Designing Clean Electricity Standards to Balance Costs, Benefits and Equity

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Executive Summary

Climate change refers to the myriad alterations in the environment caused by increasing atmospheric concentrations of greenhouse gases (GHGs). Global and U.S. GHG emissions continue to rise, and without action to curb growing emissions and to reduce the concentration of GHGs in the atmosphere, climate change will continue unabated. Despite the knowledge that human activities are causing climate change, the U.S., the world's second largest emitter, has been slow to adopt policies aimed at curbing emissions.

While an economy-wide policy to combat climate change, such as a carbon tax, would be most effective for reducing U.S. GHG emissions, it is not currently a politically feasible option. Instead, a suite of complementary policies targeted at specific high-emitting sectors of the economy, such as electricity generation, transportation, agriculture and industry, have been proposed to spur the transition to a lower-carbon economy.

In the electricity generation sector, which generates around a third of all U.S. GHG emissions, a federal Clean Electricity Standard (CES) has been proposed to reduce emissions. A CES would require utilities to sell a certain percentage of their electricity from sources qualified as clean. President Obama has supported a federal CES and in recent years several Congresspeople from both Parties have issued CES proposals.

A CES can be an effective policy to dramatically reduce electricity sector GHG emissions, but the design of the policy will significantly impact the reductions achieved and the degree of technology shift. In designing a federal CES, key design questions include:

1. Specifying target years and target levels and deciding if certain technologies will have their own specific target levels;
2. Determining how to set the baseline sales level that determines the level of compliance by covered entities;
3. Deciding what technologies qualify as clean and can be used to comply with the policy;
4. Choosing which utilities are covered by the policy and which, if any, are exempted;
5. Designing the compliance system, including setting the clean energy credits (CEC) system and alternative compliance payment (ACP) options.

In recent years, the U.S. Energy Information Administration (EIA) modeled several federal CES proposals using the National Energy Modeling System (NEMS). Using this model, EIA is able to project likely outcomes of the policy proposals and assess whether they meet the goals of reducing emissions and shifting generating capacity towards cleaner technologies. An examination of these modeling efforts reveals several key lessons for policymakers when designing a federal CES:

1. Though it is the key specification of the policy, the nominal clean energy target should be set last after the policymakers decide on distributional features such as treatment of existing nuclear and hydropower generation, qualifying technologies, baseline sales, compliance exclusions, the CEC market and ACPs. Changes in design should lead to changes in the target.

2. There are cost and predictability trade-offs for design choices related to CEC banking and ACPs. Taking into account this trade-off, policymakers should allow unlimited CEC banking and make ACPs available, but at a high enough level so as not to undermine the goals of the policy.

3. If some utilities are exempted from the policy their participation in the credit market will radically change policy impacts. Policymakers should consider the distributional impacts of allowing their participation and set the target to still reach the policy's goals.

4. Treatment of existing hydropower and nuclear resources affects the cost-effectiveness of the policy. Providing full or partial credits for these resources or excluding them from the baseline results in more cost-effective GHG reductions than allowing them to meet the target but not issuing credits for their generation. Policymakers should consider the lowest-cost way to treat these resources, taking distributional impacts into account.

5. Model projections are highly sensitive to technology cost predictions, and policymakers should request multiple cost sensitivity runs in order to understand the full range of possible policy outcomes predicted by the model. Various other sources of uncertainty, such as macroeconomic conditions, demand growth and changing residential, commercial and transportation technology choices also merit consideration.

Introduction

Climate change denotes the various shifts in the environment that are caused by increasing concentrations of greenhouse gases (GHGs) in the atmosphere. The U.S., the second largest GHG emitter in the world, has not adopted major policies aimed at curbing domestic emissions, despite the understanding that climate change is caused by human activities. An economy-wide policy, such as a carbon tax or an emissions trading scheme, would be the most cost-effective way to lower U.S. emissions, but there is a lack of political will to adopt such a policy because of continuing debates over the reality of climate change and the potential macroeconomic effects of an economy-wide policy. As such, policymakers are considering a variety of complementary policies for the electricity, transportation, agriculture and industrial sectors that can improve efficiency and lower emissions.

The electricity sector was responsible for around one third of all U.S. GHG emissions in 2010, primarily through the combustion of fossil fuels such as coal and natural gas (NG). Coal, the most polluting source of baseload electricity, generated around 44 percent of U.S. electricity in 2011, while natural gas accounted for 21 percent. Emissions-free electricity from nuclear, hydropower and other renewable resources accounted for 34 percent of 2011 generation. While U.S. reliance on traditional coal combustion for electricity has decreased over the past twenty years, the trend is fairly slow and emissions from electricity generation could be dramatically reduced by spurring a faster shift towards cleaner technologies.

A Clean Electricity Standard (CES) is an electricity sector policy that can induce a shift away from dirty technologies and towards cleaner technologies, reducing emission from the electricity sector. A CES is a type of electricity portfolio standard that sets targets for clean electricity generation as a percentage of electric utilities' sales. Following the example of successful implementation of renewable electricity standards (RES) in 29 U.S. states and D.C., a federal CES is a policy instrument that could increase the deployment of clean energy technologies while reducing U.S. GHG emissions. Over the past several years, three Senators have proposed a CES, and President Obama has voiced his support for such a policy. As such, examination of options for the design of the CES is merited to yield conclusions about optimal CES design.

This report begins with background information about the problems of climate change and electricity sector emissions, federal policy options to address climate change and how energy modeling informs policymaking. In order to better understand how a CES policy can be written to maximize cost-effective emissions reductions, this report then reviews the key design choices that policymakers face when structuring the CES, reviews the legislative history of the CES, the modeling results of proposed CES policies and draws conclusions about important lessons for policymakers.

Background

Climate Change

Climate change refers to ongoing, long-term changes in the global climate system, such as global warming, changes in weather patterns, and other effects. These effects are primarily the result of human activities that have released large amounts of GHGs into the atmosphere, such as fossil energy production and use, certain industrial activities and agriculture and forestry activities. Though once controversial, over the past 20 years, scientists, policymakers and citizens have increasingly accepted this view of anthropogenic climate change, and sought policy and behavioral changes that could reduce GHG emissions and mitigate the increasing effects of climate change. Thus, understanding the science behind climate change and the scale of the problem are critical for designing policies, like the CES, that are intended to reduce emissions.

GHGs that have increased due to human activity include carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_20) and fluorinated gases (U.S. EPA "Global Emissions"). While all these gases are naturally occurring, their concentrations in the atmosphere have increased significantly since the industrial revolution, by 39, 158 and 19 percent, respectively (U.S. EPA "Inventory," ES-2). GHGs trap energy in the atmosphere around the planet, causing warming that alters myriad climate and weather patterns.

The major GHGs vary in their global warming potential (GWP), which is the ability of each gas to trap heat in the atmosphere over a specified horizon. CO_2 is used as the baseline gas, with a 100-year GWP of one, and all other gases can be reported in terms of CO_2 equivalent (CO_2e). The U.S. Environmental Protection Agency (EPA) reports CH_4 to have a GWP of 21 and N_2O to have a GWP of 310 ("Inventory," ES-3). Using CO_2e allows analysis of total emissions levels over time that contribute to global warming.

In 2010, the EPA reported that the U.S. emitted 6,822 million metric tons of CO_2e, an increase of 10.5 percent since 1990 ("Inventory," ES-16). In terms of total emissions, the U.S. is second only to China as the world's leading emitter. The energy sector accounts for approximately 87 percent of total CO_2e emissions, and thus reducing the CO_2e intensity of the energy sector offers a significant opportunity to decrease overall U.S. GHG emissions (U.S. EPA "Inventory," ES-12).

Of total U.S. GHG emissions, CO_2 has individually accounted for roughly 78 percent of GWP-weighted emissions over the past 20 years, though it accounted for 84 percent of GWP-weighted emissions in 2010 (U.S. EPA "Inventory," ES-6). Although it has the lowest GWP, the volume of CO_2 emissions makes it the single most important cause of anthropogenic global warming. Since combustion of fossil fuels accounts for 85 percent of U.S. energy production and accounts for the vast majority of U.S. CO_2 emissions, transitioning to low or zero-GHG emitting energy generating technologies offers a chance to radically reduce total U.S. CO_2 emissions.

According to the U.S. National Aeronautics and Space Administration (NASA), CO_2 parts per million (ppm) are currently 395, up from a long-term pre-industrial level of 280 ppm

("Global Climate Change"). Without mitigation, the Intergovernmental Panel on Climate Change (IPCC) projects these levels could increase to between 500 and 970 ppm by the end of the century ("Synthesis Report"). Even with the existing ppm increase, global air and water temperatures and sea levels have risen, while land ice and arctic sea ice levels have fallen. Although estimates of the maximum acceptable increase in global temperature vary, the typical range is 1.5 to 3 degrees Celsius over pre-industrial levels. NASA reports that global temperature has already increased 1.5 degrees Fahrenheit since 1880.

The EPA reports that ever-increasing GHG concentrations will result in myriad effects, including increasing earth's average temperature, changing precipitation patterns, reducing snow and ice cover, raising sea levels, and increasing ocean acidity ("Future"). In order to avoid catastrophic changes to the environment, most scientists believe atmospheric CO_2 will need to be reduced relative to current levels, which will require major shifts in policy in the U.S. and throughout the world. In the U.S., the current politically feasible option is a sector-by-sector approach that creates policies for each high-emitting sector. The electric power sector is the largest single emitter, thus it is important to understand the dynamics of electric power generation and why its emissions are so significant.

Electricity Sector Emissions

The energy sector emitted around 87 percent of total U.S. CO_2e emissions in 2010, and the electric power industry alone was responsible for nearly 34 percent, or 2307 million metric tons, of all GHG emissions in that year (U.S. EPA "Inventory," ES-12). According to the EPA, this makes the electric power industry the economic sector with the highest emissions levels. Thus, while the CES, which affects only the electricity sector, will not have as broad an impact as an economy-wide or energy sector-wide policy, a reduction of electricity sector emissions of 50 to 75 percent would amount to a significant reduction of 17 to 26 percent of total U.S. GHG emissions. As such, understanding emissions from the electricity sector and the current electricity generation profile is critical for measuring success of the CES as a GHG emissions-reducing policy.

As shown in Figure 1, 44 percent of U.S. electricity was generated using coal in 2011. According to the U.S. EPA, stationary coal combustion is the single largest source of CO_2 emissions in the U.S. economy, accounting for 81 percent of electricity sector emissions ("Inventory," 28). Natural gas, which has lower emissions relative to coal, provided 21 percent of 2011 electricity. Electricity from nuclear power, which produces no emissions, accounted for 21 percent of U.S. electricity generation. Thirteen percent was generated by hydropower and other emissions-free renewables. Combusting coal to create electricity releases around 2 pounds per kilowatt hour (kWh), while natural gas releases around 1 pound per kWh (EIA "CO_2"). Nuclear, hydropower and other renewables do not create any GHG emissions from electricity generation. Thus, from an emissions standpoint, reducing the amount of generation from traditional coal towards cleaner sources, as a CES requires, is a positive step.

