WORKING PAPER

A Path to Greenhouse Gas Reductions in the United States: Economic Modeling of Interim National Targets

Prepared by the Nicholas Institute for Environmental Policy Solutions, Duke University

Brian Murray[1]
Martin Ross[2]
Etan Gumerman[3]

[1] *Nicholas Institute for Environmental Policy Solutions, Duke University*
[2] *RTI International*
[3] *Independent Consultant*

NICHOLAS INSTITUTE
FOR ENVIRONMENTAL POLICY SOLUTIONS
DUKE UNIVERSITY

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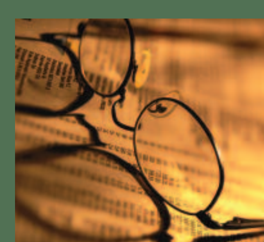
September 2007
NI WP 07-06







A Path to Greenhouse Gas Reductions in the United States: Economic Modeling of Interim National Targets*

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Abstract

Momentum is building in the U.S. to consider mandatory caps for greenhouse gas emissions. The U.S. Senate has expressed support for such action if it will not cause significant harm to the U.S. economy and will engage other countries. This position motivates the need for economic assessment of potential GHG restrictions on the U.S. economy. Toward that end, this study employs a computable general equilibrium model of the U.S. integrated into the global economy (ADAGE) and a detailed model of the U.S. energy sector (NI-NEMS) to examine the broad and deep economic implications of interim-term GHG cap-and-trade programs across sectors and regions of the U.S. economy over time. Interim target scenarios hold U.S. emissions to either 1990 or 2005 levels in the year 2020 and hold this level fixed beyond that. These 2020 emission targets are in the range of those now being considered by the U.S. Congress, though several of the Congressional proposals call for continued cuts beyond 2020. This study therefore provides a bounding assessment of the initial pathway to GHG reductions, one which can provide a first order assessment of "economic harm" and provides a platform for gauging the implications of longer term cuts should they be applied. Results suggest rather modest macroeconomic impacts on the U.S. economy of the GHG targets considered, though impacts tend to be concentrated, as expected, in the more energy intensive sectors. The electric power sector has some of the least costly options for reducing emissions through decarbonization of power generation and could end up being net sellers of GHG allowances to other sectors in a cap-and-trade program, depending on how the initial GHG allowances are allocated. In addition to synthesizing economic results from the interim targets modeled, the paper discusses the implications for longer term and deeper cuts beyond those considered here.

** The authors gratefully acknowledge the comments of Eric Williams, Richard Newell, and Tim Profeta, as well as the feedback of corporate participants in the Nicholas Institute Climate Policy Process. Any errors or omissions are the responsibility of the authors. This work is an analytical assessment of policy options and not advocacy of policy positions by the Nicholas Institute or Duke University.*

1. INTRODUCTION

Since 2003, when legislation was first introduced in the U.S. Senate calling for mandatory restrictions on the emission of greenhouse gases, momentum has been building for a federal mandate to cap greenhouse gases (GHGs). The fall elections of 2006 seemed to provide the now-proverbial "tipping point" that has accelerated momentum toward such a mandate. While the tipping point analogy might derive from the notion that Democrats gained control of both houses of Congress, federal climate policy proposals include sponsors from both parties. Just nine days after the 2006 election, Senator John McCain (R-Arizona) announced that he planned to reintroduce with Senator Joseph Lieberman (D-Connecticut) a revised version of their Climate Stewardship Act that they had previously introduced, arguing that the time was here to implement a federal GHG mandatory policy. Additional proposals by other legislators from both political parties have since been introduced.

One of the critical elements of political viability for a federal climate bill is whether it is deemed economically sound. Toward this end, in 2005 the U.S. Senate passed the following *Sense of the Senate* resolution[1]

> *Congress should enact a comprehensive and effective national program of mandatory, market-based limits and incentives on emissions of greenhouse gases that slow, stop, and reverse the growth of such emissions at a rate and in a manner that--*
>
> *(1) will not significantly harm the United States economy; and*
> *(2) will encourage comparable action by other nations that are major trading partners and key contributors to global emissions.*

In essence, the Senate recommended mandatory greenhouse gas limits as long as such limits do not cause great economic distress in the United States and do not let other key emitting nations off the hook. While this leaves open the question of what constitutes

[1] Congressional Record – Senate – **S7053** - June 22, 2005

"significant economic harm," it nonetheless creates a need for rigorous economic studies of alternative greenhouse gas limits for the U.S. economy. The purpose of this paper is to help fill that need.

Because they are directly linked to fossil fuel use, GHG regulations have the most direct impacts on the energy sector of the economy. However, due to the magnitude of the policy interventions needed to adequately address climate change risks and the pervasiveness of energy use in economic activities, very few types of policies have as much potential to cut across the entire economy as much as climate policy does. This pervasiveness calls for economic analysis tools that both examine effects within the energy sector and across all sectors of the economy. Using two economic models, one a model of the United States in a global economy that captures important macroeconomic implications and cross-sector feedbacks of such far-reaching policies, and the other a model of the U.S. energy markets that provides more detail on changes within each sector necessary to meet a set of greenhouse gas limits. The limits are met with a cap-and-trade policy that allocates emission allowances equal to the GHG cap. This allows parties subject to the cap to trade allowances among themselves at a specified allowance price, guiding mitigation toward the most cost-effective reduction opportunities in the economy.

The paper continues with a summary that further describes the analysis scenarios and provides an overview of the underlying models' structure, conceptual foundation, scope, and data. Each of the two models, ADAGE and NI-NEMS, have separate more extensive and detailed documentation to which the reader is directed if they wish to explore the model details further. Following the model descriptions, economic and emission results are presented for a reference business-as-usual scenario and two policy scenarios. Economic results include macroeconomic results nationally and for key regions, as well as those focused on energy sector outcomes. The paper concludes with a summary and discussion of policy inferences that can be drawn.

2. ANALYSIS OVERVIEW

The purpose of this exercise is to better understand potential economic responses to an interim national GHG emission target for the U.S. within and across key economic sectors and regions. By looking at an interim target (Year 2020), we focus on efforts to get a national program off the ground that aims to slow, stop, and begin to reverse national emissions in the near-term. Interim Targets potentially form the basis for a broader program of deeper cuts in the long-run, should policymakers so choose. Several of the current policy proposals being considered in Congress at this writing have GHG targets that go beyond 2020 (e.g. to 2050), but they vary widely in their stringency, with some proposals calling for an essential flattening of emissions to current levels, and others calling for very steep cuts (up to 80% below current levels by 2050). The proposed bills have been under intense debate at this time, and it is difficult to tell which long-term targets are more likely to become law or whether legislation will be phased-in with a series of interim targets. Either way, most of the proposals now under consideration have emissions targets for 2020 that fall into the range examined here (see Paltsey et al, 2007. Thus we believe the interim bounding scenarios in this paper capture a reasonable range of options for the slow-and-stop phase of any longer term strategy.

The flow of the analysis is illustrated in Exhibit 1. The following targets are set for the entire economy and include all GHGs.[2] They are set for 2020 and held constant after that[3]:

- "Flat 2005": 2005 emission levels (1,970 MMTC ; 7,223 $MMTCO_2$)
- "Flat 1990": 1990 emission levels (1,675 MMTC ; 6,142 $MMTCO_2$)

[2] The models differ slightly in how they handle the non-CO2 gases, with one model (ADAGE) directly modeling these emissions by sector and the other model (NI-NEMS) using an "offset supply function" to simulate the availability of the non-CO2 gas reductions to offset CO2 emissions at different allowance prices.

[3] The 2020 targets are held in place because the initial analyses were focused on intermediate targets. Of course, economic responses before 2020 will depend in part on expectations of post-2020 targets. That issue will be discussed later in the paper.

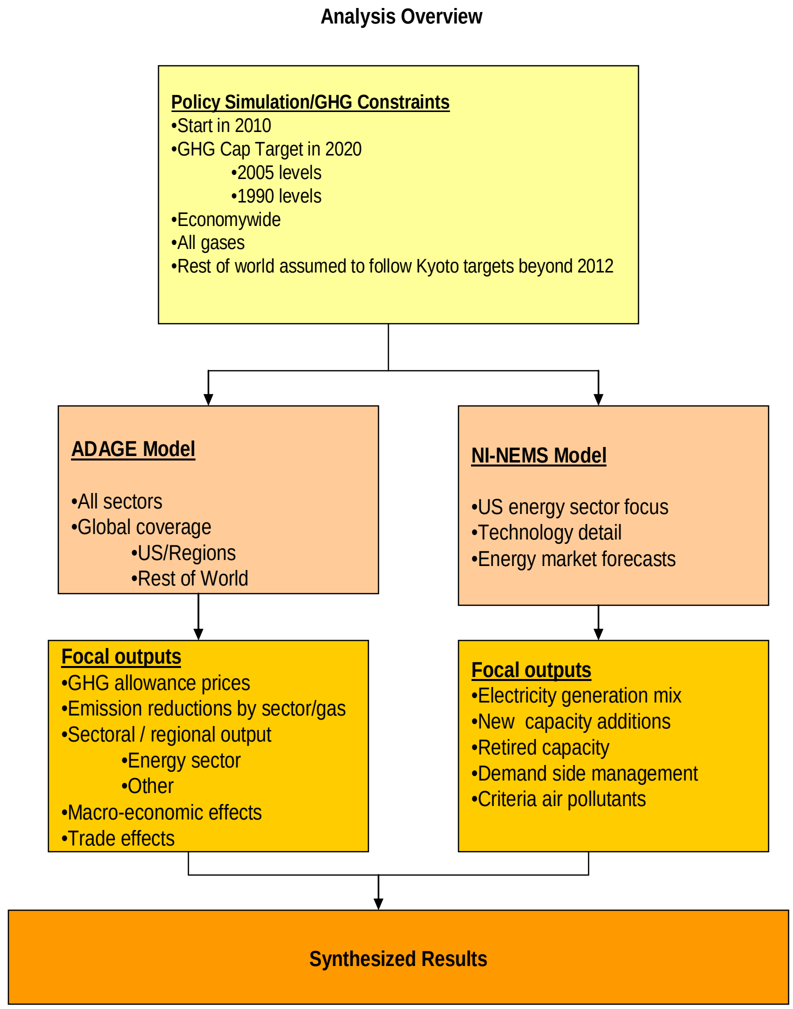


Exhibit 1. Analysis Flow from Policy Inputs to Model Outputs

Exhibit 2 shows these emissions scenarios over time relative to the reference case or "business-as-usual" (BAU). The ratcheting down toward the 2020 target starts in 2010. In the ADAGE model, which captures the global economy and GHGs, it is also assumed that other countries meet their commitments under the Kyoto Protocol and hold those levels after 2012. In these analyses, the national emission targets can be achieved through the trading of emission allowances across parties to achieve the most economically efficient solution.

