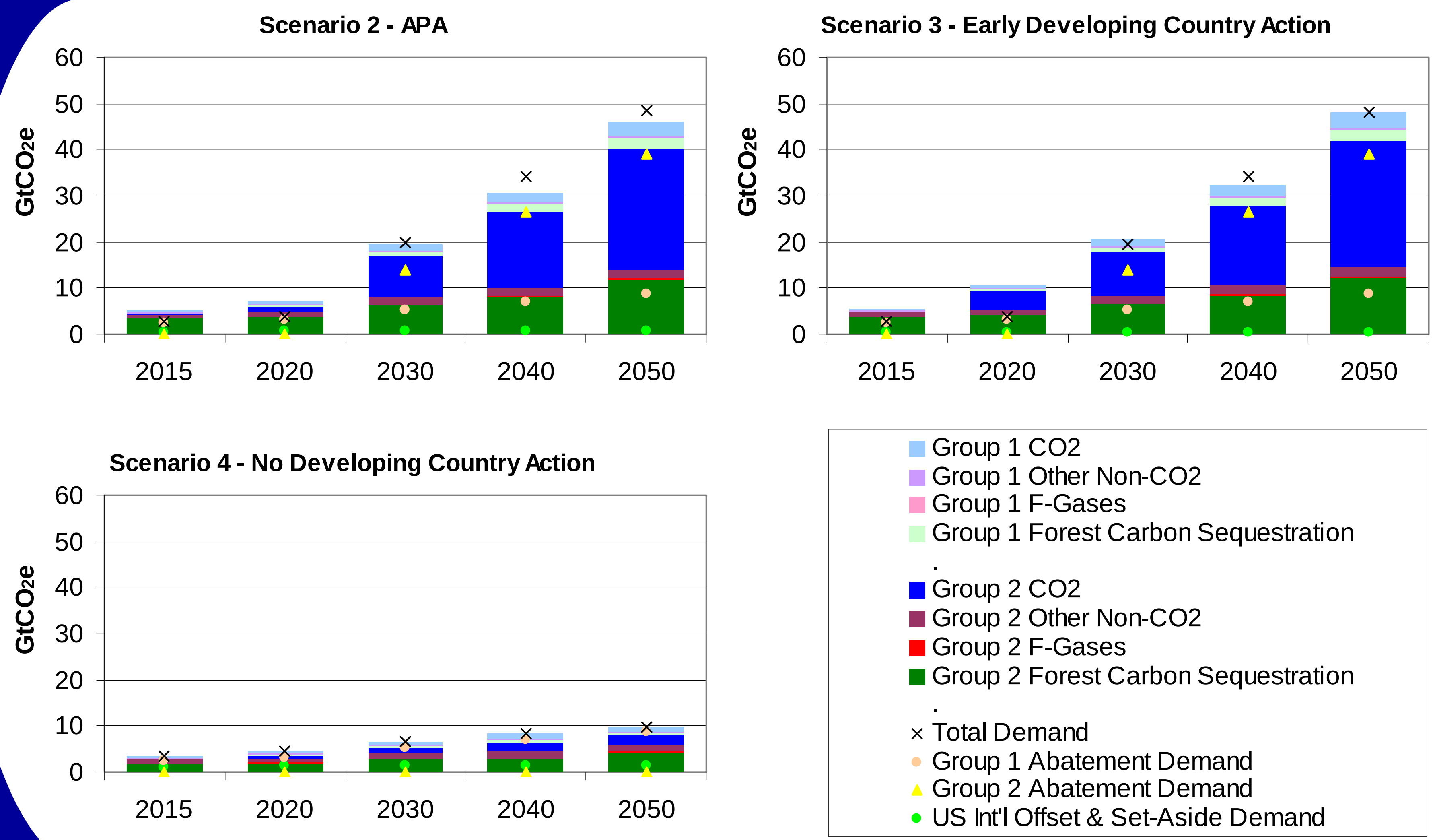
(IGEM)



- The APA limits the use of domestic and international offsets; however, in '*scenario 2 - APA*' the limits are non-binding in all years.
- The domestic offset price is equal to the allowance price.
- International offsets are subject to a turn-in-ratio so that, after the first five years, 5 tons of international GHG abatement offsets must be turned in for every 4 offsets credits received.
- The price shown here is the price before applying the turn-in-ratio. Since 1.25 allowances must be purchased for each ton of covered emissions being offset, the price to use international offsets to offset one ton of domestic emissions is equal to the product of 1.25 and the price shown here. When the limit on international offsets usage is non-binding, this product is equal to the domestic allowance price.

International GHG Abatement Supply & Demand

Impacts of International Action Assumptions



- See chart explanation on the following slide

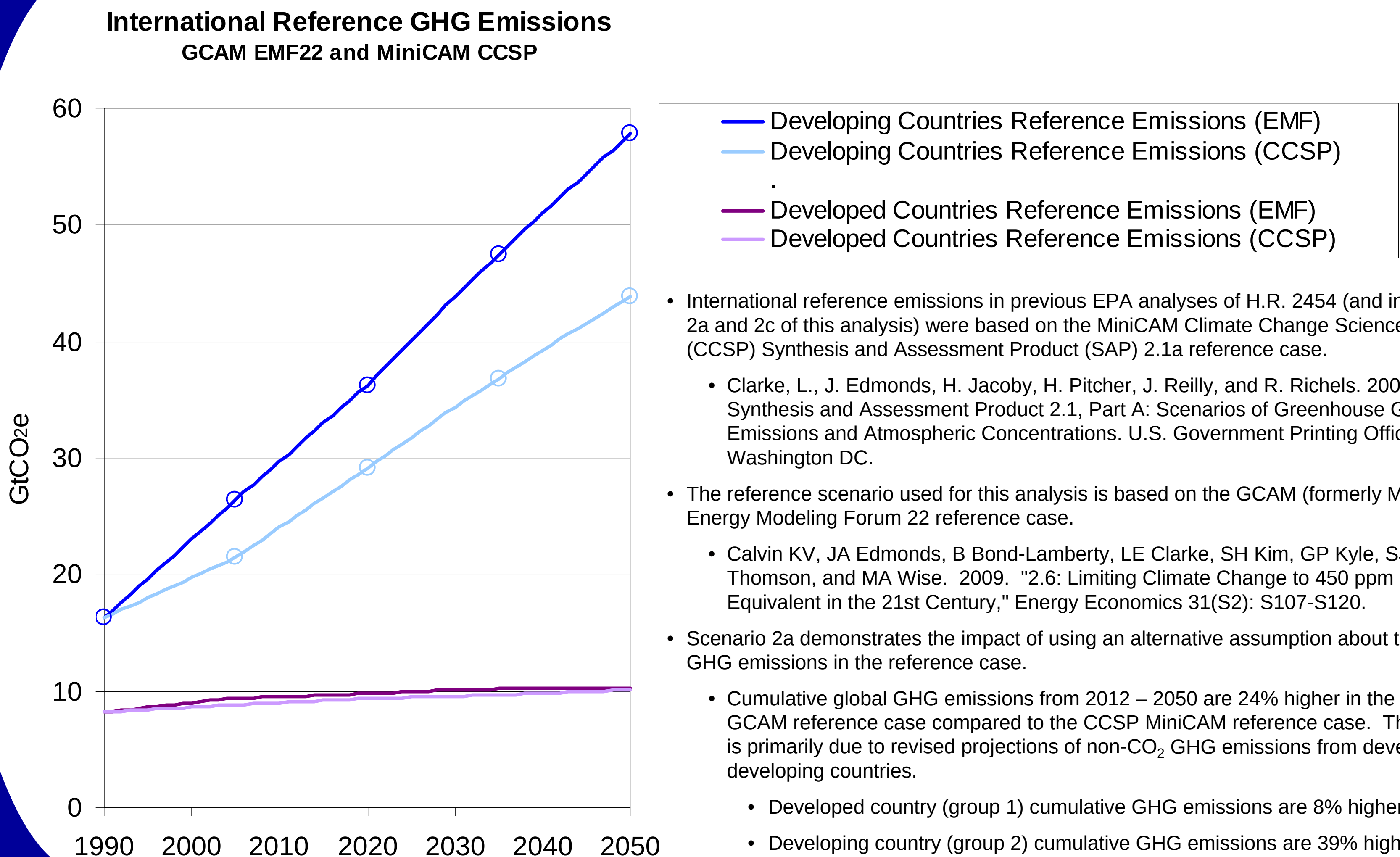
International GHG Abatement Supply & Demand

Impacts of International Action Assumptions

- The previous slide shows international GHG abatement supply by region and source across time for three different scenarios. Reference emissions for non-U.S. countries are based on the EMF 22 version of the GCAM (formerly MiniCAM) model. Abatement supply is based on the EMF 22 version of the GCAM model for CO_2, the GTM model for forestry, and the “Global Mitigation of Non-CO2 GHG” marginal abatement cost curves for F-Gases and other non-CO_2 GHG abatement.
- The slide also shows the demand for GHG abatement from developed (group 1) countries, developing (group 2) countries, as well as U.S. demand for international offsets.
  - Note that the abatement demands shown here for groups 1 & 2 are simply the difference between reference emissions and the caps. The actual total demand, accounting for banking, will be exactly equal to the supply clearing the market. The difference between the total demand and total supply depicted is the amount of banking occurring in a particular year.
- The global market for GHG abatement depicted her encompasses the cap-and-trade systems in developed and developing countries as well as the U.S. participation in the international offsets market.
  - The price of international offsets purchased by the U.S. is determined by this market.
  - Because the international offsets limits are non-binding, the price of international GHG abatement acts as a floor on the price of U.S. domestic allowances.
  - With the 4 to 5 turn in ratio for international offsets and a non-binding limit, the price of U.S. allowances will be equal to 125% of the international GHG abatement price.
- It is not possible to determine the exact mix of abatement sources contributing to the international offsets purchased by the U.S.
  - For example, if the U.S. chose to buy only forest carbon sequestration offsets from group 2, the other players in the market would meet their demand for abatement from the remaining sources. Alternatively the U.S. could purchase equal shares of international offsets from all types of abatement, and again the groups 1 & 2 would simply adjust where they purchase abatement from to again meet their demand.
- In order to represent the more limited amount of abatement that can be supplied through an offsets market compared to the abatement that can be supplied from a country with a cap on GHG emissions, the GHG marginal abatement cost (MAC) curves are adjusted based on whether or not a country is assumed to have adopted a climate policy.
  - For example the MAC curve for CO_2 from group 2 allows only 10% of the full potential in 2015, and 25% of the full potential in 2020. This is a proxy for the limited ability to employ sectoral offseting or other energy-related CO_2 offset projects. After group 2 is assumed to have adopted its own cap, reflecting the ability of a cap-and-trade system to utilize the full abatement potential, the MAC curve for CO_2 is no longer adjusted.
  - After Group 2 has adopted a climate policy (2025 under the G8 assumptions in scenario 2, 2020 under the early action assumptions in scenario 3, after 2050 in the no group 2 action assumptions in scenario 4), the CO_2 MAC is not adjusted and full potential of the CO_2 MAC is available. This reflects the availability of allowances from a cap-and-trade system covering all energy-related CO_2 once a policy is in place.

International GHG Abatement Supply & Demand

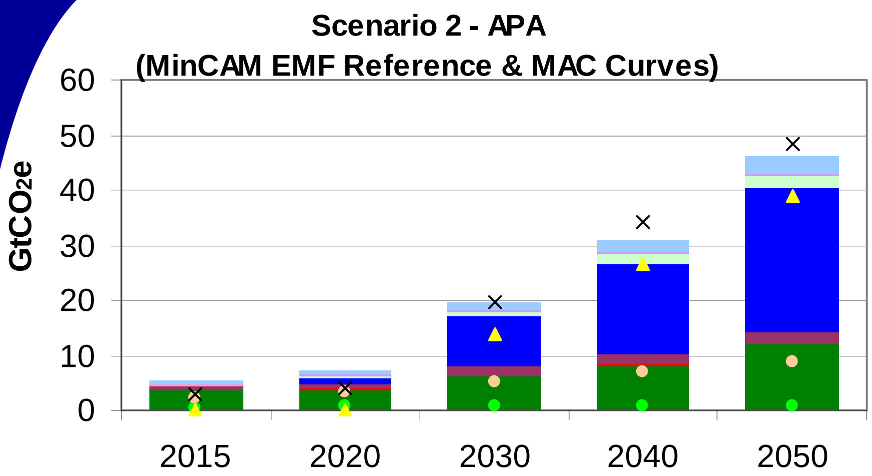
International Reference GHG Emissions Assumptions

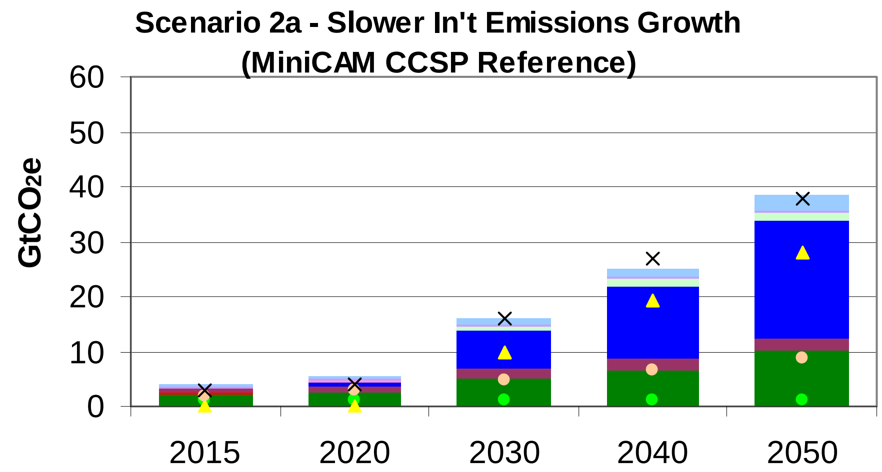


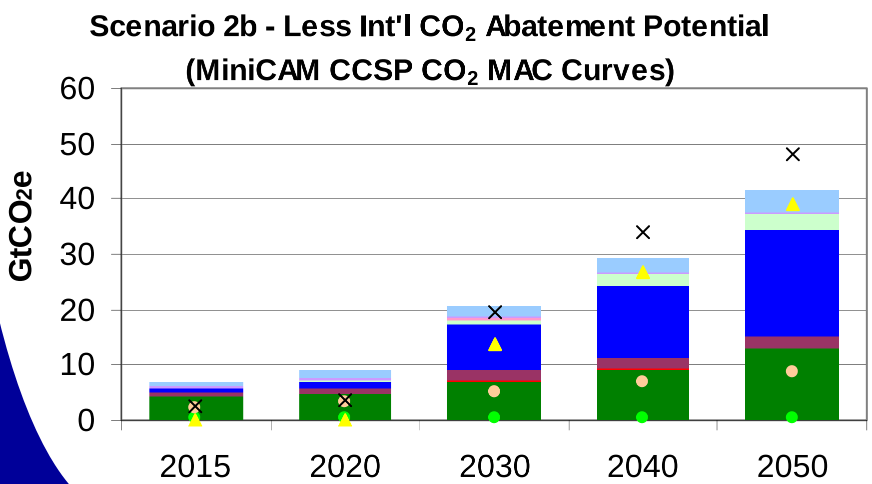
- International reference emissions in previous EPA analyses of H.R. 2454 (and in scenarios 2a and 2c of this analysis) were based on the MiniCAM Climate Change Science Program (CCSP) Synthesis and Assessment Product (SAP) 2.1a reference case.
  - Clarke, L., J. Edmonds, H. Jacoby, H. Pitcher, J. Reilly, and R. Richels. 2007. CCSP Synthesis and Assessment Product 2.1, Part A: Scenarios of Greenhouse Gas Emissions and Atmospheric Concentrations. U.S. Government Printing Office, Washington DC.
- The reference scenario used for this analysis is based on the GCAM (formerly MiniCAM) Energy Modeling Forum 22 reference case.
  - Calvin KV, JA Edmonds, B Bond-Lamberty, LE Clarke, SH Kim, GP Kyle, SJ Smith, AM Thomson, and MA Wise. 2009. "2.6: Limiting Climate Change to 450 ppm CO2 Equivalent in the 21st Century," Energy Economics 31(S2): S107-S120.
- Scenario 2a demonstrates the impact of using an alternative assumption about the non-U.S. GHG emissions in the reference case.
  - Cumulative global GHG emissions from 2012 – 2050 are 24% higher in the EMF-22 GCAM reference case compared to the CCSP MiniCAM reference case. This difference is primarily due to revised projections of non-CO_2 GHG emissions from developed and developing countries.
    - Developed country (group 1) cumulative GHG emissions are 8% higher.
    - Developing country (group 2) cumulative GHG emissions are 39% higher.