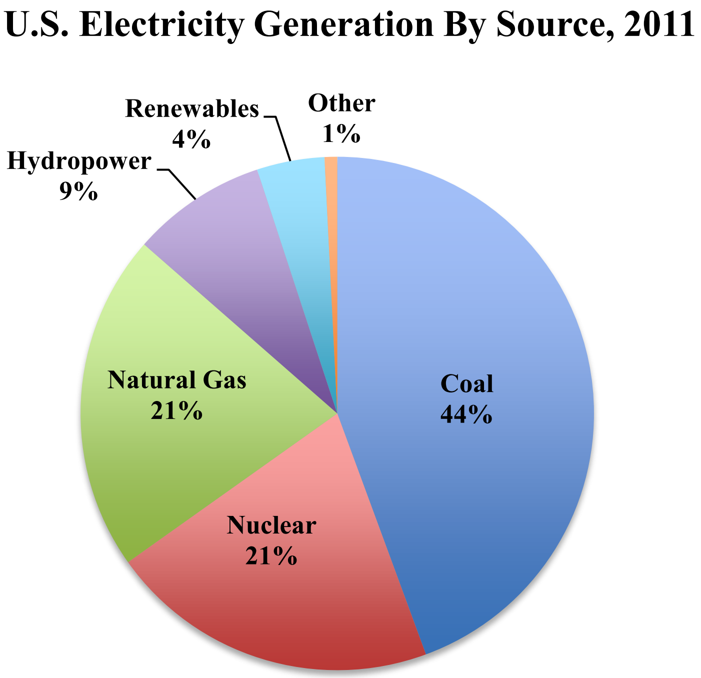

Figure 1. U.S. Generation in 2011. Source: U.S. Energy Information Administration, AER 2011, Table 8.2b.

The market has changed over the past twenty years, as shown in Figure 2, but has not shifted dramatically away from fossil fuel combustion. While coal generation has increased 8.6 percent over the period, it has decreased as a percent of total generation from 54 to 44 percent. Natural gas generation has more than doubled as a percent of total generation from 9.3 to 21.3, with significant growth in recent years due to low natural gas prices. Generation at nuclear plants has increased nearly 30 percent, but has not changed significantly as a percentage of generation. Renewables did grow dramatically by nearly five-fold, but still account for only 4 percent of generation. In order to create a more dramatic shift in generating capacity, a policy like an economy-wide regulation on emissions or a CES, promoting a shift in technologies, is necessary.

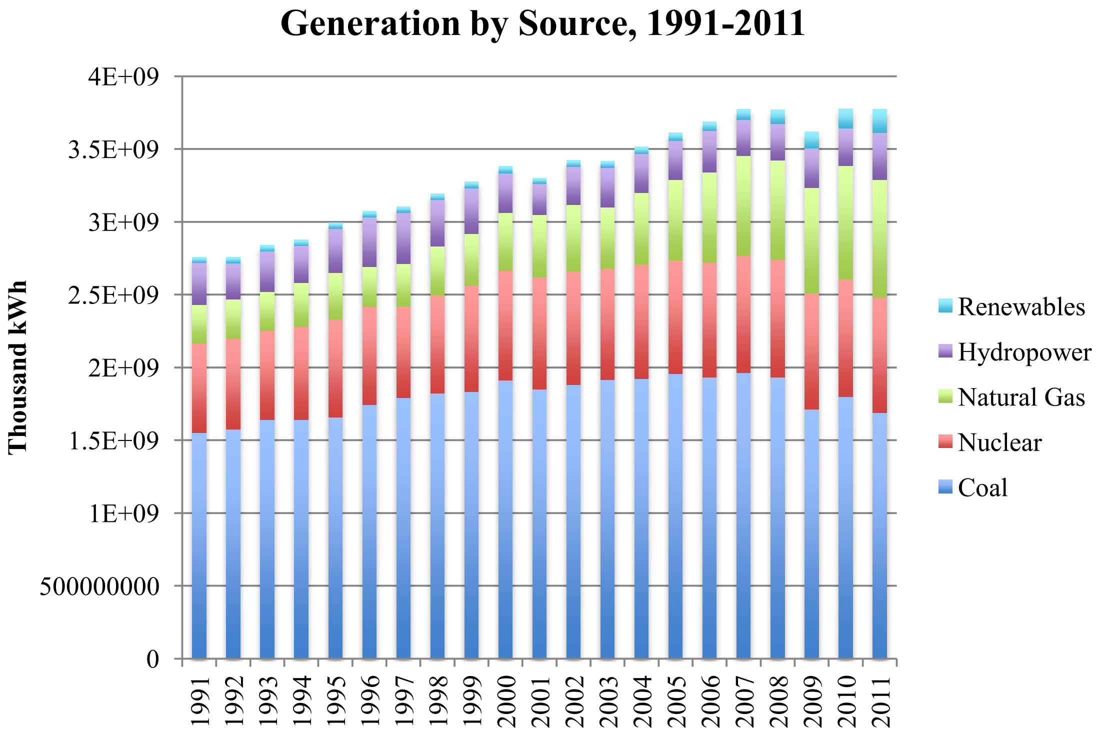

Figure 2. Generation by Source, 1991-2011. Source: U.S. Energy Information Administration, AER 2011, Table 8.2b.

Federal Policy Options to Address Climate Change

Economy-Wide Climate Change Policies

There are two primary policies to address economy-wide CO_2 emissions: a carbon tax and cap-and-trade. Both of these policies function essentially as a price on carbon. A carbon tax is a Pigovian tax—a tax on pollution or a public "bad" where businesses and individuals are otherwise unmotivated to consider the adverse harm caused by their actions. Here, it would directly tax fuels based on their GHG emissions, creating a cost for CO_2 emissions. In a cap-and-trade system, emissions are capped at a certain level and emissions permits to achieve that level of emissions are issued, trading occurs, and firms are required to submit permits according to emitted GHGs. Economists believe these policies are cost-effective mechanisms for reducing GHG emissions, meaning reductions occur in a least-cost way. The cost of permits or taxes translates into higher prices for electricity, fossil fuels, and manufactured goods that are energy-intensive. In this way, the burden of the policy is distributed across the economy and all sources of emissions are subject to higher costs. Thus, these policies create an economy-wide impetus to reduce emissions by substituting away from carbon-intensive fuels and products. While the two policies may offer different advantages and disadvantages in terms of efficiency and equity, both are economy-wide, market-based policies.

Starting in 2003 and 2007, Congressional Republicans and Democrats have on multiple occasions proposed GHG cap-and-trade legislation and a carbon tax, respectively, and both Presidential candidates in 2008 supported a cap-and-trade plan. However, the 2009 passage in the House of Representatives of a cap-and-trade bill galvanized conservative opposition to the policy. While a cap-and-trade regime or carbon tax would be the most economically effective way to reduce carbon emissions, they have not been feasible policy options following the 2010 midterm elections, as the Republican majority would not support either policy. In recent months, there has been some conservative support for a carbon tax, but neither carbon policy seems likely to return as a major agenda item in the near-term.

Clean Electricity Standards

Understanding that neither of the economy-wide carbon pricing policies are currently politically feasible, various policy alternatives have been suggested to reduce U.S. emissions through incremental and complementary approaches. For the electricity sector, one such alternative is a CES, which creates targets for clean electricity generation as a percentage of the overall electricity mix.[1] The CES is an expanded version of another proposed policy, the RES, which has also been proposed federally in recent years. In addition, a majority of U.S. states currently have a state-level RES policy in place, and a RES bill passed in the House of Representatives as part of the American Clean Energy and Security Act of 2009. As a stand-alone policy, the CES has the potential to significantly reduce GHG emissions through deployment of clean energy technologies, though its impacts are smaller than the economy-wide carbon pricing options. By using a CES to prioritize electricity generating technologies with

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[1] Although the CES is sometimes called a Clean Energy Standard, it is only a target for the electricity sector and does not have a broader impact on energy use – thus, calling it a Clean Electricity Standard is more accurate.

lower CO_2 emission intensity and setting escalating performance goals, the U.S. economy could begin a transition to a lower CO_2 generating mix.

In both his 2011 and 2012 State of the Union addresses, President Obama endorsed a CES policy of producing 80 percent of domestic energy from clean energy by 2035. As recently as March of 2012, Senator Bingaman introduced a CES policy in the Senate, and previously introduced iterations have seen bipartisan support. The CES, which notably includes nuclear power and, depending on the version, potentially cleaner fossil fuel plants in addition to renewable energy resources, is more politically popular because of its broader technology inclusion. Broader technology inclusion allows easier compliance across the country, including in areas where traditional renewable resources are scarce – particularly in the Southeast, which generated the majority of opposition to a federal RES, but where nuclear energy is popular and where biomass resources are plentiful.

The CES could be primarily framed as a climate policy or as a clean energy technology policy. There are myriad non-climate reasons why a technology policy may be attractive. Supporters may cite reduction of other non-GHG pollutants, reduced resource use, lower costs for new technologies or even economic development and job growth. Regardless of the rationale for the technology policy, a CES is more efficient at achieving its objectives as a technology policy and less effective than carbon pricing as a carbon policy. Due to the lack of political interest in climate change, the Senate CES proposals are framed as clean energy technology-focused, rather than emissions focused, rewarding generators for the type of technology used rather than tying credits specifically to the emissions level at each plant. Given that a small minority of Republicans – 27 percent in one recent study – is convinced that climate change is occurring, promoting clean technology for its non-climate benefits is likely to be more successful (Mayer et al., 1). Since they are not primarily structured to lower emissions, CES policies do not reduce GHG emissions as effectively as carbon pricing regimes. In addition, since the CES only covers the electricity sector, it would certainly be a second-best approach for reducing emissions compared to an economy-wide model. However, a technology-based CES is more politically feasible than a carbon price, particularly because it would not increase energy prices as significantly as a carbon price. That strength, however, is also a weakness if the goal of the policy is emissions reductions. Since consumers experience less cost increase with the CES, they will be less likely to substitute towards electricity conservation.

Comparison of Economy-Wide and CES Policies

	Economy-Wide	CES
Scope of Coverage:	Entire economy	Electricity sector
Relative Reduction of Emissions:	Higher	Lower
Energy Price Increases:	Higher	Lower
Cost-Effectiveness of GHG reductions:	Higher	Lower
Political Feasibility:	Low	Moderate

Introduction to Energy Modeling

In considering implementing a federal CES, it is important to examine the design choices for the policy and how the structure of the CES will affect clean energy deployment and GHG emissions. One way to analyze the policy is through use of an energy model to simulate the effects of the policy. Using a model to analyze the CES allows the policymaker to design the policy, set baseline assumptions, and forecast outcomes. The modeling results can help the policymaker to understand the economic ramifications of the policy, take a holistic view of the development of the energy market over time and project environmental and resource impacts. Thus, a modeling exercise allows policymakers to forecast the likely outcomes of the policy. As such, the choices of both the model and the assumptions are critical to obtaining the most accurate projections possible.

Modern energy models were developed following the 1973 oil crisis, when forecasters recognized the need to develop systems that better captured the complexity of the energy system. As Wirl and Sziruczek (1990) note, the interaction of engineers and economists in that era, and their differing approaches to understanding the energy system, led to the development of rich models with strong methodological underpinnings. Many of the early models that were developed in the 1970s still exist today, and have been consistently subject to reevaluation and revision, allowing them to improve and better reflect the true energy system.

Major models have been developed to evaluate domestic markets, global markets, energy and electricity-only markets, and so on. Established models include the Market Allocation (MARKAL) model, the Energy Flow Optimization Model (EFOM) and, in the U.S., the EIA's National Energy Modeling System (NEMS). Other notable models that lack applicability to the analysis are briefly noted in Appendix B.