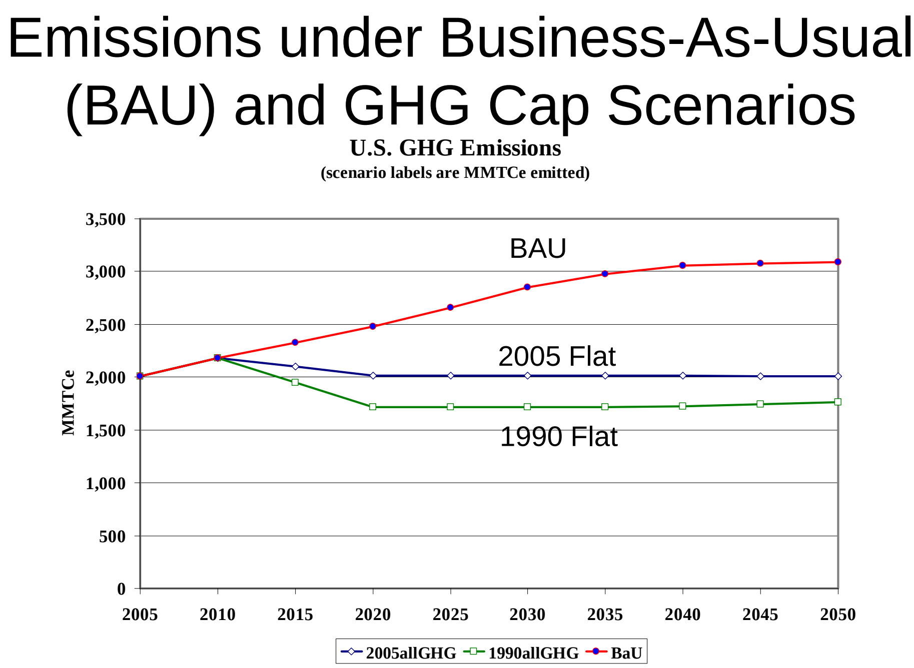


Exhibit 2. Emission Scenarios

These emissions targets are used as inputs to two economic models: ADAGE, developed by RTI International, and NI-NEMS, a version of the Energy Information Administration (EIA) of the U.S. Department of Energy's National Energy Modeling System (NEMS). NEMS is used by EIA to develop the national Annual Energy Outlook (AEO).[4]

The ADAGE and NI-NEMS models were chosen for the analysis to take advantage of the complementary methods by which they analyze GHG policies. ADAGE and other computable general equilibrium (CGE) models are typically referred to as "top-down" models because they model the larger economic system in a comprehensive and theoretically consistent manner. Such top-down models handle important economic feedback effects of the policy, and ensure that all flows within the economy balance out, but generally provide less detail on the inner workings of specific sectors and technologies. ADAGE differs in some regards from the typical CGE model in that it

[4] NEMS was customized for use by the Nicholas Institute (NI) in this analysis, hence the name *NI-NEMS*.

delves into more detail in the energy sector because of its use in climate policy analyses, but is still best described as a top-down model.

Alternatively, NI-NEMS would be more accurately described as a “bottom-up” model, with a primary focus on technology characteristics and choices within the energy sector. NI-NEMS forecasts the effects of particular technologies on energy market prices and production. This captures, for instance, how a GHG policy might change the specific technologies that producers use to make electricity (e.g., conventional coal, IGCC, solar, wind, biomass), how GHG emissions constraints affect the nature and timing of plant replacement decisions, and how all this affects demands and prices for fuel commodities such as coal, natural gas, and oil.

Due to differences in model features, we focus on different aspects of the reported outputs from each model. We use ADAGE results primarily for broader economic measures such as Gross Domestic Production (GDP), employment, sectoral distribution of emission reductions, and the GHG allowance price in an economywide cap-and-trade system. We use NI-NEMS for results related to changes in generation mix for electric power, specific decisions on new build capacity and technology use, and demand side responses in the energy and transportation sectors.

Relying on both top-down and bottom-up models to inform policy decisions is a common analytical practice. For instance, the U.S. Environmental Protection Agency (EPA) uses ADAGE and other CGE models to assess the economywide and interregional impacts of climate policy options and other forms of pollution control policy, but EPA also relies on detailed bottom-up models of the electric power sector (e.g., the IPM model developed by ICF Inc.) to delve into more sectoral detail. This dual approach has been used by EPA to examine recently promulgated clean air rules such as the Clean Air Interstate Rule (US EPA, 2005a) and Regional Haze Rule (US EPA 2005b), along with Senate Bill S. 280, the Climate Stewardship and Innovation Act of 2007 (US EPA 2007).

We now proceed with descriptions of the individual models and how they were applied to generate the analysis reported herein.

3. MODEL DESCRIPTIONS

ADAGE[5]

The RTI *Applied Dynamic Analysis of the Global Economy* (ADAGE) model is a dynamic computable general equilibrium (CGE) model capable of examining many types of economic, energy, environmental, climate-change mitigation, and trade policies. 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 then used to describe economic behaviors of these agents. ADAGE typically solves in 5-year time intervals from 2005 to 2050, and assumes that economic agents will anticipate future policies and act to mitigate their impacts. Emissions and abatement costs for six types of GHG are included in the model - CO_2, CH_4, N_2O, HFCs, PFCs, SF_6.

ADAGE is designed with an integrated, modular structure that allows it to consider both international and domestic policies, and evaluate their effects on regions and states within the United States. Computational constraints tend to limit the total size of nonlinear, intertemporally-optimizing CGE models (which is one of the motivating factors for adopting an integrated modular design). Thus, when examining energy or climate policies, data in the model are usually aggregated to represent five primary energy industries (with multiple forms of electricity generation) and five other industries (chosen based on their energy consumption patterns):

- Coal
- Crude Oil
- Electricity (*multiple types*)
- Agriculture
- Energy-Intensive Manufacturing
- Other Manufacturing

[5] The version of ADAGE used for this analysis was the version in place in Winter 2006-2007. The model has since been updated with more recent energy, greenhouse gas and economic data and more energy sector technological detail.

- Natural Gas
- Refined Petroleum
- Services
- Transportation Services

The international regions used in this analysis were selected to focus on the United States plus countries assumed to be participating in the Kyoto Protocol, along with other significantly emitting nations. Within the U.S., five regions were selected to preserve differences in electricity-generation technologies:

International

- United States
- Europe
- Canada
- Japan
- China
- Rest of World

U.S. Regions

- Northeast
- South
- Midwest
- Plains
- West

The economic data used to describe these regions and industries come from databases provided by the Global Trade Analysis Project-GTAP (https://www.gtap.agecon.purdue.edu/) and the Minnesota IMPLAN Group (http://www.implan.com/index.html). These data show production techniques and trade patterns, along with households' demands and income sources, in each region in the model. Energy data and various growth forecasts are taken from the International Energy Agency and the U.S. Department of Energy's EIA.

The theory and equations in ADAGE are based on other CGE models also designed to look at GHG emissions policies. Nested constant-elasticity-of-substitution (CES) equations are used to describe how manufacturing techniques or household behavior will change in response to the change in relative factor prices caused by such policies. Equations related to production technologies in ADAGE are largely based on the Massachusetts Institute of Technology's *Emissions Prediction and Policy Analysis*, or EPPA, model (see http://web.mit.edu/globalchange/www/eppa.html and Paltsev et al 2005). Researchers at MIT derived their CES equations and associated parameter estimates from a variety of empirical literature, expert elicitations, and "bottom-up" engineering studies. Beyond manufacturing technologies, the two models are different in regional scope and their representation of dynamics and households.

Data

The ADAGE model uses a variety of economic, energy, and emissions data sources to characterize production and consumption decisions by firms and households. These data are used to develop a balanced Social Accounting Matrix (SAM) for each region that shows current production technologies, demands for goods, income sources, and trade flows. This information is combined with economic growth forecasts and estimates of future energy production, consumption, and prices.

- ***International*** **–** Global Trade Analysis Project (GTAP) data and International Energy Agency (IEA) energy production and consumption data, along with *World Energy Outlook* forecasts. Carbon dioxide (CO_2) emissions are from IEA, and non-CO_2 GHG emissions and reduction costs are from the EPA
- ***US*** **–** State-level economic data from the Minnesota IMPLAN Group, and energy data and forecasts from the EIA: *Annual Energy Outlook*, *Manufacturing Energy Consumption Survey*, *State Energy Reports*, and various Industry Annuals. CO_2 emissions from EIA and non-CO_2 GHG emissions from EPA.

Please see the ADAGE model website (RTI International, http://www.rti.org/adage) for additional documentation of the theoretical structure, equations, parameter estimates, and data in the model.

How GHG Mitigation is Modeled

ADAGE provides several broad options for meeting a GHG emissions target[6]:

- reducing emissions by switching fuels (e.g., from coal to natural gas),
- improving energy efficiency, and
- lowering energy consumption.

[6] The most recent version of ADAGE used in EPA's S280 analysis (US EPA 2007) has more advanced generation technology switching as well as carbon, capture and storage, than the version used in this analysis. The NI-NEMS model below captures these technology features in this analysis.

Both firms and households have options for changing their actions. If, for example, petroleum prices rise, a firm can shift away from petroleum to other types of energy. A firm can also choose to employ more capital or labor in place of petroleum, thus allowing ADAGE to model improvements in energy efficiency. The ease with which firms can switch among production inputs is controlled by the equations mentioned above and will affect how the economy responses to a GHG policy. If firms are able to substitute away from energy with relative ease, the price of their output will not change much when energy prices vary. Similarly, households can take actions to switch among fuels and improve energy efficiency if energy prices rise. Energy demands, along with those for other types of goods, are also influenced by any declines in overall economic activity (e.g., Gross Domestic Product or household income).

To model a specific GHG mitigation policy, an emissions target is introduced as an additional constraint in ADAGE that limits emissions to the given level. Based on this emissions cap, the model estimates a shadow (or implicit) value on GHG emissions associated with the constraint, which can be interpreted as the price at which GHG allowances (or permits) would trade under a GHG cap-and-trade system. This price reflects costs to the economy of abating emissions as necessary to meet the policy target. If the policy is implemented as a cap-and-trade system (as was done in the model runs for this paper), the model assumes affected entities can either reduce their emissions, purchase allowances giving them the right to emit GHGs, or sell allowances if they have low-cost opportunities to reduce emissions below the number of allowances they receive under the policy. Thus, the cap-and-trade system ensures that the marginal costs of abatement are minimized across the economy by encouraging the most cost-effective reductions.

Estimated GHG allowance prices, and associated macroeconomic effects, in ADAGE will be influenced significantly by the following model characteristics and policy features:

- The degree of fuel switching between coal and natural gas, especially in electricity generation – standard parameter estimates in the model allow a fair amount of switching, which holds allowance prices down (energy efficiency improvements have a similar effect).

