U.S. Environmental Protection Agency
Office of Atmospheric Programs

Supplemental EPA Analysis of the American Clean Energy and Security Act of 2009

H.R. 2454 in the 111th Congress

Appendix

1/29/10

Appendix 1: Bill Summary, Modeling Approach and Limitations

H.R. 2454 – Bill Summary
Title I

- *Title I – Clean Energy*
  - *Subtitle A* - Combined Efficiency and Renewable Electricity Standard
    - Sec. 101 requires utilities that sell more than 4 million megawatt hours of electricity to consumers to meet a certain percentage (6% in 2012 rising to 20% in 2020) of their load electricity generated from renewable resources and energy savings. Up to one quarter (or two-fifths upon petition) of the requirement can be met with energy savings.
      - This provision is modeled in IPM. In ADAGE, the energy savings portion of the RES is modeled, but not the renewable electricity portion. IGEM does not model this provision.
  - *Subtitle B* - Carbon Capture and Sequestration
    - Sec. 114 creates a Carbon Capture and Sequestration (CCS) demonstration early deployment program.
      - This provision is modeled in IPM, but not in ADAGE or IGEM.
    - Sec. 115 promotes the commercial deployment of CCS technologies through a bonus allowance program.
      - This provision in modeled in ADAGE, IGEM, and IPM.
  - *Subtitle C* - Clean Transportation
  - *Subtitle D* - State Energy and Environmental Deployment Accounts
    - Sec. 131 establishes SEED Accounts to serve as a state-level repository for managing and accounting for all emissions allowances designated primarily for renewable energy and energy efficiency purposes.
    - Sec. 132 distributes emission allowances among states for energy efficiency and renewable energy deployment and manufacturing support.
      - The energy efficiency portions of Sec 131 and 132 are modeled in ADAGE and IPM, but not in IGEM.
  - *Subtitle E* - Smart Grid Advancement
  - *Subtitle F* - Transmission Planning
  - *Subtitle G* - Technical Corrections to Energy Laws
  - *Subtitle H* - Energy and Efficiency Centers
  - *Subtitle I* - Nuclear and Advanced Technologies
  - *Subtitle J* - Miscellaneous

- Title I, Subtitles C, E, F, G, H, I, and J are not modeled in this analysis.

H.R. 2454 – Bill Summary
Title II

- *Title II – Energy Efficiency*
  - *Subtitle A* - Building Energy Efficiency Programs
    - Sec. 201 establishes energy efficiency targets of 30% reduction below 2006 IECC by enactment, 50% reductions by Jan 1, 2014 (residential) and 2015 (commercial) and increasing 5% every three years thereafter until 2029 (residential) and (commercial)
      - This provision is modeled in ADAGE. IGEM does not model this provision.
    - Sec. 202 establishes the Retrofit for Energy and Environmental Performance (REEP) program for residential buildings, and another for commercial, funded by allowances, to provide loans certification, and other support
      - This provision is modeled in ADAGE. IGEM does not model this provision.
    - Sec 203 assistance for homeowners living in manufactured homes built before 1976 to purchase new energy efficient manufactured homes
      - This provision is modeled in ADAGE. IGEM does not model this provision.
    - Sec 204 creates a building energy performance labeling program
      - This provision is modeled in ADAGE. IGEM does not model this provision.
  - *Subtitle B* - Lighting and Appliance Energy Efficiency Programs
  - *Subtitle C* - Transportation Efficiency
  - *Subtitle D* - Industrial Energy Efficiency Programs
  - *Subtitle E* - Improvements in Energy Savings Performance Contracting
  - *Subtitle F* - Public Institutions
  - *Subtitle G* - Miscellaneous

- Title II, Subtitles B, C, D, E, F, and G are not modeled in this analysis.

H.R. 2454 – Bill Summary
Title III

- *Title III – Reducing Global Warming*
- Amends the Clean Air Act by adding "*Title VII – Global Warming Pollution Reduction Program*" that establishes a cap and trade system for greenhouse gases.
  - These provisions are included in this analysis unless otherwise noted
  - Economy-wide coverage phased in over time:
    - All electricity sources
    - Refiners/importers of petroleum with sales/distribution greater than 25kT CO_2e
    - Producers and importers of CO_2, N_2O, PFCs, SF_6, or other designated gases in amounts greater than 25kT CO_2e
    - Any stationary source (any size) in 13 special sectors incl. adipic acid, primary aluminum, ammonia, cement, HFCs, lime, nitric acid, petroleum refining, phosphoric acid, silica carbide, soda ash, titanium dioxide, coal-based liquids or gaseous fuels.
    - Industrial sources larger than 25kT CO2e
    - LDCs for gas which deliver more than 460mcf of gas (~25kT CO2e)
    - Propane (Industrial sector phases in: 2014, Residential, industrial and commercial natural gas users served by LDCs phase in: 2016)
    - Based on EPA's 2008 *Inventory of US Greenhouse Gas Emissions and Sinks* covered emissions represent approximately the following percentages of total US GHG emissions
      - 68% in Phase 1 (2012 – 2013)
      - 76% in Phase 2 (2014 – 2015)
      - 85% in Phase 3 (2016 – 2050)
  - GHG emission targets for covered sectors (targets decline in each calendar year):
    - 2012: 4,627 MtCO_2e (3% below 2005 emissions levels for covered sectors)
    - 2020: 5,056 MtCO_2e (17% below 2005 emissions levels for covered sectors)
    - 2030: 3,533 MtCO_2e (42% below 2005 emissions levels for covered sectors)
    - 2050: 1,035 MtCO_2e (83% below 2005 emissions levels for covered sectors)

H.R. 2454 – Bill Summary
Title III (continued)

- *Title III – Reducing Global Warming (Continued)*
  - Banking of allowances is unlimited, a two year compliance period allows borrowing from one year ahead without penalty, limited borrowing from two to five years ahead.
  - Offsets are limited to 2,000 $MtCO_2e$ per year split evenly between domestic and international.*
  - Offsets discounting requires entities using international offsets to submit 1.25 tons of offsets credits for each ton of emissions being offset after the first five years.
  - Supplemental emissions reductions from reduced deforestation
  - Strategic Reserve Allowances (Not modeled in this analysis)
    - Reserves allowances from the cap for the purpose of reducing price volatility
      - 2012 - 2019: 1% of allowances reserved
      - 2020 - 2029: 2% of allowances reserved
      - 2030 - 2050: 3% of allowances reserved
    - Reserve allowances auctioned off with a minimum strategic reserve allowance price that starts at twice the EPA modeled allowance price in 2012 growing at a real rate of 5 percent through 2014. In subsequent years, the minimum price is 100 percent above the rolling 36 month average price of that year's allowance vintage.
    - The models used in this analysis do not include price volatility, so the modeled price will never rise above the minimum strategic reserve allowance price. For this reason, the strategic reserve allowance has not been included in this analysis (i.e., the allowances are available for use, not reserved from the total cap).

- Amends the Clean Air Act by adding "*Title VIII – Additional Greenhouse Gas Standards*"
  - These provisions are not modeled in this analysis
    - Stationary source standards
    - Separate cap and trade system for HFCs
    - Black carbon provisions

* See appendix 2 for a discussion of how the pro rata sharing specified in Sec 722 (d) alters these limits.

H.R. 2454 – Bill Summary
Title IV

- Title IV addresses competitiveness issues and the transition to a clean energy economy. The only part of Title IV modeled here is *Subtitle A – Part 1*.

- *Title IV – Transition to a Clean Energy Economy*
  - *Subtitle A* - Ensuring Domestic Competitiveness
    - Part 1 - Preserving Domestic Competitiveness
      - Based on H.R. 7146 (Inslee / Doyle)
      - Applies to energy- or greenhouse gas-intensive industries that are also trade-intensive
      - Rebates 100 percent of the direct and indirect cost of allowances to eligible industries
      - Gradually phases out between 2025 and 2035.
    - Part 2 - International Reserve Allowance Program
      - Only applies if the President finds that direct and indirect compliance costs after being mitigated by the rebates provided in part 1 adversely impact production, jobs, or greenhouse gas emissions leakage
  - *Subtitle B* - Green Jobs and Worker Transition
  - *Subtitle C* - Consumer Assistance
  - *Subtitle D* - Exporting Clean Technology
  - *Subtitle E* - Adapting to Climate Change

H.R. 2454 – Bill Summary
Allowance Allocations

- Sec. 782 includes the following allocation of allowances, which were modeled in IGEM:
  - Electricity consumers: 43.75% in 2012, declining to 7% by 2029
  - Natural gas consumers: 9% beginning in 2016, declining to 1.8% in 2029
  - Heating oil and propane consumers: 1.875% in 2012, declining to 0.3% in 2029
  - CCS Bonus Allowances: 2% from 2014-2017; 5% from 2018-2050
  - International Forest Carbon: 5% through 2025, 3% through 2030, 2% through 2050
  - Energy Efficiency: 9.5% from 2012-2015, declining to 4.5% from 2026-2050
  - Clean vehicle technology: 3% from 2012-2017, 1% from 2018-2025
  - Domestic refiners: 2% from 2014-2026
  - International adaptation: 1% from 2012-2021, rising to 4% from 2027-2050
  - International clean technology deployment: 1% from 2012-2021, rising to 4% from 2027-2050
  - Output-Based Rebate: 15% through 2025, declines thereafter at 10% per year to phase out by 2035.
  - Necessary allowances for deficit neutrality
  - Remaining allowance value is recycled to households lump sum

- Sec 782 also includes the following allocations, not modeled in IGEM:
  - Low-income consumers: 15% from 2012-2050 (auctioned with revenue returned through Title IV C)
  - Trade-vulnerable industries: 2% in 2012, 2013, 15% in 2014, declining through 2050
  - Clean energy innovation centers: 1% from 2012-2050
  - investment in workers: 0.5% from 2012- 2021, 1% from 2022-2050
  - Domestic adaptation: 0.9% from 2012-2021, rising to 3.9% through 2050
  - Climate change health protection and promotion fund: 0.1% from 2012-2050
  - Wildlife and natural resource adaptation: 1% from 2012-2021, rising to 4% from 2027-2050

H.R. 2454 – Bill Summary
Strategic Reserve

- Strategic Reserve Allowances (Not modeled in this analysis)
  - Reserves allowances from the cap for the purpose of reducing price volatility
    - 2012 - 2019: 1% of allowances reserved
    - 2020 - 2029: 2% of allowances reserved
    - 2030 - 2050: 3% of allowances reserved
  - Reserve allowances auctioned off with a minimum strategic reserve allowance price that starts at $28 in 2012 growing at a real rate of 5 percent through 2014. In subsequent years, the minimum price is 60 percent above the rolling 36 month average price of that year's allowance vintage.
  - In 2012 – 2016, the number of allowances from the strategic reserve that may be auctioned equals 5% of the total allowances established for each year during that period. In 2017 and beyond, maximum 10% of the total allowances for each calendar year may be released into the strategic reserve.
  - Proceeds from the strategic reserve auction are deposited into a Strategic Reserve Fund, used to buy international offset credits which are then retired. New allowances equal to 80% of the number of international offset credits are established and deposited into the Strategic Reserve Fund.
  - Offsets can be bought, sold, traded, etc. as part of the Strategic Reserve Auction after the allowances for one particular year in the Reserve are sold.
  - Allowance value used for the strategic reserve is distributed proportionately among all allowance value categories.

- The models used in this analysis do not include price volatility, so the modeled price will never rise above the rolling 36 month average used to set the minimum strategic reserve allowance price.
- For this reason, the strategic reserve allowance has not been included in this analysis (i.e., the allowances are available for use, not reserved from the total cap).
- If the strategic reserve were included in the modeling, the allowances deposited in the reserve would never be released, in effect tightening the cap. In IGEM, this would result in a 1% increase in the allowance price and an 8% increase in international offsets usage.

Analytical Scenarios

Reference and Core Policy Scenarios

EPA's June 23, 2009 analysis of H.R. 2454 included 7 scenarios. This analysis includes 13 additional scenarios. 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. These scenarios do not account for the American Recovery and Reinvestment Act, which could further advance the deployment of clean energy technologies.

Scenario 1 - EPA 2009 Reference

- This reference scenario is benchmarked to the AEO 2009 forecast (March release) and includes EISA but not ARRA.
  - Identical to the reference scenario used for EPA's June 23, 2009 analysis of H.R. 2454.
  - Does not include any additional domestic or international climate policies or measures to reduce international GHG emissions
  - For domestic projections, benchmarked to AEO 2009 (March release) without the American Recovery and Reinvestment Act of 2009 (ARRA).
  - Does not include the proposed federal greenhouse gas and fuel economy program for passenger cars, light-duty trucks, and medium-duty passenger vehicles.
  - For international projections, used CCSP Synthesis and Assessment Report 2.1 A MiniCAM Reference.

Scenario 8 – Updated H.R. 2454

- This core policy scenario models the cap-and-trade program established in Title III of H.R. 2454.
  - The strategic allowance reserve is not modeled (i.e., these allowances are assumed to be available for use and not held in reserve).
- 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 (Inslee-Doyle)
  - 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 8 unless specified.

Technology and offset sensitivities requested by Senator Voinovich

- **Scenario 9 – V – No Int'l Offsets**
  - International offsets are not allowed or available.
- **Scenario 10 – 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 11 – 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 12 – 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.

Analytical Scenarios

Sensitivity Scenarios

In the following scenarios all assumptions are identical to scenario 8 unless specified.

Cap sensitivities

- **Scenario 13 – 20% 2020 Cap**
  - The 2020 cap is changed from a 17% reduction below 2005 covered emissions to a 20% reduction.
  - The 2012, 2030, and 2050 reduction targets remain the same.
  - Cap levels are reduced in the years 2013 – 2029.

- **Scenario 14 – 14% 2020 Cap**
  - The 2020 cap is changed from a 17% reduction below 2005 covered emissions to a 14% reduction.
  - The 2012, 2030, and 2050 reduction targets remain the same.
  - Cap levels are increased in the years 2013 – 2029.

Energy efficiency provision sensitivity

- **Scenario 15 – Updated H.R. 2454 scenario w/o energy efficiency provisions**
  - Removes the energy efficiency provisions included in scenario 8 (allowance allocations, building energy efficiency codes, and energy efficiency standard component of CERES).

Allocation sensitivity

- **Scenario 16 – Revenue recycling to reduce labor taxes**
  - All allowances that modeled as being returned to households lump sum in Scenario 2 are instead auctioned and the revenue used to reduce taxes on labor.

Analytical Scenarios

Sensitivity Scenarios

In the following scenarios all assumptions are identical to scenario 8 unless specified.

International action sensitivities:

- **Scenario 17 – 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 18 – 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 8 unless specified. These scenarios were run with the reduced form IGEM model, which only provides a limited set of outputs.

Technology and offset sensitivities:

- **Scenario 9a – H.R. 2454 with International Offsets Delayed 10 Years**
  - U.S. covered entities are not allowed to purchase international offsets for the first 10 years.
- **Scenario 9b – H.R. 2454 with International Offsets Delayed 20 Years**
  - U.S. covered entities are not allowed to purchase international offsets for the first 20 years.
- **Scenario 9c – H.R. 2454 with No International REDD Offsets**
  - No reduced emissions from deforestation and degradation (REDD) offsets for the U.S. or for any other country.
- **Scenario 9d – H.R. 2454 with No Domestic Offsets**
  - U.S. covered entities are not allowed to use domestic offsets.
- **Scenario 9e – H.R. 2454 with No Offsets**
  - U.S. covered entities are not allowed to use domestic or international offsets.

Analytical Scenarios

Sensitivity Scenarios

In the following scenarios all assumptions are identical to scenario 8 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 8a – Alternative (EMF) International Reference Emissions**
  - For the purpose of analyzing the international offset market, international reference emissions are based on the GCAM Energy Modeling Forum 22 reference scenario, instead of the CCSP SAP 2.1a GCAM reference scenario.
- **Scenario 8b – 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 8c – Terminal Bank**
  - All countries are required to hold a terminal bank of allowances in 2050.
- **Scenario 8d – MIT International Assumptions**
  - International policy assumptions are based on those used in the 2007 MIT report, “Assessment of U.S. Cap-and-Trade Proposals.”
    - Group 1 countries (Kyoto group less Russia) follow an allowance path that is falling gradually from the simulated Kyoto emissions levels in 2012 to 50% below 1990 in 2050.
    - Group 2 countries (rest of world) adopt a policy beginning in 2025 that returns and holds them at year 2015 emissions levels through 2034, and then returns and maintains them at 2000 emissions levels from 2035 to 2050.

Modeling Approach

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

Modeling Approach

Reference Calibration and Composition of GDP (IGEM)

- In IGEM's AEO 2009 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 2009 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 2009 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 2009 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 H.R. 2454 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.
  - Very few CGE models are capable of computing confidence intervals, so this limitation is currently shared with virtually all CGE models.
  - The use of two CGE models provides a range for many of the key results of this analysis; however, this range should not be interpreted as a confidence interval.
  - Alternate scenarios are presented to provided sensitivities on a few of the key determinants of the modeled costs of H.R. 2454.
- The CGE modeling approach generally does not allow for a detailed representation of technologies.
  - While ADAGE does represent different 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), which is a bottom-up model of the electricity sector.
  - The CGE models do not explicitly model new developments in transportation technologies. These reductions occur as households alter their demand for motor gasoline and through broad representations of improvements in motor vehicle fuel efficiency.
  - The CGE models do not explicitly represent end-use efficiency technologies.
- The time horizon of the CGE models, while long from an economic perspective, is short from a climate perspective.
- CGE models represent emissions of GHGs, but cannot capture the impact that changes in emissions have on global GHG concentrations.
  - In previous analyses, EPA has used the Mini-Climate Assessment Model (MiniCAM) to supplement to provide information on how S. 2191, S. 1766, and S. 280 affect CO_2 concentrations throughout the 21^{st} century. These analyses are available at http://www.epa.gov/climatechange/economics/economicanalyses.html.
- None of the models used in this analysis currently represent the benefits of GHG abatement.
- Using sectoral models to construct offset curves limits 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 H.R. 2454 (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 Group 2 countries. As a result of H.R. 2454, the prices of U.S. exports rise relative to prices in the rest of the world, and export volumes fall. Since exports are price-elastic the volumes fall proportionally more than the price rises and thus the value of exports declines. Imports are reduced in part by the overall reduction in spending associated with the lower levels of consumption. Additionally, commodities directly affected by the emissions cap (e.g. oil) are reduced proportionally more than other imports due to the allowance prices embodied in their cost. Import substitution counterbalances the two forces above. U.S. prices of commodities not directly affected by the policy are relatively higher, which leads to substitution away from domestically produced goods and towards imported goods. To the extent that policies in Group 1 and Group 2 countries increase world prices of affected commodities, the relative price difference between goods produced in the U.S. and goods produced abroad will be lessened. This will reduce impact on exports, and reduce the import substitution effect, both of which are driven by the relative price differential.
- ADAGE is a global model that does represent the emissions leakage associated with H.R. 2454.
  - The assumed climate policies in Group 1 and Group 2 countries are explicitly represented in ADAGE, and thus affect world prices. As a result, the relative price differences between goods produced domestically and abroad are smaller than the differences in IGEM, and thus the relative price-driven changes in imports and exports are smaller in ADAGE than in IGEM.