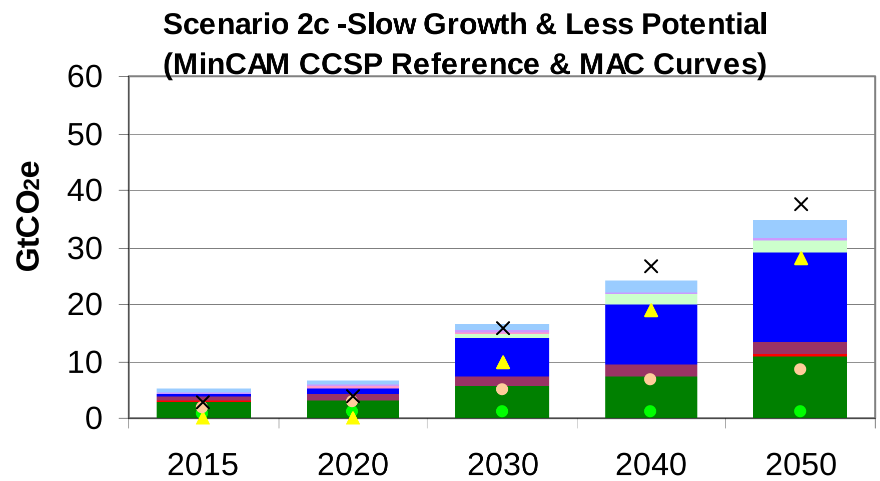
International GHG Abatement Supply & Demand

Impacts of International Reference Emissions & Abatement Potential Assumptions









- See chart explanation on the following slide, and see slide 45 of the appendix for legend.

International GHG Abatement Supply & Demand

Impacts of International Reference Emissions & Abatement Potential Assumptions

- The international market for greenhouse gas emissions abatement determines the price of international offsets.
- This market is sensitive to the assumptions about policies adopted by other countries, as shown in scenarios 2, 3, and 4 which depict varying degrees of developing country action.
- This market is also sensitive to assumptions about the growth of GHG emissions in the reference case. For any given policy, higher reference case emissions imply a greater amount of abatement that would be required to meet the cap. Conversely, lower reference GHG emissions lead to less demand for international GHG abatement and lower costs.
- Compared to EPA's previous analyses of H.R. 2454, this analysis uses updated reference emissions projections and international energy related CO_2 marginal abatement cost curves:
  - International reference emissions and international energy related CO2 MAC curves in previous EPA analyses of H.R. 2454 were based on the MiniCAM Climate Change Science Program (CCSP) Synthesis and Assessment Product (SAP) 2.1a reference case.
    - Clarke, L., J. Edmonds, H. Jacoby, H. Pitcher, J. Reilly, and R. Richels. 2007. CCSP Synthesis and Assessment Product 2.1, Part A: Scenarios of Greenhouse Gas Emissions and Atmospheric Concentrations. U.S. Government Printing Office, Washington DC.
  - The reference scenario and the international energy related CO2 MAC curves used for this analysis are based on the GCAM (formerly MiniCAM) Energy Modeling Forum 22 reference case.
    - Calvin KV, JA Edmonds, B Bond-Lamberty, LE Clarke, SH Kim, GP Kyle, SJ Smith, AM Thomson, and MA Wise. 2009. "2.6: Limiting Climate Change to 450 ppm CO2 Equivalent in the 21st Century," Energy Economics 31(S2): S107-S120.
- The new reference emissions are higher, and the energy related CO_2 MAC curves indicate more abatement potential than the previous MAC curves.
- Scenario 2a (CCSP Ref) uses the old CCSP era GCAM reference emissions to show the impact of slower international reference emissions growth.
- Scenario 2b uses the old CCSP era GCAM MAC curves to demonstrate the impact of this new assumption, and showing that differing realizations of international GHG abatement supply potential can have different impacts on the cost of the APA.
- Scenario 2c uses both the old CCSP era GCAM MAC curves and the old CCSP era GCAM reference emissions, that were used in previous EPA analyses of H.R. 2454. This scenario demonstrates the main differences between this analysis and the January 29, 2010 supplemental analysis of H.R. 2454.

Appendix 4: Modeling of Energy Efficiency Provisions

Modeling of Energy Efficiency Provisions

Provisions represented in Scenario 2 - APA

- Title I – Domestic Clean Energy Development
  - Subtitle D—Renewable Energy and Energy Efficiency
    - Sec. 1602. Rural Energy Savings Program
    - Sec. 1603. Support of state renewable energy and energy efficiency programs
- Title II – Greenhouse Gas Pollution Reduction
  - Subtitle B—Disposition of Allowances
    - Sec. 2101. Disposition of allowances
      - Industrial energy efficiency
      - Early action recognition
- Title III – Consumer Protection
  - Subtitle B—Investing in Low-carbon Heating and Energy Efficiency for Consumer Protection
    - Sec. 3101. Natural gas consumers
    - Sec. 3102. Home heating oil and propane consumers
- S. 1462, American Clean Energy Leadership Act*
  - Sec. 241. Greater energy efficiency through building codes

*Note: Included per Senate specifications to EPA

Modeling of Energy Efficiency Provisions

Two types of energy efficiency provisions represented

1. Building codes
2. Allowance allocations for energy efficiency programs
   - Rural energy savings program
   - Industrial energy efficiency
   - State renewable energy and energy efficiency
   - Early action recognition
   - Natural gas consumers
   - Home heating oil and propane consumers

Approach

- Estimated annual impacts (energy savings and costs) of energy efficiency provisions
- Accounted for impacts using ADAGE by adjusting energy demand and including associated costs.

Assumptions for analysis of allowance allocations for energy efficiency

- Cost of saved energy (CSE) at rate of $46/MWh (electric) and $6.8/mmBTU (natural gas), and average measure lives of 13 and 19 years, respectively. CSE includes "program administrator" and "participant" costs. CSE escalated at 1%/year.
- Source (available at http://www.aceee.org/pubs/u092.htm):
  - "Saving Energy Cost-Effectively: A National Review of the Cost of Energy Saved Through Utility-Sector Energy Efficiency Programs," American Council for an Energy Efficiency Economy, September 2009

Modeling of Energy Efficiency Provisions
Building Codes

- S. 1462, American Clean Energy Leadership Act
  - Sec. 241. Greater energy efficiency through building codes
    - Establishes targets for improvement and implementation of residential and commercial building codes to achieve energy savings of 30% and 50% respectively relative to 2006 IECC (residential buildings) and ASHRAE Standard 90.1-2004 (commercial buildings).
    - Requires updating of national model building energy codes, and state certification of code updates and compliance, and authorizes incentive funding for increasing and verifying compliance

- Estimated energy impacts and associated economic costs
  - Used bill provisions for energy reductions, timing, and compliance
  - Used AEO 2010 forecasts of new construction in residential/commercial sectors and HUD data for residential demolitions, and AEO forecasts of building energy intensity
  - Accounted for code-affected building end-uses and applied estimated realization rates
  - Estimated costs using EIA energy price forecasts and 10-year simple payback

Modeling of Energy Efficiency Provisions
Allowance Allocations for EE Programs

- Allowance allocations for EE programs directed under these sections:
  - Title I – Domestic Clean Energy Development
    - Subtitle D—Renewable Energy and Energy Efficiency
      - Sec. 1602. Rural Energy Savings Program (100% to EE)
      - Sec. 1603. Support of State renewable energy and energy efficiency programs (assume 75% to EE)
  - Title II – Greenhouse Gas Pollution Reduction
    - Subtitle B—Disposition of Allowances
      - Sec. 2101. Disposition of allowances
        - » Industrial energy efficiency (100% to EE)
        - » Early action recognition (67% to EE)
  - Title III – Consumer Protection
    - Subtitle B—Investing in Low-carbon Heating and Energy Efficiency for Consumer Protection
      - Sec. 3101. Natural gas consumers (50% to EE – minimum required)
      - Sec. 3102. Home heating oil and propane consumers (20% to EE – minimum required)

- Estimated energy impacts using
  - Cost of saved energy (CSE) at rate of $46/MWh (electric) and $6.8/mmBTU (natural gas), and average measure lives of 13 and 19 years, respectively
  - CSE includes “program administrator” and “participant” costs
  - CSE escalated at 1%/year

Modeling of Energy Efficiency Provisions
Caveats

- A significant energy demand price response is forecast by ADAGE. This response is driven by a number of factors including substitution away from energy consumption to other products/services, conservation behavior (e.g., turning off lights), as well as increased investments in energy efficiency.
- A portion of estimated energy demand reduction from energy efficiency provisions may be a-priori incorporated into the baseline responsiveness of demand to a price increase in ADAGE. Further analyses are needed to quantify the extent to which demand reduction may be double-counted in this scenario.
- The costs of EE provisions are captured in the estimated economy-wide cost of APA. However, a portion of these costs are estimated outside of ADAGE and then imposed within the model, rather than endogenously determined.

Energy Efficiency Modeling in Context

- The modeling of non-price policies in tandem with the analysis of GHG mitigation policy is the subject of much current research, including an on-going effort by the Energy Modeling Forum (EMF 25).
- There has been, historically, a disagreement between "top down" modeling, including the use of computable general equilibrium (CGE) models and "bottom up" or engineering economic models.
  - CGE models account for capital and labor flows between different sectors, representing the full effects of changes in prices, but they assume that markets are efficient. Because of this assumption, top down modeling implies that actors would adopt cost effective technology at an optimum rate, and that policies to increase investment in energy efficiency could come at the expense of other investments in the economy.
  - Bottom up models examine specific energy uses and show that there are large cost effective opportunities for energy efficient technologies. These studies often don't include the opportunity costs of increased investment in any particular sector.
- Economists recognize that there are market failures which may lead to sub-optimal adoption of energy saving technology.
  - Undersupply of research and development, externalities related to energy security and pollution, and principal-agent (landlord/tenant) problems are widely accepted as potential market failures.
  - Some researchers argue that asymmetric information and transaction costs also inhibit the adoption of more energy efficient investments and thus merit government intervention.
  - Economists also point to already existing market distortions, such as average cost pricing in electricity markets and energy subsidies, that may reduce investments in energy efficiency.
  - Uncertainty due to fluctuations in energy prices, irreversibility of investments and imperfect information characterize many markets and are not usually considered to be market failures.

Energy Efficiency Modeling in Context

- There are disagreements in the literature regarding the extent of these market failures (Jaffe, Newell, and Stavins 2001), though study of market failures and the cost-effectiveness of policies to reduce them has been on-going (Brown, M. 2001, IEA 2007, Brown, R., Borgeson, Koomey and Biermayer 2008).

- Policies at the state and federal level have been implemented and studied for many years.
  - Technology standards/codes (reviewed under E.O. 12866)
  - Informational programs (Energy Star)
  - Utility “demand-side management” (DSM)

- Three decades of empirical, retrospective assessment of costs and energy savings provides a knowledge base for estimating prospective costs and benefits of expanded programs in the context of national GHG emissions policy
  - California developed and implemented mandatory *ex post* measurement and correction for selection bias in utility programs
  - Costs and outcomes have also been analyzed econometrically (Horowitz 2004, 2007)
  - Aggregate ex ante efficiency potential studies are a complementary source of information (NAPEE 2007)

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Appendix 5: Additional Information on Economy-Wide Modeling (ADAGE & IGEM)

Appendix 5 Contents

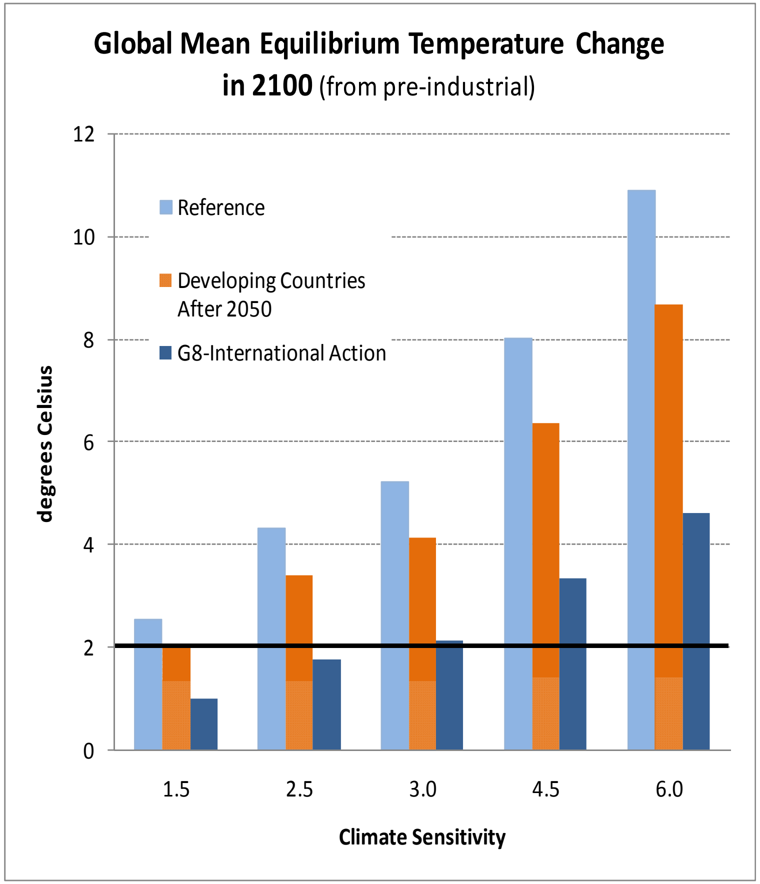
- Global Results: CO_2e Concentrations and Temperature Changes
- Economy-Wide Impacts: GHG Emissions
- Economy-Wide Impacts: Economic Costs

Global Results:

CO_2e Concentrations and Temperature Changes

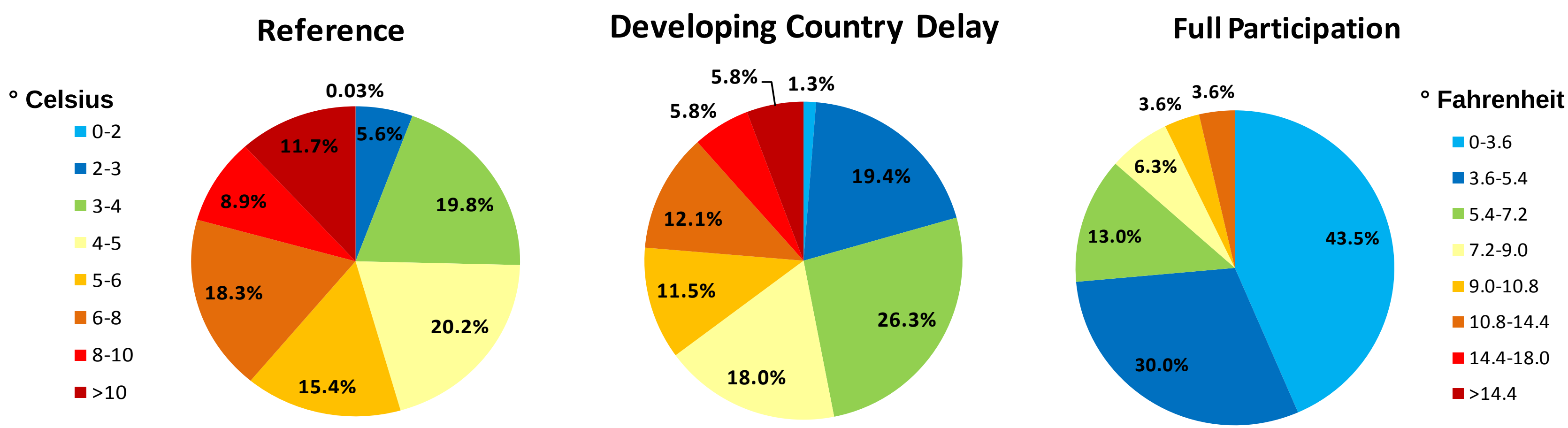
Equilibrium Global Mean Temperature Change

Impacts of International Action Assumptions (MAGICC)



- The temperature in 2100 in the 'G8 – International Action' scenario is not stabilized, so the observed change in global mean temperature in 2100 is not equal to the equilibrium change in global mean temperature. There are two reasons for this:
  - First, while the G8 international goals stabilize global GHG emissions at 50% below 2005 levels, CO_2e concentrations and temperature are not stabilized. Determining an equilibrium temperature under any scenario requires assumptions about post-2100 emissions. If emissions remain constant post-2100, CO_2e concentrations will continue to rise. Equilibrium temperature would only be achieved after CO_2e concentrations are in equilibrium.
  - Second, the inertia in ocean temperatures causes the equilibrium global mean surface temperature change to lag behind the observed global mean surface temperature change by as much as 500 years. Even if CO_2e concentrations in 2100 were stabilized, observed temperatures would continue to rise for centuries before the equilibrium were reached.
- Bar chart to the left demonstrates projections of equilibrium temperature changes (from pre-industrial time), assuming CO_2e-concentrations stabilize at 2100 levels, under various assumptions about the climate sensitivity.
- Assuming the G8 – international goals (reducing global emissions to 50% below 2005 by 2050), a 2 degree target in equilibrium is slightly exceeded under a climate sensitivity of 3.0° C.
- Continued GHG emissions reductions after 2100 are required to stabilize CO_2e concentrations at the 457 ppm levels achieved in 2100 in the G8 scenario.
- In order to achieve an equilibrium temperature change of 2 degrees (assuming CS = 3.0° C), CO_2e concentrations must be stabilized below 457 ppm, requiring continued abatement beyond the level needed to stabilize concentrations at 2100 levels.
  - It would be possible to reduce CO_2e concentrations after 2100 below 457 ppm by even further reducing GHG emissions in the next century. An 'overshoot' scenario such as this would further reduce the equilibrium temperature change, making it possible to achieve the 2 degrees C target even with a climate sensitivity of 3.0° C.

Probability of **Equilibrium** Temperature Changes Committed to in 2100, Given Reference and G8-Int'l Action Policy Scenarios



- The pie charts demonstrate the approximate probability of equilibrium tempera ranges under reference, developing country action delayed until 2050, and G8 international action scenarios.
  - The figures were developed using MAGICC 5.3 and the Roe and Baker (2007) distribution over climate sensitivity.
- Under Reference emissions (1st chart), a temperature increase of more than 3 degrees C is almost certain and probabilities are significant of reaching dangerously high temperature increases.
- Under the Policy Scenario (3rd chart), the probability is high of maintaining temperature increases below 3 degrees C.
- Under the reference emissions trajectory, the probability of equilibrium temperature change in 2100 being below 2 degrees C is less than 0.5%.
  - Policy scenario: nearly 44% probability of remaining below 2 degrees C.
- The no action case shows a probability of being *above* 6 degrees C of nearly 40%.
  - Policy scenario: a <4% probability of temperatures exceeding 6 degrees C.
- The emissions trajectory under the G8 scenario significantly increases the probability of remaining at or below 3 degrees C, compared to the reference case, while dramatically decreasing the probability of each of the higher temperature change categories.

Economy-Wide Impacts:
GHG Emissions

GHG Allowance Prices & Sensitivities

APA Scenario Comparison

	ADAGE				
	2015	**2020**	**2030**	**2040**	**2050**
Scn. 2 - APA	$18	$24	$39	$63	$102
Scn. 5 - V - No Int'l Offsets	$38	$49	$80	$129	$209
Scn. 6 - V - Ref. Nuclear & Biomass / Delayed CCS	$25	$32	$52	$84	$136
Scn. 7 - V - Ref. Nuclear & Biomass / Delayed CCS & No Int'l Offsets	$46	$59	$95	$153	$248
Scn. 8 - V - IPM Elec. Imposed on ADAGE	$22	$28	$46	$74	$120
Scn. 9 - No CCS Bonus Allowances	$19	$24	$39	$64	$104
Scn. 10 - H.R. 2454	$18	$24	$39	$63	$102

	IGEM				
	2015	**2020**	**2030**	**2040**	**2050**
Scn. 2 - APA	$18	$23	$37	$61	$99
Scn. 3 - Early Developing Country Action	$19	$24	$40	$65	$105
Scn. 4 - No Developing Country Action	$13	$17	$27	$45	$73
Scn. 5 - V - No Int'l Offsets	$24	$31	$50	$81	$133
Scn. 10 - H.R. 2454	$18	$23	$38	$61	$100

*Scenario 5 ADAGE results updated 6/30/10

U.S. covered emissions projections under APA scenario 2 (ADAGE)

	Emissions & Abatement		Percent below (above) 2005 (6,189 MtCO2e)		Percent below (above) 1990 (5,234 MtCO2e)	
	2020	*2050*	*2020*	*2050*	*2020*	*2050*
BAU covered emissions	**6,078**	**6,957**	-2%	12%	16%	33%
Covered GHG abatement	-689	-3,380				
U.S. covered emissions	**5,389**	**3,578**	-13%	-42%	3%	-32%
Domestic offsets	-408	-987				
U.S. covered emissions w/ domestic offsets	**4,981**	**2,591**	-20%	-58%	-5%	-51%
International offsets	-745	-920				
U.S. covered emissions w/ domestic & int'l offsets	**4,236**	**1,671**	-32%	-73%	-19%	-68%
Banking*	901	-617				
*Totals without Banking***						
U.S. covered emissions	**5,726**	**2,960**	-7%	-52%	9%	-43%
U.S. covered emissions w/ domestic offsets	**5,518**	**1,974**	-11%	-68%	5%	-62%
U.S. covered emissions w/ domestic & int'l offsets	**5,138**	**1,054**	**-17%**	**-83%**	-2%	-80%

* Before 2030 the models show covered GHG emissions net of offsets below the cap level. This over compliance is used to build up a bank of allowances. After 2030 the bank of allowances is drawn down, and covered GHG emissions net of offsets are above the cap level.

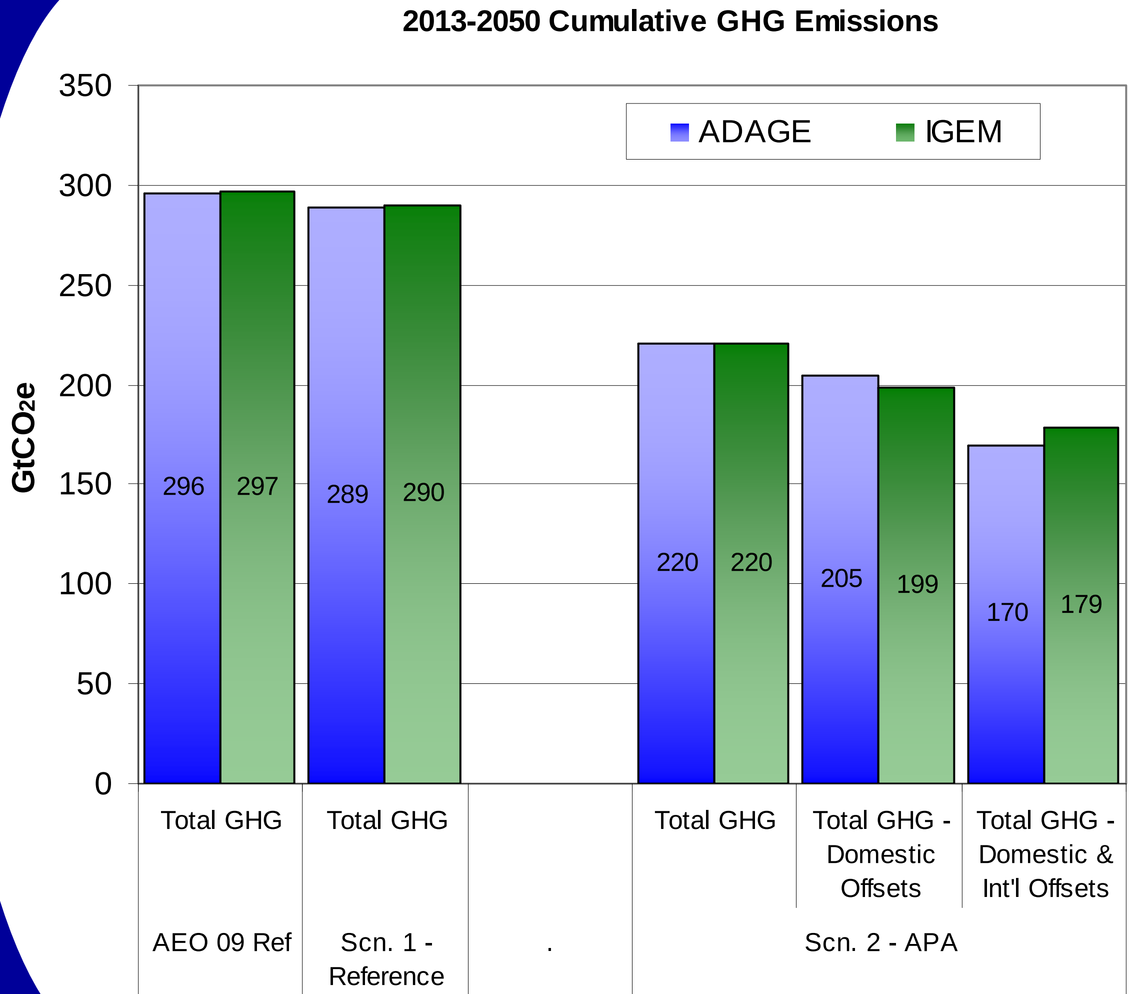
** The extra abatement driven by banking behavior generally is from additional international offset purchases, so the without banking totals in 2020 reduce international offset purchases. In 2050 the previously banked allowances submitted for compliance generally replace covered GHG abatement that would otherwise be required, so the without banking totals add to the required covered GHG abatement.

U.S. total emissions projections under APA scenario 2 (ADAGE)

	Emissions & Abatement		Percent below (above) 2005 (7,207 MtCO2e)		Percent below (above) 1990 (6,145 MtCO2e)	
	2020	*2050*	*2020*	*2050*	*2020*	*2050*
BAU covered emissions	6,078	6,957	-2%	12%	16%	33%
BAU uncovered emissions	1,176	1,102	16%	8%	29%	21%
BAU economy-wide emissions	**7,254**	**8,059**	1%	12%	18%	31%
Covered GHG abatement	-689	-3,380				
Domestic offsets (other than sequestration)	-154	-228				
HFC abatement (separate cap)	-224	-591				
NSPS for CH4	0	0				
U.S. emissions, inventory abatement	**6,187**	**3,861**	-14%	-46%	1%	-37%
Domestic offsets (sequestration)	-254	-759				
U.S. emissions, all domestic abatement	**5,933**	**3,102**	-18%	-57%	-3%	-50%
International offsets	-745	-920				
U.S. emissions (including international offsets)	**5,189**	**2,182**	-28%	-70%	-16%	-64%
Int'l forest set-asides	0	0				
Discounting of international offsets	-186	-230				
U.S. emissions, all sources of reductions	**5,003**	**1,952**	-31%	-73%	-19%	-68%
Banking*	901	-617				
*Totals without Banking***						
U.S. emissions, inventory abatement	**6,555**	**3,244**	-9%	-55%	7%	-47%
U.S. emissions, all domestic abatement	**6,437**	**2,485**	-11%	-66%	5%	-60%
U.S. emissions (including international offsets)	**6,090**	**1,565**	-15%	-78%	-1%	-75%
U.S. emissions, all sources of reductions	**5,904**	**1,335**	-18%	-81%	-4%	-78%

2012 – 2050 Cumulative GHG Emissions

Scenario 1 - Reference & Scenario 2 – APA

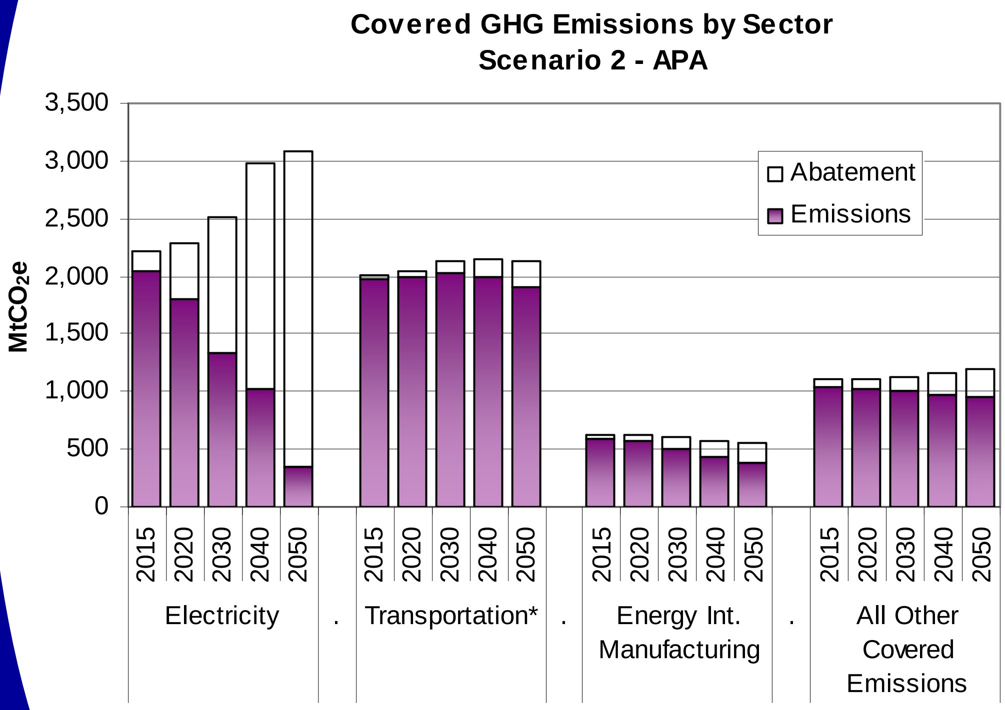


- Note that IGEM shows significantly less usage of international offsets than ADAGE in scenario 2, and the total GHG emissions net of domestic and international offsets usage in scenario 2 is lower in IGEM than in ADAGE.
- While reference case total GHG emissions are similar in ADAGE and IGEM, covered GHG emissions are higher in the ADAGE reference case compared to the IGEM reference case. This is in part due to the 5 year time steps in ADAGE and the representation of the coverage phase-in, compared to the annual time steps in IGEM.