- The ability of households to reduce energy consumption – ADAGE assumes households are willing to lower energy use, rather than forcing all reductions to come from industry.
- Overall changes in economic activity – the model estimates relatively small adjustments in industrial production and household consumption. Small changes limit the impact on GDP, but will also tend to raise allowance prices since demand for goods remains high.
- The combined influences of international and U.S. domestic GHG policies on the global economy – for example, if demand for crude oil declines in the U.S. and Europe, world crude oil prices will decline, leading to an offsetting increase in domestic demand that makes it somewhat harder to meet U.S. targets; similarly, energy-intensive manufacturing may shift overseas if U.S. competitiveness declines, affecting the U.S. economy.[7]
- Consideration of non-CO_2 emissions in the GHG mitigation policy – engineering studies typically find that non-CO_2 GHG reductions are relatively cheap methods for lowering emissions. If they are included in an emissions cap, or allowed to provide "offsets" for reductions in CO_2 emissions otherwise needed from energy markets, they will help lower allowance prices estimated by the ADAGE model.
- Finally, along with changes in international energy production, domestic resource supplies will respond to a GHG policy and can affect allowance prices – for example, declining demand for coal can lower minemouth prices, thus raising demand somewhat (delivered coal prices, including the effects of allowance costs, will generally increase).

While the initial production of natural resources for fuel is based on EIA forecasts from the *Annual Energy Outlook* (AEO), these levels can change under a climate change

[7] Current experience in the EU Emissions Trading System (ETS) is demonstrating such linkages between oil and gas price fluctuations and GHG prices, reflecting the greater difficulty put on emission reduction efforts if, for instance, these fuel price increases cause shifting to coal.

mitigation policy (baseline prices for coal, natural gas, and crude oil are also from AEO forecasts). In a policy scenario, the model determines how demands for energy resources will be affected by the need to hold GHG allowances in order to consume fossil fuels. Supplies of energy resources are simultaneously adjusted based on any related changes in energy prices and demands (parameters controlling how supplies respond to prices are based on data from the EPPA model).

Scenario Simulations

Exhibit 3 illustrates the steps followed in an ADAGE policy scenario. Before ADAGE can be used to evaluate a policy, it must be calibrated to represent the BAU baseline data and forecasts regarding the economy and energy production, consumption, and prices. First, the model's data are calibrated to a baseline equilibrium that represents expected economic growth in the absence of new policies. Then, the CES equations, or functional forms, and elasticities that control model reactions are calibrated to the chosen values, and a replication check is run to ensure the model is operating properly. At this point, the model is ready to evaluate "counterfactual" policies that move the economy away from this initial baseline equilibrium. The effects of these policies can then be evaluated by comparing the BAU baseline economy to the counterfactual solution.

The BAU baseline path for the economy in ADAGE incorporates economic growth and technology changes that are expected to occur in the absence of any new policies. Forecasts of energy production, consumption, prices, electricity generation, and overall economic growth from EIA and IEA are used to establish these growth paths. Emissions of CO_2 are controlled by the energy consumption forecasts and are combined with EPA forecasts regarding non-CO_2 gases to determine overall GHG emissions. Policy scenarios are then run by specifying a target level for these emissions and examining how the economy adjusts to meet the target through the fuel switching, energy efficiency improvements, and changes in consumption discussed above. The assumption in the ADAGE version used in this analysis is that nuclear generation will not change as the result of instituting the interim climate policy evaluated here – in some cases, this assumption has been relaxed by utilizing the capacity expansions estimated by the NI-NEMS model (see below).

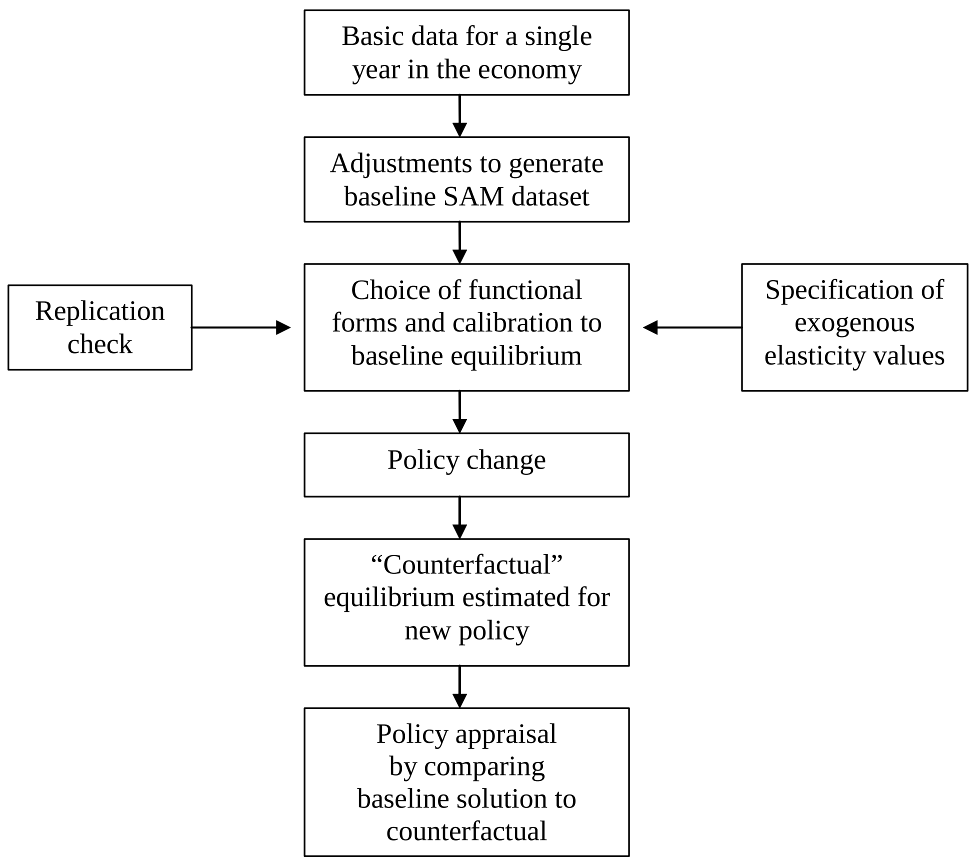


Exhibit 3. Flow Chart of Steps in Developing and Applying the ADAGE Model

This chart is adapted from Shoven and Whalley's (1992) flow diagram of a typical CGE model.

NI-NEMS

NI-NEMS is a version of EIA's NEMS that was customized for use by the Nicholas Institute. This model is used for the *Annual Energy Outlook* forecast and other energy policy analyses for Congress. NEMS is an integrated supply-demand linear programming (LP) model of the U.S. energy sector, which solves for the least-cost supply to meet market demand subject to various constraints. NI-NEMS is data driven, with substantial "bottom-up" detail on characteristics and costs of various energy technologies, and is updated annually. NI-NEMS has 12 modules which solve various prices and quantities that other modules use as inputs, while an integrating module controls the other 12 and determines when supply and demand are balanced (see Exhibit 4). NI-NEMS solves each module sequentially for each year, holding other module's results fixed, and then resolves the whole year again and again until the results are consistent from iteration to iteration. When the forecast finishes (all years 1990 to 2030), the whole forecast is repeated. Just like its annual self check for consistency, the model evaluates its results comparing the previous forecast cycle to the current cycle to determine if the forecast is stable. If not, the model starts forecasting again from 1990.[8]

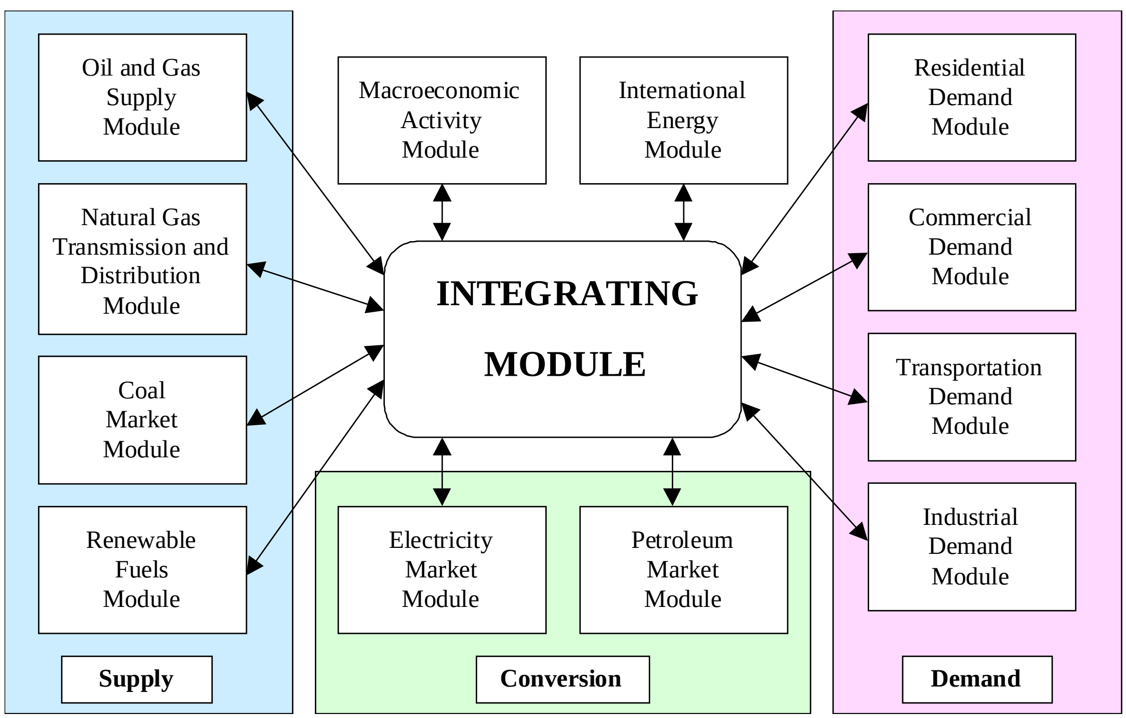


Exhibit 4. NI-NEMS Modular Structure

[8] NI-NEMS starts solving in 1990 because the first version of NEMS was finished in 1993.

The Nicholas Institute version, NI-NEMS, is directly derived from NEMS, but does not use the macroeconomic feedback portion of the model, instead focusing on technology, demand, and output responses within the energy sector.