* Emissions leakage occurs when a domestic GHG policy causes a relative price differential between domestically produced and imported goods. This causes domestic production, which embodies the GHG allowance price to shift abroad, and thus an increase in GHG emissions in other countries. Additionally, emissions leakage not associated with trade effects may occur when a GHG policy reduces domestic consumption of oil, lower demand for oil lowers the world oil price, which increases oil consumption in countries without a GHG policy thus increasing emissions.

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 for other purposes 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, which implies 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.

Peer Review

- Over the past two years, EPA has analyzed the economic impacts of three GHG cap & trade bills at the request of Members of Congress: S. 280 (McCain-Lieberman), S. 1766 (Bingaman-Specter), and S. 2191 (Lieberman-Warner).
- 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 the researchers who developed it.
  - 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 initiated an updated outside experts-based peer review of IGEM that will be completed in early 2010.

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 forthcoming 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 initiated an updated outside experts-based peer review of ADAGE that will be completed in early 2010.

- IPM
  - Periodic formal peer review of IPM includes separate expert panels on the model itself, and 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.

    - Adams, R.M., S.A. Hamilton, and B.A. McCarl. September 1984. "The Economic Effects of Ozone on Agriculture." *Research Monograph*. EPA/600-3-84-90. Corvallis, OR: USEPA, Office of Research and Development.
    - Adams, R.M., D.M. Adams, J.M. Callaway, C.C. Chang, and B.A. McCarl. 1993. "Sequestering Carbon on Agricultural Land: Social Cost and Impacts on Timber Markets." *Contemporary Policy Issues* 11:76-87
    - Chang, C.C., J.D. Atwood, K. Alt, and B.A. McCarl. 1994. "Economic Impacts of Erosion Management Measures in Coastal Drainage Basins." *Journal of Soil and Water Conservation* 49(6):606-611
    - Reilly**,** J., F. Tubiello, B. McCarl, and J. Melillo. 2000. "Climate Change and Agriculture in the United States." In *Climate Change Impacts on the United States: The Potential Consequences of Climate Variability and Change*, pp. 379-403. Report for the U.S. Global Change Research Program. New York: Cambridge University Press.
    - USEPA, 2005. Greenhouse Gas Mitigation Potential in U.S. Forestry and Agriculture, U.S. Environmental Protection Agency, EPA 430-R-05-006, Washington D.C., November 2005.
    - USEPA, 2007. "EPA S.280 mitigation cost schedules for capped sectors and domestic and international offsets." *EPA memo to the Energy Information Administration (EIA), March 2007.* Available at: www.epa.gov/climatechange/economics/economicanalyses.html.

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 behavior of employee-shareholders do not vary by industry, the initial allocation of allowances to different industries does not affect estimated model outcomes.
- In this analysis we assume that the policy is deficit neutral, which implies that the market outcomes are invariant to the auction/allocation split.
  - Private sector revenues from allocated allowances accrue to employee-shareholder households, and the government adjusts taxes lump sum to maintain deficit and spending levels.
  - Allowance auction revenues flow to the U.S. government, and are redistributed to households lump sum to the extent that deficit and spending levels are maintained. If auction revenues were directed to special funds instead of returned directly to households as modeled, the reduction in household annual consumption and GDP would be greater. If the auction revenues were instead used to lower distortionary taxes, the costs of the policy would be lower.

Revenue Recycling Issues

- 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 for other purposes 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).
    - 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

- Since emissions allowances are valuable assets, differing allowance allocation schemes can have differing equity implications.
- Equity considerations can justify allocating allowances to (or directing allowance auction revenue to) those who ultimately bear the cost of abatement.
- Who bears the ultimate burden of the costs of abatement is not determined by who is required to hold allowances (or 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 can create a windfall gain for those entities as they receive a valuable asset and pass the costs associated with abatement downstream to consumers.
  - 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 can, in some cases, raises costs.
  - E.g. allocating allowances based on the average number of production employees employed at a facility acts as a distortionary subsidy for labor.

Allowance Allocation Issues (continued)

- Distortions may also occur with tax interaction effects with labor, indirectly reducing the labor supply by increasing the distortionary effect of income taxes. (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 allocation based on a generation performance standard acts as a generation subsidy and increases overall costs compared with allocation through auction.

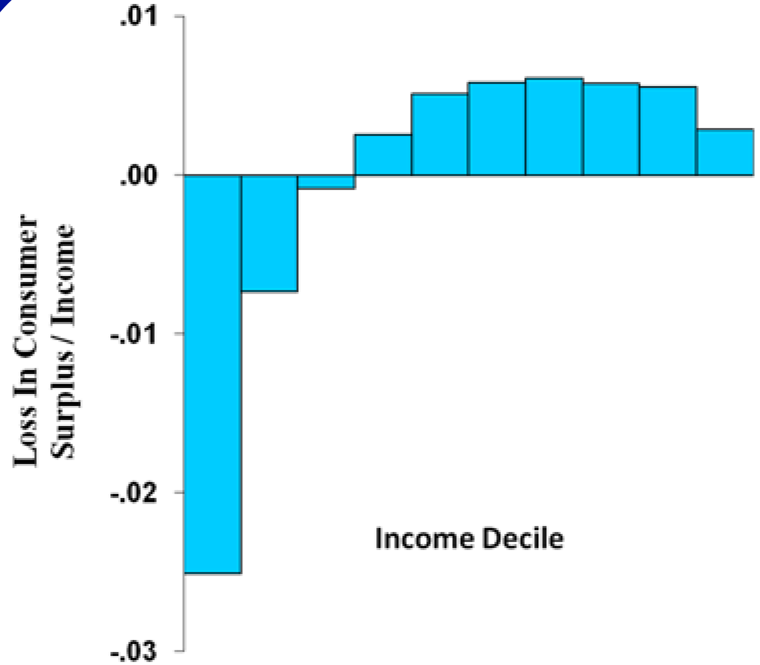
  – Fischer, Kerr, and Toman (1998) discuss the types of risk associated with different allocation systems. They note that "external" risk (e.g. changes in caps due to international agreements or improved climate science) should be borne by the emitter while "internal" risk (e.g. political or revenue based 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 allocation mechanism impacts the price of electricity, consumption, and mix of production technologies. Additionally, they show that the regional nature of the system will allow for leakage, creating profit for firms outside the region.

Near Term Incidence Analysis

Scenario 10: Reference Nuclear & Biomass/Delayed CCS

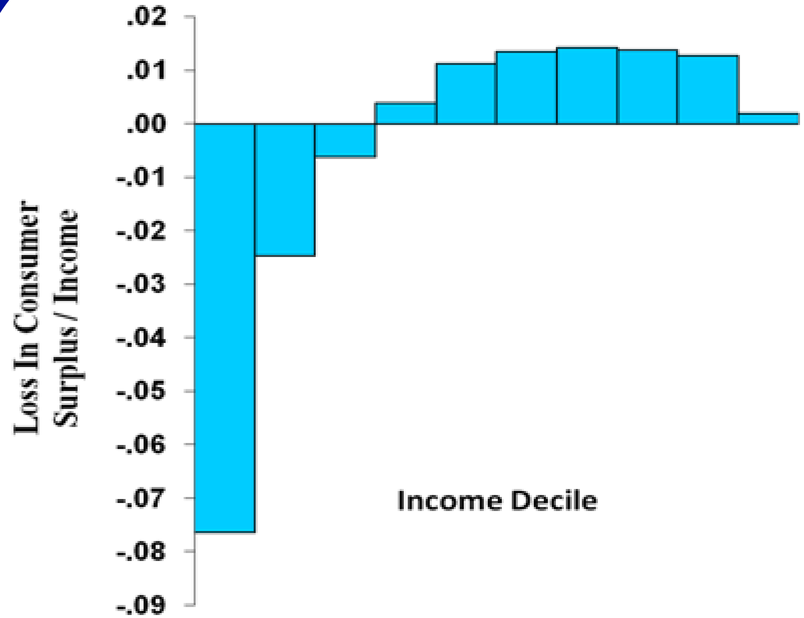


Income Decile	Average Income (2006$)	Scn. 8 Loss Per Household (2006$)	Scn. 10 Loss Per Household (2006$)
1 (lowest)	$7,200	-$160	-$179
2	$15,500	-$102	-$113
3	$23,200	-$19	-$19
4	$31,200	$69	$81
5	$39,700	$177	$203
6	$49,800	$254	$290
7	$61,700	$329	$376
8	$77,200	$394	$449
9	$100,600	$492	$560
10 (highest)	$179,400	$465	$521
Average	$58,500	$190	$217

- For this analysis, sectoral emissions in the incidence model are calibrated to the results from ADAGE Scenario 10, as are welfare costs in each sector implied by marginal abatement cost curves approximated from ADAGE results.
- The allocation of allowance value is the same as was assumed for Scenario 8 as described in the analysis in the main slides.
- Relative to Scenario 8, the cost of the rule to the average household is higher. However, the distribution of the impact of the rule follows a pattern similar to Scenario 8, but with greater magnitude for all income deciles.

Near Term Incidence Analysis

Scenario 11: Reference Nuclear & Biomass/Delayed CCS – No Int'l Offsets



Income Decile	Average Income (2006$)	Scn. 8 Loss Per Household (2006$)	Scn. 11 Loss Per Household (2006$)
1 (lowest)	$7,200	-$160	-$547
2	$15,500	-$102	-$381
3	$23,200	-$19	-$141
4	$31,200	$69	$124
5	$39,700	$177	$449
6	$49,800	$254	$671
7	$61,700	$329	$883
8	$77,200	$394	$1,065
9	$100,600	$492	$1,285
10 (highest)	$179,400	$465	$360
Average	$58,500	$190	$377

- For this analysis, sectoral emissions in the incidence model are calibrated to the results from ADAGE Scenario 11, as are welfare costs in each sector implied by marginal abatement cost curves approximated from ADAGE results.
- The allocation of allowance value is the same as was assumed for Scenario 8 as described in the analysis in the main slides.
- Relative to Scenario 8, the cost of the rule to the average household is higher.(note change in scale of vertical axis). However, the distribution of the impact of the rule follows a pattern similar to Scenario 8, but with greater magnitude for all income deciles. Lower income households are better off than in Scenario 8 because the allowance price has risen and 15% of the allocation is provided to them.
- The assumption of similar budget shares to 2006 consumption levels is a particularly important assumption for this scenario. A high allowance price will result in more significant shifts in activity across the economy and in the processes used to produce many goods. Both of these effects will influence the relative prices of goods, and thus may influence the distributional burden of the policy.

References

Bovenberg, A.L., and L.H. Goulder. 2001. Neutralizing the Adverse Industry Impacts of CO_2 Abatement Policies: What Does It Cost? In *Behavioral and Distributional Effects of Environmental Policies*, edited by C. Carraro and G. Metcalf. Chicago: University of Chicago Press.

Burtraw, D., D. Kahn, and K. Palmer. 2005. CO_2 Allowance Allocation in the Regional Greenhouse Gas Initiative and the Effect on Electricity Investors. Washington, D.C. RFF Discussion Paper No. 05-55.

Burtraw, D., K. Palmer, R. Bharvirkar, and A. Paul. 2001. The Effect of Allowance Allocation on the Cost of Carbon Emissions Trading. Washington, D.C. RFF Discussion Paper 01-30.

Congressional Budget Office (CBO). 2007. *Trade-Offs in Allocating Allowances for CO_2 Emissions*, April 25, 2007.

Fischer, C. 2004a. *Emission pricing, spillovers, and public investment in environmentally friendly technologies*. Washington, DC: Resources for the Future.

Fischer, C., and R. Newell. 2005. *Environmental and Technology Policies for Climate Mitigation*, working paper. Washington: Resources for the Future.

Fischer, C., M. A. Toman, and S. Kerr, 1998. Using Emissions Trading to Regulate U.S. Greenhouse Gas Emissions: An Overview of Policy Design and Implementation Issues. *National Tax Journal*, vol. 51, no. 3: 453-464.

Goulder, L.H., and W. Pizer. The Economics of Climate Change in Lawrence Blume and Steven Durlauf, eds., *The New Palgrave Dictionary of Economics*, Palgrave MacMillan, Ltd., forthcoming.

References (continued)

Harberger, A.C. 1962. The incidence of the Corporation Income Tax. *Journal of Political Economy* 96: 339-57.

Jorgenson, D.W., R.J. Goettle, P.J. Wilcoxen, and M.S. Ho. 2000. The Role of Substitution in Understanding the Costs of Climate Change Policy. *Pew Center on Global Climate Change*. http://www.pewclimate.org/projects/substitution.pdf

Kotlikof, L.J., and L.H. Summers. 1987. Tax Incidence in *Handbook of Public Economics*, vol. 2, chap. 15. Amsterdam: Elsevier Science Publishers.

Murray, B. C., W. N. Thurman, and A. Keeler. 2000. Adjusting for Tax Interaction Effects in the Economic Analysis of Environmental Regulation: Some Practical Considerations. U.S. E.P.A. White Paper. http://www.epa.gov/ttnecas1/workingpapers/tie.pdf

Parry, I., and A.M. Bento. 2000. Tax Deductions, Environmental Policy, and the 'Double Dividend' Hypothesis. *Journal of Environmental Economics and Management*, vol. 39, no. 1, pp. 67-95.

Neuhoff, K., M. Grubb, and K. Keats. 2005. Impact of the Allowance Allocation on Prices and Efficiency. CWPE 0552 *and* EPRG 08.Parry, I., and W.E. Oates. 2000. Policy Analysis in the Presence of Distorting Taxes. *Journal of Policy Analysis and Management* 19:603-614.

Paltsev, S., Reilly, J., Jacoby H., Gurgel, A., Metcalf, G., Sokolov, A., and J. Holak, 2007. Assessment of U.S. Cap-and-Trade Proposals. *MIT Joint Program on the Science and Policy of Global Change*. Report No. 146.

Schneider, S.H., and L.H. Goulder, 1997. *Achieving low-cost emissions targets*. Nature 389, September.

Appendix 3: Additional Information on Offsets Usage & Limits

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.

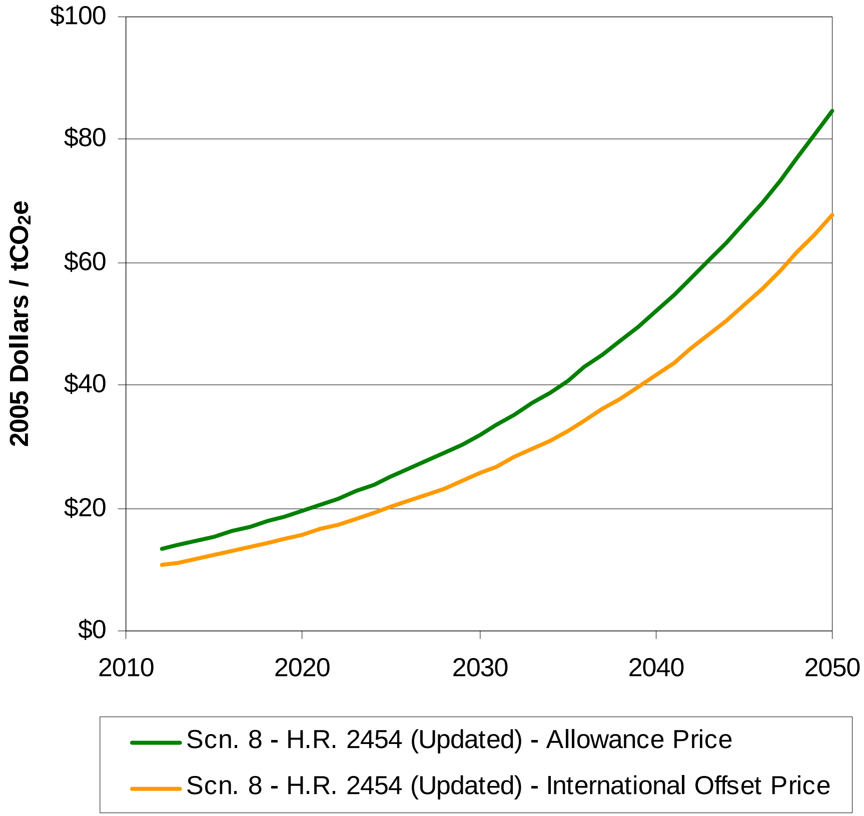
H.R. 2454 Offsets Provisions

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)



- H.R. 2454 limits the use of domestic and international offsets; however, in '*scenario 8 – Updated H.R. 2454*' 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 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.

Appendix 4: Modeling of Forestry & Agricultural Offsets

Modeling of Domestic Forestry and Agricultural Offsets

- Forest and agricultural lands in the United States currently comprise a net carbon sink of over 1,060 million metric tons of CO_2 equivalent per year (U.S. GHG inventory, EPA 2009).
- 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 Forestry and Agricultural Sector Optimization Model (FASOM) 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 commited 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.
- Modeling efforts on GHG mitigation and possible offset supply potential are not intended to model a specfic policy or to prejudge which offset types will or will not be included in climate legislation.
- For this analysis, EPA has used estimates of domestic 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, and the October 23rd analysis of S.1733.
- A fuller 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.