Energy models can be broadly defined in two categories: top-down and bottom-up. Bottom-up models are technology-rich models that attempt to "establish accounting coherence using detailed engineering representation of the energy system" (Bhattacharyya and Timilsina, 28). According to the IPCC, bottom-up models can be grouped into three categories: engineering-economics, integrated partial equilibrium and simulation models. Engineering-economics models assess each technology separately, then aggregated, integrated partial equilibrium models assess the whole energy system together, and simulation models further account for the choices of economic agents. Top-down models, which can include both econometric and computable general equilibrium (CGE) models, use historical data and economic theory to establish a predictive relationship between the dependent variable and the independent variables. Some end-use models may be built to predict interaction with the macroeconomy; for example, the MARKAL-MACRO offers macroeconomy interactions that the original MARKAL model does not. End-use models may also include aspects of an input-output model and scenario modeling.

Still other models, such as NEMS, use a hybrid method that incorporates both the "technological details of bottom-up models and the micro- and macro-economic details of econometric models" (Bhattacharyya and Timilsina, 41). These models may offer a more accurate projection by combining the strengths of both the end-use and econometric approaches.

The type of model used will have a significant impact on the estimated costs of the policies modeled. According to IPCC, these differences results from including or excluding different kinds of costs (i.e. hidden costs, welfare losses), differing methodologies to aggregate costs, feedback between demand and price, and in different underlying assumptions. For example, while MARKAL, an integrated partial equilibrium model, simultaneously computes end-use demand and prices, other models calculate these steps separately. Simulation models may account for non-cost preferences, deviating from the estimates of least-cost models. For more detailed information on the models, please see appendices C and D.

Analysis of Clean Electricity Standards

Overview of Analysis of Clean Electricity Standards

In order to better understand the ramifications of a CES policy, I undertook a qualitative analysis of the policy. I examined design choices, CES legislative history and previous studies of the CES to inform a general understanding of the policy's impacts and develop lessons learned.

Though the CES has dual objectives – GHG emissions reduction and clean energy technology deployment – the criteria of primary interest in this report is the ability of the policy to reduce emissions in a cost-effective manner. For the purposes of this report, cost-effectiveness is synonymous with least-cost per unit reduction in emissions compared with the status quo. The emissions reductions and costs of the various proposed CES scenarios will be compared with a status quo baseline and between the scenarios.

Throughout the analysis, the following outcome variables are of primary interest. These will be examined quantitatively and qualitatively in various sections of the report.

- Electric power sector CO_2 emissions levels;
- Generation mix in total generation and percentage of generation, including generation from coal, natural gas, nuclear, hydropower, non-hydropower renewables, petroleum and other;
- Technology adoption in total new plants or uprates (in gigawatts) and percentage of total installed capacity, including plants for coal, natural gas, nuclear, hydropower, non-hydropower renewables, petroleum and other;
- Average delivered prices for end-use electricity;
- National electricity expenditures;
- Depending on the structure of the CES, indicators such as use of alternative compliance payments (ACPs), price of clean energy credits (CECs), etc. (see CES design choice decisions for more information on these components);
- Costs associated with the policy over the status quo, such as negative impacts on gross domestic product (GDP).

Based on the modeling outputs available from EIA, I chose to use a metric of the ratio of the percentage reduction in cumulative electricity sector CO_2e emissions over the duration of the policy to the percentage reduction in cumulative GDP over the duration of the policy. Although this is an imperfect metric for comparing the costs and benefits, it provides a general way to understand the costs associated with varying levels of reductions and policy designs. I will refer to this as the CO_2e-GDP reduction ratio.

CES Design Choices

There are five major design decisions for policymakers considering a CES, including setting annual targets, choosing baseline sales levels, specifying qualifying technologies, choosing which entities must comply and designing the compliance system. The following section discusses each of these design decisions, options, a qualitative discussion of consequences and stakeholder alignment with options.

The point of compliance is typically the local electricity retailer, which may or may not be a utility. For simplicity in this report, I have referred to such retailers as utilities, as is common in the legislative language.

The support or criticism of stakeholders will determine whether or not a CES is politically viable. Key stakeholders in the CES include: electric utilities, including investor-owned utilities (IOUs), municipal electric utilities (munis) and electric cooperative utilities (coops); non-electric energy companies, including resource developers and technology manufacturers and their associated lobbies; special interests including environmental non-profits and advocacy groups, manufacturing trade associations, think tanks, etc.; federal, state and local utility regulators; consumers, including industrial, commercial and residential; and federal and state policymakers as proxies for these various interests.

1. Annual Targets, Including Technology-Specific Targets

A CES proposal sets a percentage of electricity that should be supplied by qualifying technologies annually, based on the level of baseline sales (see discussion of baseline sales below). The selection of the annual and final year targets has an obvious impact on the deployment and diversity of new generation. In order for the CES to be effective, policymakers must set targets that are both achievable and aspirational, that is, that can neither be met too readily through existing sources nor set so high that the regulated entities cannot comply.

Options for final targets in recent legislative proposals ranged from 50 percent to 95 percent. While different design can account for some of this spread, the aspiration of the policymaker accounts for a much larger degree of the final target variation. The final target should be set once other aspects of the policy, such as qualifying technologies and baseline, are set so that the target is reasonable under the policy's assumptions. Generally, utilities, except very progressive utilities, do not support high targets for the CES as the burden of compliance falls of them. Depending on the qualifying technologies, trade associations and individual companies that would benefit from the legislation are likely to support stronger targets, while technologies that cannot be used for compliance are likely to lobby against the CES or demand lower targets. In terms of special interests, environmental advocacy groups will support higher targets while associations representing broader manufacturing will likely oppose high targets. Consumer advocates may have concerns about cost impacts with higher targets, but will see the benefits of increased consumer health through reduced emissions, so their support is largely dependent on the overall weighing of the costs and benefits of the policy.

In addition to setting an overall target, the CES may also specify annual targets for certain technologies, referred to as "set-asides" or "carve-outs." These set-asides may significantly alter the outcome of the CES by changing the final technology distribution. Set-asides are usually intended to satisfy a particular interest group or to ensure utilities invest in particular technologies. For example, the CES could be structured to include a set-aside for renewable energy to cater to environmental advocacy organizations, or a nuclear power set-aside to cater to the major corporations that manufacture nuclear equipment and, in either case, the policymakers that advocate on behalf of those interests. As some analysts have noted, in the four states with a RES policy that resembles a CES, "utilities tend to comply … by deploying the lowest-cost qualified resources," so a set-aside may be desirable if the policymakers prefer technologies other than the lowest-cost technology, although it will increase the costs of the policy (Center for Climate and Energy Solutions, viii). Costs will be higher with set-asides because the lowest-cost option will not necessarily be deployed, but early adoption of new technologies due to set-asides will likely result in earlier cost reductions for those technologies and later cost savings in deploying those technologies.

Set-asides are strongly promoted by certain technologies that want a guaranteed market, and their trade associations and major companies will lobby for a set-aside. Depending on the technology, environmental groups may also support the set-aside if it is a renewable, rather than clean, technology. Set-asides increase regulatory burden, so may be disliked by regulators. Those concerned with the cost-effectiveness of the policy are unlikely to support set-asides.

2. Baseline Sales

The baseline sales are the level of sales that the utilities' targets are based on. Typically, the prior year's sales are used as the baseline for compliance. However, many policies consider the type of fuel used to generate electricity by the utility, and may treat certain sources differently. For example, existing generation that, if new, would qualify as clean – such as hydropower or nuclear – may be exempted from the level of baseline sales. This effectively reduces the compliance burden for utilities that already have a fair amount of clean generation on their systems. The baseline sales level is an important consideration for setting the target, as discussed above, since it may reduce the level of new clean generation needed to comply.

Generally, utilities with higher levels of existing clean generation that will not otherwise qualify will lobby for exclusion from baseline sales. Areas of the country with high levels of hydropower and nuclear will see support for the exclusion from regional and local regulators. However, since it creates an incentive to keep nuclear plants online, anti-nuclear interest groups will not support the exclusion. Holding the CES target constant, it all reduces the amount of new clean energy generating facilities that need to be built, so clean technology manufacturers and their lobbying groups prefer not to have the baseline exclusions for existing nuclear and hydropower.

Apart from qualifying technologies, facilities fall into one of two possible subdivisions. First are plants that do not count as clean technologies and which, along with the clean technologies, form the basis for the required amount of compliance. Second are plants that do not count as clean but are excluded from the utilities' baseline. Existing otherwise-qualifying plants, such as existing hydropower and nuclear power plants, could be treated as either of these types of plants. Existing hydropower and nuclear are usually subject to cut-off dates to ensure that older plants are not the only source of compliance with the policy. These decisions have an obvious impact on the amount of clean electricity that utilities need in order to comply with the policy. Policymakers may also consider counting retrofitted fossil fuel plants towards the standard, or awarding credits for fossil fuel plant retirements.

3. Qualifying Technologies

The definition of "clean" in the CES is subject to interpretation. While CES policies typically include renewable energy technologies and nuclear power due to emitting zero GHGs, a variety of fossil fuel technologies may be included as qualifying technologies if they have certain cleaner features or can meet a lower emissions goal. Technologies that policymakers could define as renewable under the CES include wind, solar, geothermal, biomass, ocean, landfill gas, incremental hydropower, new hydropower, hydrokinetic and waste-to-energy. All of these technologies are typically included in CES proposals. Although it would be possible to include existing hydropower and nuclear, these are typically not counted as qualifying technologies because utilities that owned a large amount of this generation would benefit without having made any significant investment or improvement. While this is also true of existing renewable generation, the scale of existing renewable generation is much smaller than that of existing nuclear, so including existing renewables as a qualifying technology is generally not contentious. Technologies that policymakers could define as clean under the CES include efficient natural gas combined cycle (NGCC), fossil fuels with carbon capture and sequestration (CCS) and nuclear uprates. A broader definition of clean generation increases the number of compliance options and reduces the overall cost of the policy.

Which technologies should qualify is at least in part a function of the goal of the CES. Typically, the CES is intended to deploy qualifying clean energy technology, in order to accelerate adoption of technologies with fewer negative externalities, as a primary goal and to reduce GHG emissions as a secondary goal. However, other factors may also be of interest to policymakers. For example, different types of power plants create emissions other than GHG, such as particulate matter or mercury, create waste, such as spent nuclear fuel, use large amounts of water or require land use alterations. If policymakers have additional goals for the CES, they may select different technologies or create set-asides to achieve those goals.

In order to accommodate different types of technology, including both low and zero-GHG emitting technologies, a credit system that awards credits relative to the average emissions produced may be designed, giving zero-emitting generation full credits and low-emitting technologies partial credits. Thus, renewables and nuclear receive one credit per megawatt hour (MWh) of generation while other technologies that rely on improved fossil fuel generation receive partial credits. These partial credits can reflect improvements over the baseline and be rewarded at different levels for different technologies. This type of system can increase the generation from renewable technologies compared to an equal credit system, achieving a similar objective to a technology set-aside.

As with the overall targets, the primary stakeholders that will engage on qualifying technologies are utilities, trade associations and industry lobbying groups, environmental advocacy organizations and regulators, with similar goals as in the target negotiations. In addition, due to the regional differences in resources, citizens and their representatives may push for certain technology inclusions. For example, the reason the CES typically includes nuclear power is due to the popularity and availability of the technology in the Southeast.