NI-NEMS forecasts energy supply, demand, and prices. NI-NEMS's baseline forecast includes only policies that are currently legislated, and it is sometimes referred to as the "Business-As-Usual" or BAU forecast. Five of the modules in NI-NEMS have rather detailed technology descriptions: refining, electric markets, commercial, residential, and transportation. NI-NEMS has nine demand regions which correspond to census divisions and 13 electricity supply regions (based on NERC regions). These regions are explained in EIA's electricity documentation pages 5 and 92, (EIA, 2006)

NI-NEMS tracks SO_2, NO_X, mercury and CO_2 emissions. Coal and natural gas supply regions are different than the electricity supply regions. As a bottom-up model, with much detail, the electricity module aggregates time periods to keep the capacity planning and fuel dispatch parts of the model at a manageable size. Capacity planning looks at load duration curves with 11 time slices for each region: winter peak day, summer peak day, as well as three other load levels for each of three seasons - winter, summer, and shoulder season. Electricity fuel dispatch is solved for 36 unique hours in each region. Even with these simplifications, the fuel dispatch and capacity planning are the most time consuming parts of the model to solve.

The model endogenously solves for all fuel markets except crude oil. The solutions are derived by simulating changes in supply, demand, and other constraints in each fuel market and linking together regional and national markets as appropriate. The world crude oil price in NI-NEMS is an exogenous input to the model, assumed to be determined primarily from factors outside the U.S. economy.

Demand modules are end-use driven. The residential, commercial, and transportation sectors have extensive new technology menus which allow the model to choose from a wide range of fuel switching or efficiency options when new or substitution decisions are made.

Data

Given NEMS' use in developing the Annual Energy Outlook for the U.S., NI-NEMS uses historical or current data for everything that EIA can reasonably assess, for example, regional load duration curves, supply curves, technology costs, pipeline capacity, emissions, plant data, and beyond.[9] Given the prominent role of the electricity sector in climate policy options in general and for this analysis in particular, the reader may want to pay specific attention to the "Electricity Market Module" component of the input/assumptions documents just referenced. In particular, *Table 38. Cost and Performance Characteristics of New Central Station Electricity Generating Technologies* provides the data on size, lead time, capital and operating costs, and heat rates for 19 new electric power generating technologies,. These costs and efficiency assumptions are critical in determining whether GHG caps induce the turnover of new generating technologies.

These data and assumptions are updated each year. Expert judgments from EIA analysts and outside consultants are used for future inputs (e.g. costs or efficiency improvements over time).

For more details on the NEMS model, access the model brief overview EIA (2003, http://www.eia.doe.gov/oiaf/aeo/overview/) , which also accesses the model's latest full documentation of each module.

[9] The key data inputs and driving assumptions for the model can be found at http://www.eia.doe.gov/oiaf/aeo/assumption/index.html.

How GHG Mitigation is Modeled

Exhibit 5 summarizes the different ways in which the NI-NEMS model incorporates GHG mitigation into its economic logic. The electricity sector has the largest potential for emissions reduction, in part because of the sheer volume of emissions generated, but also because of the various choices available to it in terms of fuel-switching in the short term as well as the addition of alternative lower-emitting generation technologies in the long run. NI-NEMS models electricity demand side responses and energy efficiency investments from the industrial, commercial, and residential sectors as a source of emission reductions. NI-NEMS also models mitigation through changes in direct fuel consumption in industrial production processes, for instance, switching fuels such as natural gas for coal in industrial processes. The fuel substitution possibilities in the industrial sector are more limited than they are in the electric power sector. Mitigation in the transportation sector occurs primarily through changes in vehicle efficiency and miles driven. GHG offsets from emission reduction projects from other (non-capped) sources are available and expressed as exogenous offset supply curves that are responsive to the allowance price. Most offsets come from either high greenhouse warming potential gases or landfill and natural gas methane.

Scenario Simulations

NI-NEMS's BAU baseline used in this analysis is essentially EIA's Annual Energy Outlook 2006 reference case. The differences are that NI-NEMS does not include macroeconomic feedback and is done using the Nicholas Institute's version of NEMS. The Flat 2005 and the Flat 1990 GHG policy scenarios are modifications to NI-NEMS' BAU baseline. Changes are made in five areas. The first two are done to allow NI-NEMS to reach a stable result more quickly (in the order of a day or two, instead of many days).

1. Using EIA's carbon scenario basis files.
2. Allowing the model to try and stabilize differently between cycles.

3. Turning on the Cap and Trade scenario,
4. Setting the carbon cap to either 2005 or 1990 levels.
5. Turning on the carbon offsets.

MITIGATION ACTIONS	MODULES	EXAMPLES	TIMING
Electricity Production/ Fuel Demand			
Shift production to lower-emitting sources within existing capital stock	Electricity Market and Fuel Supply Modules (4)	Reduce load coming from existing coal units Increase load coming from existing natural gas, nuclear units, and renewables	Near term
Replace higher-emitting units with lower-emitting units over time	Electricity Market and Fuel Supply Modules (4)	Retire high emitting coal plants Replace with mix of lower-emitting coal units (e.g., IGCC), natural gas units, new nuclear, renewables	Medium-Long term
Carbon capture and sequestration	Electricity Market and Fuel Supply Modules (4)	Capture emissions from coal generation and store underground	Long term
Electricity Consumption/ Final Demand			
Marginal reductions in electricity consumption	Electricity Market Residential Demand Commercial Demand Industrial Demand	Reduce demand for electricity use in current industrial and household equipment and appliances	Near-term
Energy efficiency investments	Electricity Market Residential Demand Commercial Demand Industrial Demand	Replace existing equipment/appliances with more efficient alternatives	Medium-long term
Industrial Production/Fuel Demand			
Shift away from high emitting industrial processes	Industrial Demand	Fuel switching away from coal in industrial processes.	Medium-long term
Transportation Supply/Demand			
Increase efficiency of transportation supply	Transportation Demand	Increased vehicle fuel efficiency	Medium-Long term
Reduce demand for transportation services	Transportation Demand	Reduce miles driven	Near-term
Offsets	Integrating Module	Emission reductions and carbon sequestration from non-capped sectors (e.g., forestry, agriculture, landfills)	Near-term

Exhibit 5. Key Sources of GHG Mitigation in NI-NEMS

4. MODEL RESULTS

Simulating the GHG emission targets scenarios referenced above, the two models collectively produce a range of results on the environmental and economic effects of the policy targets. The two models achieve the same level of emissions reductions in somewhat different ways due to differences in their underlying nature (top-down and bottom-up). In *ADAGE*, emission reductions are primarily through reduced demand for energy due to input substitution and output shifts in the economy and secondarily through reduced carbon intensity of electricity production through fuel/capacity-switching from coal and oil generation to natural gas. Reductions in NI-NEMS come primarily through fuel/capacity-switching in electricity generation from coal and oil to renewables, nuclear, natural gas and some IGCC+CCS in later years (depending on the scenario) and secondarily through reduced energy use.

Results by key categories are presented below.

GHG Emissions

The GHG allowance price is a key economic indicator of a given cap-and-trade proposal, as it reflects the marginal cost of achieving the targeted level of emission reductions at a given point in time. Some parties will cut their emissions up to the point where it is cheaper to buy the allowance at the market price. Alternatively, others will sell their allowances up to the point that the price they receive in the market covers their marginal cost. In equilibrium, marginal cost should be equalized across all parties in the allowance market.

Exhibit 6 presents the allowance price trajectory for the 1990 and 2005 flat scenarios, along with a variation on each that will be described below. The 2005 flat scenario yields a GHG allowance price of about $4 per ton ($CO_2$ equivalent) in 2015 and $9 per ton in 2020. The 1990 flat scenario yields prices of $8 and $26 in 2015 and 2020, respectively. To put this in present context, emission allowances for 2008, the first year of the Kyoto

Protocol compliance period are now trading on the European Union Emissions Trading System for about $25-33 per ton CO_2 when converted from current euros to 2005 dollars.[10] (Point Carbon, 2007)

Exhibit 6 also shows alternative scenarios in which the 1990 and 2005 targets are met with a ramped-up availability of renewable fuels, subject to variations on the NI-NEMS results. This lowers the allowance price, and the effect is most pronounced in the 1990 flat scenario, where accelerated adoption of renewables lowers the allowance price from $26 per ton to $16 in 2020.

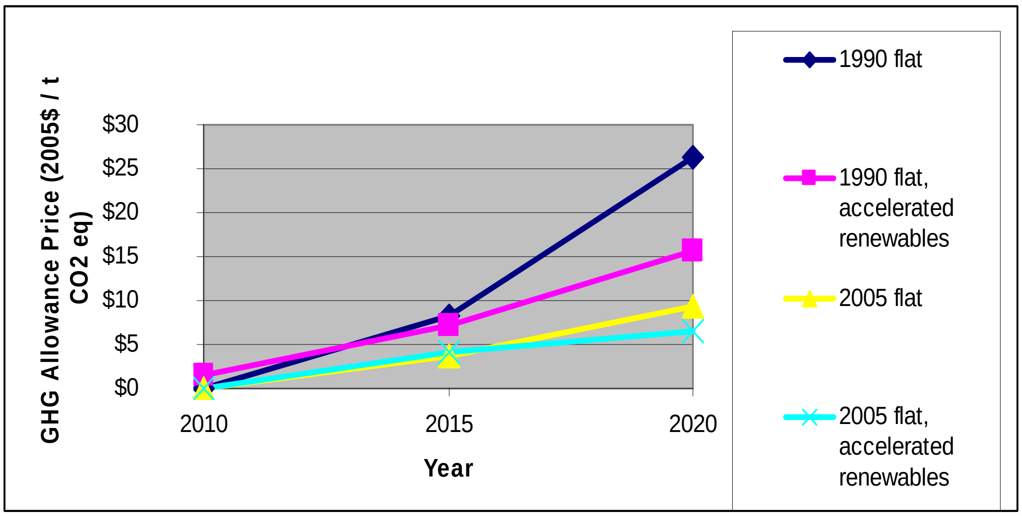
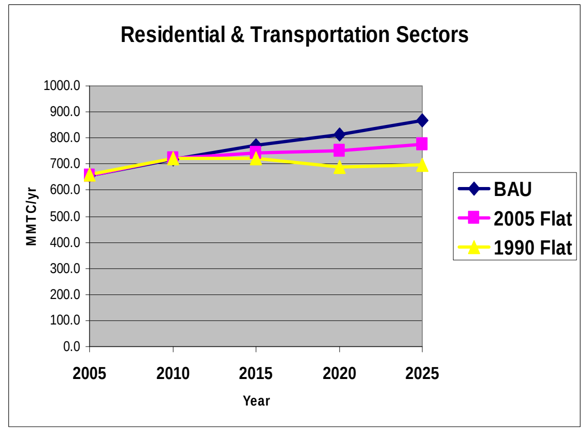