Appendix 5: Modeling of Energy Efficiency Provisions

Modeling of Energy Efficiency Provisions

Provisions represented in Scenario 2 (HR 2454)

- Title I – Clean Energy
  - Subtitle A—Combined Efficiency and Renewable Electricity Standard (Sec. 101-102)
  - Subtitle D—State Energy and Environment Development Accounts (Sec. 131-132)
- Title II – Energy Efficiency
  - Subtitle A—Building Energy Efficiency Programs (Sec. 201-204)
- Title III – Reducing Global Warming Pollution
  - Subtitle B—Disposition of Allowances (Sec. 321)
    - Specifically, accounted for allocation of emission allowances for energy efficiency to
      - Natural gas consumers (Sec. 782 and 784),
      - Home heating oil and propane consumers (Sec. 782 and 785), and
      - Energy Efficiency and Renewable Energy (Sec. 782)

Provisions not represented in Scenario 2 (HR 2454)

- Title I – Clean Energy
  - Subtitle E—Smart Grid Advancement (Sec. 141-146)
  - Subtitle H—Energy and Efficiency Centers (Sec. 171-173)
- Title II – Energy Efficiency
  - Subtitle A—Building Energy Efficiency Programs (Sec. 205-206)
  - Subtitle B—Lighting and Appliance Energy Efficiency Programs (Sec. 211-219)
  - Subtitle D—Industrial Energy Efficiency Programs (Sec. 241-245)
  - Subtitle E—Improvements in Energy Savings Performance Contracting (Sec. 251)
  - Subtitle F—Public Institutions (Sec. 261-264)
  - Subtitle G—Miscellaneous (Sec. 271-274)

Modeling of Energy Efficiency Provisions

- Three types of energy efficiency provisions are represented
  1. Building codes
  2. Allowance allocations for energy efficiency programs
     - To natural gas local distribution companies
     - To states
  3. Energy savings contribution to Combined Efficiency and Renewable Electricity Standard
- Annual impacts (energy savings and costs) of EE provisions are estimated outside of the ADAGE model
- These impacts are represented in ADAGE by adjusting reference demand and incorporating costs
- Economy-wide impacts from the EE provisions are then estimated by ADAGE
- Estimates of costs for 2. and 3. are based on public sources of Cost of Saved Energy
  - Cost of saved energy (CSE) at rate of $46/MWh (electric) and $3/mmBTU (natural gas), and average measure lives of 10 and 15 years, respectively. CSE includes “program administrator” and “participant” costs. CSE escalated at 1%/year.

  Sources:
  - National Action Plan for Energy Efficiency (July 2006)
  - National Action Plan for Energy Efficiency Vision for 2025: Developing a Framework for Change (Nov. 2007) (National Action Plan documents available at www.epa.gov/eeactionplan)
  - American Council for an Energy Efficient Economy, Saving Energy Cost-Effectively: A National Review of the Cost of Energy Saved Through Utility-Sector Energy Efficiency Programs (Sep 2009)

Modeling of Energy Efficiency Provisions
Building Codes

Building Codes

- Title II – Energy Efficiency, Subtitle A—Building Energy Efficiency Programs, Sec. 201. Greater Energy Efficiency in Building Codes
  - Establishes targets for improvement and implementation of residential and commercial building codes to achieve 30%, 50%, and, ultimately, 75% reductions in energy use in buildings, phasing in from enactment through 2030.
  - Defines state/local compliance, establishes reporting requirements, provides allowances to states/locals to support compliance/enforcement efforts, and provides for federal enforcement under certain conditions.
- Estimated energy impacts and associated economic costs.
  - Used bill provisions for energy reductions, timing, and compliance.
  - Used AEO 2009 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 rate of 50% to account for shortcomings in implementation of codes at State level.*
  - Estimated incremental new building construction costs using EIA energy price forecasts from AEO 2009 (March) and 10-year simple payback.

* **"Estimated realization rate" accounts for the fact that even when building codes are "on the books" the level of implementation and enforcement are less than 100%. Historically these rates are not well measured but anecdotally are known to be quite low in some states (<50%) with great variation by State. Due to stronger enforcement provisions and funding support provided for within this bill, we've used a rate of 50% as a reasonable but conservative estimate.**

Allowance Allocations for EE Programs

- Title I – Clean Energy, Subtitle D—State Energy and Environment Development Accounts (Sec. 131-132)
- Title II – Energy Efficiency, Subtitle A—Building Energy Efficiency Programs (Sec. 202-204)
- Title III – Reducing Global Warming Pollution, Subtitle B—Disposition of Allowances (Sec. 321)
- **Specifically, accounted for allocation of emission allowances for EE programs to
  - Natural gas consumers (Sec. 782 and 784)
    - 33% of total for EE w/ allowances going to natural gas LDCs
  - Home heating oil and propane consumers (Sec. 782, 785)
    - 50% of total for EE w/ allowances going to States
  - Energy Efficiency and Renewable Energy (Sec. 782)
    - 75% of total for EE w/ allowances going to States
- Estimated energy impacts using
  - Cost of saved energy (CSE) at rate of $46/MWh (electric) and $3/mmBTU (natural gas), and average measure lives of 10 and 15 years, respectively
  - CSE includes “program administrator” and “participant” costs
  - CSE escalated at 1%/year
- **Note: savings from these EE programs do not count towards CERES requirements

Combined Efficiency & Renewable Electricity Standard (CERES)

- Title I – Clean Energy, Subtitle A—Combined Efficiency and Renewable Electricity Standard (Sec. 101-102)
  - Allows for electricity savings to meet 25% to 40% of standard
  - Savings must be achieved through measures implemented after enactment
- Accounted for electricity savings
  - Met 25% of standard using electricity savings; left standard at 20% from 2040-2050
  - Adjusted for affected entity size cutoff of 4 million MWh
  - Adjusted for exclusion from base amount of non-qualified hydro, new nuclear, and CCS
  - Adjusted for BAU energy savings from utility DSM programs
- Estimated energy impacts and associated economic costs using
  - Cost of saved energy (CSE) at rate of $46/MWh (electric) and $3/MMBTU (gas) and average measure lives of 10 (electric) and 15 (gas) years
  - 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.
- While the costs of the energy efficiency programs are applied to the manufacturing and services sectors of ADAGE, the cost of saved energy for energy efficiency programs is not endogenous to the model.

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)

References

Brown, Marilyn A. 2001. "Market Barriers to Energy Efficiency." Energy Policy 29 (14), pp. 1197-1208.

Brown, Rich, Sam Borgeson, Jonathan Koomey, and Peter Biermayer. 2008. *U.S. Building-Sector Energy Efficiency Potential.* Berkeley, CA: Lawrence Berkeley National Laboratory LBNL-1096E.

Climate Change Science Program, Synthesis and Assessment Product 2.1, Oct. 2008

EIA (2008). *Energy Market and Economic Impacts of S. 2191, the Lieberman-Warner Climate Security Act of 2007.* EIA, Office of Integrated Analysis and Forecasting. Washington, DC.

Enkvist, Naucler, and Rosander (2007). "A Cost Curve for Greenhouse Gas Reduction." The McKinsey Quarterly: p. 35-45.

Fischer (2005). "On the Importance of the Supply Side in Demand-Side Management." *Energy Economics*, v. 27, n. 1: 165-180.

Gillingham, Newell, and Palmer (2009). "Energy Efficiency Economics and Policy." Forthcoming in *Annual Review of Resource Economics*. v. 1

References (continued)

Horowitz, Marvin J. 2004. "Electricity Intensity in the Commercial Sector: Market and Public Program Effects." The Energy Journal 25 (2), pp. 1-23.

Horowitz, Marvin J. 2007. "Changes in Electricity Demand in the United States from the 1970s to 2003." The Energy Journal 28 (3), pp. 93-119.

Huntington (1994). “Been Top-Down so Long it Looks Like Bottom Up to Me.” *Energy Policy*, v. 10: 833-839.

IEA. 2007. *Mind the Gap: Quantifying Principal-Agent Problems in Energy Efficiency.* Paris, France: International Energy Agency.

Jaffe, Newell and Stavins (2001). "Energy Efficient Technologies and Climate Change Policies: Issues and Evidence." In *Climate Change Economics and Policy*, Toman, Michael A., ed., Washington, D.C.: Resources for the Future. p.171 - 181.

Jaffe and Stavins (1994). “The Energy-Efficiency Gap: What Does it Mean?” *Energy Policy*, v. 10: 804-810.

Koopmans and te Velde (2001). “Bridging the Energy Efficiency Gap: Using Bottom-Up Information in a Top-Down Energy Demand Model.” *Energy Economics*, v.23: 57-75.

References (continued)

Levinson and Niemann (2004). “Energy Use by Apartment Tenants When Landlords Pay for Utilities.” *Resource and Energy Economics*, v. 26: 51-75.

Metcalfe (1994). “Economics and Rational Conservation Policy.” *Energy Policy*, v. 10: 819-825.

Metcalfe and Hassett (1999). "Measuring the Energy Savings From Home Improvement Investments: Evidence From Monthly Billing Data." *The Review of Economics and Statistics,* v. 81, n. 3: 516-528.

Nichols (1994). “Demand-Side Management: Overcoming Market Barriers or Obscuring Real Costs?” *Energy Policy*, v. 10: 840-847.

Parry, Sigman, Walls and Williams (2006). "The Incidence of Pollution Control Policies." *The International Yearbook of Environmental and Resource Economics 2006/2007* . Tom Tietenberg and Henk Folmer, Eds. Northampton, MA: Edward Elgar. p. 1-42

Sebold and Fox (1985). “Realized Savings form Residential Conservation Activity.” *The Energy Journal*: v. 6, n. 2: 73-88.

Van Soest and Bulte (2001). “Does the Energy Efficiency paradox Exist? Technological Progress and Uncertainty.” *Environmental and Resource Economics*, v. 18, n. 1: p.101-112

Appendix 6: Additional Information on Economy Wide Modeling (ADAGE & IGEM)

Appendix 5 Contents

- Additional Economy-Wide Impacts:
  GHG Emissions & Economic Costs
- Additional Energy Sector Modeling Results
- Additional Global Results:
  CO_2e Concentrations and Temperature Changes
- Additional Global Results:
  Trade Impacts & Emissions Leakage
- IGEM Modeling Updates
- Full Consumption Impacts
- Comparison to EPA's Analysis of H.R. 2454

Additional Economy-Wide Impacts: GHG Emissions & Economic Costs

GHG Allowance Prices & Sensitivities

H.R. 2454 Scenario Comparison

	ADAGE		
	2015	**2030**	**2050**
Scn. 8 - H.R. 2454 (Updated)	$16	$33	$87
Scn. 9 - No Int'l Offsets	$39	$82	$216
Scn. 10 - Ref. Nuclear & Biomass / Delayed CCS	$18	$38	$99
Scn. 11 - Ref. Nuclear & Biomass / Delayed CCS & No Int'l Offsets	$52	$108	$284
Scn. 12 - IPM Elec. Imposed on ADAGE	$16	$34	$91
Scn. 15 - No EE provisions	$16	$34	$89
Scn. 17 - Early Developing Country Action	$16	$34	$90
Scn. 18 - No Developing Country Action	$11	$23	$60

	IGEM		
	2015	**2030**	**2050**
Scn. 8 - H.R. 2454 (Updated)	$15	$32	$85
Scn. 9 - No Int'l Offsets	$24	$49	$130
Scn. 13 - 20% 2020 Cap	$15	$32	$85
Scn. 14 - 14% 2020 Cap	$15	$32	$85
Scn. 16 - Revenue Recycling - Labor Tax Cut	$15	$32	$85
Scn. 17 - Early Developing Country Action	$17	$34	$91
Scn. 18 - No Developing Country Action	$10	$22	$57

U.S. covered emissions projections under H.R. 2454 scenario 8 (ADAGE)

	Emissions & Abatement		Percent below (above) 2005 (6,091 MtCO2e)		Percent below (above) 1990 (5,152 MtCO2e)	
	2020	*2050*	*2020*	*2050*	*2020*	*2050*
BAU covered emissions	**6,110**	**7,174**	0%	18%	19%	39%
Covered GHG abatement	-826	-3,503				
U.S. covered emissions	**5,284**	**3,670**	-13%	-40%	3%	-29%
Domestic offsets	-182	-598				
U.S. covered emissions w/ domestic offsets	**5,102**	**3,072**	-16%	-50%	-1%	-40%
International offsets	-904	-1,044				
U.S. covered emissions w/ domestic & int'l offsets	**4,197**	**2,028**	-31%	-67%	-19%	-61%
Banking*	859	-990				
*Totals without Banking***						
U.S. covered emissions	**5,284**	**2,680**	-13%	-56%	3%	-48%
U.S. covered emissions w/ domestic offsets	**5,102**	**2,082**	-16%	-66%	-1%	-60%
U.S. covered emissions w/ domestic & int'l offsets	**5,057**	**1,038**	**-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.

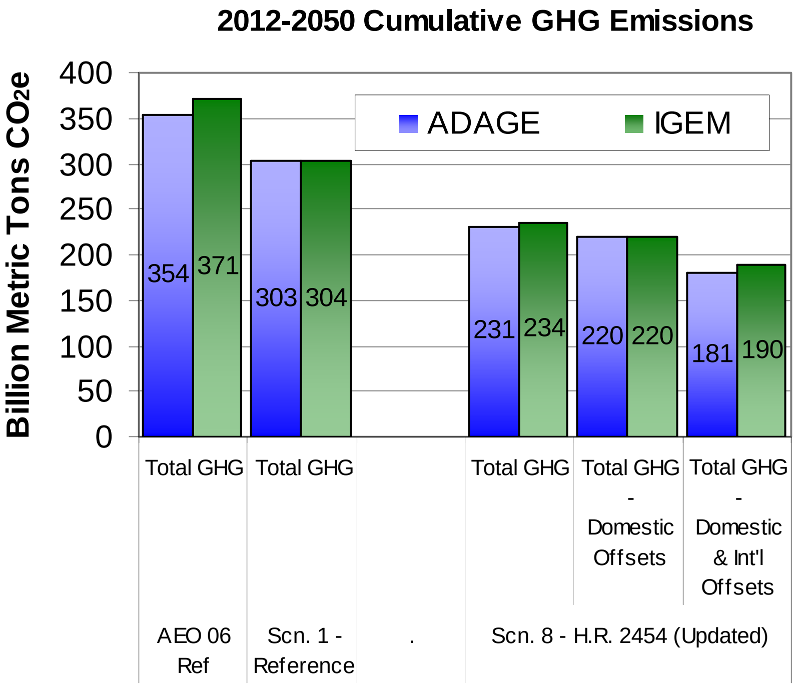
** The extra abatement driven by banking behavior generally is from additional international offset purchases, so the without banking totals in 2020 reduce international offset purchases. In 2050 the previously banked allowances submitted for compliance generally replace covered GHG abatement that would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

U.S. total emissions projections under H.R. 2454 scenario 8 (ADAGE)

	Emissions & Abatement		Percent below (above) 2005 (7,130 MtCO2e)		Percent below (above) 1990 (6,148 MtCO2e)	
	2020	*2050*	*2020*	*2050*	*2020*	*2050*
BAU covered emissions	6,110	7,174	0%	18%	19%	39%
BAU uncovered emissions	1,280	1,205	23%	16%	29%	21%
BAU economy-wide emissions	**7,390**	**8,379**	4%	18%	20%	36%
Covered GHG abatement	-826	-3,503				
Domestic offsets (other than sequestration)	-12	-54				
HFC abatement (separate cap)	-224	-591				
NSPS for CH4	-130	-143				
U.S. emissions, inventory abatement	**6,198**	**4,088**	-13%	-43%	1%	-34%
Domestic offsets (sequestration)	-170	-544				
U.S. emissions, all domestic abatement	**6,028**	**3,544**	-15%	-50%	-2%	-42%
International offsets	-904	-1,044				
U.S. emissions (including international offsets)	**5,124**	**2,499**	-28%	-65%	-17%	-59%
Int'l forest set-asides	-295	-24				
Discounting of international offsets	-226	-261				
U.S. emissions, all sources of reductions	**4,603**	**2,214**	-35%	-69%	-25%	-64%
Banking*	859	-990				
*Totals without Banking***						
U.S. emissions, inventory abatement	**6,198**	**3,098**	-13%	-57%	1%	-50%
U.S. emissions, all domestic abatement	**6,028**	**2,554**	-15%	-64%	-2%	-58%
U.S. emissions (including international offsets)	**5,983**	**2,499**	-16%	-65%	-3%	-59%
U.S. emissions, all sources of reductions	**5,463**	**1,224**	-23%	-83%	-11%	-80%

2012 – 2050 Cumulative GHG Emissions

Scenario 1 - Reference & Scenario 8 – Updated H.R. 2454



- Discounted offsets would provide an additional 6 to 9 GtCO_2e of cumulative abatement in IGEM and ADAGE respectively.
- International forestry set-asides would provide an additional 6 GtCO_2e of cumulative abatement in IGEM and ADAGE respectively.
- New source performance standards (NSPS) for CH_4 are estimated to provide an additional 5 GtCO_2e of cumulative abatement.*
- The separate cap for HFC's is estimated to provided an additional 16 GtCO_2e of cumulative abatement.*
- Cumulative emissions net of offsets, and all abatement described above is 146 and 158 GtCO_2e in ADAGE and IGEM respectively.
- For comparison, a target that reduces total U.S. GHG emissions gradually to 1990 levels by 2020 and to 80% below 1990 levels by 2050 results in 2012 – 2050 cumulative emissions of 168 bmt CO_2e.

* The costs of the separate HFC cap is not modeled in this analysis.