Total US GHG Emissions & Sources of Abatement

Scenario 1 - Reference & Scenario 2 – APA (ADAGE)

- CO_2 emissions from the electricity sector represent the largest source of domestic reductions.
- Only about 5% of covered sector GHG reductions come from transportation, although transportation is currently responsible for 28% of GHG emissions in the U.S.
- These emission estimates do not take into account full lifecycle GHG emissions, including international land use impacts.

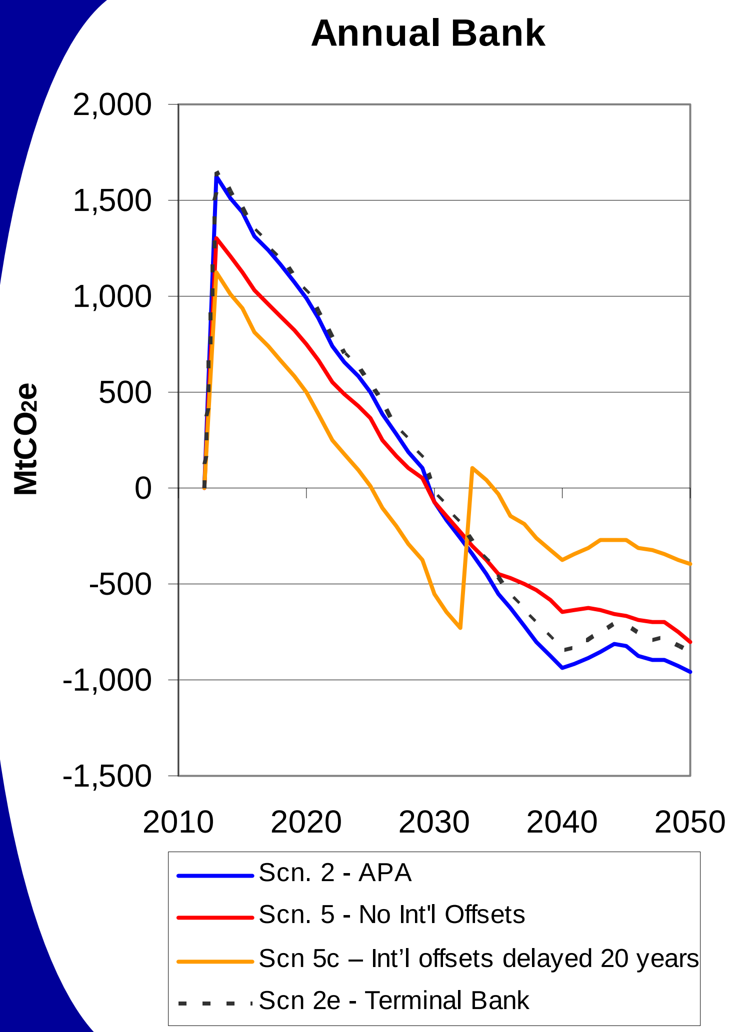


* Transportation emissions consist of the ADAGE transportation category and residential category (which is primarily made up of personal automobile use).

- The increase in gasoline prices ($0.18 in 2015, $0.37 in 2030, and $0.98 in 2050 under Scenario 2 - APA) that results from the allowance price is not sufficient to substantially change consumer behavior in their vehicle miles traveled or vehicle purchases at the prices at which low GHG emitting automotive technologies can be produced.
- The relatively modest indirect price signal on vehicle manufacturers from this particular cap-and-trade policy creates little incentive for the introduction of low-GHG automotive technology.
- 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.

GHG Allowance Banking

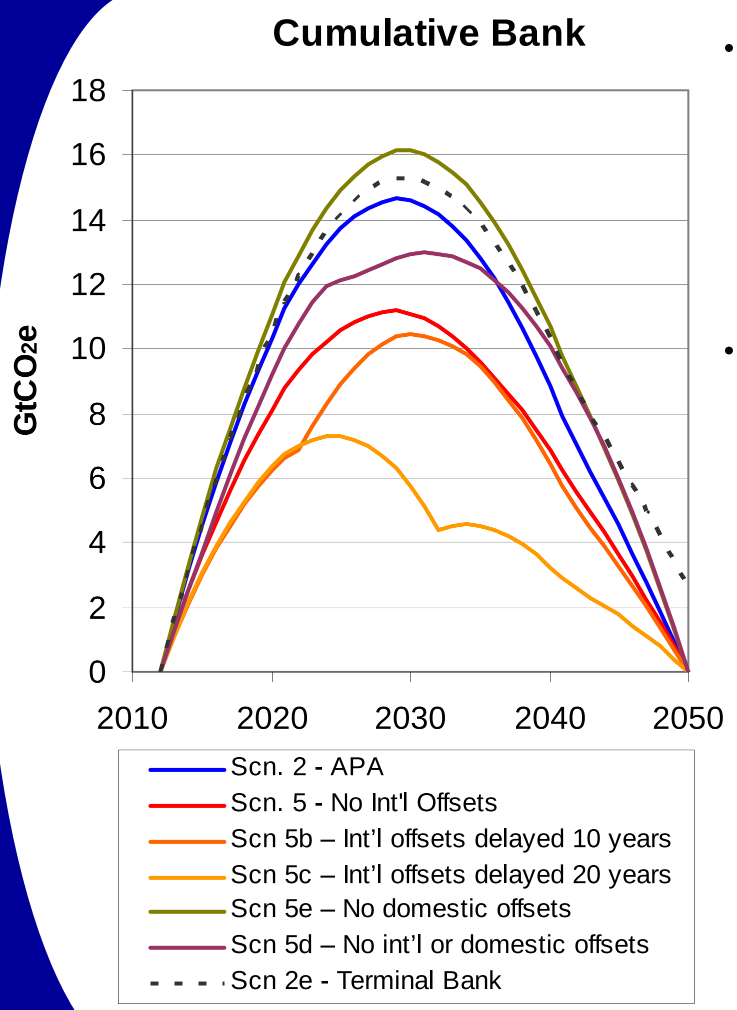
Scenario Comparison (IGEM)



- The APA allows for unlimited banking of allowances. As a result the rate of growth in allowance prices is equal to that of the interest rate, exogenously set at 5% in both models.
  - 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.
- In all modeled scenarios, a bank of allowances is built up in early years and drawn down in later years so that the cumulative covered emissions (net of offsets) over the 2012 – 2050 period is equal to cumulative emissions allowed under the cap.
- The IGEM model builds up a larger bank of allowances than the ADAGE model. The reason for this is mobility of capital in the two models. ADAGE has a putty-clay capital structure with quadratic capital adjustment costs, while IGEM has perfectly mobile capital. The capital adjustment costs in ADAGE slow down the movement of capital, and make it harder to build up a large bank of allowances in early years.

GHG Allowance Banking

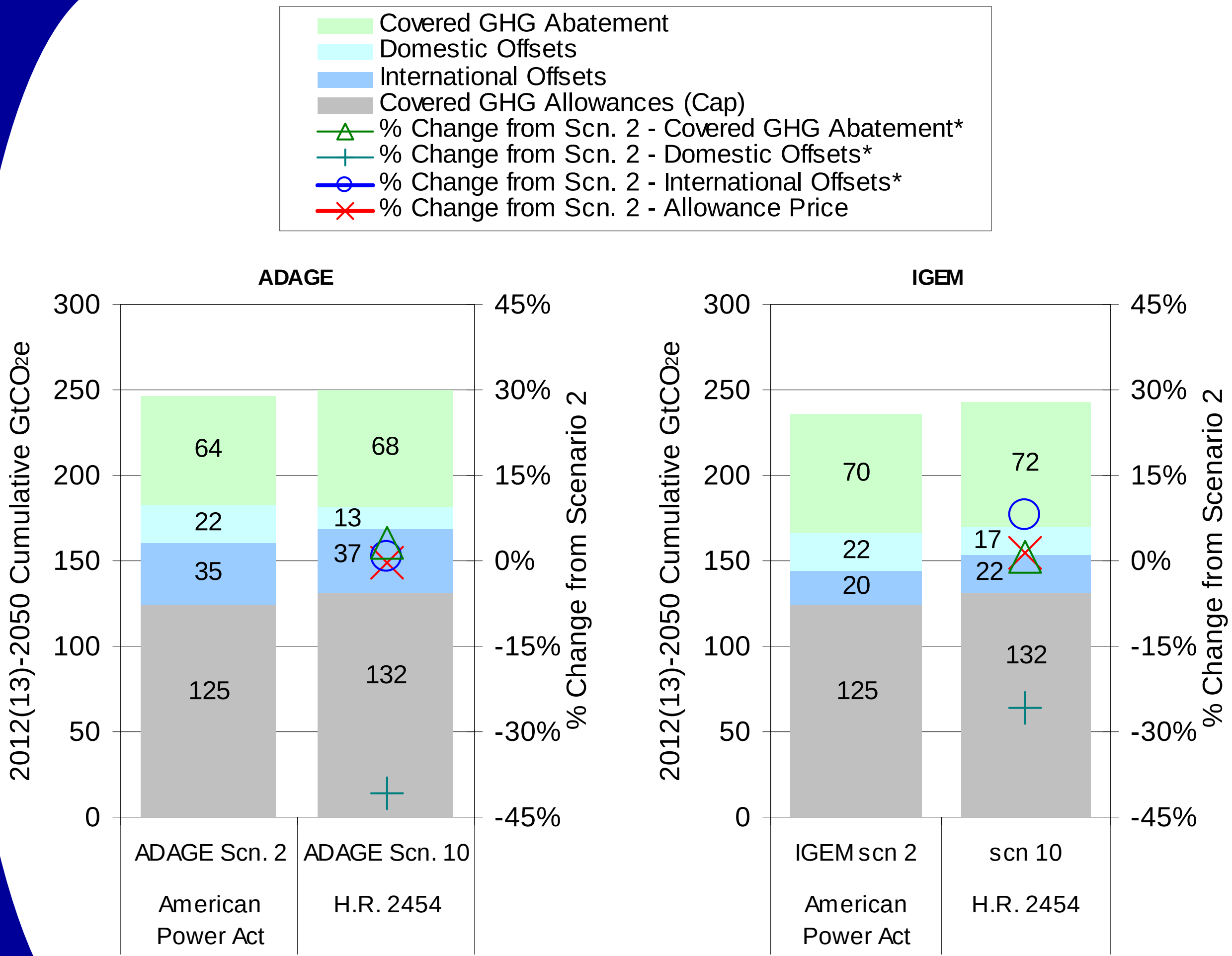
Scenario Comparison (IGEM)



- As modeled, the allowance bank goes to zero in 2050. However, the APA specifies a constant cap past 2050. The banking behavior predicted by the models is dependent on the complete credibility of the caps. Beginning in 2012, firms bank allowances in anticipation of rising allowance prices that are driven in part by the out-year caps. If firms believe that Congress may revise the caps upward, then the incentive for banking is diminished, as an upwardly revised cap would reduce the value of banked allowances. If the caps past 2050 are credible, then a positive bank would still be held in 2050 at the end of the model run, and allowance prices would accordingly be higher than forecast here.
- As a proxy for constant post 2050 caps, domestically and internationally, we run a scenario in the reduced form version of IGEM that requires a positive terminal bank in 2050.
  - In order to determine the size of the terminal bank needed, we extrapolate US and international policy case emissions past 2050, and calculate the cumulative amount by which the post 2050 cap is exceeded before emissions fall to the cap level. We then iteratively solve the reduced form IGEM model to converge on a new allowance price path and required 2050 bank. This process results in the following terminal banks:
    - In the U.S. the required 2050 bank is 2.5 $GtCO_2e$. The bank is exhausted and the post-2050 cap is met exactly by 2057.
    - In the international market the required 2050 bank is 1.6 $GtCO_2e$. The bank is exhausted and the post 2050 cap is met exactly in 2053.
  - Requiring the U.S. and the international market to hold these banks in 2050 increases the allowance price by 1% over IGEM scenario 2 results; and international offsets usage in the U.S. increases by 10%.
  - After the bank is exhausted, the allowance price would be expected to grow at a rate less than 5% per year as the caps are met exactly in each year and there is no longer any incentive to bank allowances.

2012(13) – 2050 Cumulative Covered U.S. GHG Emissions & Abatement

APA vs. H.R. 2454



* Because H.R. 2454 begins in 2012 and the APA begins in 2013, cumulative numbers presented for the two bills are over slightly different time periods. The percentage changes in different sources of abatement are presented as the change in the average annual abatement from each source.

- The APA and H.R. 2454 differ in their treatment of landfill, natural gas system, and coal mine CH4, which are allowed as offsets under the APA, but subject to NSPS under H.R. 2454. Because of this difference, both ADAGE and IGEM show less usage of domestic offsets under H.R. 2454 than under the APA (41% less in ADAGE, and 26% less in IGEM).
- Because of the larger number of allowances placed in the cost containment reserve in the APA compared to the number of allowances placed in the strategic reserve in H.R. 2454, the caps are effectively looser under H.R. 2454 in the core scenarios.
- The energy efficiency provisions in H.R. 2454 result in a greater reduction in electricity demand than the energy efficiency provisions in the APA (see slide 35 of the main analysis for more details), this results in less of a downward pressure on allowance prices in the APA compared to H.R. 2454 (note the EE provisions are modeled in ADAGE, but not in IGEM).
- International offset usage is 8% higher under H.R. 2454 compared to under the APA in IGEM, and is unchanged in ADAGE.
- Allowance prices under H.R. 2454 are 0.3% lower than under the APA in ADAGE, and 1.4% higher in IGEM.