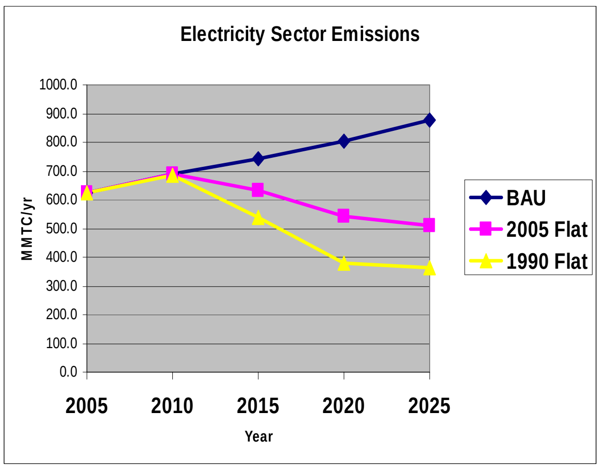
Exhibit 6. GHG Allowance Prices by Scenario
Sources: ADAGE and NI-NEMS

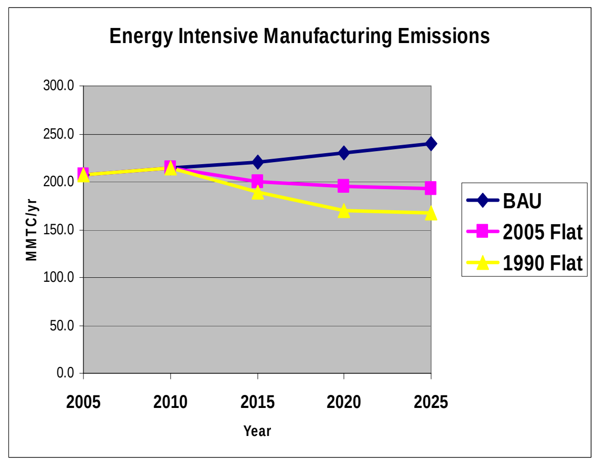
Different sectors face different costs for cutting their emissions. A cap-and-trade system allows sectors with high mitigation costs to purchase allowances from lower-cost sectors, thereby redistributing the emissions reduction effort across the economy. This is evident in Exhibit 7, which shows that the electric power sector makes the deepest cuts, followed by the energy-intensive manufacturing sector. In contrast, emissions in the transportation and household sectors[11] flatten out below BAU, but do not demonstrate much reduction.

[10] In Summer 2007, EU ETS price quotes have ranged from about 18-24 euros per ton, CO_2 for 2008 vintage. Converted to dollars using current euro-dollar exchange rate and the GDP price deflator to put in 2005$

[11] Transportation and household sectors are combined in order to capture all forms of transportation emissions, both commercial and for household use of motor vehicles.





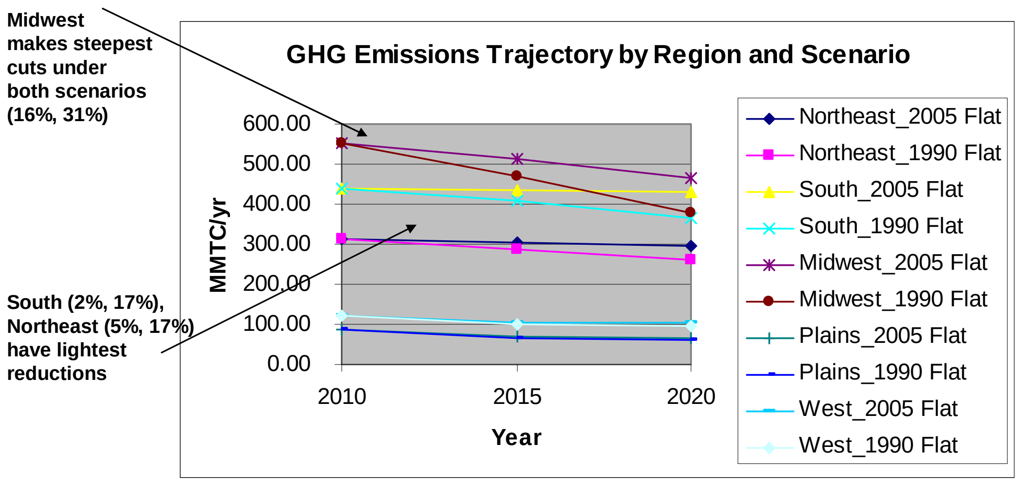


Source: ADAGE

Exhibit 7. Emission Pathways by Key Sectors

Emission reduction opportunities and costs also vary by region of the country (Exhibit 8). Cuts are steepest in the Midwest, in part because the current reliance on electric power generation from coal in that region provides a large emissions base from which reductions can occur. Emission reductions are smaller proportionately in the Northeast and West, which rely somewhat more on natural gas, hydroelectric, and nuclear power generation.

Emission Reductions by Region

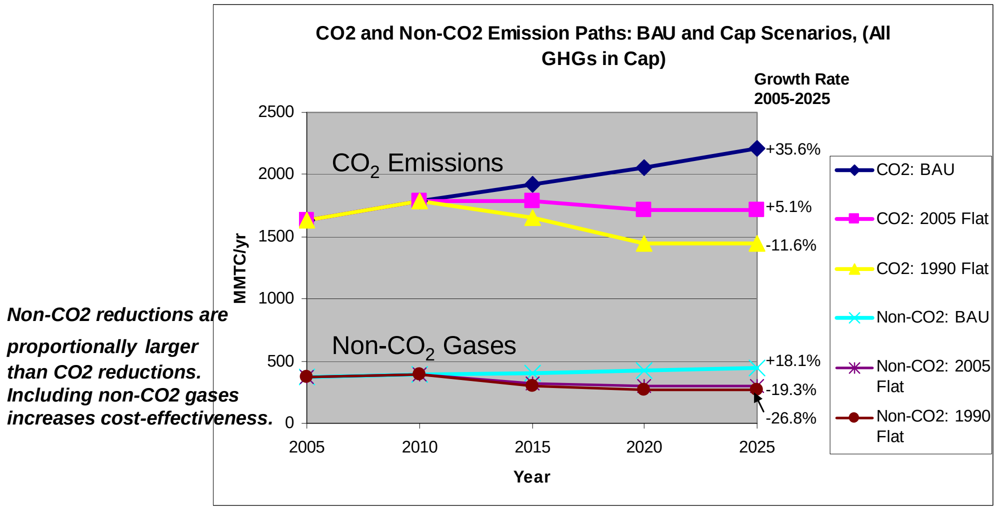


Source: ADAGE

Exhibit 8. Emission Reductions by Region

Exhibit 9 shows the breakdown of GHG emission reductions between CO_2 and non-CO_2 species (such as methane, nitrous oxides, and the fluorinated gases). Due to sheer scale, CO_2 reductions dominate non-CO_2 reductions, but non-CO_2 reductions are larger in proportion to their baseline amount. Non-CO_2 reductions are less expensive to achieve, thus including these gases in the cap brings down the total cost of hitting a GHG target and enhances the efficiency of the trading regime.

CO_2 and Non-CO_2 emissions by scenario



Source: ADAGE

Exhibit 9. Emissions path by Species

Macroeconomic Performance and Trade Effects

As a measure of the aggregate output of the economy, Gross Domestic Product (GDP) provides a summary metric of the macroeconomic impact of the policy scenarios. As shown in Exhibit 10, estimated GDP impacts are relatively small, ranging from a 0.15% decline in GDP in 2020 under the 2005 target to 0.4% under the 1990 target. While such a decline still measures in the tens of billions of dollars, this needs to be viewed in the context of an economy that is substantially larger than it is today. To put this in context, this amounts to approximately one-half to one day's worth of GDP in 2020.[12] Employment is clearly also a key economic variable and has effects about the same as GDP (0.18-0.4 % decline).

[12] Based on 250 working days per year.

Caps have Small Effect on National GDP and Employment

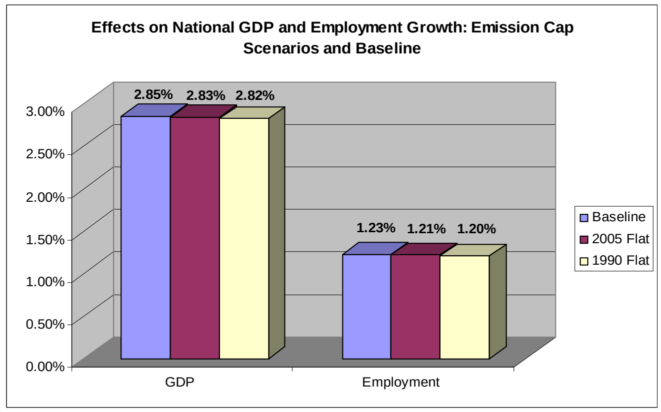
Effect on GDP and Employment Levels in 2020

	2005 Flat	1990 Flat
GDP	-0.15%	-0.40%
Employment	-0.18%	-0.40%

Additional time required to Make up lost GDP in Year 2020?

2005 Flat = 0.4 days
1990 Flat = 1.0 days

Effect on GDP and Employment Growth Rates, 2005-2020



Source: ADAGE

Exhibit 10. Macroeconomic Effects

Adopting GHG caps in the U.S. changes the terms of trade, raising relative prices of U.S. goods.[13] Exhibit 11 summarizes changes in trade flows with the rest of the world, and China specifically, by key sectors under each of the target scenarios. In general, we see a modest decline in exports and a small increase in imports. Changes in trade flows are larger in proportional terms than the changes in GDP or employment because traded goods are just a subset of all produced and consumed goods. Moreover, trade flows are generally more sensitive to changes in relative prices than aggregate production and consumption, as they essentially reflect changes in market share rather than changes in the size of the market. The agricultural trade flow is affected by the role it plays as a supplier of offset credits to the other sectors, which leads to a slight contraction in agricultural output. Changes in transportation service flows are driven by two factors: (1)

[13] As discussed in the scenario descriptions, countries subject to the Kyoto Protocol are assumed to meet their Kyoto targets throughout these scenarios. All other countries face no GHG caps under these scenarios.

these services are impacted by the aggregate level of traded goods requiring these services to move into and out of the United States, and (2) the provision of transportation services may shift locations around the world to reflect how changes in relative prices of fuel alter costs of transporting goods.

U.S. Trade Balances in 2020

- Modest decreases in U.S. exports to Rest of World (ROW), including China, as competitiveness changes
- Limited leakage of GHG emissions as the result of imports from ROW
- Some declines in total imports as GDP growth slows

		Rest of World		China	
Scenario	**U.S. Industry**	**Exports to:**	**Imports from:**	**Exports to:**	**Imports from:**
2005 Flat	Agriculture	-1.4%	1.6%	-2.4%	1.8%
	Energy-Intensive Manuf.	-0.6%	0.4%	-1.0%	0.6%
	Other Manufacturing	-0.8%	-0.7%	-0.7%	-0.5%
	Services	-0.7%	-0.5%	-1.4%	-0.3%
	Transportation	-1.1%	1.5%	-2.5%	1.7%
1990 Flat	Agriculture	-3.3%	4.7%	-4.5%	5.5%
	Energy-Intensive Manuf.	-1.6%	1.5%	-1.4%	2.2%
	Other Manufacturing	-1.5%	-1.5%	-1.0%	-0.8%
	Services	-1.5%	-1.2%	-2.1%	-0.5%
	Transportation	-2.7%	4.3%	-5.0%	5.1%

Exhibit 11. Trade Effects

Exhibit 12 focuses on the manufacturing sector's changes in total output, exports, imports and energy use. As would be expected, energy-intensive manufacturing sectors (e.g., primary metals, paper, chemicals, etc.) have somewhat more pronounced effects than the rest of manufacturing. Also, the figure shows all of these sectors cutting their energy consumption by more than the declines in output, indicating substantial increases in energy efficiency.