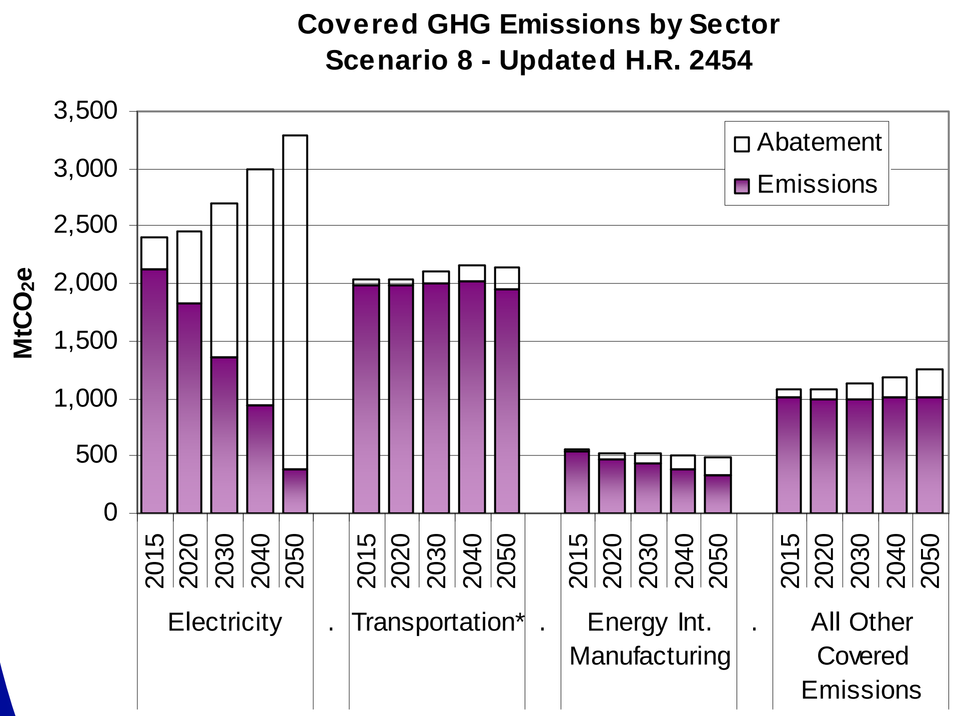
% Reduction from Scenario 1 - Reference

	ADAGE	IGEM
Total GHG Emissions	-24%	-23%
Total GHG Emissions - Domestic Offsets (sinks)	-28%	-28%
Total GHG Emissions - Domestic Offsets - International Offsets	-40%	-37%

Total US GHG Emissions & Sources of Abatement

Scenario 1 - Reference & Scenario 8 – Updated H.R. 2454 (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 ($0.16 in 2015, $0.30 in 2030, and $0.81 in 2050 under Scenario 8 – Updated H.R. 2454) 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.

Total Abatement Cost

Scenario 8 – Updated H.R. 2454

Table: Total Abatement Cost Calculations
Scenario 8 - H.R. 2454 (Updated)

	2015	2020	2030	2040	2050
Total Allowance Value (Billion 2005 Dollars)					
ADAGE	$79	$103	$117	$123	$90
IGEM	$77	$99	$113	$119	$88
Domestic Covered Abatement (MtCO2e)					
ADAGE	408	827	1,679	2,477	3,505
IGEM	843	1,161	1,656	2,204	3,193
Domestic Offset Abatement (MtCO2e)					
ADAGE	174	182	267	351	598
IGEM	216	222	329	430	736
International Offsets & Set-Asides (MtCO2e before discounting)					
ADAGE	1,416	1,415	1,349	1,436	1,329
IGEM	1,038	1,231	1,065	998	969
Allowance Price ($/tCO2e)					
ADAGE	$16	$20	$33	$54	$87
IGEM	$15	$20	$32	$52	$85
Offset Price ($/tCO2e)					
ADAGE	$16	$20	$33	$54	$87
IGEM	$15	$20	$32	$52	$85
International Offset/Credit Price ($/tCO2e before discounting)					
ADAGE	$13	$16	$26	$43	$70
IGEM	$12	$16	$26	$42	$68
Domestic Covered Abatement Cost (Billion 2005 Dollars)					
ADAGE	$3	$8	$28	$67	$153
IGEM	$6	$11	$26	$57	$135
Domestic Offset Abatement Cost (Billion 2005 Dollars)					
ADAGE	$1	$2	$4	$9	$26
IGEM	$2	$2	$5	$11	$31
International Offset Payments (Billion 2005 Dollars)					
ADAGE	$18	$23	$36	$62	$93
IGEM	$13	$19	$27	$42	$66
Total Abatement Cost (Billion 2005 Dollars)*					
ADAGE	$22	$33	$68	$138	$272
IGEM	$21	$33	$59	$110	$232

- 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 $28 billion. On a per household basis, the total abatement cost in 2020 is $223 and $225 in IGEM and ADAGE respectively.

Consumption

Scenario 1 – Reference & Scenario 8 – Updated H.R. 2454

ADAGE	2015	2020	2030	2040	2050
Ref. Total C (Billion 2005 $)	$11,575	$13,168	$17,079	$21,655	$26,752
Change in Total C (Billion 2005 $)	-$2	-$8	-$62	-$146	-$260
Ref. Consumption per Household	$92,202	$99,888	$117,973	$140,233	$164,348
% Change (Scn. 8)	-0.01%	-0.06%	-0.36%	-0.67%	-0.97%
Consumption Loss per Household ($)	-$13	-$62	-$427	-$944	-$1,599
NPV Cost per HH ($)	-$10	-$37	-$153	-$208	-$216

Average Annual NPV cost per Household	**-$117**
Total NPV Cost per Household (2010-2050)	**-$4,810**
Total Cost as an Annual Annuity Loss (2010-2050)	**-$280**

IGEM	2015	2020	2030	2040	2050
Ref. Total C (Billion 2005 $)	$9,705	$10,990	$13,962	$17,567	$21,642
Change in Total C (Billion 2005 $)	-$4	-$1	-$22	-$117	-$223
Ref. Consumption per Household	$75,531	$80,507	$91,686	$105,202	$119,168
% Change (Scn. 8)	-0.04%	-0.01%	-0.16%	-0.66%	-1.03%
Consumption Loss per Household	-$32	-$8	-$148	-$699	-$1,226
NPV Cost per HH	-$24	-$5	-$53	-$154	-$166

Average Annual NPV cost per Household	**-$74**
Total NPV Cost per Household (2010-2050)	**-$3,015**
Total Cost as an Annual Annuity Loss (2010-2050)	**-$176**

- 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 $74 - $117 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 $4,810 in 2010, or a consumption loss of $280 each year from 2010 through 2050. This is equivalent to a consumption loss of $0.77 per day, every day through 2050.

Consumption

H.R. 2454 Scenario Comparison (ADAGE)

	ADAGE	2015	2020	2030	2040	2050
Scn. 1 - Reference	Ref. Consumption per Household	$92,202	$99,888	$117,973	$140,233	$164,348
Scn. 8 - H.R. 2454 (Updated)	% Change	-0.01%	-0.06%	-0.36%	-0.67%	-0.97%
	Consumption Loss per Household ($)	-$13	-$62	-$427	-$944	-$1,599
	NPV Cost per HH ($)	-$10	-$37	-$153	-$208	-$216
	Average Annual NPV cost per Household			**-$117**		
Scn. 9 - V - No Int'l Offsets	% Change	-0.23%	-0.35%	-0.92%	-1.32%	-1.60%
	Consumption Loss per Household ($)	-$216	-$354	-$1,084	-$1,848	-$2,622
	NPV Cost per HH ($)	-$162	-$207	-$389	-$407	-$355
	Average Annual NPV cost per Household			**-$291**		
Scn. 10 - V - Ref. Nuclear & Biomass / Delayed CCS	% Change	-0.20%	-0.24%	-0.55%	-0.80%	-1.03%
	Consumption Loss per Household ($)	-$186	-$242	-$646	-$1,125	-$1,695
	NPV Cost per HH ($)	-$139	-$141	-$232	-$248	-$229
	Average Annual NPV cost per Household			**-$194**		
Scn. 11 - V - Ref. Nuclear & Biomass / Delayed CCS & No Int'l Offsets	% Change	-0.38%	-0.55%	-1.29%	-1.85%	-2.05%
	Consumption Loss per Household ($)	-$348	-$545	-$1,522	-$2,600	-$3,375
	NPV Cost per HH ($)	-$260	-$318	-$546	-$573	-$457
	Average Annual NPV cost per Household			**-$417**		
Scn. 15 - No EE provisions	% Change	-0.02%	-0.07%	-0.37%	-0.69%	-1.00%
	Consumption Loss per Household ($)	-$17	-$67	-$439	-$966	-$1,635
	NPV Cost per HH ($)	-$13	-$39	-$158	-$213	-$221
	Average Annual NPV cost per Household			**-$120**		
Scn. 17 - Early Developing Country Action	% Change	0.01%	-0.08%	-0.43%	-0.73%	-0.99%
	Consumption Loss per Household ($)	$7	-$77	-$507	-$1,023	-$1,630
	NPV Cost per HH ($)	$5	-$45	-$182	-$225	-$221
	Average Annual NPV cost per Household			**-$128**		
Scn. 18 - No Developing Country Action	% Change	-0.11%	-0.15%	-0.31%	-0.40%	-0.50%
	Consumption Loss per Household ($)	-$102	-$151	-$366	-$560	-$827
	NPV Cost per HH ($)	-$76	-$88	-$132	-$123	-$112
	Average Annual NPV cost per Household			**-$102**		

Consumption

H.R. 2454 Scenario Comparison (IGEM)

	IGEM	2015	2020	2030	2040	2050
Scn. 1 - Reference	Ref. Consumption per Household	$75,531	$80,507	$91,686	$105,202	$119,168
Scn. 8 - H.R. 2454 (Updated)	% Change	-0.04%	-0.01%	-0.16%	-0.66%	-1.03%
	Consumption Loss per Household ($)	-$32	-$8	-$148	-$699	-$1,226
	NPV Cost per HH ($)	-$24	-$5	-$53	-$154	-$166
	Average Annual NPV cost per Household			**-$74**		
Scn. 9 - V - No Int'l Offsets	% Change	-0.05%	0.00%	-0.27%	-0.96%	-1.48%
	Consumption Loss per Household ($)	-$41	$0	-$245	-$1,011	-$1,761
	NPV Cost per HH ($)	-$30	$0	-$88	-$223	-$238
	Average Annual NPV cost per Household			**-$107**		
Scn. 13 - 20% 2020 Cap	% Change	-0.04%	-0.02%	-0.16%	-0.67%	-1.04%
	Consumption Loss per Household ($)	-$30	-$12	-$150	-$703	-$1,235
	NPV Cost per HH ($)	-$23	-$7	-$54	-$155	-$167
	Average Annual NPV cost per Household			**-$74**		
Scn. 14 - 14% 2020 Cap	% Change	-0.03%	-0.01%	-0.17%	-0.67%	-1.01%
	Consumption Loss per Household ($)	-$25	-$5	-$154	-$700	-$1,202
	NPV Cost per HH ($)	-$19	-$3	-$55	-$154	-$163
	Average Annual NPV cost per Household			**-$74**		
Scn. 16 - Revenue Recycling - Labor Tax Cut	% Change	0.10%	0.25%	0.22%	0.02%	-0.40%
	Consumption Loss per Household ($)	$78	$204	$204	$18	-$481
	NPV Cost per HH ($)	$58	$119	$73	$4	-$65
	Average Annual NPV cost per Household			**$46**		
Scn. 17 - Early Developing Country Action	% Change	-0.04%	0.00%	-0.18%	-0.71%	-1.09%
	Consumption Loss per Household ($)	-$31	-$1	-$162	-$743	-$1,297
	NPV Cost per HH ($)	-$23	$0	-$58	-$164	-$175
	Average Annual NPV cost per Household			**-$78**		
Scn. 18 - No Developing Country Action	% Change	-0.02%	-0.01%	-0.10%	-0.47%	-0.70%
	Consumption Loss per Household ($)	-$18	-$10	-$95	-$492	-$835
	NPV Cost per HH ($)	-$14	-$6	-$34	-$108	-$113
	Average Annual NPV cost per Household			**-$50**		

Consumption

Scenario 1 – Reference & Scenario 8 Updated H.R. 2454

Table: Impacts on Average HH Consumption

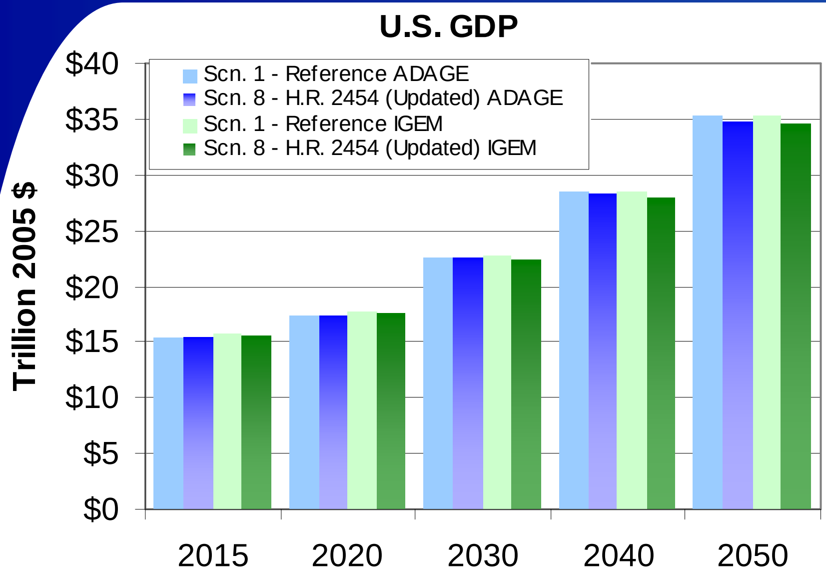
	2010	2015	2020	2025	2030	2035	2040	2045	2050
Current Average HH Consumption (2010)									
ADAGE	$83,909								
IGEM	$69,814								
Average HH Consumption in *Scenario 1 - Reference*									
ADAGE		$92,202	$99,888	$107,898	$117,973	$128,895	$140,233	$151,989	$164,348
IGEM		$75,531	$80,507	$85,734	$91,686	$98,389	$105,202	$112,166	$119,168
Average HH Consumption in *Scenario 8 - Updated H.R. 2454*									
ADAGE		$92,189	$99,826	$107,766	$117,546	$128,246	$139,290	$150,679	$162,750
IGEM		$75,499	$80,499	$85,698	$91,539	$97,962	$104,504	$111,201	$117,942
Increase in Average HH Consumption in *Scenario 1 - Reference* Compared to 2010									
ADAGE		9.9%	19.0%	28.6%	40.6%	53.6%	67.1%	81.1%	95.9%
IGEM		8.2%	15.3%	22.8%	31.3%	40.9%	50.7%	60.7%	70.7%
Increase in Average HH Consumption in *Scenario 8 - H.R. 2454* Compared to 2010									
ADAGE		9.9%	19.0%	28.4%	40.1%	52.8%	66.0%	79.6%	94.0%
IGEM		8.1%	15.3%	22.8%	31.1%	40.3%	49.7%	59.3%	68.9%
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 8 – Updated H.R. 2454

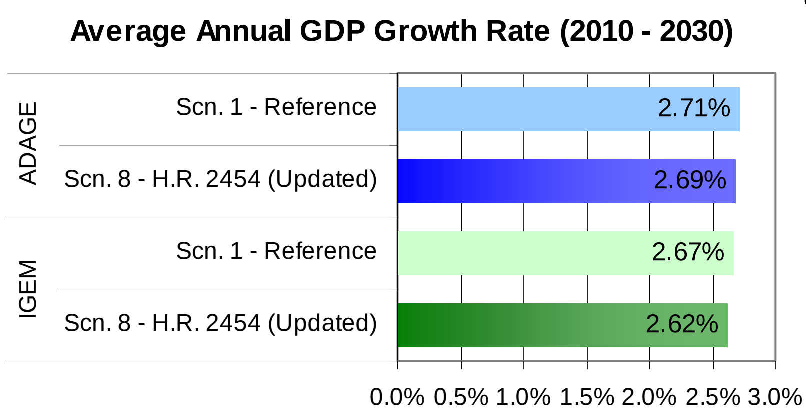


ADAGE

	2015	2020	2030	2040	2050
Reference	$15.4	$17.4	$22.6	$28.6	$35.4
Scn 8 - H.R. 2454	$15.4	$17.4	$22.5	$28.4	$34.9
Absolute Change	-$0.004	$0.008	-$0.106	-$0.241	-$0.498
% Change	-0.02%	0.05%	-0.47%	-0.84%	-1.41%

IGEM

	2015	2020	2030	2040	2050
Reference	$15.7	$17.7	$22.7	$28.5	$35.4
Scn 8 - H.R. 2454	$15.7	$17.6	$22.4	$27.9	$34.6
Absolute Change	-$0.037	-$0.068	-$0.280	-$0.522	-$0.858
% Change	-0.24%	-0.38%	-1.23%	-1.83%	-2.42%



- Other ways to frame these GDP reductions are as follows:
  - In the reference case, GDP in ADAGE is $22.6 trillion in 2030. In "*scenario 8 – Updated H.R. 2454*" GDP reaches $22.6 trillion approximately three months later than in the reference case.
  - In IGEM the reference case GDP is $22.7 trillion in 2030. In *"scenario 8 – Updated H.R. 2454"* GDP reaches $22.7 trillion six months later than in the reference case.
  - Under "*scenario 8 – Updated H.R. 2454*", average annual GDP growth between 2010 and 2030 is approximately 2 basis points lower in ADAGE and 5 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 H.R. 2454 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. Forthcoming.

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.