Economy-Wide Impacts: Economic Costs

Total Abatement Cost

Scenario 2 - APA

Table: Total Abatement Cost Calculations
Scenario 2 - APA

	2015	2020	2030	2040	2050
Total Allowance Value (Billion 2005 Dollars)					
ADAGE	$85	$123	$139	$147	$108
IGEM	$81	$115	$127	$134	$99
Domestic Covered Abatement (MtCO2e)					
ADAGE	326	689	1,520	2,436	3,381
IGEM	632	966	1,682	2,440	3,382
Domestic Offset Abatement (MtCO2e)					
ADAGE	377	408	522	657	987
IGEM	369	398	513	630	978
International Offsets & Set-Asides (MtCO2e before discounting)					
ADAGE	1,000	931	1,180	1,215	1,149
IGEM	522	653	653	653	653
Allowance Price ($/tCO2e)					
ADAGE	$18	$24	$39	$63	$102
IGEM	$18	$23	$37	$61	$99
Offset Price ($/tCO2e)					
ADAGE	$18	$24	$39	$63	$102
IGEM	$18	$23	$37	$61	$99
International Offset/Credit Price ($/tCO2e before discounting)					
ADAGE	$15	$19	$31	$51	$82
IGEM	$14	$18	$30	$48	$79
Domestic Covered Abatement Cost (Billion 2005 Dollars)					
ADAGE	$3	$8	$30	$77	$173
IGEM	$6	$11	$31	$74	$167
Domestic Offset Abatement Cost (Billion 2005 Dollars)					
ADAGE	$3	$5	$10	$21	$51
IGEM	$3	$5	$10	$19	$48
International Offset Payments (Billion 2005 Dollars)					
ADAGE	$15	$18	$37	$61	$94
IGEM	$7	$12	$19	$32	$52
Total Abatement Cost (Billion 2005 Dollars)*					
ADAGE	$21	$31	$76	$159	$318
IGEM	$16	$27	$60	$125	$266

- Total allowance value is the value of allowances issued in each year (i.e. allowance price multiplied by the cap level).
- The allowance price is equal to the marginal cost of abatement.
- The offset price is the marginal cost of abatement for uncovered sectors and entities in the U.S. When the limit on offset usage is non-binding, the offsets price is equal to the allowance price.
- The international offset price is the marginal cost of abatement outside of 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 marginal allowance price but at lower prices. In most cases, the relationship between emission reduction and the marginal price is a convex 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 offset payments are calculated for each model as the product of the amount of international offsets purchased and the international credit price.
  - 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 offsets as they are all purchased at the full price of international allowances and those payments are sent abroad.
- Covered abatement occurs within the CGE models and thus the associated abatement cost is an ex-post general equilibrium cost.
- Offset abatement is generated by external MAC curves, and thus the associated abatement cost is an ex-ante partial equilibrium cost.
- Total abatement cost is simply the sum of domestic covered abatement cost, domestic offset abatement cost, and payments for international credits.

* CBO's analysis of H.R. 2454 uses a metric similar to "Total Abatement Cost" presented here and finds a cost per household of $175. The CBO figure is in 2010 dollars and is scaled to the 2010 size of the economy. The 2020 total abatement costs in IGEM and ADAGE, in 2010 dollars and scaled to the 2010 size of the economy, is $23 and $26 billion respectively. On a per household basis, the total abatement cost in 2020 is $182 and $223 in IGEM and ADAGE respectively.

Consumption

Scenario 1 – Reference & Scenario 2 - APA

ADAGE	2015	2020	2030	2040	2050
Ref. Total C (Billion 2005 $)	$11,308	$13,199	$17,061	$21,334	$26,104
Change in Total C (Billion 2005 $)	-$16	-$23	-$79	-$145	-$224
Ref. Consumption per Household	$88,883	$98,150	$114,362	$132,181	$153,437
% Change (Scn. 2)	-0.14%	-0.17%	-0.46%	-0.68%	-0.86%
Consumption Loss per Household ($)	-$122	-$169	-$529	-$901	-$1,316
NPV Cost per HH ($)	-$91	-$99	-$190	-$199	-$178

Average Annual NPV cost per Household	**-$146**
Total NPV Cost per Household (2010-2050)	**-$5,985**
Total Cost as an Annual Annuity Loss (2010-2050)	**-$349**

IGEM	2015	2020	2030	2040	2050
Ref. Total C (Billion 2005 $)	$9,615	$10,875	$14,021	$17,713	$21,850
Change in Total C (Billion 2005 $)	$0	$2	-$23	-$128	-$241
Ref. Consumption per Household	$75,387	$80,829	$94,582	$108,841	$123,455
% Change (Scn. 2)	0.00%	0.01%	-0.16%	-0.72%	-1.10%
Consumption Loss per Household	-$3	$12	-$153	-$786	-$1,360
NPV Cost per HH	-$2	$7	-$55	-$173	-$184

Average Annual NPV cost per Household	**-$79**
Total NPV Cost per Household (2010-2050)	**-$3,225**
Total Cost as an Annual Annuity Loss (2010-2050)	**-$188**

- The costs described here include the effects of higher energy prices, price changes for other goods and services, impacts on wages and returns to capital, and the value of auction revenues returned lump sum to households. The cost does not include the impacts on leisure.
- In the model the loss in consumption is calculated in each year and divided by the household size (~2.5) to find the cost per household.
- The economic discount rate (5%) is applied to find the net present value (NPV) of the cost in each year in the future.
- The total NPV cost per household is found by summing the NPV consumption loss per household over the years 2010 – 2050. This represents the total cost of the policy per household as a one time consumption loss in 2010.

- Average annual NPV cost per household is found by summing the NPV cost per household over all years and dividing by the number of years, which results in the $79 - $146 figure. This represents the cost per household in an average future year discounted back to today.
- The total cost as an annual annuity loss converts the total cost of the policy in terms of consumption loss per household, into a stream of equal size consumption losses in each year through 2050. For example, given the ADAGE numbers, a household would be indifferent between a onetime consumption loss of $5,985 in 2010, or an undiscounted consumption loss of $349 each year from 2010 through 2050.

Consumption

APA Scenario Comparison (ADAGE)

	ADAGE	2015	2020	2030	2040	2050
Scn. 1 - Reference	Ref. Consumption per Household	$88,883	$98,150	$114,362	$132,181	$153,437
Scn. 2 - APA	% Change	-0.14%	-0.17%	-0.46%	-0.68%	-0.86%
	Consumption Loss per Household ($)	-$122	-$169	-$529	-$901	-$1,316
	NPV Cost per HH ($)	-$91	-$99	-$190	-$199	-$178
	Average Annual NPV cost per Household			**-$146**		
	Total NPV cost per Household			-$5,985		
Scn. 5 - V - No Int'l Offsets	% Change	-0.25%	-0.36%	-0.96%	-1.37%	-1.71%
	Consumption Loss per Household ($)	-$220	-$354	-$1,093	-$1,808	-$2,623
	NPV Cost per HH ($)	-$164	-$207	-$392	-$399	-$355
	Average Annual NPV cost per Household			**-$289**		
	Total NPV cost per Household			-$11,829		
Scn. 6 - V - Ref. Nuclear & Biomass / Delayed CCS	% Change	-0.13%	-0.21%	-0.67%	-1.04%	-1.41%
	Consumption Loss per Household ($)	-$113	-$205	-$771	-$1,374	-$2,158
	NPV Cost per HH ($)	-$84	-$120	-$277	-$303	-$292
	Average Annual NPV cost per Household			**-$204**		
	Total NPV cost per Household			-$8,362		
Scn. 7 - V - Ref. Nuclear & Biomass / Delayed CCS & No Int'l Offsets	% Change	-0.29%	-0.44%	-1.17%	-1.68%	-1.91%
	Consumption Loss per Household ($)	-$255	-$430	-$1,340	-$2,224	-$2,933
	NPV Cost per HH ($)	-$191	-$252	-$481	-$490	-$397
	Average Annual NPV cost per Household			**-$350**		
	Total NPV cost per Household			-$14,347		
Scn. 9 - No CCS Bonus Allowances	% Change	-0.14%	-0.17%	-0.48%	-0.71%	-0.85%
	Consumption Loss per Household ($)	-$121	-$166	-$546	-$932	-$1,300
	NPV Cost per HH ($)	-$90	-$97	-$196	-$205	-$176
	Average Annual NPV cost per Household			**-$149**		
	Total NPV cost per Household			-$6,095		
Scn. 10 - H.R. 2454	% Change	-0.12%	-0.14%	-0.43%	-0.67%	-0.83%
	Consumption Loss per Household ($)	-$107	-$138	-$491	-$883	-$1,275
	NPV Cost per HH ($)	-$80	-$81	-$176	-$195	-$172
	Average Annual NPV cost per Household			**-$138**		
	Total NPV cost per Household			-$5,641		

*Scenario 5 ADAGE results updated 6/30/10

Consumption

APA Scenario Comparison (IGEM)

	IGEM	2015	2020	2030	2040	2050
Scn. 1 - Reference	Ref. Consumption per Household	$75,387	$80,829	$94,582	$108,841	$123,455
Scn. 2 - APA	% Change	0.00%	0.01%	-0.16%	-0.72%	-1.10%
	Consumption Loss per Household ($)	-$3	$12	-$153	-$786	-$1,360
	NPV Cost per HH ($)	-$2	$7	-$55	-$173	-$184
	Average Annual NPV cost per Household			**-$79**		
	Total NPV cost per Household			-$3,225		
Scn. 3 - Early Developing Country Action	% Change	-0.01%	0.01%	-0.18%	-0.77%	-1.16%
	Consumption Loss per Household ($)	-$6	$10	-$173	-$839	-$1,428
	NPV Cost per HH ($)	-$5	$6	-$62	-$185	-$193
	Average Annual NPV cost per Household			**-$84**		
	Total NPV cost per Household			-$3,445		
Scn. 4 - No Developing Country Action	% Change	0.00%	0.02%	-0.15%	-0.55%	-0.82%
	Consumption Loss per Household ($)	-$4	$13	-$146	-$600	-$1,010
	NPV Cost per HH ($)	-$3	$8	-$52	-$132	-$137
	Average Annual NPV cost per Household			**-$61**		
	Total NPV cost per Household			-$2,484		
Scn. 5 - V - No Int'l Offsets	% Change	-0.01%	0.01%	-0.23%	-0.94%	-1.39%
	Consumption Loss per Household ($)	-$6	$8	-$222	-$1,023	-$1,715
	NPV Cost per HH ($)	-$5	$5	-$80	-$225	-$232
	Average Annual NPV cost per Household			**-$103**		
	Total NPV cost per Household			-$4,239		
Scn. 10 - H.R. 2454	% Change	-0.03%	0.03%	-0.22%	-0.71%	-1.08%
	Consumption Loss per Household ($)	-$23	$23	-$205	-$772	-$1,330
	NPV Cost per HH ($)	-$17	$14	-$74	-$170	-$180
	Average Annual NPV cost per Household			**-$81**		
	Total NPV cost per Household			-$3,301		

Consumption

Scenario 1 – Reference & Scenario 2 - APA

Table: Impacts on Average HH Consumption

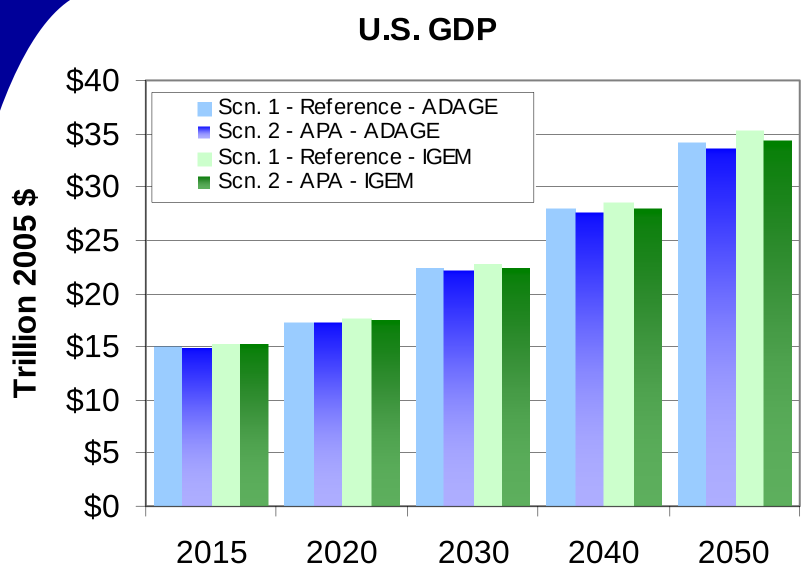
	2010	2015	2020	2025	2030	2035	2040	2045	2050
Current Average HH Consumption (2010)									
ADAGE	$81,500								
IGEM	$70,656								
Average HH Consumption in *Scenario 1 - Reference*									
ADAGE		$88,883	$98,150	$106,163	$114,362	$122,726	$132,181	$142,374	$153,437
IGEM		$75,387	$80,829	$87,523	$94,582	$101,750	$108,841	$116,237	$123,455
Average HH Consumption in *Scenario 2 - APA*									
ADAGE		$88,760	$97,981	$105,937	$113,832	$122,038	$131,280	$141,228	$152,121
IGEM		$75,384	$80,841	$87,533	$94,429	$101,222	$108,055	$115,155	$122,094
Increase in Average HH Consumption in *Scenario 1 - Reference* Compared to 2010									
ADAGE		9.1%	20.4%	30.3%	40.3%	50.6%	62.2%	74.7%	88.3%
IGEM		6.7%	14.4%	23.9%	33.9%	44.0%	54.0%	64.5%	74.7%
Increase in Average HH Consumption in *Scenario 2 - APA* Compared to 2010									
ADAGE		8.9%	20.2%	30.0%	39.7%	49.7%	61.1%	73.3%	86.7%
IGEM		6.7%	14.4%	23.9%	33.6%	43.3%	52.9%	63.0%	72.8%
Benefits from Reduced Climate Change									
		Not Estimated	Not Estimated	Not Estimated	Not Estimated	Not Estimated	Not Estimated	Not Estimated	Not Estimated

- This analysis is a cost-effectiveness analysis, not a cost-benefit analysis. As such, the benefits of reducing GHG emissions were not determined in this analysis.
- The consumption loss is the cost of achieving the climate benefits that would result from this bill.

- The difference in reference consumption between the two models arises from an important accounting distinction. The Jorgenson-IGEM accounts treat consumer durables like housing differently than they are treated in the U.S. National Income Accounts (NIA). Specifically, expenditures on these appear as part of investment, not consumption as in the NIA, while their capital services flows are added both to consumption and GDP. This accounting treatment lowers consumption's share of GDP and raises investment's share of GDP in comparison to pure NIA-based ratios.
- While it is tempting to focus on levels, it is the absolute and relative changes and their underlying causes that matter most once a common scale among variables of interest and across methodologies has been achieved.
- Model outcomes to policy changes are more than likely to be qualitatively very robust and relatively insensitive across small compositional differences within a methodology and a common scale.
- See Appendix 1 for a detailed discussion of the IGEM composition of GDP.