Assuming existing nuclear and hydropower do not qualify, excluding existing nuclear and hydropower from the baseline compliance level benefits utilities that have significant amounts of these sources on their systems, and these utilities and their proxies will lobby for treatment that benefits them. However, as it reduces the overall level of compliance necessary, clean technology firms and environmental advocacy organizations will oppose such treatment.

In addition, the CES may explicitly or implicitly promote energy efficiency, either by including it as a qualifying technology, with or without an upper limit for compliance, or by creating an energy efficiency set-aside. At the federal level, none of the proposed CES policies have had an energy efficiency set-aside. Energy efficiency improvements are generally inexpensive and can help to achieve GHG or air quality goals, and some stakeholders would like to promote energy efficiency technologies in the market. Including energy efficiency as a qualifying technology thus promotes the lowest-cost route to compliance. However, energy efficiency credits would create verification and quantification challenges. An energy efficiency requirement or specific instructions on treatment of energy efficiency in the CES would likely increase the deployment of energy efficiency technologies. Additional titles in CES legislation specifying complementary policies such as decoupling and lost revenue recovery – both of which reduce the financial disincentive for utility energy efficiency investments - would be useful if energy efficiency is specifically promoted in the CES.

Energy efficiency firms and trade associations would lobby for specific treatment of energy efficiency, and consumer advocates and environmental advocacy organizations likely would as well. Regulators and utilities, which face a burden in verification and quantification, would likely not support specific energy efficiency treatment.

4. Compliance Exclusions

The CES may require only certain types of entities to comply. For example, electricity providers with sales below a certain threshold may be considered too small to comply, or the policy may exempt certain types of providers, such as munis or coops. In typical federal RES proposals, utilities below 4 million MWh of sales in a given year are exempt from the policy, and a level near this is most likely for CES compliance exclusions.

Smaller utilities, which often include munis and coops, may be at a disadvantage in meeting the CES because of lack of capital and financing mechanisms. This is often cited as a reason to exempt these utilities. Other options include subjecting the smaller utilities, or the munis and coops as a proxy for smaller utilities, to a lower standard than IOUs, or lengthening the compliance period for each required increase in clean electricity generation.

Most utilities would prefer not to have to comply with the regulation and would seek exemption if possible. In addition, exempted utilities may be able to sell clean energy credits onto the market at a profit, and have an additional impetus to seek exemption. However, those who benefit from a higher target – manufacturers, trade associations and environmental advocacy groups – would prefer a more inclusive approach to compliance.

5. Compliance System Design

Other design features mostly address the design of the compliance system. These features include a. how the CEC market and trading system is structured, b. whether utilities can "bank" extra credits in one year for use in future years and c. the level of the ACP a utility can pay rather than use credits from generated electricity.

Utilities can demonstrate compliance with the policy by owning clean electricity generation, by directly purchasing clean electricity generation from another party for delivery over the grid, by purchasing CECs or, in some systems, by buying ACPs. Credits may be issued for different technologies at different levels, for example, by providing credits based on relative emissions reductions from various technologies. CECs are issued to generators, and they can sell the electricity and credits bundled together or separately. Although a system without tradable credits is theoretically possible, it is likely than any proposal would include tradable CECs because this will be much more cost-effective. As the Congressional Budget Office (2011) found in its report on CES cost-effectiveness, tradable CECs allow flexibility in the CES to promote least-cost compliance, and this system will be more economically efficient. This system is likely, however, to make some states or regions net buyers or sellers of credits, which raises distributional questions for stakeholders. In a system with annual targets, banking credits helps to smooth the impacts of the policy's increasing targets, and this is an important feature to help reduce costs over time.

ACPs effectively cap the price of the CECs on the market, and can provide a lower-cost option for compliance. This can provide an overall cost-cap for the policy and prevent energy prices from exceeding a set level. However, if the cost of ACPs is low enough that they are used, utility compliance through ACPs reduces the amount of investment in clean technology and GHG reduction. Revenue from ACPs could be used for any number of purposes, including promoting other GHG mitigating projects. Consumer advocates are likely to support an ACP as a price cap for the program, while environmental advocacy groups would not support a low ACP as it reduces the level of clean technology build-out.

CES Legislative History

There have been six Congressional proposals for a federal CES in the past decade in 2006, 2009, 2010, 2011 and 2012. Demonstrating the bipartisan interest in the policy, Republicans sponsored three of the four officially proposed drafts. Additionally, two proposals were modeled by EIA in 2011 but not officially proposed. In addition to Congressional proposals, President Obama has publically called for a federal CES in two State of the Union addresses.

In 2006, Senator Norm Coleman (R-MN) proposed the first federal CES, which he called a "clean energy portfolio standard," as an amendment to the Public Utilities Regulatory Policies Act of 1978 (PURPA) (U.S. EIA "CEPS," 17). All subsequent federal CES proposals have been introduced as amendments to PURPA. However, Senator Coleman never formally introduced the bill, likely due to multiple other proposals for CO_2-mitigating policies that other members of Congress sponsored during that time.[2]

In 2009, Senator Lindsey Graham (R-SC) issued a discussion draft on the Clean Energy Act of 2009, but did not introduce the bill, and in September 2010 he introduced the Clean Energy Standard Act of 2010. Both of these bills included a CES. The 2010 bill was referred to committee and there were no hearings or votes. Senator Graham introduced the bill as interest in a federal RES under a proposal from Senators Jeff Bingaman (D-NM) and Sam Brownback (R-KS) was growing. Senator Graham, a pro-nuclear energy Republican, is largely credited with fueling the political interest away from a federal RES and towards a federal CES option. As Senator Graham said when he introduced the legislation, "From my part of the country, that's a bad proposal because it doesn't acknowledge nuclear power as being a low, carbon-free source of energy, and it disadvantages nuclear power" (Howell).

In June 2010, Senator Lugar (R-IN) introduced the Practical Energy and Climate Plan Act of 2010, a multifaceted policy which included a "diverse energy standard" similar to Senator Graham's original CES proposal. Senator Graham signed on as one of three cosponsors to the legislation. The bill was referred to the Senate Finance Committee and there were no hearings or votes.

President Obama proposed a federal CES in his January 2011 State of the Union address, and mentioned the policy again in his 2012 State of the Union address. President Obama proposed a CES with a target of 80 percent by 2035. According to the White House, using the methodology of the proposed CES, the U.S. had already reached a 40 percent level in 2011 (1). The CES would qualify renewable energy and nuclear energy for full credits and give partial credits to "clean coal" and "efficient natural gas" (U.S. White House, 2). While his proposal propelled interest in the policy, it was not a fully developed CES proposal and did not specify many necessary design details.

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[2] Due to the length of time since this proposal and the many departures of this policy from more recent proposals, I do not examine Senator Coleman's specifications and EIA's related modeling outputs in detail.

Following President Obama’s endorsement of the CES, Senator Bingaman, Chairman of the Senate Committee on Energy and Natural Resources (ENR), pursued a federal CES. In March 2011 Senator Bingaman and ENR Ranking Member Lisa Murkowski (R-AK) issued a white paper asking for feedback on how to structure a CES. In August and September 2011 Senator Bingaman requested that EIA model a CES using NEMS in order to inform the policymaking process. In March 2012 Senator Bingaman introduced the “Clean Energy Standard Act of 2012,” which was also modeled by EIA using NEMS. The bill had ten cosponsors, all Democrats. Although ENR held hearings in May 2012, the legislation was never voted on. Senator Bingaman did not seek reelection in 2012 and is no longer in office.

In July 2011, Congressman Ralph Hall (R-TX), Chairman of the House Committee on Science, Space and Technology, requested that EIA run a modeling exercise on a CES with fairly tight restrictions. Congressman Hall released the EIA modeling as a report “on President Obama’s proposed CES” (U.S. House). Congressman Hall’s goal was to undermine support for the CES by framing it as “an expensive new tax on the American people” that was a “surefire way to raise electricity prices and lose jobs” and he did not introduce it as legislation.

Previous CES Specifications and Modeling

Comparison of CES Proposals

	Lugar (2010)	**Graham (2010)**	**Bingaman Baseline (2011)**	**Bingaman Proposed (2012)**	**Hall (2011)**
First Target	2015: 15%	2013:13%	2015: 45%	2015: 24%	2013: 44.8%
Final Target	2050: 50%	2050: 50%	2050: 95%	2035: 85%	2035: 80%
Qualifying Technologies 1. Renewables	New and existing renewables;	New and existing renewables, incremental geothermal;	New and existing renewables;	New and existing renewables;	New and existing renewables;
2. Hydropower	New hydropower and uprates built within three years of enactment;	New hydropower since 2001 and hydropower updates built since 1992;	New hydropower and uprates built after enactment;	New hydropower built since 1992 and hydropower uprates since 1992;	New and existing hydropower;
3. Nuclear	New nuclear;	New nuclear and nuclear uprates within 3-years prior to enactment;	New nuclear and uprates built after enactment;	New nuclear since 1992 and nuclear uprates since 1992;	New and existing nuclear;
4. Fossil Fuels	Coal with CCS and other sources that produce 80 percent reduction in emissions compared to average emissions rate of US generation.	Coal-mined methane, coal with CCS;	New and existing coal or NG plants with a CO_2 intensity lower than a new supercritical coal plant are granted partial credits, proportional to their emissions reduction, ranging from .15 to .95 credits.	New and existing coal or NG plants with a CO_2 intensity lower than a new supercritical coal plant are granted partial credits, proportional to their emissions reduction, ranging from .15 to .95 credits.	Coal or NG with CCS earns .9 credits and NGCC plants earn .5 credits.
5. Other		Fossil fuel retirements.			
Energy Efficiency	Can be used to comply with any amount of the target, but EE CECs cannot be sold out of state.	Can be used to comply with up to 25 percent of the target.	Not addressed.	Not addressed other than CHP receiving credits.	Not addressed.
Baseline Sales	Existing hydropower built more than 3 years prior to enactment is excluded from base.	Existing hydropower built prior to 2001 and existing MSW is excluded from base.	Existing hydropower and nuclear built prior to enactment can be used towards goal but are not issued credits.	Existing hydropower and nuclear built prior to 1992 is excluded from base.	No exclusions.
Compliance Exclusions	None.	Utilities with less than 4 million MWh in previous year and Hawaii.	None.	Utilities with less than 2 million MWh in 2015, decreasing through 2025 to 1 million MWh cut-off.	None.
Credits Banking	Unlimited banking.	Unlimited banking.	Unlimited banking.	Unlimited banking.	No banking.
ACPs	5¢ per kWh	3.5¢ per kWh	Not available.	3¢ per kWh	Not available.

Figure 3. Comparison of CES Proposals.

Lugar CES

Senator Lugar's proposed CES was not modeled by EIA. The proposed CES had the following features:

1. **Annual targets:** The first compliance year is 2015 with a target of 15 percent. The final target is 50 percent in 2050 and beyond.

2. **Baseline sales:** Existing hydropower built more than 3 years prior to enactment is excluded from baseline sales.

3. **Qualifying technologies:** New and existing renewables including wind, solar, biomass, coal-mined methane, geothermal, landfill and biogas, marine and hydrokinetic, waste-to-energy; new hydropower and uprates within three years of enactment; new nuclear; coal with CCS and other sources that produce 80 percent reduction in emissions compared to average emissions rate of US generation. Existing hydropower is excluded from the baseline. Energy efficiency can also be used to comply with any level of the requirement.

4. **Compliance exclusions:** All electric utilities must comply.