Additional Energy Sector Modeling Results

Nuclear & CCS Limits in ADAGE

- The constraints on Nuclear and CCS capacity additions in ADAGE have been updated to reflect the constraints in IPM.
- These constraints are applied in ADAGE to incremental capacity additions above what is projected in the reference scenario.
- 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)

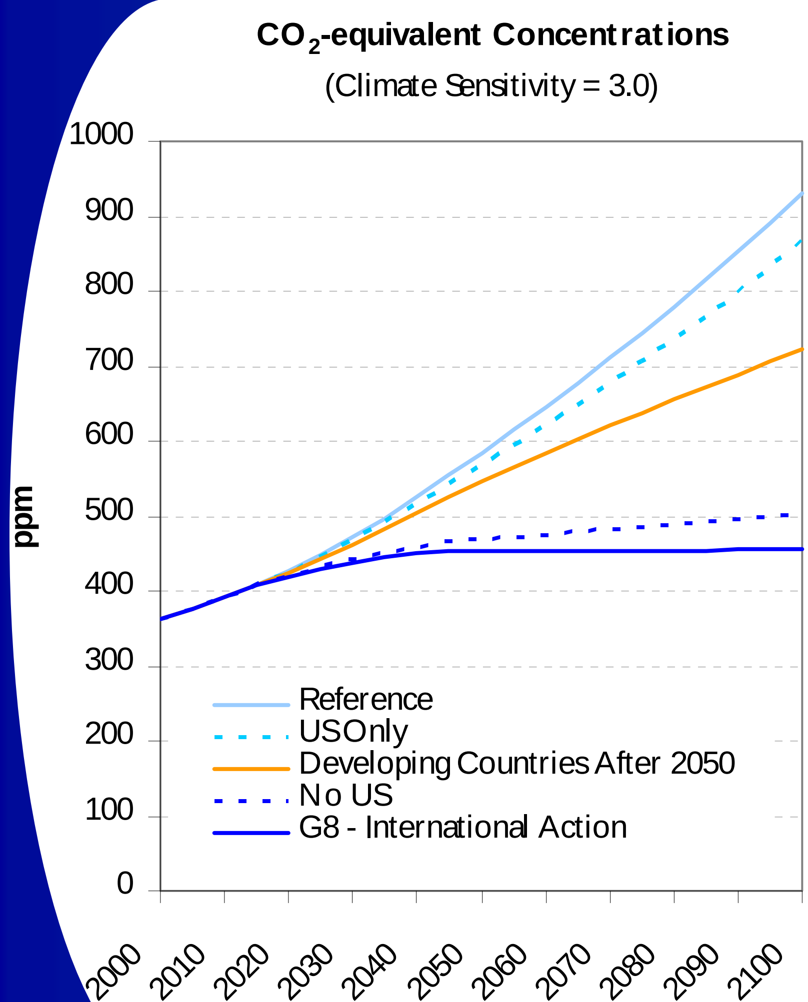
	Nuclear	CCS		Nuclear	CCS
2015	N/A	N/A		N/A	0
2020	12	0		0	27
2025	24	0		0	48
2030	40	0	**OR**	0	80
2035	60	0		0	120
2040	90	0		0	200
2045	140	0		0	325
2050	210	0		0	450

Additional Global Results:

CO_2e Concentrations and Temperature Changes

CO_2e Concentrations

Impacts of International Action Assumptions (GCAM & MAGICC)

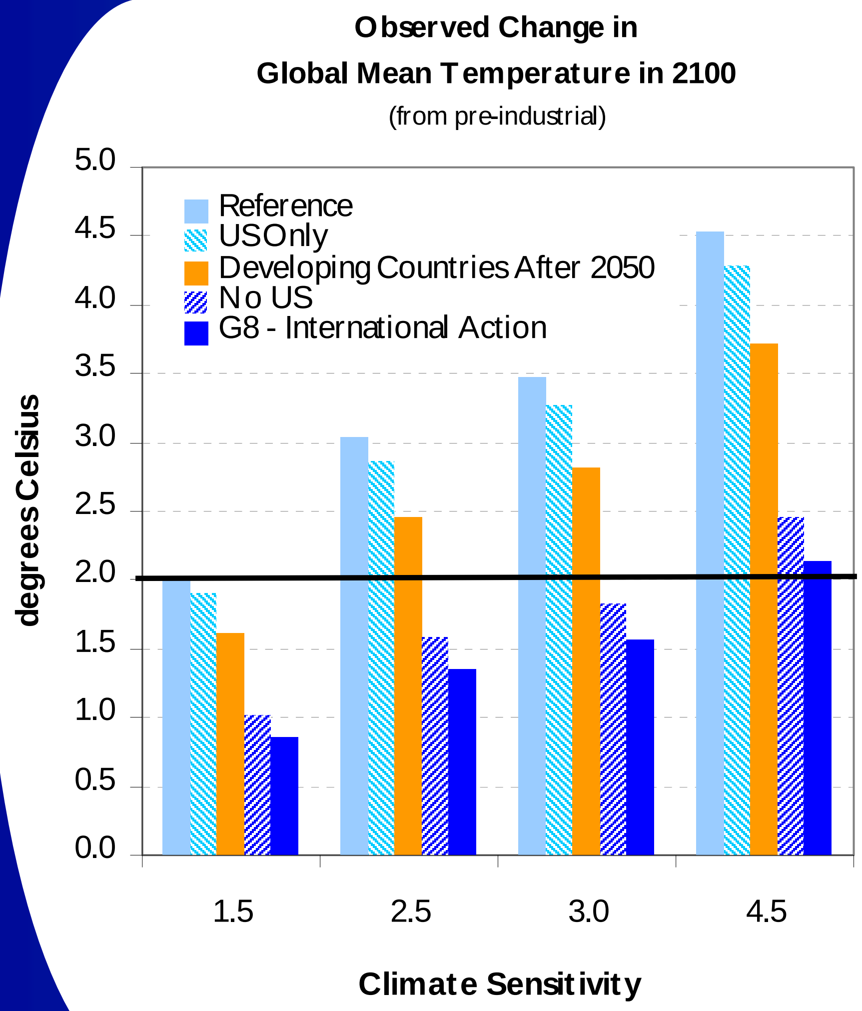


- CO_2e concentrations through 2100 are presented here assuming a climate sensitivity of 3.0 (CS is the equilibrium temperature response to a doubling of CO_2. 3.0 is deemed "most likely" by the IPCC).
- The five scenarios shown here are:
  - **Reference**: no climate polices or measures adopted by any countries.
  - **US Only**: US adopts H.R. 2454, all other countries follow BAU emissions.
  - **Developing Countries After 2050**: US and developed (group 1) countries same as G8 scenario. Developing (group 2) countries adopt policy in 2050 holding emissions constant at 2050 levels.
  - **No US**: US follows BAU emissions, all other counties same as G8 scenario.
  - **G8 - International Assumptions**: Consistent with G8 agreement to reduce global emissions to 50% below 2005 levels by 2050. US adopts H.R. 2454, developed countries (group 1) reduce emissions to 83% below 2005 levels by 2050, and developing (group 2) countries cap emissions beginning in 2025, and return emissions to 26% below 2005 levels by 2050. All countries hold emissions targets constant after 2050.*
- CO_2e concentrations are approximately 457 ppm in 2100 under G8 – international action assumptions.
  - Note that CO_2e concentrations are not stabilized in these scenarios. To prevent concentrations from continuing to rise after 2100, post-2100 GHG emissions would need to be further reduced. (For example, stabilization of CO_2 concentrations at 457 ppm would require net CO_2 emissions to go to zero in the very long run).
- No participation from developing countries before 2050 would increase CO_2e concentrations to 723 ppm in 2100, while reference assumptions produce CO_2e concentrations of 931 ppm in 2100.
- Removing US action from the G8 scenario raises CO_2e concentrations by 46 ppm in 2100 to 503 ppm. Adding US action to the reference scenario lowers CO_2e concentrations by 64 ppm in 2100 to 868 ppm

* Note that the main scenarios do not model post 2050 caps, doing so would likely raise allowance prices by 2%.

Global Mean Temperature Change in 2100

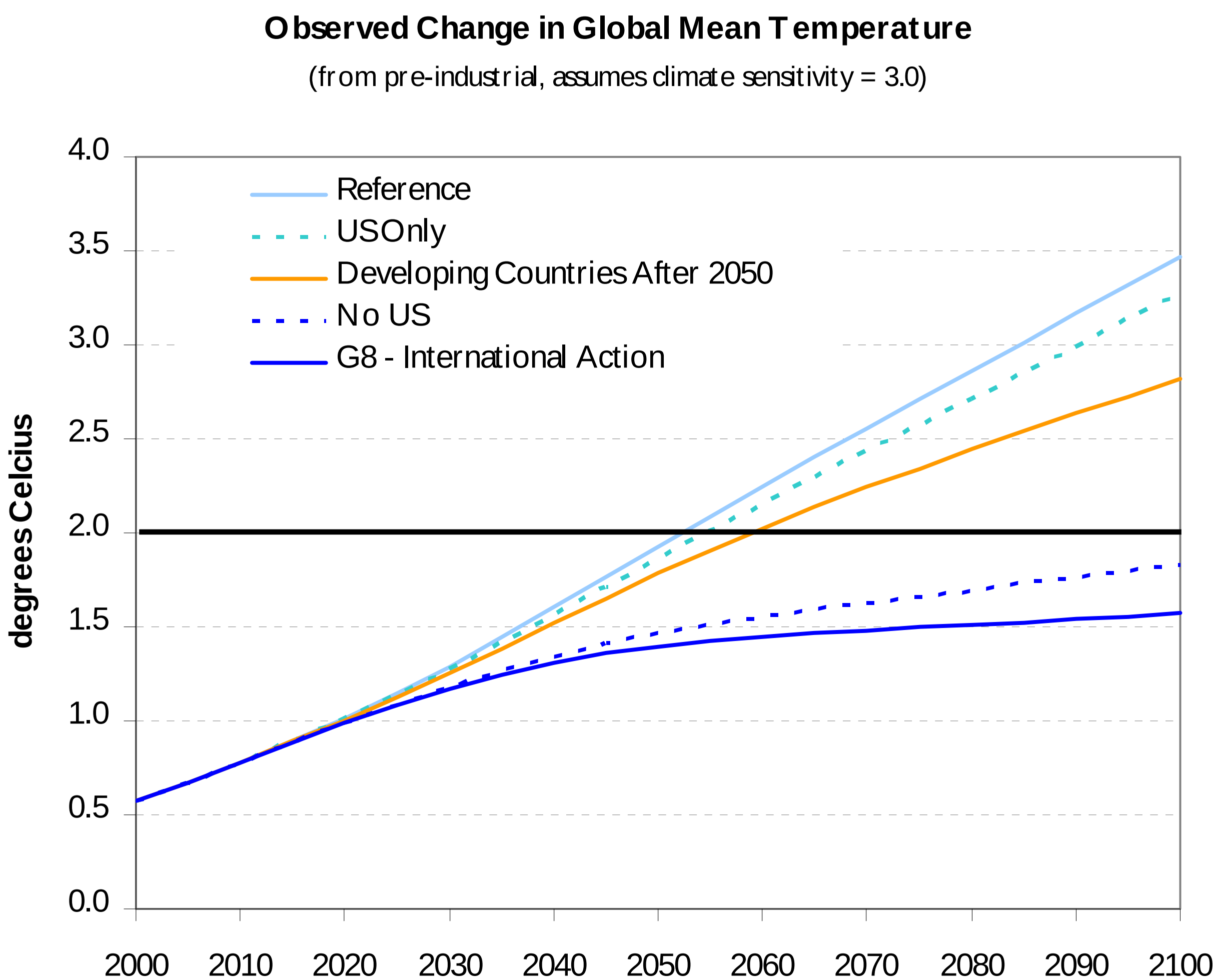
Impacts of International Action Assumptions (GCAM & MAGICC)



- Bar chart to the left demonstrates projections of observed temperature changes (from pre-industrial time) in 2100 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 2100 is attainable under a climate sensitivity of 3.0.
- 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.
- Continued GHG emissions reductions after 2100 could 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), 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.

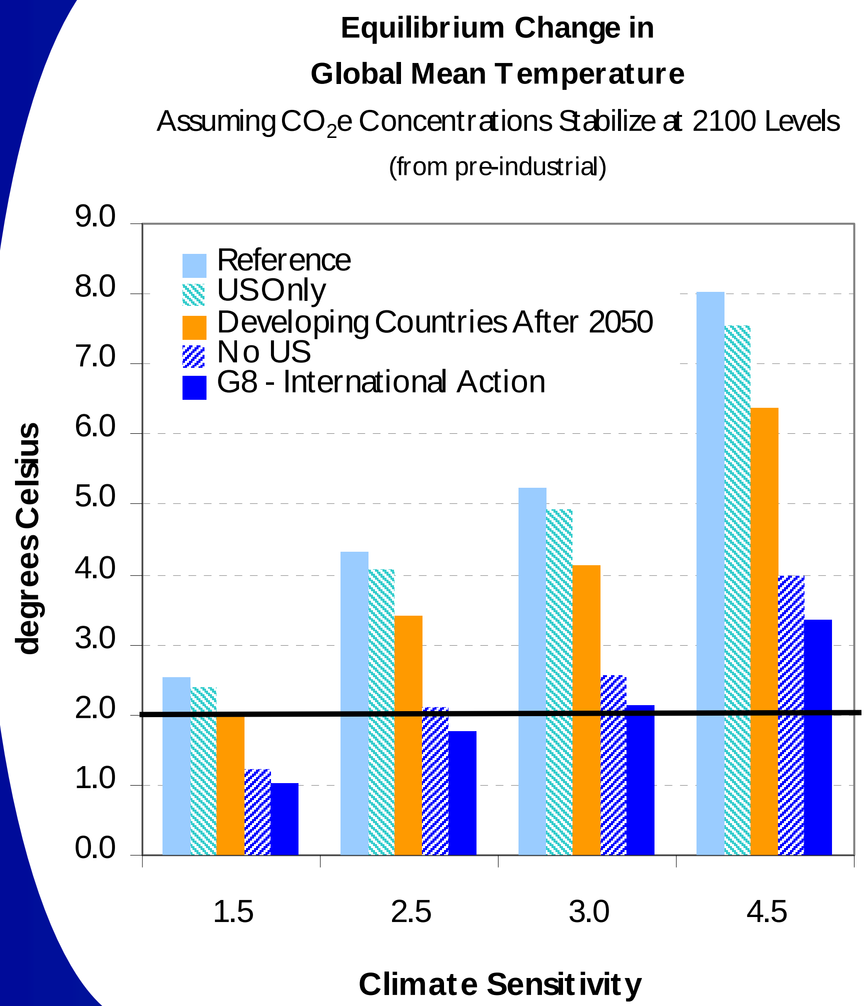
Observed Global Mean Temperature Change

Impacts of International Action Assumptions (GCAM & MAGICC)



Equilibrium Global Mean Temperature Change

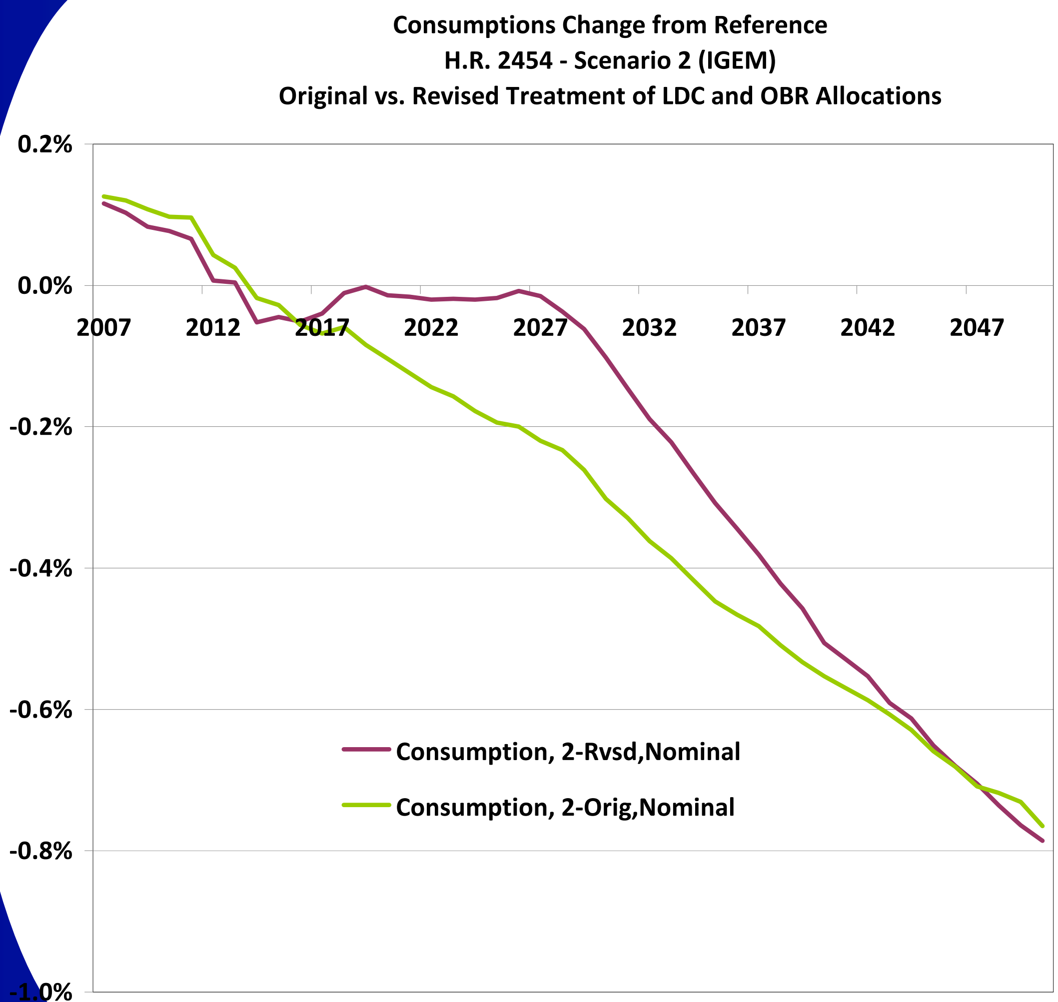
Impacts of International Action Assumptions (GCAM & MAGICC)



- 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.
- 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), 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.