GDP

Scenario 1 – Reference & Scenario 2 - APA

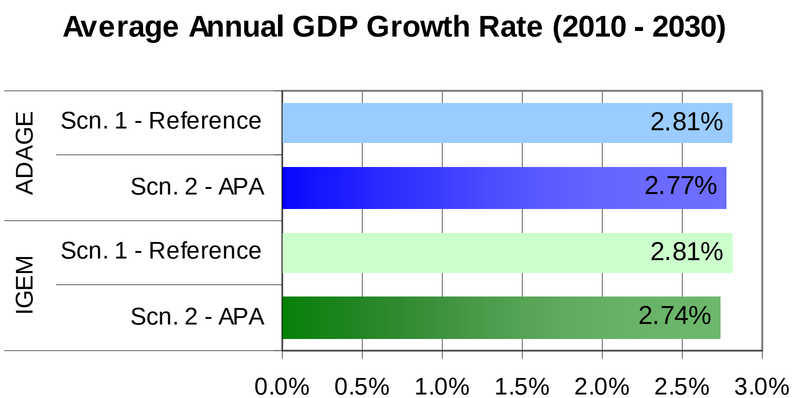


ADAGE

	2015	2020	2030	2040	2050
Reference	$14.9	$17.3	$22.4	$28.0	$34.3
Scn 2 - APA	$14.9	$17.3	$22.2	$27.6	$33.6
Absolute Change	-$0.020	$0.010	-$0.157	-$0.327	-$0.626
% Change	-0.13%	0.06%	-0.70%	-1.17%	-1.83%

IGEM

	2015	2020	2030	2040	2050
Reference	$15.2	$17.6	$22.7	$28.6	$35.4
Scn 2 - APA	$15.1	$17.5	$22.4	$28.0	$34.4
Absolute Change	-$0.041	-$0.064	-$0.330	-$0.579	-$0.940
% Change	-0.27%	-0.37%	-1.45%	-2.03%	-2.66%



- Other ways to frame these GDP reductions are as follows:
  - In the reference case, GDP in ADAGE is $22.4 trillion in 2030. In "*scenario 2 – APA*" GDP reaches $22.4 trillion approximately four months later than in the reference case.
  - In IGEM the reference case GDP is $22.7 trillion in 2030. In *"scenario 2 - APA"* GDP reaches $22.7 trillion eight months later than in the reference case.
  - Under "*scenario 2 – APA*", average annual GDP growth between 2010 and 2030 is approximately 4 basis points lower in ADAGE and 7 basis points lower in IGEM than in the reference scenario.

GDP

Discussion

- The structure of the IGEM model tends to lead to larger GDP impacts for a given allowance price than the ADAGE model.
- The compensated elasticity of labor supply is the driving force behind the relatively large economic impacts for a given allowance price in IGEM. The second stage of the household decision process is the allocation of full consumption between leisure and goods and services. The parameter that governs this decision plays a dominant role in model outcomes. Unfortunately there is not a consensus in the literature about what value this parameter should take. In ADAGE, this consumption-leisure parameter is adopted from values of related parameters in the empirical literature. Much of the empirical literature examines the effect of a real wage increase on the willingness to supply additional labor hours without simultaneously considering the impact on labor force participation. Attempts to combine both impacts in a single parameter have yielded estimates ranging from 0.1 to 0.6 for the compensated elasticity of labor supply. IGEM estimates the time-varying compensated elasticity of labor supply as part of a comprehensive model of household behavior and finds values ranging from 0.8 to 1.0. (Jorgenson et. al 2008).
  - In a sensitivity case run for a previous EPA analysis, the consumption-leisure tradeoff in IGEM was constrained so that the average compensated labor supply elasticity was reduced from its estimated value of 1.03 to a constrained value of 0.48. In this sensitivity the decline in GDP was reduced by approximately 20%, and the decline in consumption was reduced by 50%.
  - Jorgenson et. al (2008) shows an experiment reducing the compensated labor supply elasticity that reduces GDP impacts by 25 to 20 percent.
  - Goettle and Fawcett (2009) ran an experiment as part of the EMF-22 exercise reducing the compensated labor supply elasticity in half, and found the resulting welfare impact was also halved.
  - Jorgenson et al. (2009a) describes an experiment reducing the responsiveness of labor supply from 0.8 to 0.3 in IGEM reduces the impact on GDP by a third, and reduces the impact on household consumption by 70 to 80%. This bounded range of outcomes is useful in the absence of a definitive consensus on the value of the compensated elasticity of labor supply that should be used in these models.
- Changes in consumption may be a better measure of the costs of the APA than changes in GDP since utility (and thus welfare) is a direct function of consumption.

References

Goettle, R.J., and Fawcett, A.A. (2009), The structural effects of cap and trade climate policy. Energy Economics. 31(Supplement 2).

Jorgenson, D.W., Goettle, R.J., Wilcoxen, P.J. and Ho, M.S. (2009), Cap and Trade Climate Policy and the Mechanisms of Economic Adjustment. Journal of Policy Modeling. Forthcoming.

Jorgenson, D.W., Goettle, R.J., Wilcoxen, P.J. and Ho, M.S. (2008). The Economic Costs of a Market-based Climate Policy. Arlington, VA: Pew Center on Global Climate Change. June.

Jorgenson, D.W., Goettle, R.J., Wilcoxen, P.J. and Ho, M.S. (2000). The Role of Substitution in Understanding the Costs of Climate Change Policy. Arlington, VA: Pew Center on Global Climate Change. September.

Nuclear & CCS Limits in ADAGE

- The constraints on Nuclear and CCS capacity additions in ADAGE reflect the constraints in IPM.
- These constraints are applied in ADAGE to all capacity additions including what is projected in the reference scenario.
  - Note that the reference scenario now reflects nuclear retirements occurring after the 2035 time horizon of AEO 2010 as existing plants reach the end of their 60 year permitted lifetimes. These projected retirements are based on IPM modeling that extends beyond the 2025 time horizon used by IPM in this analysis.
- These constraints limit the market penetration of the various electricity generating sources to ensure realistic build patterns in response to CO_2 regulatory policies.
- The limits were determined based upon various factors, including:
  1. Historical deployment patterns
  2. Potential to expand domestic engineering, construction, and manufacturing base
  3. Ability to educate and train workforce (this is particularly true for new coal with CCS and nuclear plants due to the highly technical nature of building these facilities)
- Because new nuclear and new coal with CCS are both complicated technologies that require sophisticated planning, engineering, and construction support, the same engineering/construction firms would be building both of these facilities and there would be a dynamic between the greater resources needed to build one technology relative to the other, in addition to the inherent limitations of increasing the skilled workforce.
  - To reflect this dynamic, EPA has incorporated a technology curve in the model, whereby the amount of new nuclear and coal with CCS is limited but also incorporates a trade-off between each technology (i.e., if you build more of one, you must build less of the other).
  - The amount of each technology that is built in ADAGE is determined in an economic manner, up to the limits.
- CCS retrofits to the existing coal fleet are represented in IPM, but not in ADAGE.

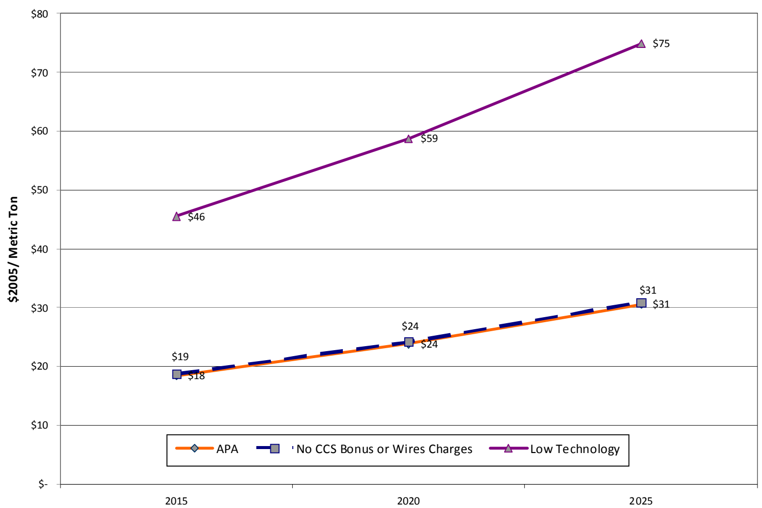
Cumulative New Capacity Limitations in ADAGE for Nuclear and Coal with CCS (GW)

	Nuclear	CCS		Nuclear	CCS
2015	N/A	N/A		N/A	0
2020	12	0		0	27
2025	24	0		0	48
2030	40	0	**OR**	0	80
2035	60	0		0	120
2040	90	0		0	200
2045	140	0		0	325
2050	210	0		0	450

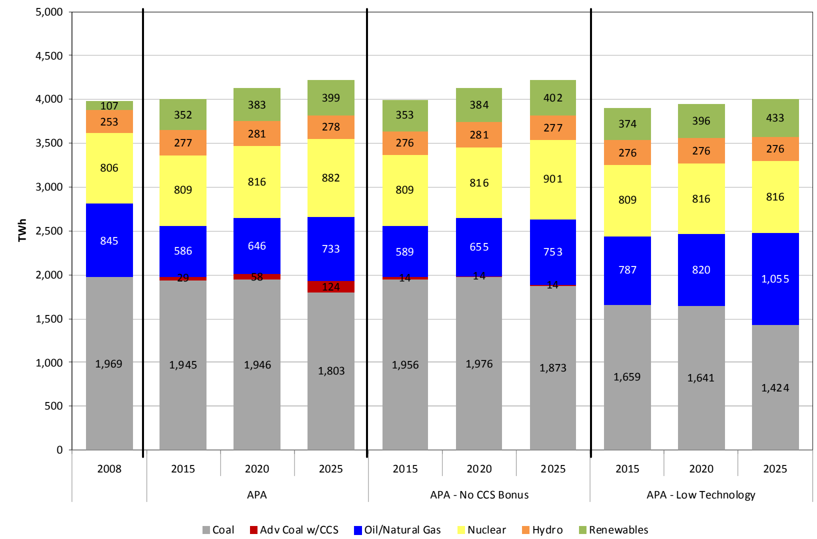
Appendix 6: Additional Information on Near Term Electricity Sector Modeling (IPM)

Sensitivities – No CCS Bonus or Wires Charges (Scn. 7) and Low Technology with No Int'l Offsets (Scn. 9)

Allowance Prices



Generation Mix

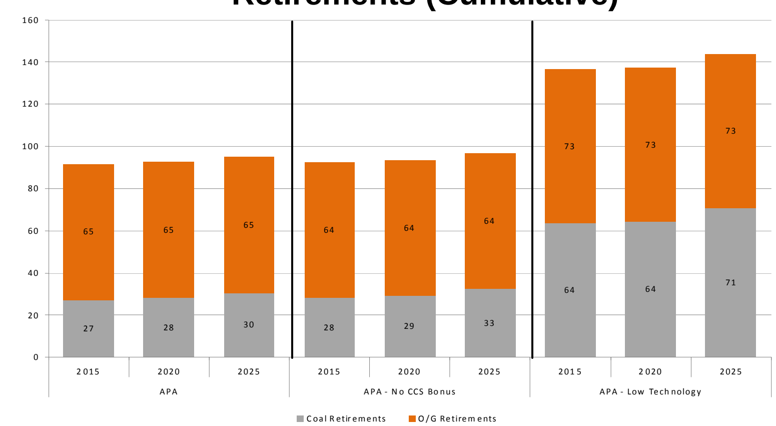


•Allowance prices are relatively similar in the core policy scenario and the no bonus allowance scenario. However, prices more than double when low-emitting technologies are constrained.

•Without bonus allowances or wires charges, it is not economic to deploy new or retrofit coal with CCS in the near-term.

•Without more nuclear, biomass or coal with CCS capacity, retirements increase and natural gas becomes a more attractive option for compliance. Renewables, including solar, also grow and overall generation falls.

Retirements (Cumulative)



Technology Deployment: Carbon Capture and Storage

EPA analyses of cap-and-trade legislation clearly show the importance of technology in achieving climate goals. Today, there is already considerable interest and activity in low- and non-emitting technologies like CCS, nuclear, and biomass. A cap-and-trade system would serve to make these technologies more cost-competitive for widespread commercialization.

<u>CCS:</u>

- CCS technology feasibility has been demonstrated for decades in industrial applications and is used widely by the oil and gas industry. Although challenges remain for larger scale applications, the basic engineering has been applied at numerous facilities for long periods of time.
- There are nearly 3 GW of CCS power plant projects in planning, design, and/or construction phases, some of which are already capitalizing on existing funding opportunities. Several projects have obtained funding and commenced or scheduled operation.
  - We Energies' Pleasant Prairie Plant (Pleasant Prairie, WI): Technology currently operational in test phase (Source: We Energies Press Release, 10/08/2009).
  - AEP's Mountaineer Plant (New Haven, WV): Technology currently operational in test phase with plans to transition from the current 20 MW CCS pilot demonstration to a 235 MW full module demonstration in 2015 (Source: AEP Press Release, 12/09/2009).
  - Tenaska's Taylorville Energy Center (Taylorville, IL): Plans to operate a 750 MW IGCC with CCS in 2014. Taylorville is approved by DOE for a loan guarantee of up to $2.6 billon subject to contingencies (Source: DOE, Tenaska Press Release, 03/03/2010).
  - Tenaska's Trailblazer Energy Center (Sweetwater, TX): Requested permitting in 2008 for a 600 MW supercritical pulverized coal plant with CCS, which Tenaska plans to operate in 2015 (Source: Tenaska Press Release, 06/04/2009).
  - Hydrogen Energy California (Kern County, CA): Requested permitting in 2008 for a 250 MW IGCC with CCS and was awarded with $308 million from DOE in July 2009. Hydrogen Energy International, a joint venture between BP and Rio Tinto, projects the plant to start operation in September 2015 (Source: Hydrogen Energy International interview with California Energy Markets, 10/02/2009).

Sources: Worley-Parsons (http://www.globalccsinstitute.com/downloads/Status-of-CCS-WorleyParsons-Report-Synthesis.pdf), Department of Energy, Company statements.
List of projects is not intended to be a comprehensive list.

Technology Deployment: Nuclear

Nuclear License Applications at the Nuclear Regulatory Commission

Combined License Applications Received

Proposed New Reactor(s)	Applicant	Design
Bell Bend Nuclear Power Plant	PPL Bell Bend, LLC	U.S. EPR
Bellefonte Nuclear Station, Unit 1	Tennessee Valley Authority (TVA)	AP1000
Calvert Cliffs, Unit 3	Calvert Cliffs 3 Nuclear Project, LLC and UniStar Nuclear Operating Services, LLC	U.S. EPR
Comanche Peak, Units 3 and 4	Luminant Generation Company, LLC (Luminant)	US-APWR
Fermi, Unit 3	Detroit Edison Company	ESBWR
Levy County, Units 1 and 2	Progress Energy Florida, Inc. (PEF)	AP1000
North Anna, Unit 3	Dominion Virginia Power (Dominion)	ESBWR
Shearon Harris, Units 2 and 3	Progress Energy Carolinas, Inc. (PEC)	AP1000
South Texas Project, Units 3 and 4	South Texas Project Nuclear Operating Company (STPNOC)	ABWR
Turkey Point, Units 6 and 7	Florida Power and Light Company (FPL)	AP1000
Virgil C. Summer, Units 2 and 3	South Carolina Electric & Gas (SCE&G)	AP1000
Vogtle, Units 3 and 4	Southern Nuclear Operating Company (SNC)	AP1000
William States Lee III, Units 1 and 2	Duke Energy	AP1000

Issued Design Certifications

Design	Applicant
Advanced Boiling Water Reactor (ABWR)	General Electric (GE) Nuclear Energy
System 80+	Westinghouse Electric Company
Advanced Passive 600 (AP600)	Westinghouse Electric Company
Advanced Passive 1000 (AP1000)	Westinghouse Electric Company

Design Certification Applications Currently Under Review

Design	Applicant
AP1000 Amendment	Westinghouse Electric Company
ABWR Design Certification Rule (DCR) Amendment	South Texas Project Nuclear Operating Company
Economic Simplified Boiling-Water Reactor (ESBWR)	GE-Hitachi Nuclear Energy
U.S. Evolutionary Power Reactor (U.S. EPR)	AREVA Nuclear Power
U.S. Advanced Pressurized-Water Reactor (US-APWR)	Mitsubishi Heavy Industries, Ltd.