5. **Compliance system design:** The policy uses a tradable CEC system and unlimited banking is available. ACPs are available at 5 cents per kWh. CECs from energy efficiency may not be sold out of the state in which they are generated.

Graham CES

Senator Graham's proposed CES was not modeled by EIA. The proposed CES had the following features:

1. **Annual targets:** The first compliance year is 2013 with a target of 13 percent. The final target is 50 percent in 2050 and beyond.

2. **Baseline sales:** Existing hydropower built prior to 2011 and all existing municipal solid waste (MSW) is excluded from baseline sales.

3. **Qualifying technologies:** New and existing renewables including wind, solar, geothermal, ocean, biomass, landfill gas, marine and hydrokinetic, coal-mined methane; coal with CCS; new hydropower since 2001 and hydropower updates since 1992; incremental geothermal; waste-to-energy; new nuclear and nuclear uprates within 3-years prior to enactment; fossil fuel retirements. Existing hydropower and MSW is excluded from the baseline. Energy efficiency can be used to satisfy up to 25 percent of the requirement.

4. **Compliance exclusions:** Utilities with less than 4 million MWh of sales in the prior year are exempt. Hawaii is also exempt.

5. **Compliance system design:** The policy uses a tradable CEC system and unlimited banking is available. ACPs are available at 3.5 cents per kWh.

Original Bingaman CES

Senator Bingaman's interest in the CES in 2011 and 2012 led to several CES modeling efforts. In August 2011, Senator Bingaman requested that the EIA analyze various CES scenarios in order to develop his CES proposal. In his request, Senator Bingaman specified a baseline scenario for the analysis and requested seven side cases examining alternative designs. The baseline scenario, referred to as the BCES by EIA, uses the following design features:

1. **Annual targets:** The first compliance year is 2015 with a target of 45 percent. The targets ramp up to 95 percent in 2050 and in every year after 2050. Senator Bingaman's targets were roughly twice as high as the Republican Senators' proposals.

2. **Baseline sales:** Existing hydropower and nuclear built prior to enactment can be used towards goal but are not issued credits.

3. **Qualifying technologies:** New and existing renewable energy sources, including wind, solar, geothermal, biomass, MSW and landfill gas earn full credits under the BCES. Incremental generation at existing hydropower and nuclear plants due to uprates receive full credits, as do all new hydropower and nuclear plants. Existing hydropower and nuclear plants do not receive credits but can be counted towards the utility's goal. Some new and existing fossil fuel plants with a carbon intensity lower than that of a new supercritical coal plant are granted partial credits, proportional to their emissions reduction, ranging from .15 credits for integrated gasification combined cycle (IGCC) coal plants without CCS to .95 credits for natural gas plants that sequester CO_2 emissions, as follows:

    - Natural gas plants that capture and sequester their CO_2 emissions (0.95 BCES credits)
    - Coal plants that capture and sequester their CO_2 emissions (0.9 BCES credits)
    - Existing NGCC units (0.48 BCES credits)
    - New gas combined-cycle units (0.59 BCES credits)
    - Existing gas combustion turbines (0.16 BCES credits)
    - New gas combustion turbines (0.45 BCES credits)
    - IGCC coal plants without CCS (0.15 BCES credits)

4. **Compliance exclusions:** All electric utilities must comply.

5. **Compliance system design:** The policy uses a tradable CEC system and unlimited credit banking is available. There is no ACP in the baseline case.

In order to respond to Senator Bingaman's request, EIA used the NEMS model to simulate BCES and the various scenarios and predict the impacts of the alternatives. The EIA analysis compares the results of the NEMS model runs of the BCES with the EIA's Annual Energy Outlook (AEO) 2011 report reference case. The AEO report projects trends in the U.S. energy sector given the current market and existing policy. Thus, the BCES scenario builds on the AEO reference case by adding the assumptions of the BCES into the analysis and uses the AEO reference case as a baseline for how the BCES could change future U.S. energy trends.

The EIA found that the BCES would have major impacts over the reference case in terms of deployment of clean technology and reduced GHG emissions. EIA projected that electricity sector CO_2e emissions would decrease 43 percent relative to the reference case in 2035, driven by a modest 4 percent reduction in total generation, a halving of coal-fired generation, 60 percent growth in natural gas generation and 83 percent growth in renewable generation. EIA projected this policy would decrease 2035 GDP by only .5 percent, increase total electricity expenditures by 15 percent and increase average electricity prices by 20 percent relative to the reference case. The ratio of cumulative emissions reductions to cumulative GDP loss over the duration of the policy, the CO_2e -GDP reduction ratio, is 76.9.

Senator Bingaman also requested that EIA examine seven side cases. These side cases can be illustrative in terms of how the design features affect outcomes of the modeling exercise. The seven sensitivity runs include:

1. AC: The All Clean (AC) case gives full credit to existing nuclear and hydropower generation (vs. counting towards the target but not getting credits);
2. PC: The Partial Credit (PC) case gives .1 credits to existing nuclear and hydropower generation, .5 credits to NGCC (vs. .59 in baseline) and no credits to gas combustion and coal without CCS (vs. range of .15-.45 in baseline);
3. RB: The Revised Baseline (RB) case excludes existing nuclear and hydropower from the baseline (vs. counting towards the target but not getting credits);
4. SUE: The Small Utilities Exempted (SUE) case exempts utilities with less than 4 million MWh in sales from complying, though they can still sell credits into the market. This exempts around 25 percent of sales in the market;
5. C2.1: The Credit Cap 2.1 (C2.1) case provides unlimited ACPs at 2.1 cents per kilowatt hour in 2015, increasing 5 percent per year above the inflation rate annually thereafter;
6. C3.0: The Credit Cap 3.0 (C3.0) case is the same as C2.1, but starts with ACPs at 3 cents per kilowatt hour in 2015;
7. S+C: The Standards and Codes (S+C) case increases efficiency standards for covered and currently uncovered products.

The first four side cases illustrate how different designs can change the achieved level of clean energy of the program. As shown in Figure 4, while the nominal target in 2035 is 80 percent for all scenarios, the treatment of hydropower and nuclear, baseline definitions and compliance exclusions produce a range of actual clean energy achievement. In SUE, excluding small utilities essentially halves the actual goal, although only 25 percent of utilities are excluded (see discussion below for additional detail). Only when hydropower and nuclear power are counted as full credits in AC is the nominal target of 80 percent consistent with the actual level of clean energy generation achieved.

	Baseline	**1. AC**	**2. PC**	**3. RB**	**4. SUE**
Achieved Level	56%	80%	58%	74%	42%

Figure 4. Actual Level of Clean Energy Achieved in 2035 for BCES Scenarios with Nominal 80% Target. C2.1, C3.0 and S+C are excluded as they do not impact target level.

Overall, the side case runs show similar trends as BCES, but vary in terms of impacts. As shown in Figure 5, the three side cases that have different treatments of existing nuclear and hydropower – AC, PC and RB – all drive around a 60 percent reduction in 2035 electricity sector CO_2e emissions, greater than the 43 percent in BCES. These three scenarios all incentivize a more rapid shift away from coal-fired generation by providing some nuclear incentives. In AC and PC, this is particularly due to higher nuclear deployment and less natural gas-fired generation. AC incentivizes keeping nuclear plants online, while PC disincentivizes coal and incentivizes keeping nuclear plants online. RB incentivizes nuclear plants to stay online, but less so than AC or PC, and accelerates NG deployment.

AC, PC and RB incent the greatest reductions in electricity sector CO_2e emissions of all the side cases, and all have a higher CO_2e -GDP reduction ratio than BCES indicating a more cost-effective policy. Though they result in roughly 50 percent greater GHG reductions in 2035, the impact on GDP is proportionally much smaller than BCES per percentage GHG reduction. AC and RB both have greater impacts on consumers than BCES because they force quicker coal retirements and new clean plant builds relative to BCES or the other side cases, but perhaps the negative economic impacts are somewhat mitigated by the economic development associated with building new plants. The RB plant has the highest ratio of the AC, PC, RB and BCES scenarios, indicating the most cost-effective compliance. The PC case has the same GDP impact as BCES, while achieving much higher emissions, and results in lower impacts to consumers due to fewer new builds.

The SUE case results in the highest CO_2e -GDP reduction ratio of the side cases at 124.4. However, a major reason for this high ratio is that the emissions reductions are much smaller and so lower-cost compliance strategies can be used. This case has only a marginal impact on electricity prices and expenditure – 1.1 percent and 1.4 percent increases, respectively – but decreases emissions 23.2 percent relative to the reference case in 2035. Interestingly, total generation is almost equal to the reference case. SUE causes a 25 percent reduction in coal-fired generation relative to the reference case in 2035, though based on the starting installed capacity this essentially means that SUE does not force coal retirements, but provides incentives against building any new coal-fired capacity. New capacity builds are primarily in nuclear power and renewables. SUE is also cost reducing relative to other cases because small utilities can generate credits but do not need to use them and they can thus sell them on to the market and lower the price of credits. In 2025, the credit price for SUE is 2.9 cents per kWh, relative to an average 5.9 cents across the other side cases. In 2035, the credit price is 4.7 cents per kWh, relative to an average 10.1 cents across the other cases. With credits less than half the price of alternatives, SUE is a lower-cost policy, but drives lower emissions reductions. If policymakers pursue an exemption for small utilities, it is important to consider whether to allow these players to participate in the credits market and how it impacts the strategies of covered utilities.

In C2.1 and C3.0, the ACP functions as a price cap to keep program costs down and both scenarios achieve a higher CO_2e -GDP reduction ratio than BCES. In both cases, availability of the ACP results in lower credit prices and thus lower program costs. However, when the price is set at 2.1 cents, emissions reductions are almost halved relative to the BCES, indicating more compliance through ACPs and less through switching to cleaner technologies. These two side cases demonstrate the value in having an ACP, but setting it at a high enough level that it works as a price ceiling but not so inexpensive to act as a deterrent from switching to cleaner technologies.

The final case, S+C, building efficiency and appliance standards are markedly higher. As a result, total generation in 2035 is 10 percent lower than in the reference case due to lower demand and emissions are 50.6 percent lower than the reference case. Otherwise, the technology deployment is similar to BCES. The CO_2e -GDP ratio is the lowest of all the Bingaman cases at 67.6. While consumer impacts through electricity prices are lower, the policy has a ripple effect through the economy that causes the greatest cumulative reduction in GDP with a .42 percent cumulative reduction relative to the reference case. S+C demonstrates the potentially important role that other complementary titles could have in CES legislation.

Across BCES and the seven side cases, the average 2035 reduction in emissions relative to the baseline was 45 percent, the average cumulative reduction in emissions was 24 percent, the average cumulative reduction in GDP was .3 percent and the average CO_2e -GDP reduction ratio was 94.2.