Manufacturing Sector Effects, 2020

- Changes in output are similar across manufacturing industries
- Energy-intensive sectors face some additional import competition and tend to reduce energy consumption more to lower production costs

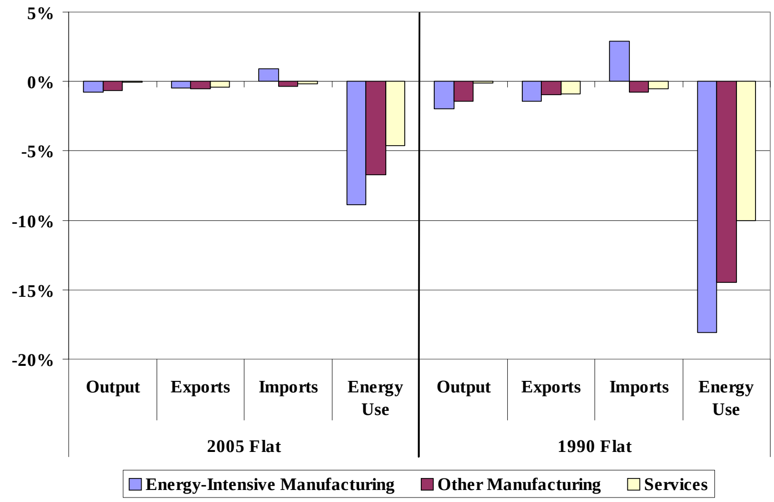


Exhibit 12.

Regional variation in changes in GDP (Exhibit 13) is not extreme - effects in the West are somewhat higher than average and effects in the Northeast and Midwest somewhat lower than average. The slightly smaller GDP effects in the Midwest is interesting given that emission reductions there are somewhat higher than average, but this reflects the influence of emission allowance revenues. In these model simulations, allowances are allocated for free by historic emissions ("grandfathered") and thus regions with relatively high levels of historic emissions, such as the Midwest, are endowed with higher allowances revenues.[14] The allowances raise regional incomes and positively counter negative GDP impacts that otherwise occur. Similar interactions occur in the West, which is relatively energy efficient and would normally require fewer adjustments to

[14] Other allowance allocation schemes could have different regional welfare implications. For one, the grandfathering is based on historic emissions; if the allocation was updated to reflect emissions shares as they evolve, this could change the distribution of allowance over time, favoring those regions less able to make cuts and, problematically, providing a marginal disincentive for emission reductions. If allocation was based on population rather than emissions, then regions with lower per capita emissions and/or higher population growth rates would be advantaged (Ross et al, forthcoming).

meet a given emissions target. However, distributing allowances based on past emissions reduces the amount allocated to the West, lowering regional incomes in the scenario.[15]

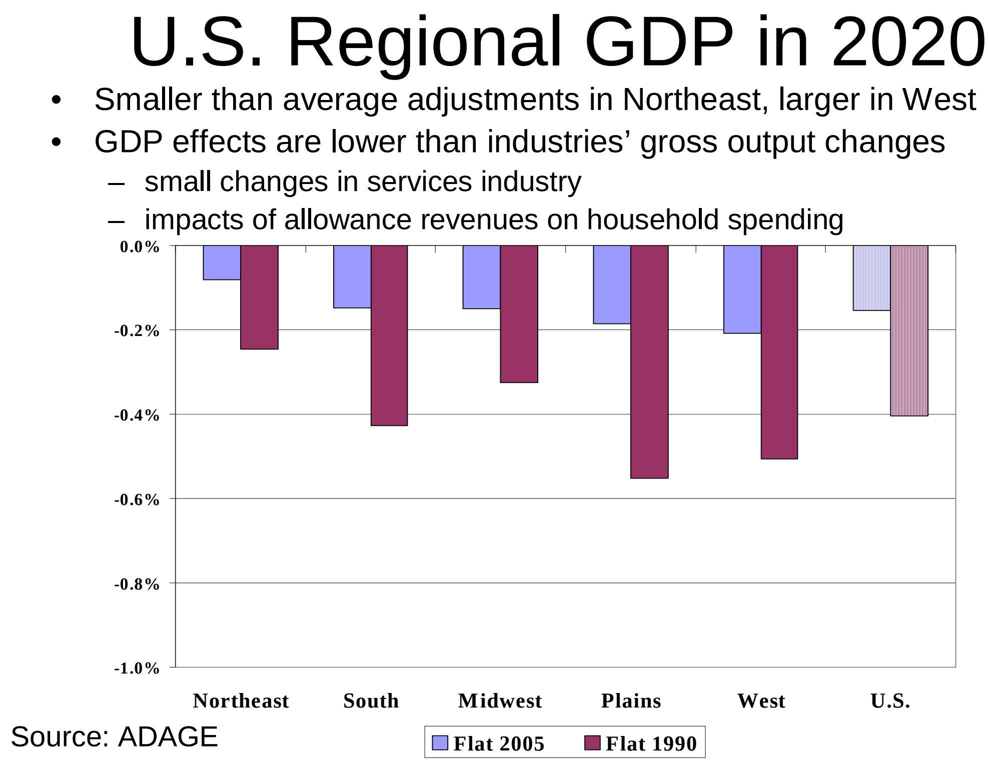


Exhibit 13.

Electric Power Sector

The electric power sector is the largest single source of GHG emissions in the U.S. economy, and the modeling results indicate it is also the largest and most cost-effective source of GHG reductions under a national cap. Exhibit 14 shows that the caps are met with substantial reductions in the electric power sector and a slowdown in the (still positive) growth rate of emissions in the other sectors. By achieving emission cuts out of

[15] The state of California is now working out a system of GHG caps at the state level. These caps are not included in the baseline projection here, but if adopted, they would alter the inter-regional impacts of a federal policy that includes California.

proportion to its baseline emission contributions, the electric power sector is a net seller of emission allowances to the other sectors.

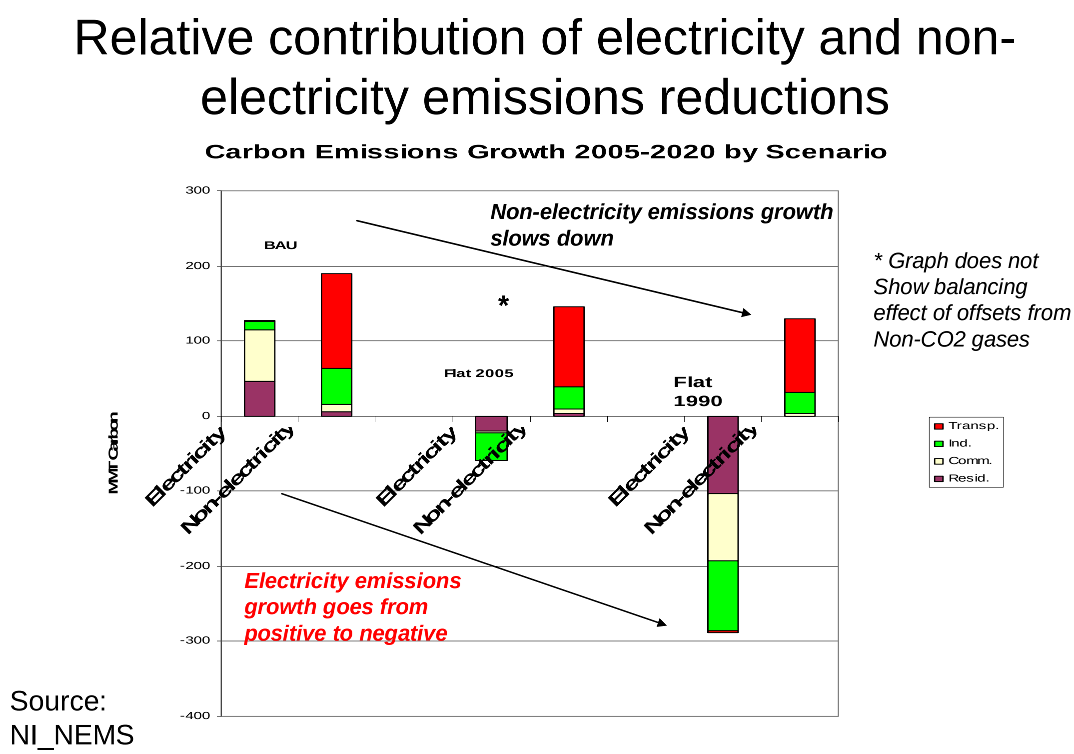


Exhibit 14. Emission Reductions: Electric Power Sector vs. Other Sectors

Electric power emission reductions come primarily from a shift in coal-fired power generation to less carbon intensive generation (natural gas, biomass, and wind). To meet the 2005 target, coal generation is projected to drop from 51 to 39 percent of sector output in 2020 (Exhibit 15), natural gas is projected to rise from 20 to 24 percent, and renewables (which includes hydro power) rise from 10 to 17 percent. Nuclear's share of 2020 generation rises by one percent to 20 percent under the 2005 target scenario, and rises to 21 percent under the 1990 target scenario. Natural gas rises to 30 percent of sector generation under the 1990 target scenario and renewables to 27 percent.