Issued Early Site Permits

Site	Applicant
Clinton ESP Site	Exelon Generation Company, LLC
Grand Gulf ESP Site	System Energy Resources Inc.
North Anna ESP Site	Dominion Nuclear North Anna, LLC
Vogtle ESP Site	Southern Nuclear Operating Company

- The U.S. has extensive experience with nuclear power and has rapidly expanded deployment of nuclear power in the past.
- The U.S. Nuclear Regulatory Commission expects to have a total of 22 applications for 31 units (30-40 GW) through 2011.*
  - Typical units are usually 1 - 1.3 GW in size
- The NRC has established a streamlined process for licensing new nuclear power plants.
- The NRC has certified several reactor designs as meeting all safety requirements, and the agency expects to certify two more designs in the near term.

* http://www.nrc.gov/reactors/new-reactors/new-licensing-files/expected-new-rx-applications.pdf

Technology Deployment: Biomass

The U.S. has used biomass for electricity production for decades.

- There are over 190 facilities (7.5 GW) that currently use biomass as the primary fuel and many others that co-fire biomass with coal.

Some utilities have recently completed or are planning to convert coal facilities to biomass:

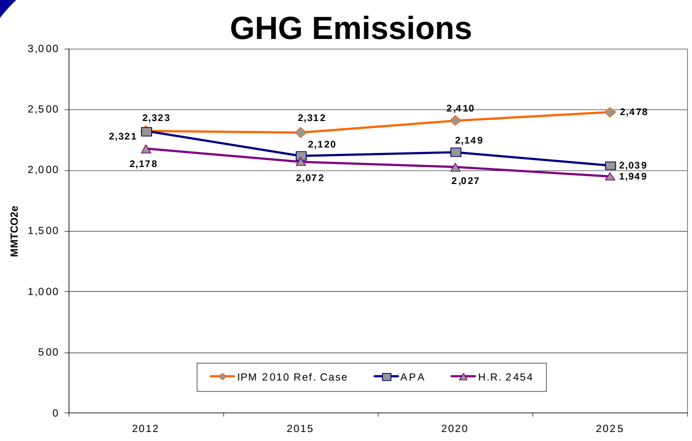
- R.E. Burger Station (OH): 2 x 156 MW units - 20% coal / 80% biomass (FirstEnergy)
- E.J. Stoneman Power Plant (WI): 53 MW (DTE Energy Services)
- Buena Vista Biomass Power Facility (CA): 18 MW (Buena Vista Biomass Power)
- Schiller Station (NH): Completed 50 MW (Public Service of New Hampshire)
- Bayfront (WI): 30 MW planned (Xcel Energy)
- Mt. Poso Cogen (CA): 44 MW (Millennium Energy)
- Montville Generating Station (CT): Co-firing with 40MW from biomass out of total 82MW (NRG)

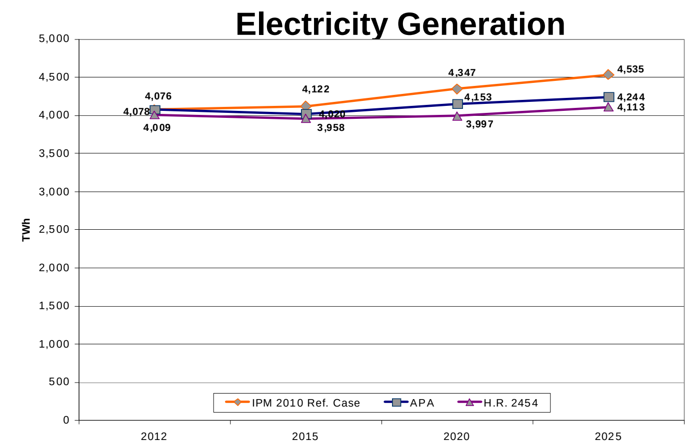
Sample new projects under development:

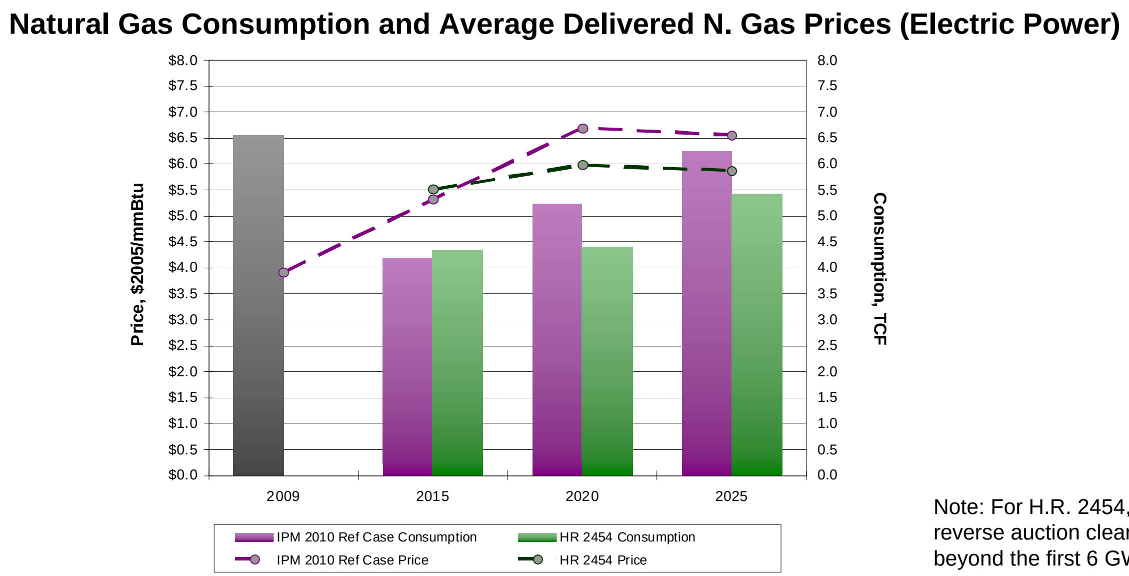
- Sacul Biomass Plant (TX): 100 MW (Southern Power)
- Deerhaven Generating Station (FL): 100 MW planned (Gainesville Regional Utilities)
- Savannah River Cogeneration Plant (SC): 15 MW (Washington Savannah River Company)

Note: List of projects is not intended to be a comprehensive list.
Sources: Department of Energy, Energy Information Administration, EPA, company statements.

Sensitivity – H.R. 2454 (Scenario 10)

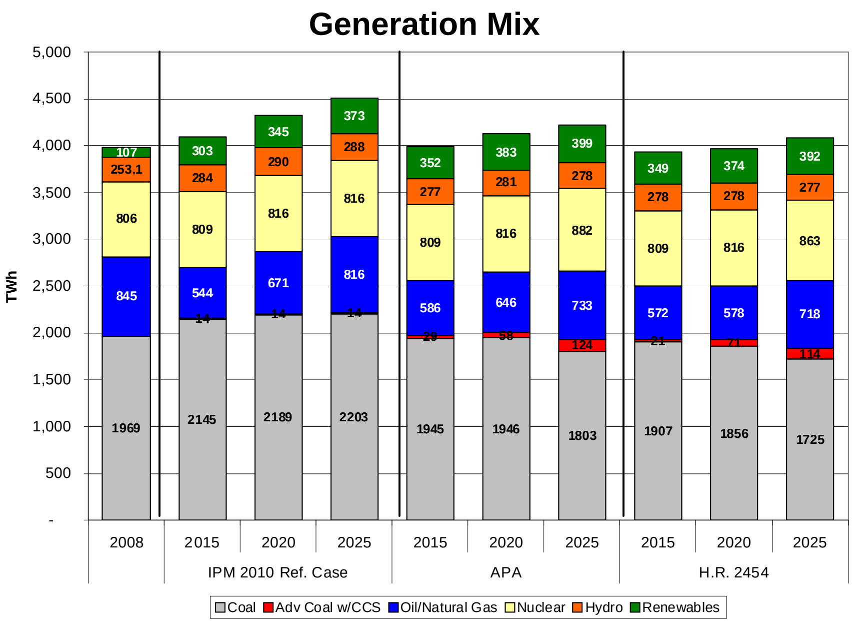


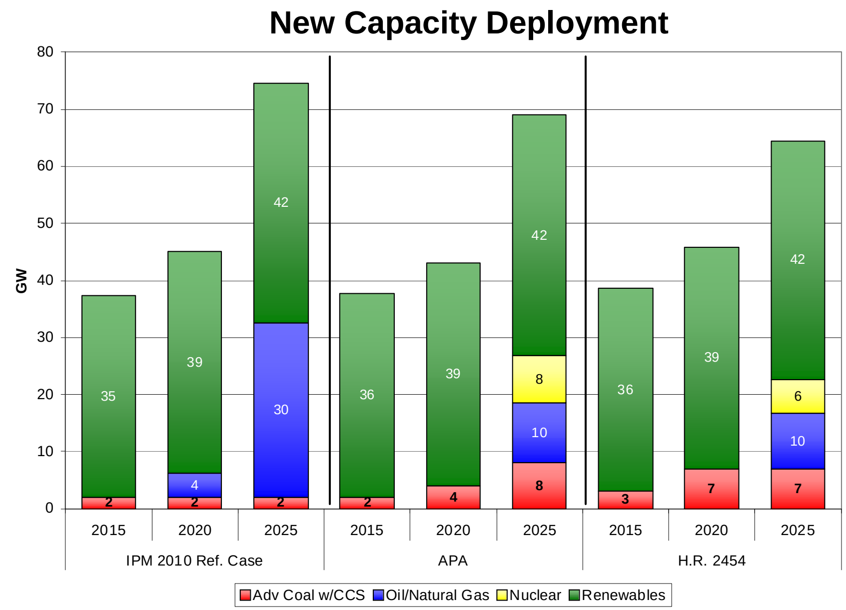




Note: For H.R. 2454, $50/ton was used as the reverse auction clearing price for generation beyond the first 6 GW.

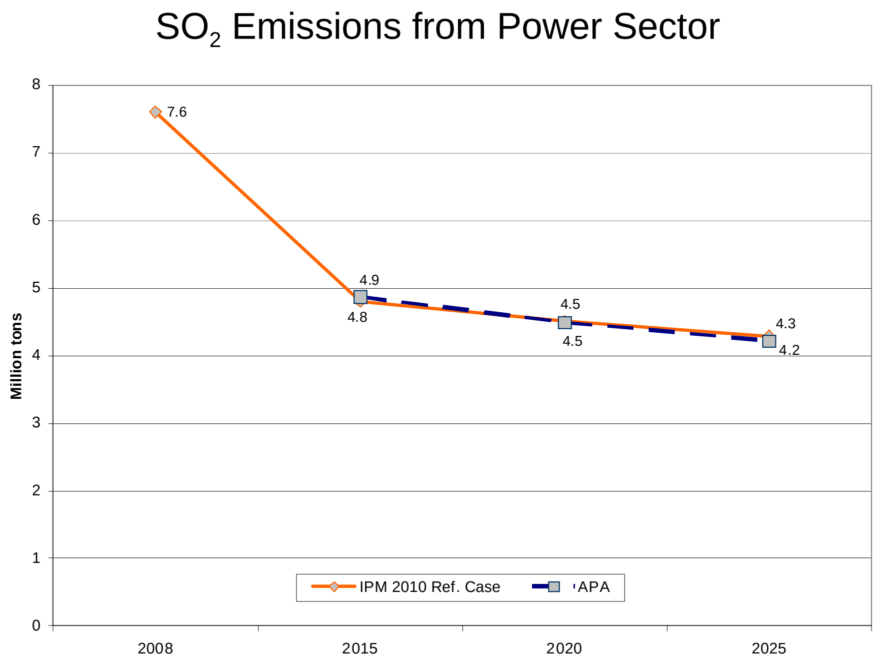
Sensitivity – H.R. 2454 (Scenario 10)

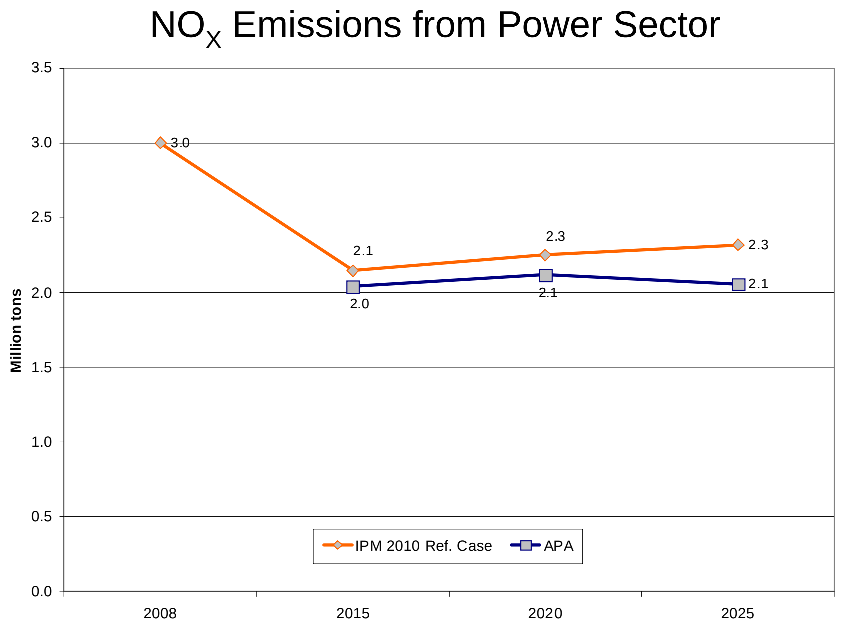




Greater demand response in H.R. 2454 results in lower generation compared to APA and fewer new capacity additions. H.R. 2454 also does not include the additional incentives for new nuclear power that were modeled for APA. In addition, bonus allowance structures and the amount collected from wires charges are different in the two scenarios and affect IPM modeling results.

SO_2 and NO_X Emissions





More Details on Key Updates Included in IPM 2010 Ref. Case

- **Electricity Demand Growth:**
  - EPA uses the AEO 2010 update as the basis for future electricity demand projections for the reference case (roughly 0.85% growth).
- **Cost of New Power Technologies:**
  - The capital charge rate for new coal-fired capacity construction has been increased by 3 percentage points in the reference case – an adjustment that AEO 2009 introduced to reflect the implicit cost being added to GHG-intensive projects to account for additional risk associated with future climate regulation. The adjustment factor was removed in the policy scenarios.
- **Renewable Capacity:**
  - Renewable capacity prior to 2012 is calibrated to the AEO 2010 update, which shows substantially increased near-term renewable deployment in reaction to ARRA's extension and revision of financial incentives such as production and investment tax credits.
- **CCS in Reference Case Projection:**
  - The AEO 2010 forecasts 2 GW of CCS capacity in the reference case for the year 2017. 1 GW is ascribed to the financial incentives for CCS included in the Emergency Economic Stabilization Act of 2008, and 1 GW is added to reflect ARRA 2009 appropriated funding to DOE for CCS deployment.
  - In IPM 2010 Ref. Case, 2017 is included in the results mapped to the reported year 2015, and correspondingly, 2 GW of CCS are reported for 2015 in the reference case analysis.

Note: For more detail on the assumptions used in EPA's application of IPM, please see more detailed documentation for IPM at http://www.epa.gov/airmarkets/progsregs/epa-ipm/index.html.