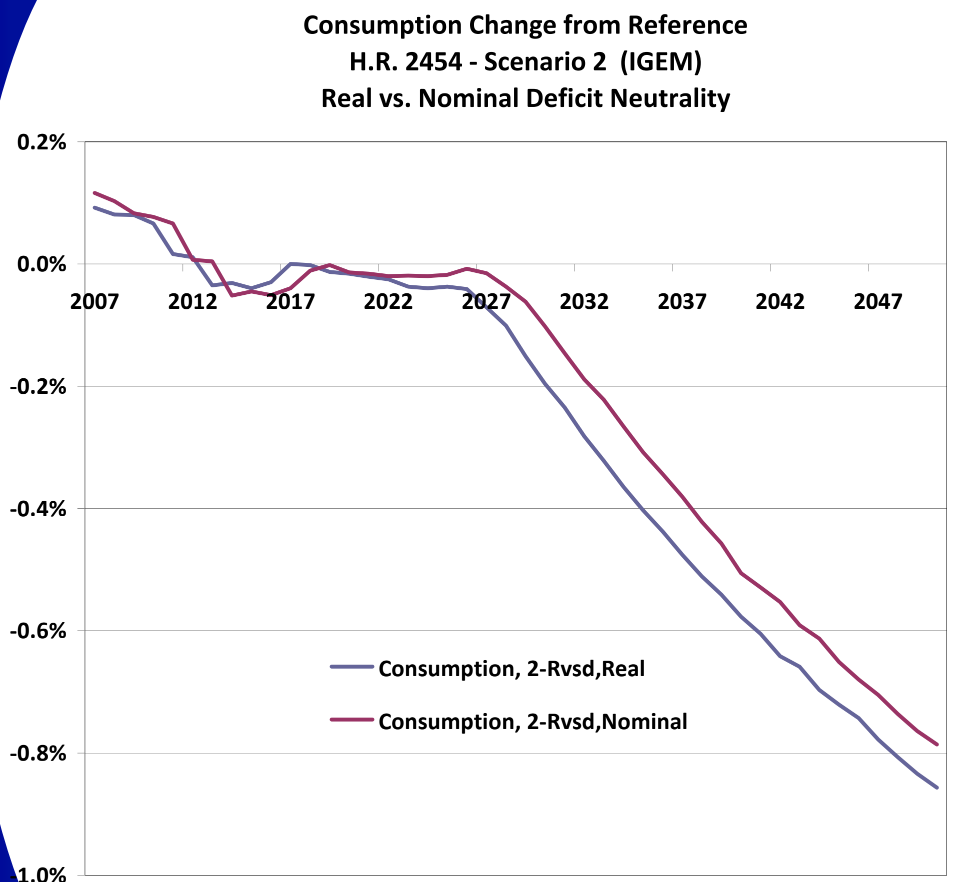
IGEM Modeling Updates

Revised Treatment of Allowance Allocations in IGEM



- In the June 23, 2009 analysis of H.R. 2454, IGEM modeled the LDC allocation and the output based rebate allocation using a share adjustment that scaled down the allocation based on the share of the IGEM sector that was receiving the allocation.
  - This share adjustment is needed when modeling sectoral price shocks.
  - However, the share adjustment is not needed when modeling sectoral expenditure effects such as the H.R. 2454 allocations.
- The graphic to the left depicts the percentage change in consumption from reference for scenario 2 from the June 23, 2009 analysis with the original approach including the share adjustment and the revised approach without the share adjustment.
- In the original approach, the share adjustments on the LDC and trade protected industries led to an understatement of the subsidies.
- With the revised approach the subsidies are at their correct levels.
- By the late 2020's, the subsidies disappear and the model results begin to converge.
- Because there is a change in the time path of consumption losses, the average annual cost per household (i.e. the 2010 through 2050 average of the net present value of the per household consumption loss) changes from $80 with the original approach as reported in the June 23, 2009 analysis, to $55 with the revised approach.
- As modeled, this change does not impact allowance prices.

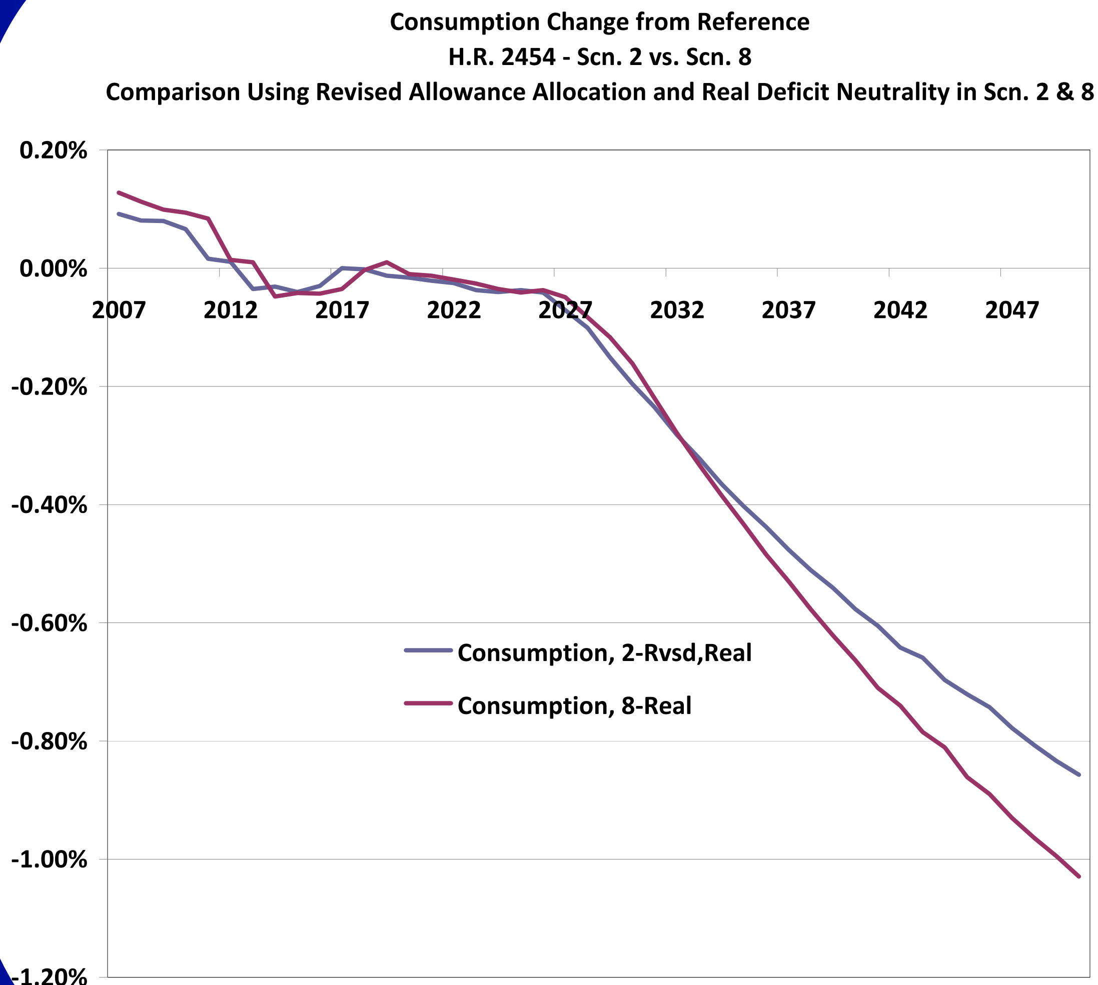
Real vs. Nominal Deficit Neutrality



- The second change to the IGEM modeling approach since the June 23, 2009 analysis is to target real instead of nominal deficit neutrality.
- This change was made to because of the inclusion of '*scenario 16 – revenue recycling to reduce labor taxes*' in this analysis.
- In our policy analyses to date, there were no alternative recycling considerations beyond subsidies, rebates and lump sum redistributions. Deficit neutrality in the nominal budgetary sense was the operational assumption. Under lump sum recycling, nominal versus real matters very little in terms of the macroeconomic and inter-industry effects of climate policy, e.g. the magnitudes of GDP, consumption, investment, and other changes are quite similar. Indeed the distinction between nominal and real only matters significantly for the welfare rankings in simulation runs involving revenue recycling through adjustments in the marginal tax rate on labor income.
- It should be noted that targeting nominal government purchases leads to both deficit and revenue neutrality, while targeting real purchases leads to only deficit neutrality.
- It should also be noted that there is no theoretically "correct" choice for achieving deficit neutrality – nominal versus real. This degree of freedom arises in IGEM because its numeraire price is the after-tax wage received by households, and not the GDP price deflator. The saving investment balance in IGEM is expressed in nominal terms and so it seems logical to deal with deficit neutrality in the budgetary sense. However, it is also true that budgets envision a particular market basket of physical goods and services that, within reason, should be maintained irrespective of price changes. Here deficit neutrality in real terms seems the logical constraint.
- The graphic to the left depicts annual consumption losses in scenario 2 with real and nominal deficit neutrality (using the revised treatment of allowance allocations discussed in the previous slide for both scenarios).
- Because there is a change in the time path of consumption losses, the average annual cost per household (i.e. the 2010 through 2050 average of the net present value of the per household consumption loss) changes from $55 with the revised approach for allowance allocations and nominal deficit neutrality, to $68 with the revised approach for allowance allocations and real deficit neutrality.
- As modeled, this change does not impact allowance prices.

Consumption Loss From Reference (IGEM)

Scenarios 2 vs. 8 Comparison Accounting for Model Developments



- With the changes in how the model treats allowance allocations and deficit neutrality accounted for, we can compare scenarios 2 and 8 to show just the effect of the revised assumptions about international action have on consumption impacts.
- The consumption impacts are similar in the early years as the allowance allocations that return allowance value to households minimize the consumption impacts; however, after those allocations phase out, the higher allowance prices in scenario 8 result in greater consumption losses.
- The average annual cost per household (i.e. the 2010 through 2050 average of the net present value of the per household consumption loss) changes from $68 in scenario 2 with the revised approach for allowance allocations, real deficit neutrality, and MIT international assumptions; to $74 in scenario 8 with the revised approach for allowance allocations, real deficit neutrality, and the G8 international action assumptions.

Consumption Loss From Reference (IGEM)

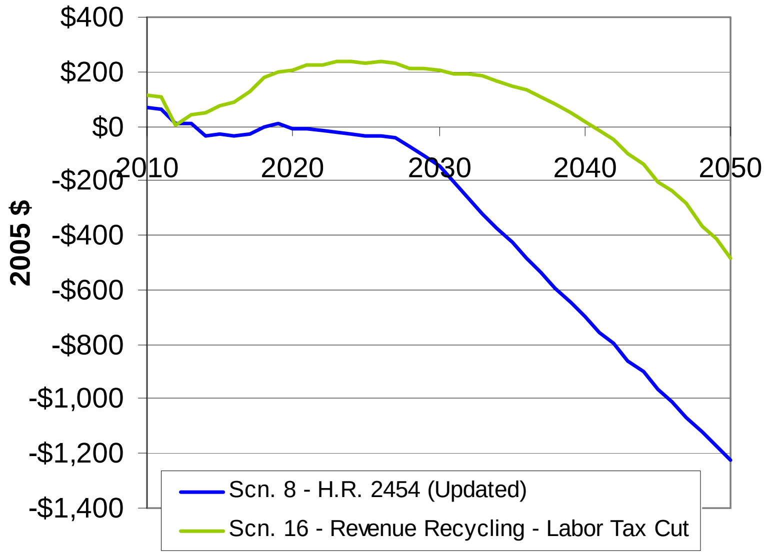
Scenarios 2 vs. 8 Comparison Accounting for Model Developments

	IGEM	2015	2020	2030	2040	2050
Scn. 1 - Reference	Ref. Consumption per Household	$75,531	$80,507	$91,686	$105,202	$119,168
H.R. 2454 - Scn. 2	% Change	-0.03%	-0.10%	-0.30%	-0.55%	-0.77%
	Consumption Loss per Household ($)	-$21	-$84	-$277	-$582	-$912
	NPV Cost per HH ($)	-$16	-$49	-$99	-$128	-$123
	Average Annual NPV cost per Household			**-$80**		
H.R. 2454 - Scn. 2 - Revised Subsidies & Nominal G	% Change	-0.05%	-0.01%	-0.10%	-0.51%	-0.79%
	Consumption Loss per Household ($)	-$34	-$11	-$94	-$532	-$937
	NPV Cost per HH ($)	-$25	-$7	-$34	-$117	-$127
	Average Annual NPV cost per Household			**-$54**		
H.R. 2454 - Scn. 2 - Revised Subsidies & Real G	% Change	-0.04%	-0.02%	-0.20%	-0.58%	-0.86%
	Consumption Loss per Household ($)	-$30	-$13	-$180	-$607	-$1,021
	NPV Cost per HH ($)	-$23	-$8	-$65	-$134	-$138
	Average Annual NPV cost per Household			**-$68**		
Scn. 8 - H.R. 2454 (Updated)	% Change	-0.04%	-0.01%	-0.16%	-0.66%	-1.03%
	Consumption Loss per Household ($)	-$32	-$8	-$148	-$699	-$1,226
	NPV Cost per HH ($)	-$24	-$5	-$53	-$154	-$166
	Average Annual NPV cost per Household			**-$74**		

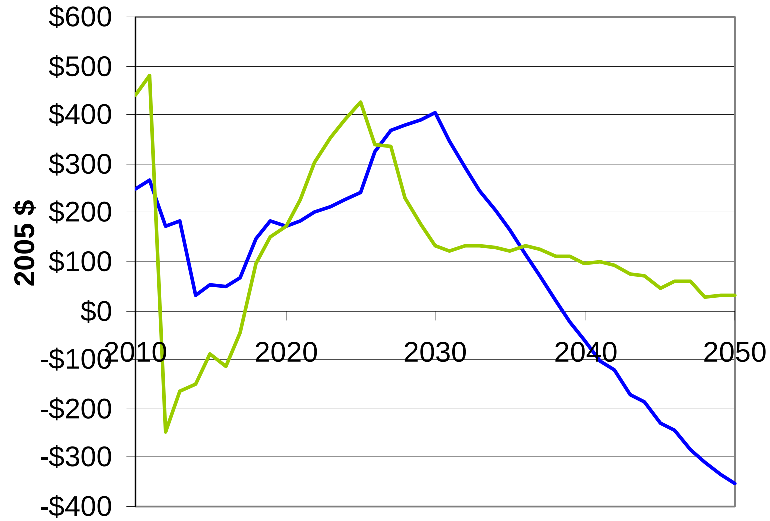
Full Consumption Impacts

Consumption vs. Full Consumption Welfare Impacts (IGEM)

Change in Consumption (Goods & Services) per Household



Change in Full Consumption (Goods & Services and Leisure) per Household



- Returning allowance value to households via a reduction in the labor tax rate increases consumption drastically relative to the other scenarios.
  - Returning allowance value through a decrease in the labor tax increases wages, encourages more work over leisure over the next several decades, lowers prices economy-wide relative to the lump sum case, and raises consumption and GDP;
  - Eventually, the increasing cost of mitigation reduces the real value of wages, reversing the effect.
  - The distributional impacts of these allocation schemes are not analyzed here, since the model only has a single representative agent household. See the 'Near Term Incidence Analysis' section for details.
- Full consumption (including leisure) is also increased when allowance value is returned to households via a reduction in the labor tax rate, although the impact is not as dramatic as with consumption of goods & services.
  - The infinite time horizon equivalent variation in consumption is 33% smaller in scenario 16 than it is in scenario 8, and the infinite time horizon equivalent variation in full consumption is 20% smaller in scenario 16 compared to scenario 8.
  - The equivalent variation in full consumption is the present value of lifetime changes in household utility for full consumption (goods, services and leisure) valued at base case prices and interest rates. Alternatively, the equivalent variation in full expenditure is the present value of lifetime changes in household utility for consumption (goods and services only) valued at base case prices and interest rates.

Further Discussion (IGEM)

- The first stage of the household decision process is the allocation of full consumption over time, where full consumption is the consumption of both goods & services as well as leisure.
  - This intertemporal allocation of consumption is what results in a slight increase in consumption in the initial years of the policy.
  - Because the intertemporally optimizing households with perfect foresight in the model see higher prices in the future, they desire to consume relatively more today as compared to a more expensive future (additionally there can be less motivation to invest today for a less productive future).
  - This effect is common to all intertemporally optimizing CGE models (as opposed to recursive dynamic CGE models).
- 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, the compensated elasticity of labor supply, plays a dominant role in model outcomes, and in particular is the driving force behind the relatively large impacts of recycling auction revenues through reduced labor taxes in IGEM.
  - 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.
- The implication of this is that the gains and losses in consumption may be exaggerated due to the assumption about how labor supply responds to changes in the real wage.
  - Reviews of empirical studies suggest roughly 1/3 the responsiveness in IGEM (Fuchs et al 1991; Blundell et al1999), though a more recent study including labor force participation decisions suggest closer to 2/3 the responsiveness in IGEM (Fullerton and Metcalf 2001).
  - A sensitivity analysis using a less (1/3) responsive labor supply for a similar policy found both consumption gains and losses were more than 70% smaller than the base case (Jorgenson et al 2008).