	Ref	**Baseline**	**1. AC**	**2. PC**	**3. RB**	**4. SUE**	**5. C2.1**	**6. C3.0**	**7. S+C**
Decrease in electricity sector CO_2e emissions (relative to reference)	-	-42.9%	-59.7%	-60.6%	-61.5%	-23.2%	-22.0%	-40.4%	-50.6%
Cumulative decrease in electricity sector CO_2e emissions 2015-2035	-	-24.6%	-32.1%	-29.1%	-35.1%	-11.2%	-12.5%	-20.3%	-28.4%
Decrease in GDP (relative to reference)	-	-0.48%	-0.62%	-0.48%	-0.30%	-0.18%	-0.14%	-0.31%	-0.83%
Cumulative decrease in GDP over duration of policy	-	-0.32%	-0.41%	-0.34%	-0.35%	-0.09%	-0.11%	-0.19%	-0.42%
Increase in total electricity expenditures (relative to reference)	-	15.1%	17.5%	12.9%	19.4%	1.4%	6.7%	9.4%	4.6%
Increase in electricity prices (relative to reference)	-	20.2%	26.6%	18.1%	27.7%	1.1%	8.5%	12.8%	17.0%
CO_2e-GDP reduction ratio	-	76.9	78.3	85.6	100.3	124.4	113.6	106.8	67.6
Qualifying technologies as percent of total sales	-	72.0%	92.0%	93.0%	70.0%	45.0%	43.0%	56.0%	70.0%
Total generation (billion kWh)*	5142	4916	4811	4950	4831	5131	5049	5007	4620
Total generation (% reduction relative to reference)	-	-4.4%	-6.4%	-3.7%	-6.0%	-0.2%	-1.8%	-2.6%	-10.2%
Coal-fired generation (% of all generation)	42.5%	21.2%	15.5%	18.9%	15.3%	31.7%	32.1%	24.2%	21.3%
Coal-fired generation (relative to reference)	-	-50.0%	-63.4%	-55.5%	-64.1%	-25.3%	-24.5%	-43.0%	-49.9%
NG generation (% of all generation)	25.1%	40.3%	38.2%	33.5%	41.5%	24.9%	28.4%	31.6%	38.5%
NG generation (relative to reference)		60.2%	52.1%	33.2%	65.2%	-1.0%	12.8%	25.6%	53.0%
Nuclear generation (% of all generation)	16.9%	15.9%	23.2%	25.6%	20.7%	21.5%	18.5%	20.9%	16.2%
Nuclear generation (relative to reference)	-	-5.6%	37.2%	51.9%	22.5%	27.6%	9.4%	24.0%	-4.1%
Non-hydro renewable generation (% of all generation)	8.2%	15.0%	15.2%	14.7%	14.6%	14.3%	13.5%	15.5%	15.8%
Non-hydro renewable generation (relative to reference)	-	83.3%	86.0%	80.1%	78.7%	75.4%	65.6%	89.7%	94.0%

Figure 5. Comparison of BCES Scenarios and Reference Case in 2035.
*All generation does not add up to 100% because hydropower, petroleum and other were excluded

Proposed Bingaman CES

Senator Bingaman ultimately introduced a CES with different specifications than BCES. The proposed CES was called BCES12 by EIA when the agency modeled the policy's impacts and included the following features:

1. **Annual targets:** The first compliance year is 2015 with a target of 24 percent. The targets ramp up to 84 percent in 2035 and in every year after 2035. The early targets were weaker relative to BCES, at 24 percent vs. 40 percent in BCES. The final target was lower at 84 percent compared to 95 percent in BCES, but the final year was 15 years sooner than in BCES.

2. **Baseline sales:** Existing hydropower and nuclear built prior to 1992 is excluded from the base.

3. **Qualifying technologies:** As in BCES, new and existing renewable energy sources, including wind, solar, geothermal, biomass, MSW and landfill gas earn full credits under the BCES. A hybrid of the RB and PC side cases, incremental generation at existing hydropower and nuclear plants due to uprates after 1991 receive full credits, as do all hydropower and nuclear plants placed online in 1992 or after. Pre-1992 hydropower and nuclear plants do not receive credits but can be used to reduce the utility's sales baseline. Partial credits were specified as in BCES, except combined heat and power (CHP) facilities with efficiencies of greater than 50 percent could also qualify (see BCES qualifying technologies for credit amounts).

4. **Compliance exclusions:** Unlike BCES or any of the side cases, utilities with sales less than 2 million MWh in annual sales in 2015 are exempted. The exemption level decreases linearly to 1 million MWh in annual sales in 2025 and beyond.

5. **Compliance system design:** As in BCES, the policy uses a tradable CEC system and unlimited credit banking is available. As in C3.0, ACPs are available at 3 cents per kWh in 2015 and increasing with inflation.

EIA used the NEMS model to simulate BCES12 and predict the impacts of the alternatives. The EIA analysis compared BCES12 with the EIA's early release AEO2012 report reference case, so the baseline is slightly different from the BCES analysis. EIA projected that CO_2e emissions would decrease 43.5 percent relative to the reference case in 2035, similar to the 42.9 percent reduction in BCES, driven by a small 4.5 percent reduction in total generation, a 52 percent reduction of coal-fired generation, 14 percent growth in natural gas generation, 70 percent growth in nuclear and 40 percent growth in renewable generation. Due to the nuclear treatment, the policy incents nuclear generation, though this rapid nuclear build-out is highly sensitive to nuclear prices. Relative to the reference case, EIA projected this policy would decrease 2035 GDP by only .5 percent, increase total electricity expenditures by 12 percent and increase average electricity prices by 18 percent. The CO_2e -GDP reduction ratio is 96.1, significantly higher – and thus more cost-effective – than BCES, and slightly than the BCES 8-case average ratio of 94.2.

The environmental non-profit and advocacy group Union of Concerned Scientists (UCS) was critical of the results of the EIA modeling. According to UCS, EIA used inappropriate cost estimates for wind, solar and nuclear. UCS claims that EIA's cost estimates for solar and wind started too high, and failed to decrease as rapidly as some experts predict. It also asserted that the overnight cost used for new nuclear plants was less than half the costs of currently proposed new nuclear plants. Different cost assumptions would likely result in a very different built out and total cost than those projected by EIA in the BCES12 run.

Resources for the Future (RFF)(2012) also modeled BCES12 using its in-house Haiku electricity markets model. The baseline case is "calibrated" to the EIA reference case, in this case, AEO2011. RFF also assessed the effect of BCES12 with different assumptions, including a high natural gas price scenario and a scenario with new environmental regulations from the Mercury and Air Toxics Standards (MATS). RFF found a 41 percent reduction in CO_2 emissions relative to their baseline case, versus a 44 percent reduction in CO_2e found by EIA. RFF also modeled the CES with and without the ACP, finding that not offering an ACP option reduced CO_2 emissions by 65 percent relative to the baseline. Exempting small utilities had only a marginal effect on CO_2e reductions, though whether these small utilities can sell credits onto the market will have a major effect.

Hall CES

Congressman Hall proposed a CES that was notably less flexible than other proposals. Although all existing nuclear and hydropower could be used to meet the target, there were no exclusions for small utilities, no banking of credits and no ACPs available. Congressman Hall's CES, called HCES by EIA, was designed to maximize the costs of the CES in order to criticize the policy. However, the HCES also led to significant reductions in CO_2e relative to the baseline, above and beyond BCES, because of its stringency. Further, its CO_2e-GDP ratio was similar to Senator Bingaman's proposed CES at 93.9.

The proposed CES, called HCES by EIA, had the following features:

1. **Annual targets:** The first compliance year is 2013 with a target of 44.8 percent. The final target is 80 percent in 2035 and beyond.

2. **Baseline sales:** No exclusions.

3. **Qualifying technologies:** New and existing renewables including wind, solar, geothermal, biomass, MSW, landfill gas; new and existing hydropower; new and existing nuclear; coal or natural gas with CCS receive .9 credits and NGCC receives .5 credits.

4. **Compliance exclusions:** No exclusions.

5. **Compliance system design:** The policy uses a tradable CEC system without banking. There are no ACPs.

EIA modeled HCES using NEMS, based on the AEO2011 Reference Case, as in the BCES analysis. EIA also ran sensitivity runs based on higher and lower nuclear, renewable, coal and natural gas costs. EIA projected that CO_2e emissions would decrease 60.4 percent relative to the reference case in 2035, more than 33 percent more than either Bingaman case, caused by a 6.5 percent reduction in total generation, a 53 percent reduction of coal-fired generation, 39 percent growth in both natural gas and nuclear generation and 71 percent growth in renewable generation. Cumulative CO_2e reductions were 31 percent over the duration of the policy. Relative to the reference case, EIA projected this policy would only decrease 2035 GDP by .3 percent, increase total electricity expenditures by 18.5 percent and increase average electricity prices by 29 percent. As shown in Figure 6, the sensitivity runs reveal that technology build-out is highly sensitive to changes in technology costs with 25 to 58 percent reductions in capacity in the high cost cases relative to the low cost cases.

	Capacity with High Cost (GW)	**Capacity with Low Cost (GW)**	**Difference (GW)**
Coal	447	878	431
Natural Gas	1503	1996	493
Nuclear	874	1564	690
Non-Hydro Renewables	531	1256	725

Figure 6. 2035 Capacity of Various Technologies with High and Low Cost Assumptions

Comparison of Modeling Results

	Bingaman Baseline (2011)	**Bingaman Proposed (2012)**	**Hall (2011)**
Decrease in 2035 electricity sector CO_2e emissions (relative to reference)*	-42.9%	-43.5%	-60.4%
Cumulative decrease in electricity sector CO_2e emissions 2015-2035°	-24.6%	-22.1%	-31.0%
Decrease in 2035 GDP (relative to reference)	-0.48%	-0.53%	-0.29%
Cumulative decrease in GDP over duration of policy	-0.32%	-0.23%	-0.33%
Increase in total electricity expenditures (relative to reference)	15.1%	12.1%	18.5%
Increase in electricity prices (relative to reference)	20.2%	18.3%	28.7%
CO_2e-GDP reduction ratio	76.9	96.1	93.9
Total generation (billion kWh)	4916	4828	4807
Total generation (% reduction relative to reference)	-4.4%	-4.5%	-6.5%
Coal-fired generation (% of all generation)	21.2%	18.7%	19.8%
Coal-fired generation (relative to reference)	-50.0%	-51.6%	-53.4%
NG generation (% of all generation)	40.3%	30.7%	34.9%
NG generation (relative to reference)	60.2%	13.5%	38.7%
Nuclear generation (% of all generation)	15.9%	30.1%	23.4%
Nuclear generation (relative to reference)	-5.6%	70.1%	38.9%
Non-hydro renewable generation (% of all generation)	15.0%	13.3%	14.0%
Non-hydro renewable generation (relative to reference)	83.3%	40.4%	70.9%

Figure 7. Comparison of Modeled CES Results in 2035.

*Reference for Bingaman Baseline and Hall is AEO2011 while Bingaman Proposed used the AEO2012 Early Release.

°EIA only reported data for all policies through 2035, although final year of Bingaman Baseline is 2035. First Hall year is 2013.

Lessons for Designing a CES

From the discussion of CES design and modeling outcomes, I draw five key lessons for policymakers designing a CES policy. The first lesson concerns a general design strategy to ensure the policy is effective at reaching its goal. The next three lessons all concern specific design features and my recommendations for how policymakers should approach them. The final lesson concerns a general best practice for modeling long-term electricity policies.

1. **Though it is the key specification of the policy, the nominal clean energy target should be set last after the policymakers decide on distributional features such as treatment of existing nuclear and hydropower generation, qualifying technologies, baseline sales and compliance exclusions. Changes in design should lead to changes in the target.**

The nominal target alone is not a good indicator of what the policy will achieve. Treatment of existing nuclear and hydropower generation, the definition of baseline sales for covered entities and the exclusion of some entities may have a dramatic impact on the actual level of the clean energy target. As seen with the BCES analysis, modifying these features can effectively halve the target. Thus, policymakers must be deliberate in their decisions concerning these features and set the target based on how they have designed the rest of the policy. Setting the target first, and then designing the features later – as the Obama Administration essentially attempted when it supported a CES level without determining the details first – risks poor policy design and undesirable distributional impacts.