Key Insights from IPM Results for the Near-Term

- The price of carbon emissions under APA in conjunction with complementary measures (e.g., energy efficiency, technology incentives) leads to reduced electricity demand and a shift towards lower emitting technologies.
  - The electricity demand reduction includes allowance allocations, building energy efficiency codes, and other energy savings.
- The shifts in electricity production away from GHG-intensive facilities are somewhat modest in the shorter-term, due primarily to lower emissions in the baseline, increased capital costs for new power generating technologies, lower allowance prices, additional renewable energy, and lower overall electricity demand.
- The carbon price incurred by various emitting technologies (e.g., coal) does not result in a notable increase in new nuclear plants in the shorter-run, due primarily to large reduction in electricity demand.
- Provisions in APA provide incentives for CCS, nuclear power, and renewables simultaneously which may end up having unintended consequences. The combined effects of these multiple incentives may potentially act against each other, at least in the near-term. In addition, the cumulative impact of such incentives may distort the carbon price signal and raise the total cost of emissions abatement, especially where these incentives displace low-cost energy efficiency improvements. The consequences will have greater impact in the longer term, beyond the time period modeled in IPM.
- Because of considerable uncertainty regarding technology cost and performance, the reverse auction approach for CCS would help determine the appropriate incentive for the technology without over or under incentivizing.

Effects of the Bonus Allowances

- **The bonus allowances for CCS has notable effects on markets**
  - Allowance prices are lower in scenarios that include bonus allowances because the bonus allowances encourage the use of CCS that would otherwise be uneconomic. The carbon reductions provided by these technologies allow the economy to reach a given emission cap at lower prices for carbon allowances.
  - The lower allowance prices, in turn, lead to lower electricity prices largely by limiting the effect of allowance costs on generation costs at fossil-fueled power plants.*
- **The bonus programs are not cost-free**
  - By giving the energy sector incentives to reduce carbon using uneconomic technologies, bonus allowances substitute high-cost for low-cost emission reductions. The net effect is to increase the costs of meeting a given cap.
  - By keeping electricity prices lower than they otherwise would have been, bonus allowances indirectly reduce consumers' incentives for saving energy. Without those energy-saving actions, the total cost of meeting a given emission cap is higher.
  - These inefficiencies lead to "deadweight losses" and are not factored in the power sector modeling.
- **The tendency of bonus allowances to drive up the total costs of meeting the cap could be mitigated or even reversed if the impact on the deployment of CCS led to lower costs for those technologies. That possibility, however, has not been modeled.**

* In competitive markets, lower allowance prices cut electricity prices by reducing marginal generation costs. In cost-of-service areas, lower costs for purchasing allowances keep average generation costs down, and those lower costs are passed on to consumers.

Representation and Effects of the CCS Bonus Allowances and Wires Charges

- Similar to H.R. 2454, APA requires EPA to establish a reverse auction that would yield an appropriate financial incentive to spur deployment of CCS, neither over- or under-incentivizing the technology. A fixed portion of allowances are reserved for incentivizing carbon capture and storage technology.
- In all scenarios, the first 10 GW of CCS capacity receive a $96 per ton bonus and the next 10 GW receive $85 per ton (plus $10 for deployment before 2017), since the bill sets the bonus level for the first 20 GW of CCS deployed.
- A reverse auction bonus allowance value of $50/ ton was used in this analysis. The capacity assumed to be built due to other sources of funding (such as the bill's early deployment provisions) also receives the bonus allowance value. A total of up to 72 GW of capacity is eligible for bonus allowances in this bill.
- The $20 billion in wires charges results in 12 GW of advanced coal with CCS being deployed. Of this, 6 GW are new construction and 6 GW are retrofits of existing facilities which are "hardwired" into IPM.
- There is significant uncertainty with regards to CCS technology availability and cost, thus making it difficult to ascertain the precise level of incentive that will lead to any given level of CCS deployment. The reverse auction approach for CCS bonus allowances is designed to elicit from market participants the minimum per-ton bonus value necessary to incentivize CCS deployment.

Effects of Allocating Allowances to Electricity Local Distribution Companies

- Under lump sum rebate allocation, consumers pay higher electricity rates but receive payments irrespective of their consumption; therefore, the payments do not dampen the price incentive for more efficient use of electricity.
- Where allowance value is rebated to consumers on the basis of quantity consumed, electricity prices will be lower and thus consumption will be higher than would have occurred otherwise. Higher consumption yields higher GHG emissions from the power sector, which means other reductions will be needed that could lead to higher economy-wide allowance prices. EPA is doing additional analysis to examine the extent to which LDC allocation value impacts power prices, emissions, allowance prices, and developments in power sector generation and capacity.
- Note that any evaluation of the impact on consumers must examine electricity prices and total electric power consumption (e.g., monthly bills) together with other costs (e.g., efficiency investments) to get the full picture.

Technology Penetration Limits in ADAGE & IPM

- Feasibility constraints are included in both ADAGE and IPM in order to limit the market penetration of the various electricity generating sources to ensure realistic build patterns in response to CO_2 regulatory policies.
- These limits are imposed on new renewable, nuclear, and coal with CCS technology.
- The limits were determined based upon various factors, including:
  1. Historical deployment patterns
  2. Potential to expand domestic engineering, construction, and manufacturing base
  3. Ability to educate and train workforce (this is particularly true for new coal with CCS and nuclear plants due to the highly technical nature of building these facilities)
- Because new nuclear and new coal with CCS are both complicated technologies that require sophisticated planning, engineering, and construction support, the same engineering/construction firms would be building both of these facilities and there would be a dynamic between the greater resources needed to build one technology relative to the other, in addition to the inherent limitations of increasing the skilled workforce.
  - To reflect this dynamic, EPA has incorporated a technology curve in the models, whereby the amount of new nuclear and coal with CCS is limited but also incorporates a trade-off between each technology (i.e., if you build more of one, you must build less of the other).
  - The amount of each technology that is built is determined in an economic manner, up to the limits.
- CCS retrofits to the existing coal fleet are also limited in IPM and are constrained separately on the assumption that these projects can be handled by smaller and more specialized firms.

Incremental / Cumulative New Capacity Limitations in IPM for Renewables

GW	2015	2020	2025
Wind	30 / 30	45 / 75	65 / 140
Other Renewables	10 / 10	15 / 25	20 / 45
All Renewables	40 / 40	60 / 100	85 / 185

Cumulative New Capacity Limitations in IPM for Nuclear and Coal with CCS*

GW	Nuclear	CCS	OR	Nuclear	CCS	CCS Retrofit
2015	N/A	Hardwire (2 GW, or 4 projects)		N/A	Hardwire (2 GW, or 4 projects)	N/A
2020	12	0		0	27	5
2025	24	0		0	48	13

Note: In addition to the renewable capacity limitations, a 20% cap is set on the amount of electricity generation in a model region that can come from wind.

* Post 2015 new CCS constraints exclude the 2 GW of hardwired capacity. CCS retrofit capacity reflects pre-retrofit capacity (e.g., before CCS parasitic load is taken into account).

Renewable and Transmission Challenges and IPM Modeling Limitations

Challenges to Developing and Integrating Renewables:

- Location: Wind and geothermal generation must be sited where the resources are available, leading to increased need for new transmission capacity. Biomass resource locations and transmission requirements will differ from existing fossil sources.
- Dispatch: Generation from some renewable resources cannot be adjusted ("dispatched") by system operators to meet changes in electrical load, so other sources of electricity are still critical for the power system to meet demand fluctuations.
- Intermittency: Wind and solar resources produce power only when there is sufficient wind or sunlight, so these resources need additional backup sources to meet reliability requirements for adequate capacity. Larger regions can support greater percentages of intermittent resources, but capacity from non-intermittent sources will still be needed.
- Communication and Control: Coupling renewable generation with flexible demand response can help address challenges to dispatch and intermittency. However, further development of a "smart grid" is needed, so that loads can be integrated and coordinated with the generation patterns of renewable resources.

IPM Base Case 2010 Transmission Modeling Limitations:

- Transmission constraints within IPM regions are not modeled.
- Transmission constraints between regions are modeled in IPM, but IPM does not currently attempt to model the construction of new transmission capacity.

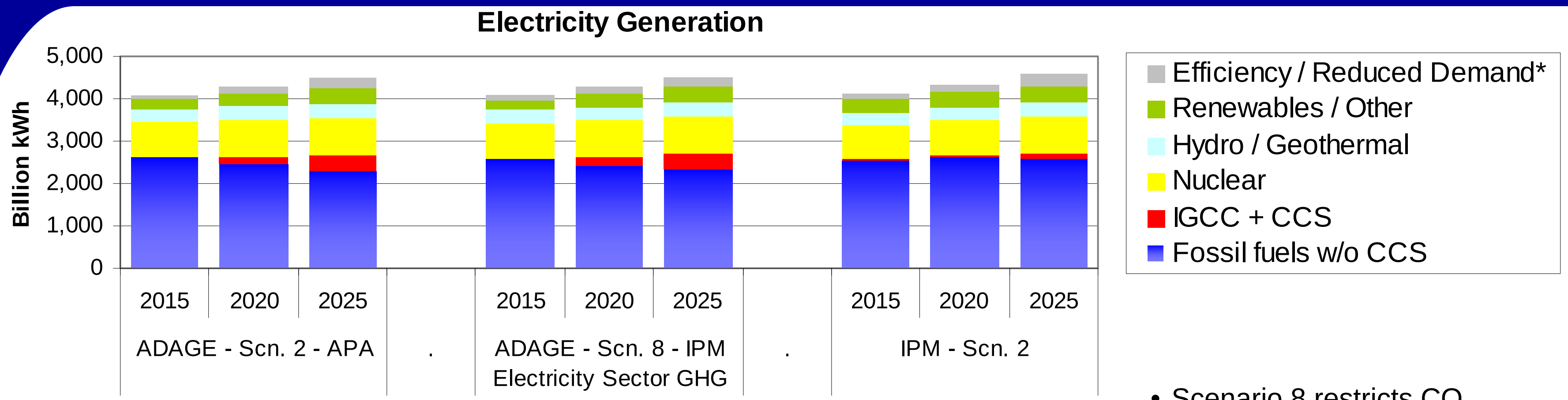
General IPM Modeling Limitations

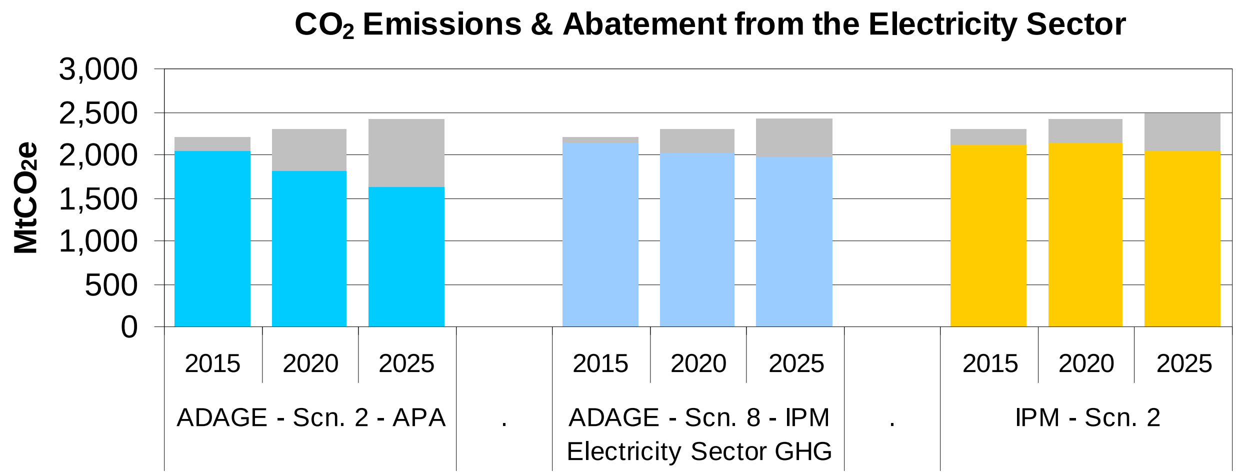
- The EPA version of the IPM model focuses on the near-term impacts and only produces reportable results through 2025.
  - Model does not see longer term changes in electricity demand and CO_2 allowance prices (due to lowering of the cap over the entire timeframe of the bill).
  - This will affect projections for new capacity additions and retrofit decisions in later years.
- EPA's application of IPM does not incorporate several technological innovations that can become available over time (e.g., ultra-supercritical coal, advanced renewables) or enhanced energy efficiency that could lead to demand reductions.
  - The model provides a good sense over the next 15 of how the power sector could operate with expected demand, fuel prices, technologies, and other factors, based on EPA's best information available.
- Geographic deployment, cost, and performance of CCS is highly uncertain and still being developed in EPA's modeling applications.
- Allowance allocation and auctioning are not accounted for in the modeling.
- While IPM endogenously builds new capacity, the model places an exogenous constraint on the total amount of most new capacity builds.
- Non-economic considerations for significant expansion of new coal with CCS, nuclear power, and renewables which are not reflected in IPM include the need for new transmission, siting concerns, and permitting.
- The EPA version of the IPM model assumes a 60 year life for nuclear power plants.
  - In IPM, only inputs and assumptions that are "on the books“ are included for modeling
  - Authorities are yet to start figuring out the permit/extension requirements beyond 60 years. It will remain uncertain at least for another decade what the requirements for extension are going to be.
  - The ability to test reactor vessels seems to have engineering challenges
  - This assumption does not affect the near-term IPM modeling, but does have implications for the longer-term ADAGE modeling

Interpreting IPM Findings within ADAGE

- The IPM model projects policy-responsive decision-making at a much finer scale within the power sector, while the ADAGE model projects much broader multi-sector responses that bring the entire economy into equilibrium with the greenhouse gas emissions cap.
  – IPM uses the allowance price and electricity demand-response from ADAGE so that its findings are consistent with the overarching economic equilibrium conditions.
  – IPM's projections may be consistent with ADAGE's equilibrium even though specific findings from IPM do not necessarily "replicate" ADAGE's profile of the power sector.
- IPM projects fewer emission reductions from the power sector than ADAGE projects for the years 2012-2025.
  – IPM findings are consistent with the equilibrium allowance price modeled by ADAGE. The allowance price projected by ADAGE is not set specifically by the near-term mitigation potential from any single sector. Instead, it reflects cumulative abatement supply and demand from all sectors through 2050. Part of the near term behavior of the power sector in the ADAGE model is motivated by higher prices in years past the end of the IPM time horizon.
  – In order to test the sensitivity of ADAGE's long-term equilibrium projection to IPM's detailed representation of near-term power sector mitigation, a separate scenario was run in ADAGE that approximated power sector emissions from IPM's core policy scenario (see next slide).

ADAGE Scenario with IPM Power Sector Abatement





- Scenario 8 restricts CO_2 abatement in the electricity sector in ADAGE to the levels achieved in IPM by adjusting elasticities related to energy efficiency improvements and fuel switching and the depreciation rate of the existing capital in the electricity sector.
- Allowance prices in scenario 12 are 18% higher than in scenario 8 and international offsets usage increases by 7%.

Appendix 7: 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 five 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 documented in: U.S. EPA, 2009. *Updated Forestry and Agriculture Marginal Abatement Cost Curves*. Memorandum to John Conti, EIA, March 31, 2009.
- 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

Global Climate Assessment Model (GCAM)

- GCAM (formerly known as 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 was also used in the development of the Regional Greenhouse Gas Initiative (RGGI).
- 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

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This analysis is available online at:
www.epa.gov/climatechange/economics/economicanalyses.html