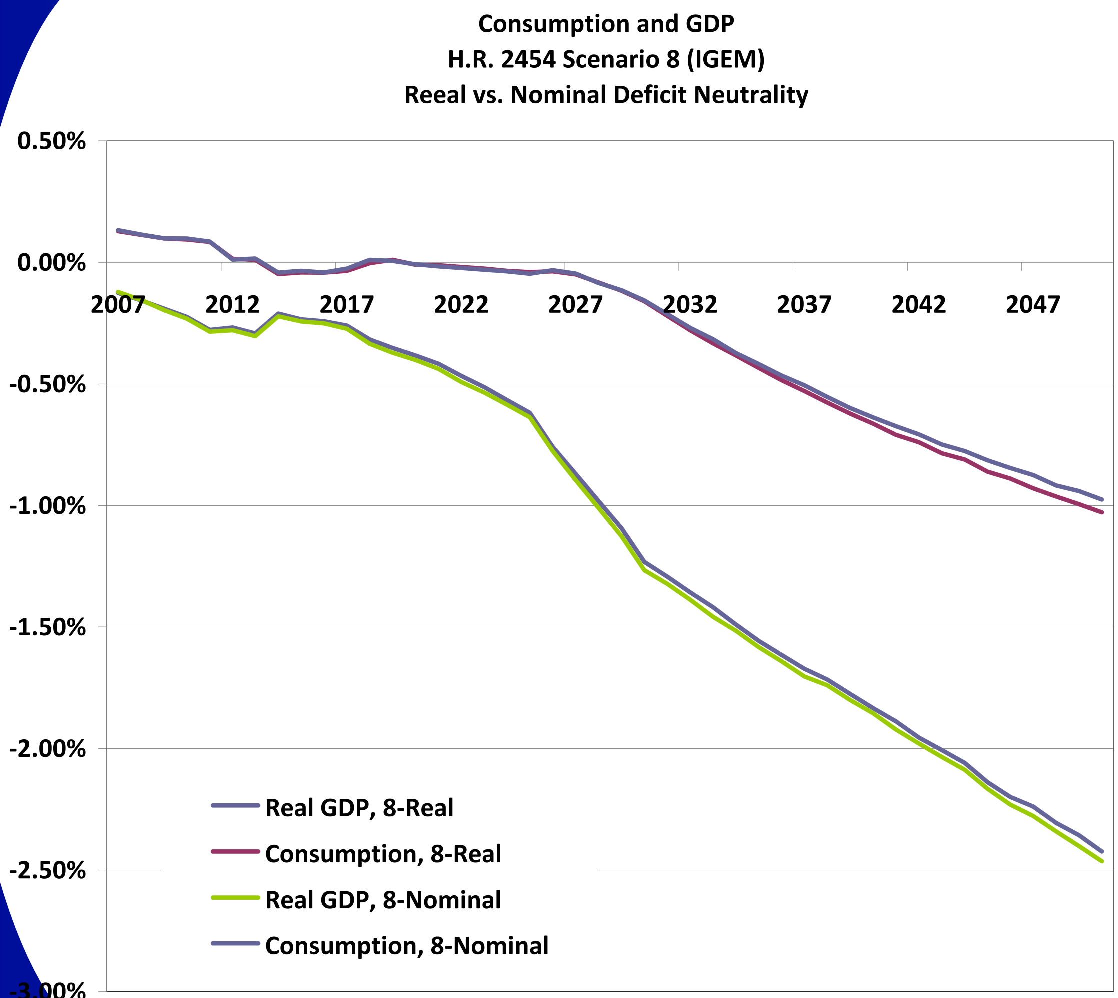
Consumption vs. Full Consumption Welfare Impacts

The Importance of Real vs. Nominal Deficit Neutrality (IGEM)

- As discussed in the IGEM model updates section of this appendix, how we choose to achieve deficit neutrality is key to the welfare rankings between the core policy case and the revenue recycling sensitivity. In preliminary IGEM runs, when deficit neutrality is achieved in nominal terms, revenue recycling through reduced labor taxes results in smaller consumption (goods & services) losses, but larger full consumption (goods & services and leisure) losses.
- This anomaly arises because government purchases crowd out consumption spending when deficit neutrality is targeted in nominal terms. The lower labor tax results in lower prices economy-wide as the pre-tax reservation wage now is lower. Lower prices combined with base case nominal government expenditures mean that real government purchases rise largely at the expense of real household purchases. That consumption cannot increase enough to offset the reduction in leisure (due to the increase in labor supply and demand) explains the full consumption and welfare effects. Were full consumption to be re-defined to cover government as well as consumption and leisure purchases, revenue recycling with the labor tax would be unambiguously welfare improving. As it stands the crowding out by governments leads to a counter-intuitive, yet entirely explainable, general equilibrium outcome.
- The anomaly in the welfare rankings disappears when deficit neutrality is targeted in real terms. The change in indexed real government purchases is directionally the same and numerically comparable in scenarios with real or nominal deficit neutrality. However, with real deficit neutrality, consumption is no longer crowded out and revenue recycling is welfare improving in terms of both consumption and full consumption.
- It should be noted that targeting nominal government purchases leads to both deficit and revenue neutrality, while targeting real purchases leads to only deficit neutrality.
- It should also be noted that there is no theoretically “correct” choice for achieving deficit neutrality – nominal versus real. This degree of freedom arises in IGEM because its numeraire price is the after-tax wage received by households, and not the GDP price deflator. The saving investment balance in IGEM is expressed in nominal terms and so it seems logical to deal with deficit neutrality in the budgetary sense. However, it is also true that budgets envision a particular market basket of physical goods and services that, within reason, should be maintained irrespective of price changes. Here deficit neutrality in real terms seems the logical constraint.

Labor Demand/Supply and Leisure Demand

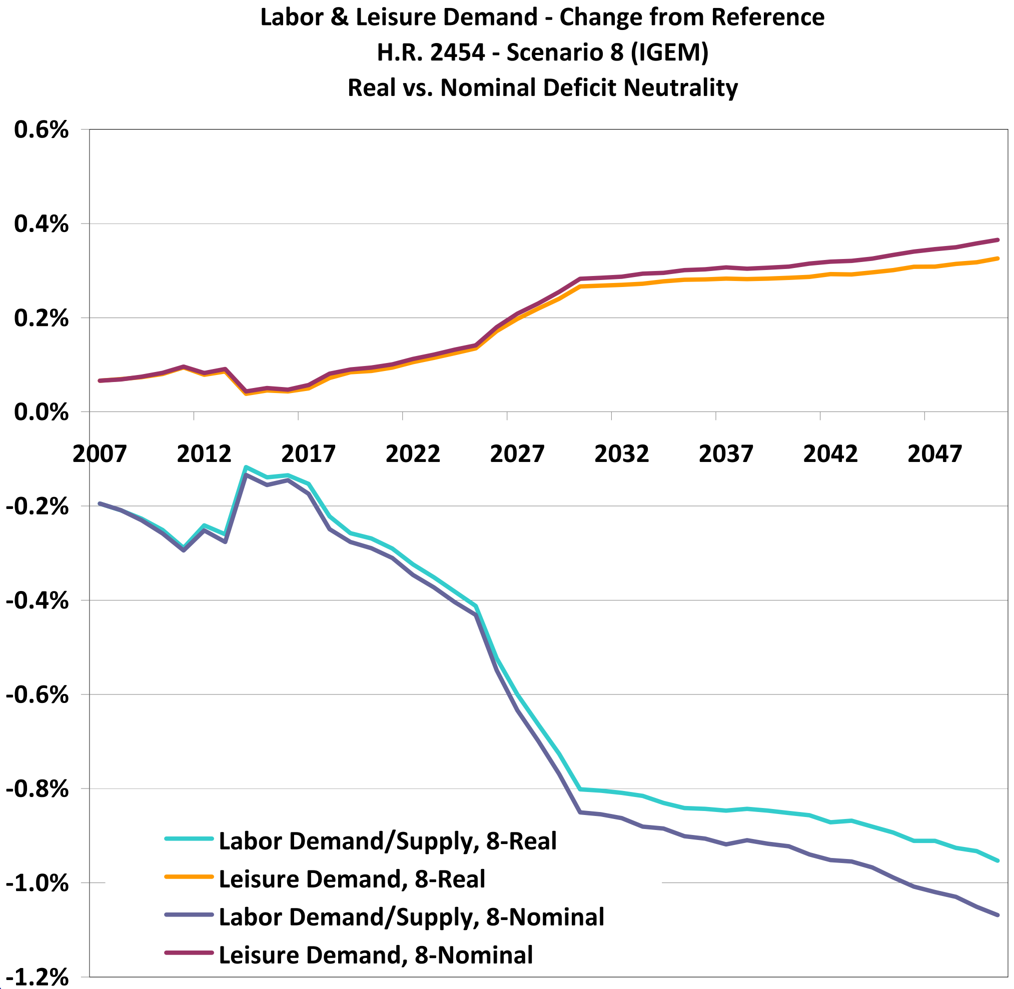
The Importance of Real vs. Nominal Deficit Neutrality (IGEM)



- In our policy analyses to date, there were no alternative recycling considerations beyond subsidies, rebates and lump sum redistributions. Deficit neutrality in the nominal budgetary sense was the operational assumption. Under lump sum recycling, nominal versus real matters very little in terms of the macroeconomic and inter-industry effects of climate policy, e.g. the magnitudes of GDP, consumption, investment, and other changes are quite similar. Indeed the distinction between nominal and real only matters significantly for the welfare rankings in simulation runs involving revenue recycling through adjustments in the marginal tax rate on labor income.

Labor Demand/Supply and Leisure Demand

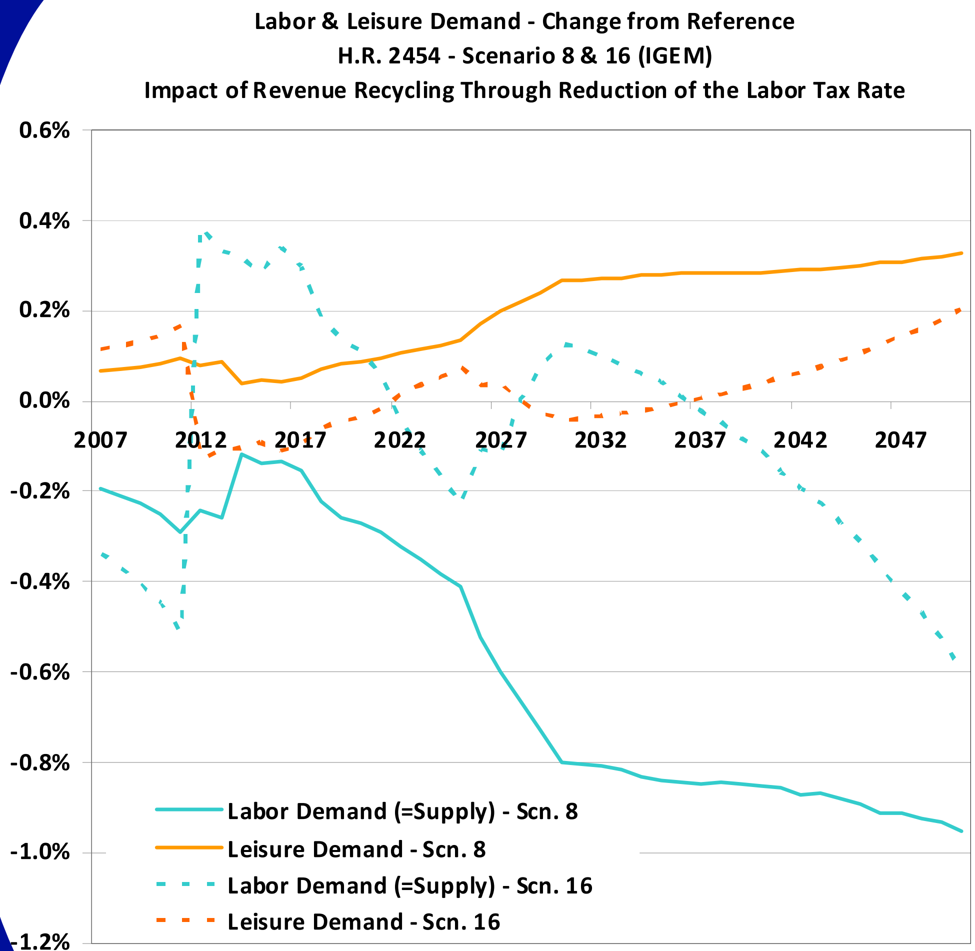
The Importance of Real vs. Nominal Deficit Neutrality (IGEM)



- The key differences in targeting real versus nominal government spending to achieve deficit neutrality lie in the labor-leisure results – the macro and industry impacts being virtually the same.
- Because governments are large employers, there occurs a larger reduction in labor demand (and supply) when nominal spending is restored to its base case levels (i.e., quantities must fall to offset higher prices).
- Thus, labor demand is lower so leisure demand is higher.
- When targeting real government spending, labor demand by governments essentially is unaffected and the new mix of labor and capital secures nearly identical macro behavior.

Labor Demand/Supply and Leisure Demand

The Impact of Revenue Recycling (IGEM)



- While the impact of the policy on consumption provides a useful metric of how the policy impacts households, the picture is incomplete because it does not take into account the impact on leisure.
- Full consumption accounts for household consumption of goods and services as well as consumption of leisure.
- While consumption is much less adversely impacted in scenario 16 with revenue recycling through a reduction in the marginal tax rate on labor, compared to scenario 8 where the allowance value that is returned to households is returned lump sum; the difference in full consumption is much less dramatic.
- The primary reason for this can be seen in the figure to the left. The reduced marginal tax rate on labor in scenario 16 causes households to substitute away from leisure and towards work and consumption of goods and services relative to scenario 8. When looking just at consumption of goods and services, the benefit of greater labor supply and greater earnings show up in the form of greater consumption of goods and services; however, the effect of reduced leisure does not show up in consumption. Full consumption captures both of these effects.

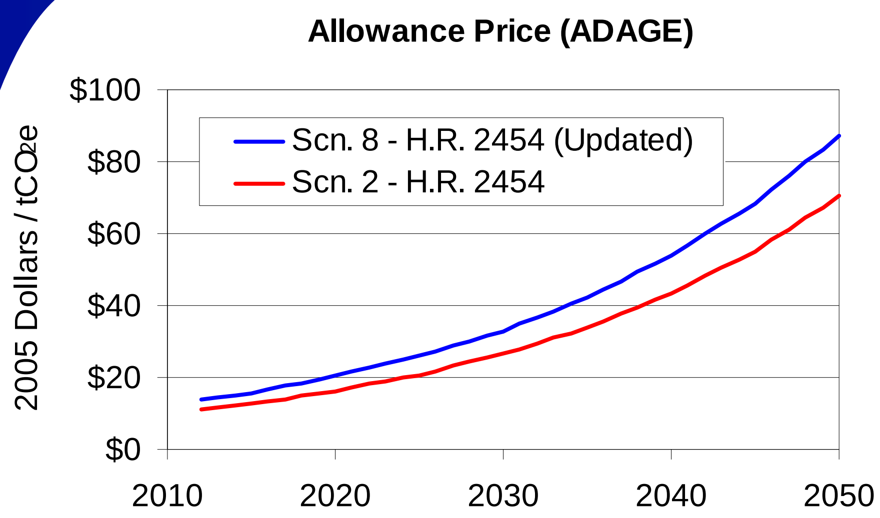
References

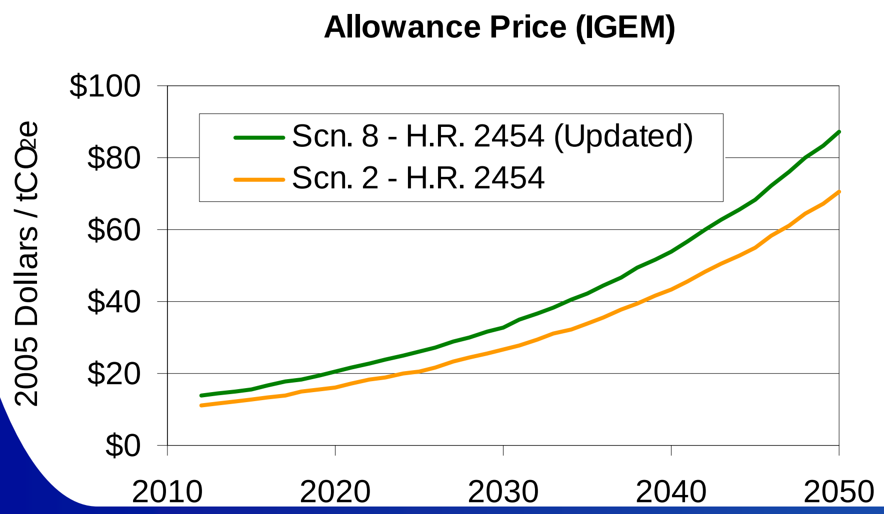
- Blundell, R. and T. MaCurdy. 1991. Labor Supply: A Review of Alternative Approaches. In *Handbook of Labor Economics*, edited by O. Ashenfelter and D. Card. New York: Elservier
- Fuchs, V.R., A.B. Krueger, and J.M. Poterba. 1998. Economists Views about Parameters, Values and Policies: Survey Results in Labor and Public Economics. *Journal of Economic Literature* 36: 1387-425
- Fullerton, D., and G. Metcalf . 2002. Cap and Trade Policies in the Presence of Monopoly and Distortionary Taxation. *Resource and Energy Economics* 24: 327-347.
- Jorgenson, D.W., R.J. Goettle, P.J. Wilcoxen, and M.S. Ho. 2000. The Role of Substitution in Understanding the Costs of Climate Change Policy Washington: The Pew Center on Global Climate Change.
- Jorgenson, D.W., R.J. Goettle, P.J. Wilcoxen, and M.S. Ho. 2008. The Economic Costs of a Market-based Climate Policy. Washington: The Pew Center on Global Climate Change.

Comparison to EPA's Analysis of H.R. 2454

Comparison to EPA's June 23, 2009 Analysis of H.R. 2454

Allowance Prices





Scn 8 - Updated H.R. 2454

	2015	2030	2050
ADAGE	$16	$33	$87
IGEM	$15	$32	$85

Scn 2 - H.R. 2454

	2015	2030	2050
ADAGE	$13	$27	$70
IGEM	$13	$26	$69

- Scenario 8 in EPA's supplemental analysis of H.R. 2454 differs from scenario 2 from the June 23, 2009 analysis of H.R. 2454 in two respects:
  - The June analysis used assumptions about climate policies adopted by other countries based on the MIT report, "Assessment of U.S. Cap-and-Trade Proposals," whereas this supplemental analysis used assumptions based on the recent G8 agreement.
  - In the June analysis, ADAGE used a constraint on nuclear power based on the CCSP SAP2.1a report; whereas in this supplemental analysis, ADAGE used a joint constraint on Nuclear and CCS taken from IPM.
- Compared to scenario 2, allowance prices are 25% higher in ADAGE and 23% higher in IGEM in scenario 8.
- The differences in allowance prices between scenario 2 from the June analysis and scenario 8 from this analysis are primarily due to the change in international assumptions.