2. **There are cost and predictability trade-offs for design choices related to CEC banking and ACPs. Taking into account this trade-off, policymakers should allow unlimited CEC banking and make ACPs available, but at a high enough level so as not to undermine the goals of the policy.**

The CES can be designed as a relatively flexible tool, with unlimited CEC banking and ACPs available, or a less flexible tool with no or limited CEC banking and no ACPs. More flexible policies will lead to more low-cost compliance and reduce the overall cost of the program but provide less program predictability in terms of when and how much new technology comes online. Less flexible policies will lead to higher-cost compliance and increase program costs, but technology build-out and impacts will be more predictable.

Considering CEC banking, it is clear that unlimited banking is a desirable feature. Unlimited banking does reduce the predictability of certain years within the program, but it does not harm the overall integrity of the program. Instead, unlimited banking allows smoothing in the program that will result in lower-cost compliance and lower the burden of compliance for covered utilities. Unlimited banking does not reduce the ultimate level of emissions reduction, since it does not change compliance requirements, but it may change the levels of technology build-out since it provides more flexibility for utilities.

Considering ACPs, ACPs should be available to reduce the overall costs of the policy, but at a high enough level that they do not undermine the policy's goals. The BCES, C2.1 and

C3.0 cases provide an opportunity to look at ACP impacts in otherwise identical cases. In C2.1 the ACP level was set too low, and too many utilities chose to comply through ACPs. As a result, emissions reductions from the program were just half those in the BCES case. In C3.0, the ACP level was set such that it created a downward pressure on the price of credits and reduced the costs of the policy by more than a third, but had a trivial impact on emissions reductions. Providing an ACP at the right level is able to reduce program costs without reducing program effectiveness. When designing a CES, careful consideration of the ACP level is merited to achieve this balance. One option for choosing the ACP level would be to consider the social cost of CO_2 emissions and try to design the policy such that emissions reductions that cost up to the social cost are implemented but reductions that are costlier than the benefit are not.

3. **If some utilities are exempted from the policy their participation in the credit market will radically change policy impacts. Policymakers should consider the distributional impacts of allowing their participation and set the target to still reach the policy's goals.**

If policymakers determine that exempting smaller utilities or some other utility class is politically necessary or desirable for reducing cost impacts or distributional reasons, then they must consider the effects of allowing these utilities to sell credits into the credit market. The SUE side case demonstrates the importance of this design feature. Excluding small utilities, but allowing them to sell credits, floods the market with inexpensive credits and there will be significant shifting towards existing qualifying generation and credits and less shifting towards new technology builds. While it is true that the SUE case was relatively inexpensive, the emissions reductions were only half that of the baseline case. Treatment of exempted utilities and their market interactions with covered utilities must be considered when setting the policy's target.

4. **Treatment of existing hydropower and nuclear resources affects the cost-effectiveness of the policy. Providing full or partial credits for these resources or excluding them from the baseline results in more cost-effective GHG reductions than allowing them to meet the target but not issuing them credits. Policymakers should consider the lowest-cost way to treat these resources, taking distributional impacts into account.**

The Bingaman side cases showed that changes to the treatment of existing hydropower and nuclear resources results in very different outcomes. Excluding existing nuclear and hydropower resources resulted in the most cost-effective GHG reductions, on an electricity sector wide basis, but provided a large windfall for utilities that already had these resources. If these distributional impacts are undesirable, allowing full or partial credits for these resources can result in higher GHG reductions than not providing them with credits. This still creates a distributional advantage for some utilities, and the policymaker must weigh these distributional effects against the greater GHG reductions.

Essentially, the treatment of existing nuclear and hydropower resources in these more cost-effective scenarios keeps more of these existing resources from retiring and being replaced by other plants. If the CES promotes nuclear power, it makes sense to try to keep these plants running as a key part of the policy. However, additional work on novel options for treating these resources, and NEMS runs changing their treatment and predicting outcomes, would be helpful in designing the most effective policy. Policymakers should consider options such as various levels of partial credits or credits for extending plant life, improving efficiency or uprates to maximize the benefits of these existing resources.

5. **Model projections are highly sensitive to technology cost predictions, and policymakers should request multiple cost sensitivity runs in order to understand the full range of possible policy outcomes predicted by the model. Various other sources of uncertainty, such as macroeconomic conditions, demand growth and changing residential, commercial and transportation technology choices also merit consideration.**

A single run of a model like NEMS will not be very useful in understanding the range of possible outcomes. NEMS is a detailed technology model, but there are many possible assumptions about the future costs of technologies and the cost and learning curves that can impact its projections. As the HCES sensitivity runs revealed, changes to these assumptions will result in very different impacts in terms of technology build-out. Policymakers should request sensitivity runs that include high and low cost assumptions in order to understand the range of potential costs, macroeconomic impacts, technology build-outs and emissions reductions that could result from the policy.

In addition, sensitivity runs examining other sources of uncertainty, such as macroeconomic conditions, demand growth and changing residential, commercial and transportation technology choices are critical to developing expected impacts for the CES.

Conclusion

Modeling exercises on previously proposed CES policies have shown that the policy can dramatically shift the generation mix and GHG emissions in the electricity sector. However, the effectiveness of the policy in reducing emissions and spurring technology change, its cost-effectiveness and its distributional impacts depend on the design of the policy. Policymakers must consider how annual targets, technology set-asides, setting of baseline sales, selection of qualifying technologies, inclusion or exclusion of certain utilities and the structure of the compliance system will affect the policy's likely outcomes and weigh costs, benefits and distributional impacts of the policy in selecting the design.

From the review of previous modeling exercises, expanded lessons on these design questions are revealed. First, the clean electricity target of the policy should be set following the design of the policy – the policy design can change the actual electricity generated by clean technology by up to half under the same target. Second, there are cost and predictability trade-offs for design choices related to CEC banking and ACPs. Unlimited CEC banking should be available and ACPs should be available, but at a fairly high level. Third, if some utilities are exempted from compliance with the policy, policymakers must consider if they can participate in the credit market and the implications of that treatment for the target. Fourth, issuing full or partial credits or removing existing nuclear and hydropower resources from the baseline results in lower-cost compliance. Fifth, the projected outcomes of the policies are highly cost-dependent, and running the model with alternative cost assumptions as well as with other uncertainty analysis is necessary for a full understanding of policy outcomes. With these lessons in mind, policymakers can better design a federal CES that meets the policy's goals.

Appendix A. List of Abbreviations

ACP: Alternative Compliance Payment
AEO: Annual Energy Outlook
BCES: Bingaman Clean Energy Standard modeled in 2011
BCES12: Bingaman Clean Energy Standard proposed in 2012
CCS: Carbon capture and sequestration (or storage)
CEC: Clean energy credit
CES: Clean electricity standard (or clean energy standard in other reports)
CGE: Computable general equilibrium
CH_4: Methane
CHP: combined heat and power
Coop: Cooperative electric utility
CO_2: Carbon dioxide
CO_2e: Carbon dioxide equivalent
DOE: U.S. Department of Energy
EIA: U.S. Energy Information Administration
ENR: Senate Committee on Energy and Natural Resources
EPA: U.S. Environmental Protection Agency
EPANMD: EPA national MARKAL model
ETSAP: Energy Technology and Systems Analysis Program (ETSAP), part of IEA
GDP: Gross domestic product
GHG: Greenhouse Gas(es)
GWP: Global warming potential
HCES: Hall Clean Energy Standard
IAEA: International Atomic Energy Agency
IEA: International Energy Agency
IEPE: Institute of Energy Policy and Economics
IGCC: Integrated gasification combined cycle
IOU: Investor-owned utility
IPCC: Intergovernmental Panel on Climate Change
kW: kilowatt
kWh: kilowatt hour
MARKAL: Market Allocation Model
MATS: Mercury and Air Toxics Standards
MSW: Municipal solid waste
Muni: Municipal electric utility
MW: Megawatt
MWh: Megawatt hour
NASA: National Aeronautics and Space Administration
N_20: Nitrous oxide
NEMS: National Energy Modeling System
NERC: North American Electric Reliability Corporation
NG: Natural gas
NGCC: Natural gas combined cycle
NIEPS: Nicholas Institute for Environmental Policy Solutions

Ppm: parts per million
PURPA: Public Utilities Regulatory Policies Act of 1978
RES: Renewable electricity standard (or renewable energy standard)
RFF: Resources for the Future
SEI: Stockholm Environment Institute
T&D: Transmission and distribution
TIMES: The Integrated MARKAL EFOM System
UCS: Union of Concerned Scientists
UNFCCC: United National Framework Convention on Climate Change
USGS: United States Geological Survey

Bingaman Side Case Acronyms:
AC: All Clean case
C2.1: Credit Cap 2.1 case
C3.0: Credit Cap 3.0 case
PC: Partial Credit case
RB: Revised Baseline case
S+C: Standards and Codes case
SUE: Small Utilities Exempt case

NEMS Acronyms:
CMM: Coal Market Module
EMM: Electricity Market Module
IEM: International Energy Module
MAM: Macroeconomic Activity Module
NGTDM: Natural Gas Transmission and Distribution Module
OGSM: Oil and Gas Supply Module
OLOGSS: Onshore Lower 48 Oil and Gas Supply Submodule
PADDs: Petroleum Administration for Defense Districts
PMM: Petroleum Market Module
RFM: Renewable Fuels Module

Appendix B. List of Major Models

Name; Developer; Attributes

- Brookhaven Energy System Optimization Model (BESOM); Brookhaven National Lab, original basis for MARKAL
- Energy Flow Optimization Model (EFOM); Commission of the European Communities; bottom-up, optimization-based, input to MARKAL-TIMES model
- Haiku; Resources for the Future; electricity only
- Long Range Energy Alternatives Planning System (LEAP); SEI; bottom-up
- Market Allocation Model (MARKAL); ETSAP; bottom-up, optimization-based, large family of models
  - MARKAL-MACRO: Includes interaction with the macroeconomy
  - EPA MARKAL Technology Database (EPANMD); U.S. EPA; EPA version of MARKAL, U.S. domestic
- Model for the Analysis of Energy Demand (MAED); IAEA; bottom-up, energy demand only (no supply)
- National Energy Modeling System (NEMS); EIA; hybrid, U.S. domestic model
- Prospective Outlook on Long-Term Energy Systems (POLES); IEPE; no emissions data
- System for the Analysis of Global Energy Markets (SAGE); U.S. DOE EIA; Global, based on MARKAL
- The Integrated MARKAL-EFOM System (TIMES); combination of two bottom-up, optimization models
- Wien Automatic System Planning (WASP); IAEA; electricity planning, developing economics

Appendix C. In-Depth Analysis of Selected Models

The client had specifically considered using either the NEMS or MARKAL model. Only models that include supply and demand side coverage, U.S. domestic markets and energy system-wide coverage including both energy and electricity were considered. The three models considered all allow users to input their own data, build scenarios and project outcomes. They vary most greatly in terms of their granularity and their ease of use.