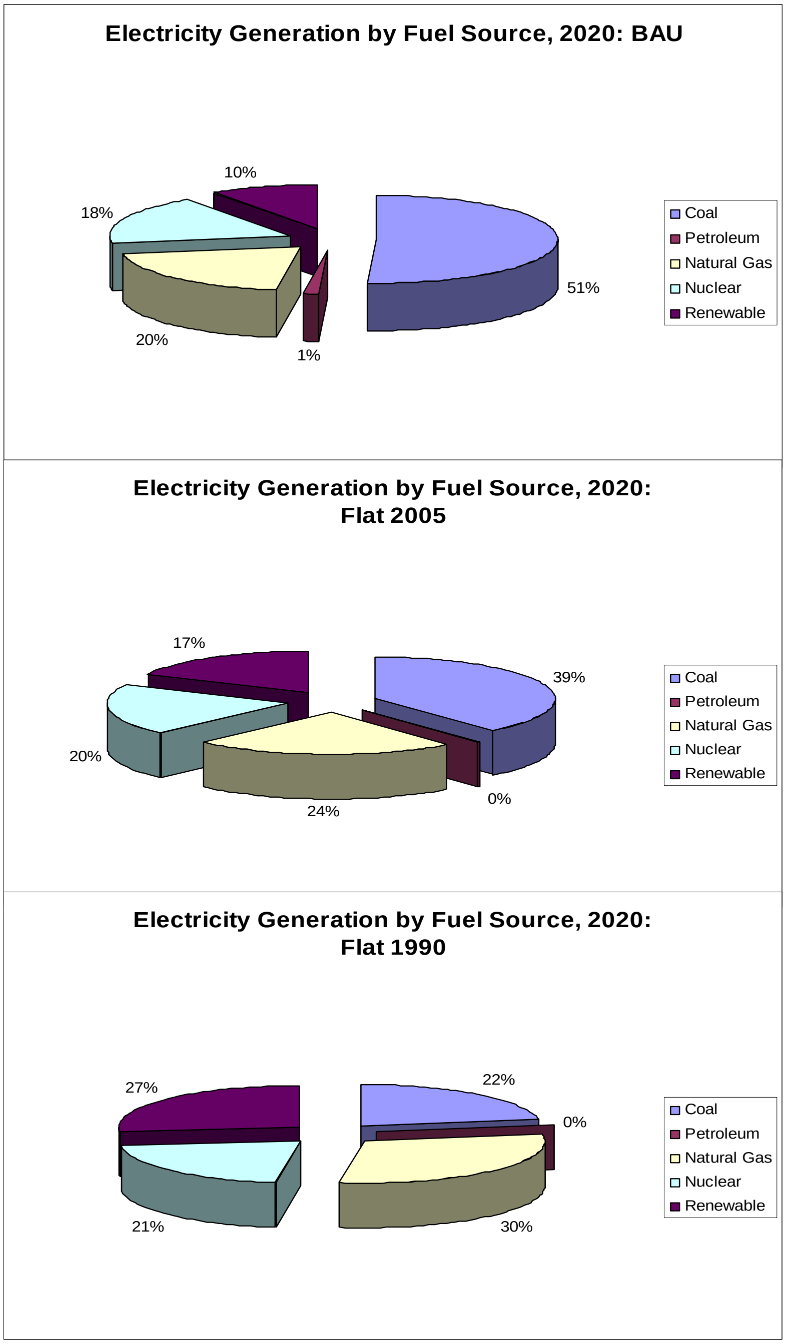


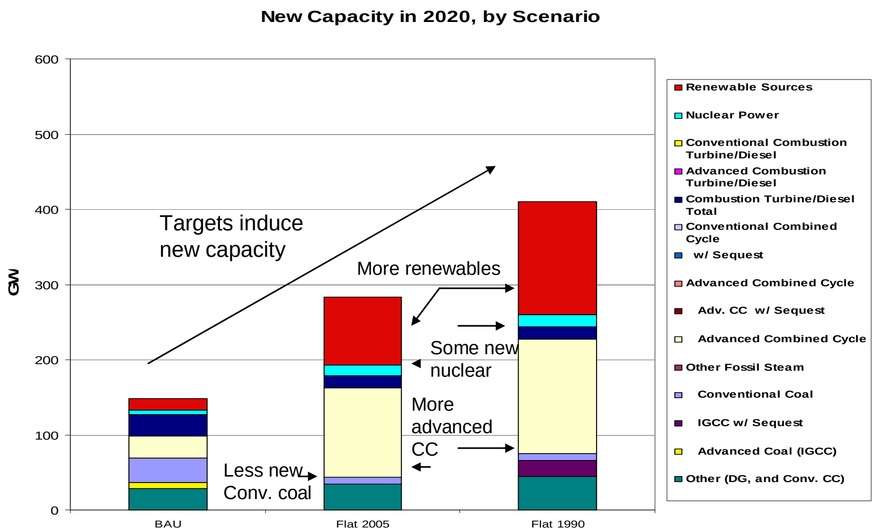
Exhibit 15. Electric Generation Mix by Scenario
Source: NI-NEMS

It is important to recognize that the targets in these scenarios are set for the Year 2020 and held constant thereafter. This (along with the modest allowance prices) substantially limits the role that carbon, capture, and storage (CCS) plays in the short-term electricity sector's response strategy. CCS involves the removal of CO_2 from the flue stream of a coal-generating unit (normally using an integrated gasification combined cycle or IGCC technology in the combustion process), and pipes the CO_2 for below-ground storage, rather than release to the atmosphere.

CCS is a very promising strategy and one that is expected to play a vital role if substantial long-term reductions are targeted beyond 2020. The post-2020 timeframe is relevant for CCS because CCS still needs to be demonstrated for broad scale commercial application, which will take some time, and because, while effective, it will likely be more expensive than the other options such as fuel-switching (MIT, 2007). CCS does not penetrate in most of this paper's scenarios because of the shorter time horizon and the somewhat modest emission targets evaluated.

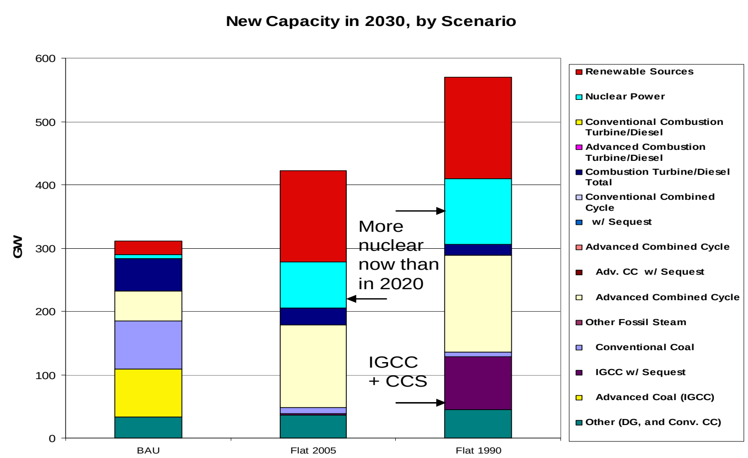
Exhibit 16 shows new generation capacity development in the power sector by 2020 and 2030 under BAU and the two emission targets. The targets induce an acceleration of capital replacement over BAU, with a roughly doubling of BAU capacity built by 2020 under the 2005 target and about a tripling of capacity built under the 1990 target. Consistent with the changes in generation mix described above, the new capacity shows primarily renewables and natural gas replacing conventional coal capacity additions in 2020. In 2030, more nuclear capacity is added under both policy targets and IGCC + CCS capacity is added by 2030 in the more stringent 1990 target scenario.

New Capacity Additions in 2020 by Scenario



Source: NI_NEMS

New Capacity Additions in 2030 by Scenario



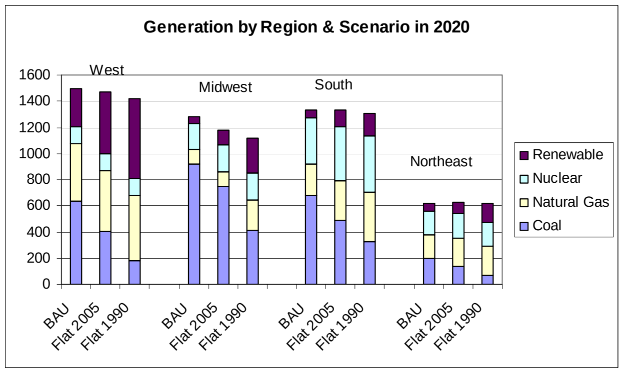
Source: NI_NEMS

Exhibit 16. New Capacity by Scenario

Exhibit 17 depicts the generation response by region. All regions show a decline in coal use, but the substitution response varies by region, with renewables taking up much of the slack in the West and Midwest, as natural gas and nuclear play a stronger role in the South (especially nuclear in the 2030 time frame). Demand reductions, represented by a decline in the height of the generation bars in Exhibit 16 in going from BAU to the target scenarios, also contributes to the decline in each region's sector emissions.

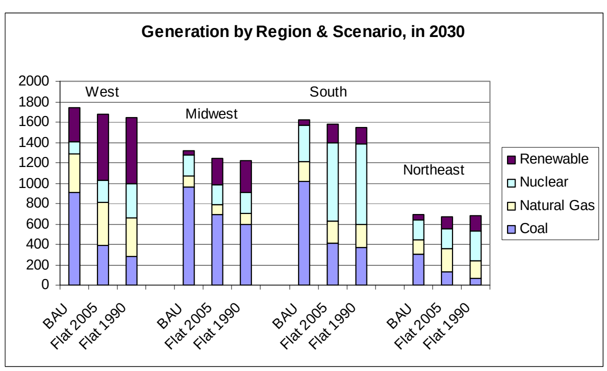
The decline in generation demand is driven by – and from a producer's revenue standpoint, is offset by – a rise in the electricity price in each region. As shown in Exhibit 18, total electricity revenue rises in each region as output falls, indicating that the price increase is larger than the drop in generation. This reaffirms the notion that electricity demand is generally inelastic, whereby a 1% increase in price leads to a less than 1% reduction in quantity demanded. The national average rise in electricity price for each scenario is given in Exhibit 19. The initial price effect in 2015 is modest (4-8 percent increase above baseline), rising to 9-20 percent in 2020 as the cap gets tighter, and up to 17-32% in 2030 as growth in economic activity makes the cap more binding.

Electricity Generation Source by Region and Scenario: 2020



Source: NI_NEMS

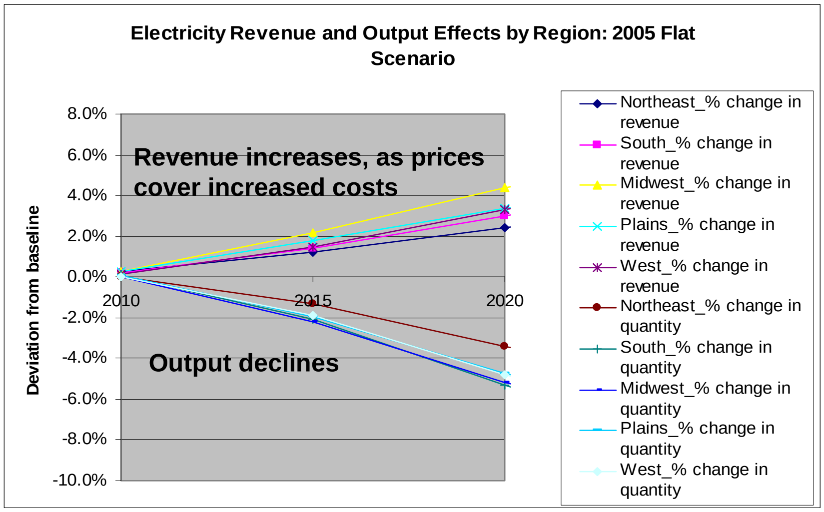
Electricity Generation Source by Region and Scenario: 2030