Comparison to EPA's June 23, 2009 Analysis of H.R. 2454

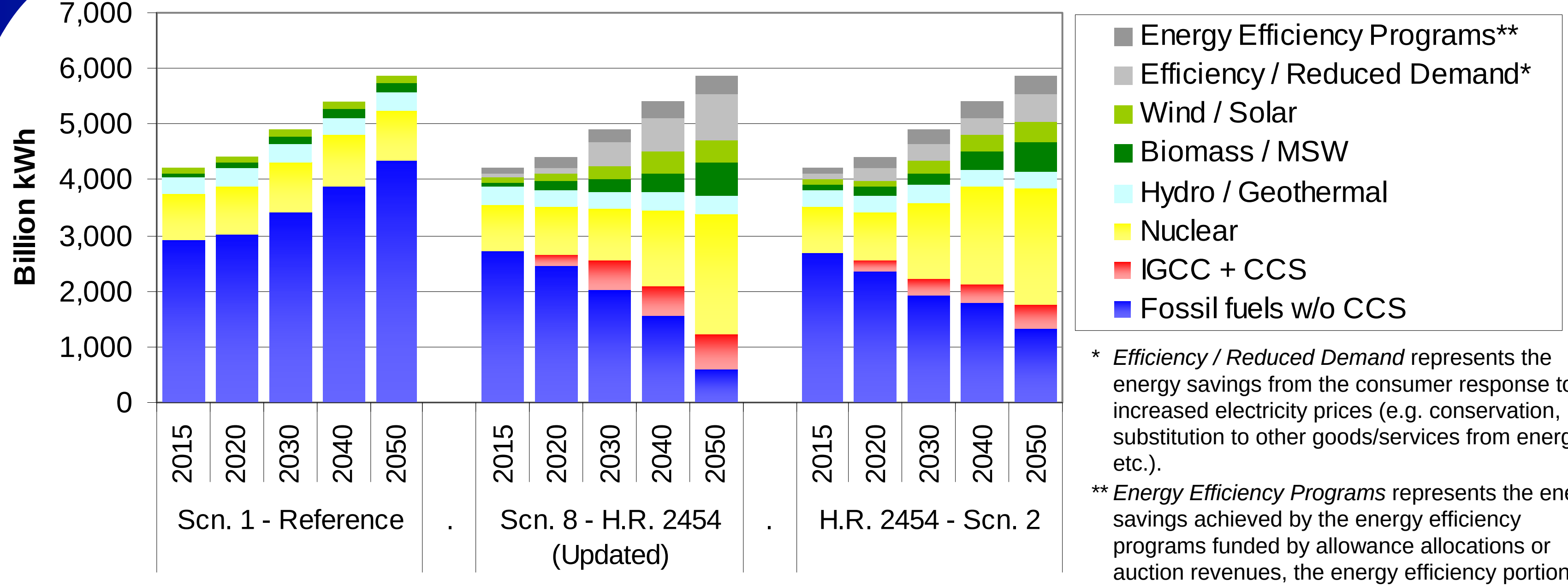
Consumption Impacts (ADAGE)

	ADAGE	2015	2020	2030	2040	2050
Scn. 1 - Reference	Ref. Consumption per Household	$92,202	$99,888	$117,973	$140,233	$164,348
H.R. 2454 - Scn. 2	% Change	-0.08%	-0.11%	-0.31%	-0.55%	-0.78%
	Consumption Loss per Household ($)	-$70	-$105	-$366	-$771	-$1,287
	NPV Cost per HH ($)	-$53	-$61	-$132	-$170	-$174
	Average Annual NPV cost per Household			**-$111**		
Scn. 8 - H.R. 2454 (Updated)	% Change	-0.01%	-0.06%	-0.36%	-0.67%	-0.97%
	Consumption Loss per Household ($)	-$13	-$62	-$427	-$944	-$1,599
	NPV Cost per HH ($)	-$10	-$37	-$153	-$208	-$216
	Average Annual NPV cost per Household			**-$117**		

- The average annual cost per household is the 2010 through 2050 average of the net present value of the per household consumption loss.
- The costs above include the effects of higher energy prices, price changes for other goods and services, impacts on wages, and returns to capital. Importantly, the cost estimates reflect the value of emissions allowances returned lump sum to households, which offsets much of the cap-and-trade program's effect on household consumption.
- 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.

Comparison to EPA's June 23, 2009 Analysis of H.R. 2454

Electricity Generation (ADAGE)



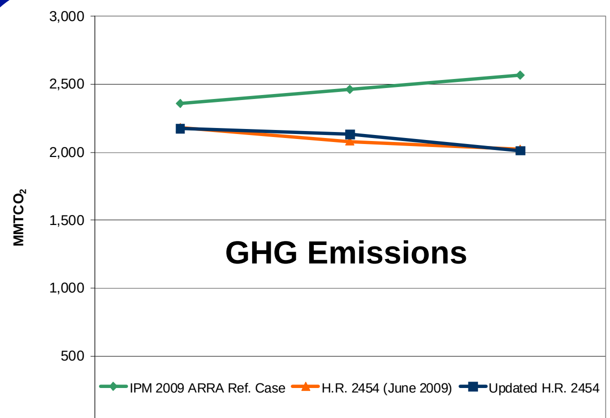
* *Efficiency / Reduced Demand* represents the energy savings from the consumer response to increased electricity prices (e.g. conservation, substitution to other goods/services from energy, etc.).

** *Energy Efficiency Programs* represents the energy savings achieved by the energy efficiency programs funded by allowance allocations or auction revenues, the energy efficiency portion of the RES, and the impact of revised building codes.

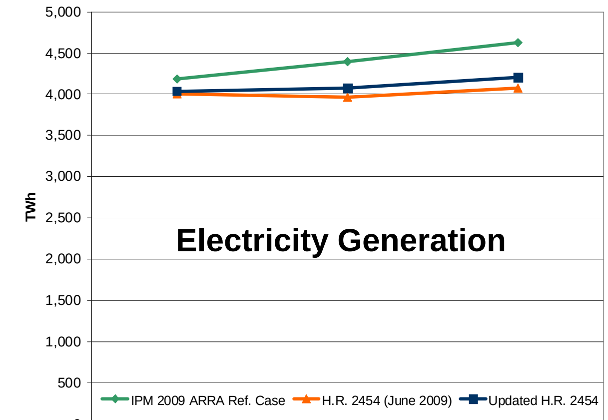
- The primary differences in the electricity generation mix between scenario 8 in this analysis and scenario 2 from the June 23, 2009 H.R. 2454 analysis are due to the higher allowance prices in scenario 8.
- Additional differences arise because of the new joint constraint on nuclear and CCS based on the IPM constraints used in scenario 8 of this analysis.
  - Under these new constraints, the CCS bonus allowances in the early years promote new CCS capacity at the expense of new nuclear capacity.
  - The old constraints did not include this interaction between nuclear and CCS constraints, so additional CCS driven by the bonus allowances did not reduce the amount of nuclear that could be built.

Appendix 7: Additional Information on Near Term Electricity Sector Modeling (IPM)

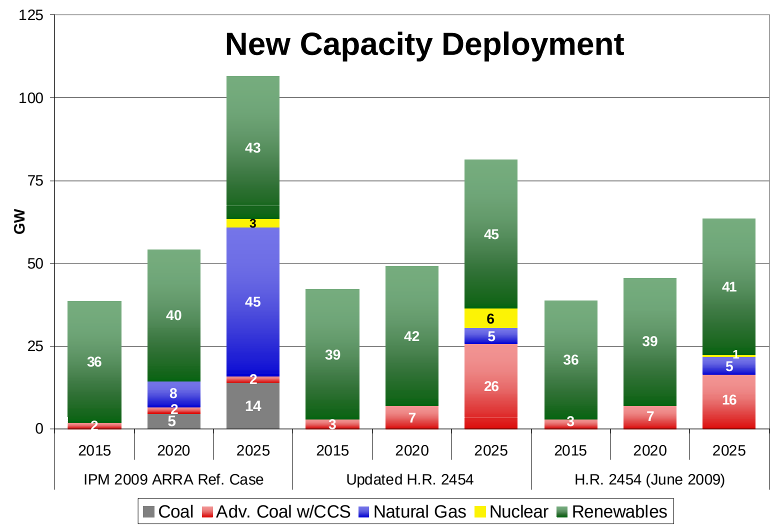
Comparison to June 2009 H.R. 2454 Analysis



	2015	2020	2025
IPM 2009 ARRA Ref. Case	2,359	2,462	2,566
H.R. 2454 (June 2009)	2,180	2,081	2,024
Updated H.R. 2454	2,177	2,131	2,013



	2015	2020	2025
IPM 2009 ARRA Ref. Case	4,184	4,395	4,623
H.R. 2454 (June 2009)	4,001	3,964	4,074
Updated H.R. 2454	4,038	4,071	4,204



More Details on Key Updates Included in IPM 2009 ARRA Ref. Case

- **Electricity Demand Growth:**
  - EPA uses the AEO 2009 ARRA update as the basis for future electricity demand projections for the reference case (roughly 0.9%).
  - ARRA lowered the AEO 2009 projection of electricity demand growth slightly, but not as significantly as the decline in projected electricity demand growth between AEO 2008 (~1.5%) and AEO 2009 (~1%).
- **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 and Biomass Supply:**
  - Renewable capacity prior to 2012 is calibrated to the AEO 2009 ARRA 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.
  - New supply curves and non-power-sector demand for biomass were adopted from the AEO 2009 ARRA update.
- **CCS in Reference Case Projection:**
  - The AEO 2009 ARRA 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 2009 ARRA 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 H.R. 2454 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 energy savings component of CERES.
- 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.
- The CCS early deployment provisions, along with the bonus allowance provision for CCS, incentivize penetration of *new* coal capacity with CCS technology.
  - New coal with CCS is projected to penetrate in 2015 and continue deploying through 2025 in response to the bill's early deployment program and the financial incentives as part of the bonus.
  - Some *existing* coal plants find it economic to retrofit with CCS starting in 2020, assisted by the CCS bonus.
- Some oil/gas steam units are projected to retire, compared with the reference case, and some additional coal units also retire. Some of these units may be "mothballed," retired, or kept running to ensure generation reliability. The model is unable to distinguish among these potential outcomes. Most uneconomic units are part of larger plants that are expected to continue generating.
- 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.

Analysis of CCS Technology

- The CCS bonus provision is modeled as a fixed incentive in IPM. H.R. 2454 directs EPA to conduct a reverse auction to set the per-ton value of bonus allocations beyond the first 6 GW, which could potentially optimize the incentive necessary to spur additional deployment of CCS. The total bonus is set as a portion of all allowances, starting at 1.75% of allowances and rising to 5% through 2050.
- EPA also has discretion to set the value of additional bonus allocation if a reverse auction is infeasible. For purposes of this analysis, the model assumed a range of fixed values to reflect possible values of CCS bonus support.
- Allowance prices in the updated H.R. 2454 analysis are higher than in the original H.R. 2454 analysis, resulting in fewer allowances that must be distributed as part of the fixed incentive and thus more deployment of incentivized CCS.
- H.R. 2454 also contains complementary measures for renewable energy, which were not modeled in ADAGE. This provision could dampen allowance prices, which would lessen the economic incentive for CCS in the longer term (both by displacing the fossil share of new necessary generation and by reducing the cost of emitting).
- 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.
- Cost assumptions are basically uniform nationwide in IPM, but in reality, there is likely to be more variability in risk profiles, capital costs, and transport/storage costs that would result in a wider range of CCS costs than IPM currently reflects.*

* The next version of the EPA reference case using IPM will reflect more regional variability for CCS costs, particularly transportation and storage costs, and updated capital costs. 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.

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

- H.R. 2454 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 (starting at 1.75% of allowances and rising to 5% through 2050).
- The reverse auction was not specifically included in IPM. Instead, some scenarios were modeled with a range of bonus values to simulate a spectrum of incentives that could result in an actual reverse auction.
- In all scenarios, the first 3 GW of CCS capacity receive a $100 per ton bonus and the next 3 GW receive $90 per ton, since H.R. 2454 sets the bonus level for the first 6 GW of CCS deployed.
- For subsequent capacity, the core IPM H.R. 2454 scenario has a bonus of $40 per ton. 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.
- 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 the Combined Efficiency and Renewable Electricity Standard (Cont'd)

- The RES portion of CERES increases deployment of renewable capacity and drives a more substantial increase in renewable generation than the cap-and-trade program yields on its own.
  - The RES also reduces average natural gas prices and gas consumption by about 1-3% throughout the model's time horizon, compared to cap-and-trade alone.
  - Wholesale electricity prices fall by 1-2% through 2020 and return to about the same level in 2025. Initial analysis indicates that retail electricity prices rise slightly relative to the core H.R. 2454 scenario in later years.
  - The impact on a household's electricity bill, however, would be offset to the extent that efficiency gains would reduce overall power consumption.
- H.R. 2454 includes an alternative compliance payment (ACP) of $25 per MWh. This updated analysis projects that the federal Renewable Electricity Credit (REC) price reaches that level in 2020 but falls back to about $4.70 per MWh in 2025.
  - Use of the ACP in 2020 is very limited (accounting for about 3.4% of the total CERES compliance burden).
  - H.R. 2454 also allows States to petition for the right to meet up to 40% of the CERES with electricity savings. Additional use of efficiency to meet the standards would lower federal Renewable Electricity Credit (REC) prices, potentially reducing use of the ACP.
  - This analysis does not take into account the effect of ACP payments, which H.R. 2454 reserves for States to increase the deployment of renewables or increase electricity savings.

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 (4 GW, or 8 projects)		N/A	Hardwire (4 GW, or 8 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 variable power sources (e.g., wind).

* Post 2015 new CCS constraints exclude the 4 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 2009 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.

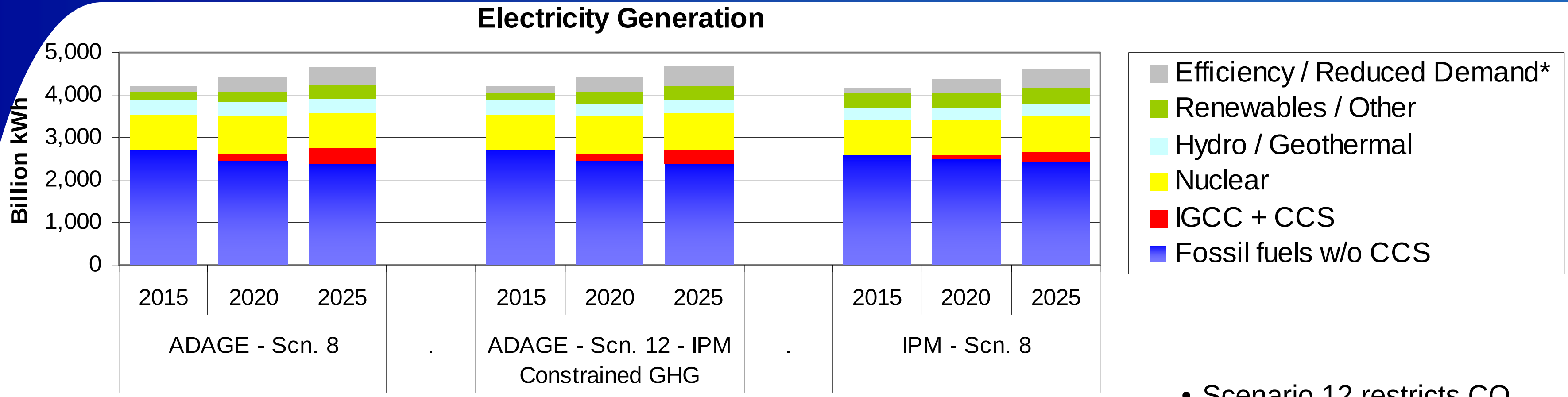
General IPM Modeling Limitations

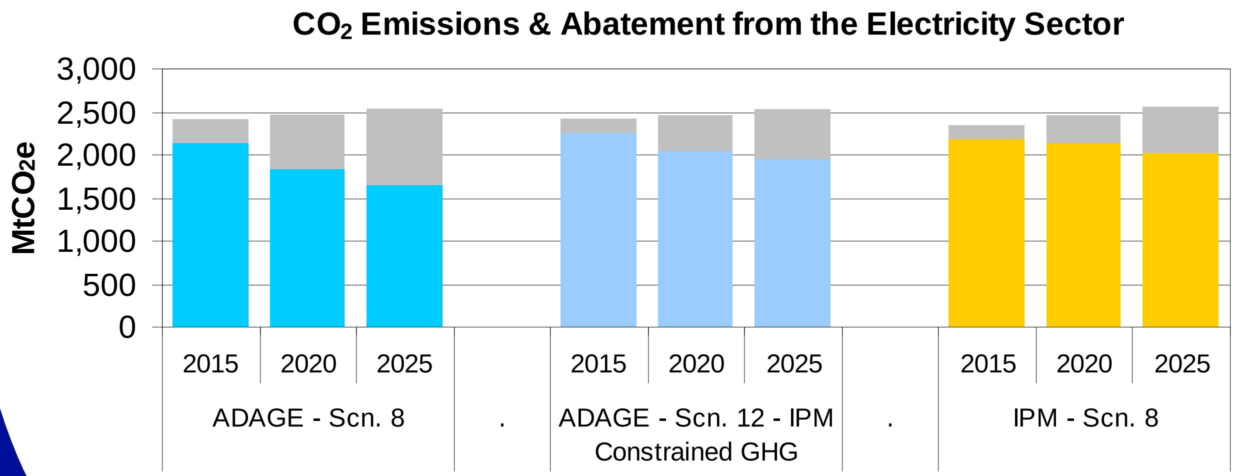
- The EPA version of the IPM model focuses on the near-term impacts and only produces reportable results through 2025.
  - Model does not see longer term changes in electricity demand and CO_2 allowance prices (due to lowering of the cap over the entire timeframe of the bill).
  - This will affect projections 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 to 20 years 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.
- There are non-economic considerations for significant expansion of new coal with CCS, nuclear power, and renewables which are not reflected in IPM, such as the need for new transmission, siting concerns, and permitting.
- IPM assumes a 60 year life for nuclear power plants.

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 12 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 4% higher than in scenario 8 and international offsets usage increases by 23%.

Appendix 8: 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

Contact Information

The analysis was conducted by EPA's Office of Atmospheric Programs.

Contact: Allen A. Fawcett
Tel: 202-343-9436
Email: fawcett.allen@epa.gov

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