Source: NI_NEMS

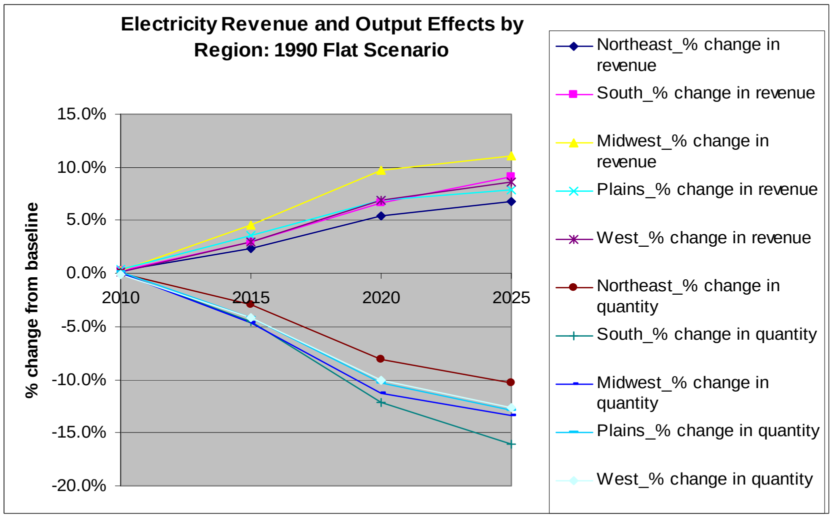
Exhibit 17. Changes in Generation Mix by Region

Effects on Regional Electricity Revenue and Output: 2005 Flat



Source: ADAGE

Effects on Regional Electricity Revenue and Output: 1990 Flat



Source: ADAGE

Exhibit 18. Electricity Output and Revenue Effects

Exhibit 19. National Average Electricity Price Effects Relative to Baseline
(Percent Above Baseline)

Scenario	2015	2020	2025	2030
1990 Flat	8%	20%	26%	32%
2005 Flat	4%	9%	13%	17%

Source: ADAGE

5. CONCLUSIONS

This paper estimates the economic and emissions effects of an economywide cap-and-trade program, with caps set at interim GHG emission targets for the United States by the year 2020. While several of the policy proposals now before Congress propose longer term emission targets, their targets for 2020 roughly fall in the range of 1990 and 2005 emissions levels evaluated here. As such, this analysis provides an initial assessment of the economic effects of achieving these interim policy targets and provides further insights into how these effects would be amplified or muted depending on what one assumes about the trajectory of emission targets called for after 2020.

This analysis addresses these matters by jointly employing two economic models to examine climate policy options, one (ADAGE) is a general equilibrium model of the world economy, with specific representation of all sectors and regions within the U.S. economy. Because of its use for climate and energy policy, ADAGE has additional detail on the U.S. energy sector, but for more detailed assessment of responses and impacts within the U.S. energy sector we turn to NI-NEMS, a customized version of the National Energy Modeling Systems (NEMS) model used by the U.S. Energy Information Administration. Together, these models combine a unique breadth and depth of analysis necessary for climate policy.

The results of the modeling analyses produced several key insights that can inform policymakers as they consider the range of GHG cap-and-trade options before them, as summarized below.

- ***The macroeconomic impacts of meeting the two emissions targets are fairly modest for the economy as a whole, though more adjustments are expected in energy-intensive sectors than in other sectors that are less dependent on energy production or use.*** Under business-as-usual (BAU), gross domestic product is expected to rise in absolute terms by more than 50 percent from 2005-2020. Under the climate caps, GDP is projected to be from 0.15 to 0.40 percent smaller in 2020 than this BAU level under the 2005 and 1990 target scenarios respectively. In other words, the economy is slated to grow substantially with or without the policies in place. The marginal effect of GDP loss would be equivalent to less than one day of economic output. This estimate does not include the value of economic benefits generated (costs avoided) by reducing climate risks. If unmitigated climate risks cost the economy more than the economic opportunity costs measured here, than more extensive action may be warranted. If the climate risk cost to the economy is smaller than the costs estimated here, less aggressive action may be warranted. Complementary research is needed to pair these costs with benefits, perhaps building off of the recent work by Stern (2006) and Nordhaus (2007) and synthesis of the IPCC Working Group II.
- ***U.S. adoption of GHG caps could affect trade flows with the rest of the world.*** In these simulations, other countries are projected to continue with their Kyoto commitments for the time being. This means that the United States would join Kyoto Annex I countries in taking on commitments, thereby losing trade advantage procured when Kyoto was rejected in the United States. In addition, like the other Annex I countries, this would endow non-Annex I trading partners such as China with terms of trade advantages over the United States. In these scenarios, the trade disadvantages lead to only a modest drop in exports to, and increase in imports from, the rest of the world. The magnitude of these trade

effects in the longer term will, of course, depend on how each group of nations adopts future GHG commitments and how technologies and costs change in adopting vs.non-adopting countries

- ***Initial allowance prices would likely be modest, then rise as the target becomes more stringent.*** An economywide cap-and-trade program achieving these emissions targets is projected to produce allowance prices in the range of $4-8 per ton of CO_2 in 2015, rising to $7-26 per ton in 2020. For context, this largely falls below the futures prices trading on the EU ETS for the first commitment period of the Kyoto Protocol during the summer of 2007 ($25-35 per ton). However, the comparison should not be taken too far as the EU ETS has, like most commodity markets, proven to be somewhat volatile in response to, among other things, previously unknown information on member country national emissions levels and changes in expectations about post-2012 policy options. Presumably a world in which the United States, European Union and other countries would jointly participate in a global carbon market would tend to equalize prices across countries, but this would depend on negotiations between countries to ensure that the reduction efforts are harmonized and linked to a common goal.
- ***Electric power accounts for a disproportionate share of the emission reductions due to more cost-effective opportunities in that sector***. It is less costly to decarbonize electric power through fuel switching, the adoption of low-carbon generation technologies such as renewable power and nuclear power, and demand reductions than it is to reduce emissions in other major sectors of the economy. This suggests that the electric power sector could produce more than their share of emissions and could be a net seller of allowances to the other sectors if allowances are allocated across sector in proportion to their emissions. Similarly, the economic impacts on energy-intensive businesses as a group (or other affected groups such as households) will depend on allowance allocations, which could be used to offset effects on particularly disadvantaged areas of the economy.
- ***Integrated Gasification Combined Cycle (IGCC) with Carbon Capture and Storage (CCS) plays a minor role in these mitigation scenarios, but will be more important if the targeted cuts are deeper or sustained longer than they are in***

this study. This underscores a very important policy implication. If firms in the power sector expect to be held to targets in the 1990-2005 range by 2020 and kept constant thereafter (as is simulated in this paper), they will not likely opt for IGCC+CCS as a strategy by 2020. However, if they expect deeper reductions beyond 2020, other economic studies suggest that IGCC+CCS will be an integral part of the solution (Paltsev et al. 2007, US EPA 2007), which has important implications for the future of coal. Widespread adoption of IGCC+CCS could allow coal to roughly maintain its current share of the electric power market under some long-term reduction scenarios (e.g., US EPA, 2007), rather than experiencing the decline shown here. Because NI-NEMS does not forecast beyond 2030, we can only suspect without further analysis that IGCC+CCS would likely be implemented if the flat caps were kept in place beyond 2030.

- ***As with IGCC+CCS, the role of nuclear power as a mitigation response is relatively small in these scenarios, but would likely grow substantially with deeper long-term targets.*** Any significant expansion in nuclear power would require solutions to current problems associated with safe nuclear storage capacity, certainty of long-term uranium supplies and overcoming public concerns about safety issues.
- ***Renewable sources comprise a large share of the generation response to a GHG cap.*** Advances in renewable technologies and the availability of a corresponding infrastructure are expanding rapidly today, but will need to grow even more dramatically to meet the generation needs indicated in these results. Concerns about supply availability across time and space must be addressed by developing an efficient portfolio of renewable options that can integrate with base load generation and ensure reliable sourcing.
- ***While interregional differences in impacts are not that extreme, they exist and are a factor to consider politically.*** Regional GDP impacts are a bit higher in the West than in other regions, but this is determined to some extent by the assumed "grandfathering" method for allocating emission allowances. Grandfathered allowances are distributed based on historic emissions. The western United States has historically been more GHG efficient than other regions because of their fuel

sources (e.g., hydro power and natural gas play a much larger role than coal) so they might receive fewer allowances in the allocation scheme and also might find it more costly to make marginal reductions than higher emitting regions. This would reduce the ability of Western emitters to sell allowances on the carbon market and reduce income opportunities relative to other regions. This situation could be remedied by alternative allocation schemes that are based more on output levels or that otherwise reward those sources with lower emissions intensities.

In summary, the scope and expectations of the climate policy matter. The economic impacts of the policy scenarios simulated here – setting national GHG targets to 1990 and 2005 levels by 2020 respectively and leaving them fixed – can best be described as discernible and unevenly distributed across the economy, but modest from a macroeconomic point of view. Thus starting down the path toward long-term reductions need not cause the significant economic harm referenced in the 2006 Sense of the Senate resolution.

At a recent forum of economic modelers of climate change policy, some panelists expressed concern about the accuracy and value of economic simulations incorporating very long term emission targets (40-50 years plus).[16] The concern is that short- to interim-term results are greatly affected by modeled expectations of policy targets 40-50 years hence. Forward-looking economic models, such as those used in this analysis, will anticipate steep future cuts and start taking actions today to minimize costs expected well in the future. While this is the most economically efficient way to manage GHG restrictions, it may cause more aggressive and costly actions today than might actually unfold given policy uncertainty and less than perfect foresight of economic agents. As uncertain as the scope, breadth and depth of interim targets out to 2020 may be, the depth

[16] *Economic Modeling of Federal Climate Legislation*. Symposium hosted by the Nicholas Institute for Environmental Policy Solutions, Duke University. July 18-19, 2007. Washington, DC. Presentations at conference website (http://www.nicholas.duke.edu/econmodeling/)

of any future cuts beyond 2020 is even more so. This point, in part, explains this paper's strategy in focusing on interim targets (2020) and holding them constant into the future.

Yet, the scientific community strongly counsels further emissions cuts be imposed past 2020. If deeper cuts are proposed after 2020 and results are examined past 2030, we would presumably see larger impacts on the economy and potentially different responses (e.g., much more IGCC+CCS, more nuclear power if the infrastructure is there, larger demand response and less reliance on basic fuel-switching from coal to natural gas). Moreover, deep long term cuts would likely yield an evolution of technological development and change that is difficult to predict or model. Modeling expectations and responses under long-term emissions targets and stochastic technological developments is clearly a fruitful area for the economic modeling community to focus on in order to better guide climate policy development.

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for more information please contact:

Nicholas Institute for Environmental Policy Solutions
Duke University
Box 90328
Durham, NC 27708
919.613.8709
919.613.8712 fax
nicholasinstitute@nicholas.duke.edu