The choice between MARKAL and NEMS ultimately concerns the following organizational preferences:

- ***Capacity of client staff to run analysis:*** MARKAL will be easier to learn and use in-house than NEMS, unless the client wanted to develop its own database for MARKAL. In this case, either model would be challenging to run entirely in-house. It would be difficult to develop in-house capacity to run NEMS.
- ***Cost:*** MARKAL will have costs associated with purchasing the model and required tools, while NEMS will have costs associated with hiring a third-party to run the analysis (unless NIEPS is willing to provide the analysis).
- ***Acceptance***: NEMS is a better-known model, and offers more detail for the U.S. market than MARKAL using EPANMD. It also better incorporates macroeconomic interaction. NEMS may be more accepted by consumers of the report.

The following consideration should not be considered when choosing between the models:

- ***Time Horizon***: Though NEMS is only currently structured to run through 2040, this is not a limiting factor as third parties can extend the program.

MARKAL and TIMES

MARKAL Information and Potential for Use

- MARKAL is a recognized model, though less well known in the U.S. than NEMS.
- It is a bottom-up, optimization-based model without a built-in macroeconomic interaction.
- MARKAL can be run using very long-term scenarios.
- MARKAL can only be run using a database specific to a market, which can either be developed by the user or a third-party version can be used. The only free third-party version of MARKAL for the U.S. is the EPANMD model, which includes a technology database based on sources such as EIA. EPANMD offers an excellent suite of baseline assumptions.
- Although it is a complex model, MARKAL is easier to learn than NEMS. Additionally, EPA may offer assistance in training to users interested in using the EPANMD database. Running scenarios not included in MARKAL requires skill but is possible.

- MARKAL is expensive, and requires a variety of additional software features to run.

If the client wanted to use MARKAL as the basis for its analysis, it would be possible to run the analysis in-house using the EPANMD database. Developing a database would likely be prohibitively difficult, though EPANMD can be modified. EPA may be able to train the client's staff in the use of MARKAL and the database. However, MARKAL may be more limited than NEMS in terms of granular inputs and representation of the U.S. market.

Background

The basis for MARKAL and TIMES was one of the earliest energy models, known as the Brookhaven Energy System Optimization Model (BESOM), developed at Brookhaven National Lab. BESOM was further developed by a collaborative effort run at the International Energy Agency (IEA) by the Energy Technology Systems Analysis Program (ETSAP) into the original Market Allocation, or MARKAL, model. The Energy Flow Optimization Model (EFOM), a similar model, has been combined with MARKAL to create the Integrated MARKAL EFOM System (TIMES). While MARKAL is still available for download, TIMES is now the preferred product as it supports higher quality analysis by incorporating the best features of MARKAL and EFOM. However, MARKAL requires a database to run. A user can either develop a database, which is costly and time-consuming, or use a free database. The EPA national model and technology database (EPANMD) is available as a free download but is only usable with the original MARKAL model, and not with TIMES.

MARKAL Model Features

MARKAL is a bottom-up, optimization based model that uses linear optimization to find the least-cost result. The model covers the entire energy system, based on detailed technological modeling of the system. MARKAL accommodates rigid time periods and includes an integrated supply and demand model. MARKAL can accommodate regional differences if the underlying database does so, as EPANMD does. EPANMD runs to 2055.

In an interview, Pizer noted that MARKAL has difficulty showing how technologies may shift over time due to the way the linear probability model is written. This could be a challenge in the client's analysis. However, MARKAL offers users more flexibility in terms of developing their own model compared to NEMS.

TIMES Model Features

TIMES was designed to be the ideal tool for exploring "possible energy futures based on contrasted scenarios" (IEA 2, pg. 7). Like MARKAL, TIMES is an end-use, data-driven, linear optimization-based model, which arrives at a lowest cost supply solution to a set of user-inputted energy system features. As an end-use model, TIMES relies on extensive technology modeling, and can also output environmental and emissions impacts. It has also been modified to increase the price-responsiveness of the model, increasing the accuracy of projections concerning policies such as a price on CO_2. TIMES can be multi-period and multi-regional, and can accommodate both linear and non-linear constraints. TIMES is based on four components: demand, supply, policy scenarios and a "techno-economic" component of technical and economic parameters. Although TIMES has a variety of useful updates over MARKAL, the EPANMD database cannot be run in TIMES.

In addition to paying an R&D contribution to use MARKAL or TIMES, these models require a user-interface, the GAMS modeling system and an optimizing solver.

Model Applications

- MARKAL and TIMES are widely used around the world by major organizations that undertake comprehensive energy modeling.

NEMS

NEMS Information and Potential for Use

- NEMS is a well-recognized model for the U.S., is backed by rigorous analysis and data, incorporates both top-down and bottom-up aspects for a more integrated partial equilibrium, provides a granular look at the entire U.S. energy system and is optimization-based. With more conservative outputs, it may have higher acceptance.
- Although currently limited through 2040, the model can be modified to develop results through 2050.
- NEMS is a very complicated model with a challenging user interface. Developing enough familiarity with the program to run it successfully would require significant resources and training, and there are few options to acquire such training. Most organizations use third parties, such as OnLocation Inc., to develop and run NEMS models for them. Running scenarios not included in NEMS requires advanced skills.
- NEMS is free, though some third-party software may be required to run it.

NEMS is widely considered the best model for the U.S. in terms of detail and macroeconomy interactions. However, if the client wanted to use NEMS as the basis for its analysis, it would likely need to outsource the work to a third-party consultant.

Background

The U.S. Department of Energy's Energy Information Administration (EIA) first developed NEMS in 1993. This U.S.-only model is used by EIA in its "Annual Energy Outlook" (AEO) report, which details the expected course of energy production, consumption and market trends through 2035, and also to prepare other U.S. government analyses on proposed policies.

NEMS Model Features

NEMS is a hybrid models that incorporates aspects of both an end-use and econometric model. Like TIMES, NEMS is based on a rich representation of energy technology, but it maintains a basis in the behavioral analysis that defines econometric approaches. Although EIA runs of NEMS for the AEO are "policy-neutral," using only existing policies to model business-as-usual outcomes, users can modify the model to run policy scenarios.

NEMS produces national and regional data, based on existing Census, NERC and EIA-defined subdivisions. NEMS is based on four supply modules (oil and gas, natural gas transmission and distribution, coal, renewables), four end-use demand modules (residential, commercial, industrial, transportation), a macroeconomy module to model interaction with the broader economy, an international markets module to simulate global market interactions, and an integrating module that achieves a general equilibrium across the model. NEMS uses the modules to solve for energy prices and consumption across the regions, and continues to run in sequence until the model finds convergence through economic equilibrium in supply and demand for each year in the projection.

NEMS is backed by decades of research and analysis, and "offers a tremendous advantage over anything else in terms of familiarity and longevity in the marketplace" (Pizer, 10/15/2012). Compared with MARKAL, NEMS offers greater detail and is considered extremely robust because the model develops inputs for assumptions rather than allowing the user to input them (Gumerman, 10/15/2012). Johnson suggested that, although both NEMS and MARKAL are partial equilibrium models, NEMS "does a better job of overcoming some of the challenges of partial equilibrium … [for example], doing iterative runs" (Johnson, 10/16/2012). Given the prominence of NEMS as a model, Johnson, a MARKAL user, recommended comparing results from other systems to NEMS results to examine and explain how they differ (Johnson, 10/16/2012).

In terms of modeling emissions reductions, NEMS typically returns higher costs for reductions and is considered more conservative. This could increase acceptance of the results if they are perceived to be more conservative. NEMS includes some built-in scenarios, such as a carbon tax, but more complex scenarios require modeling on the part of the user. NEMS takes a considerable amount of time to run, and may not always converge and find a solution.

NEMS can be readily downloaded, but EIA notes "most people who have requested NEMS in the past have found out that it was too difficult or rigid to use" (EIA). It requires some software additions to run the system fully.

Model Applications

- NEMS is widely used within U.S. government agencies, particularly DOE, and has some outside users in academia and non-profits. Most non-profits wishing to use

NEMS use a third-party consultant to develop and run the system using their own baseline assumptions.[3]

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[3] Some major environmental groups that use NEMS contract with the firm OnLocation, Inc. Clients include NRDC, UCS, RFF and others. Of the reports I found from other environmental organizations, I could not identify any that had not worked with this organization. EIA lists major users of NEMS as EPRI, Duke University, GTI and OnLocation, Inc.

Appendix D. NEMS Model Assumptions

NEMS is based on four supply modules (oil and gas, natural gas transmission and distribution, coal, renewables), four end-use demand modules (residential, commercial, industrial, transportation), a macroeconomy module to model interaction with the broader economy, an international markets module to simulate global market interactions, and an integrating module that achieves a general equilibrium across the model. The modules are integrated as shown in the figure below.

Legislation and regulations included in the assumptions (as of 12/31/2011):

- Mercury and Air Toxics Standards (MATS)
- Cross-State Air Pollution Rule (CSAPR)
- New fuel efficiency standards for medium- and heavy-duty vehicles (HDVs)
- California's cap-and-trade program authorized by Assembly Bill (AB) 32
- Global Warming Solutions Act of 2006
- EPA policy memo regarding compliance of surface coal mining operations in Appalachia, issued on July 21, 2011
- American Recovery and Reinvestment Act of 2009

The purpose of each module and its associated assumptions are explored below. Unless otherwise indicated, all assumptions apply to the reference case.

INDIVIDUAL MODULES

I. Macroeconomic Activity Module (MAM):

The MAM models interaction between energy markets and the U.S. economy. These interactions may go in either direction, with energy markets influencing the broader economy or macroeconomic features, such as economic growth rates and interest rates, influencing the energy market.

Key Assumptions:

- **Real GDP**: 2.5 percent average annual GDP growth per year between 2010-2035 in reference case vs. average annual growth of 3.0 percent in the high-growth scenario and 2.0 percent in the low-growth scenario.

  Inputs to Real GDP:
  - **Nonfarm Employment Growth:** 1.0 percent average growth per year 2010-2035.
  - **Productivity** (output per hour in nonfarm businesses): 1.9 percent average growth per year 2010-2035, improving other the period due to increasing capital stock and technology changes.

- **Population Growth**: .9 percent per year growth between 2010-2035 from the Census Bureau's middle series population projection.

II. International Energy Module (IEM):

The IEM models how changes in the domestic petroleum market impact the international petroleum market. The IEM derives annual oil prices and the global supply curve, calculates global supply and demand at the regional levels, and calculates the amounts and locations of annual U.S. petroleum imports.

Key Assumptions:

- **Global Oil Prices** (in $2009 per barrel): Reaches $145 in 2035. Prices around $120 in 2015, steadily increasing to $145 over the 2015-2035 period.
- **OPEC Supply:** Assumes OPEC continues to show a "disciplined production approach," increasing production over the period to continue producing around 42 percent of global total liquids. Iraq does not start to maintain steady growth until 2015.
- **Non-Domestic Resource Exploration and Development Costs:** Uses data on existing fields through 2015, and estimation on a country-by-country basis using expected technically recoverable resources for the remainder of the 2015-2035 period.
- **Non-Domestic National GDP Growth:** Uses IHS Global Insight projections of GDP growth by region.
- **Non-Domestic Demand:** Uses projected oil prices and GDP growth rates to predict demand outside of the U.S.

SUPPLY MODULES

The supply modules for oil, natural gas and coal use production regions specific to each fuel.

III. Oil and Gas Supply Module:

The Oil and Gas Supply Module (OGSM) comprehensively analyzes regional crude oil and natural gas exploration and development using four submodules: 1. the Onshore Lower 48 Oil and Gas Supply Submodule (OLOGGS); 2. the Offshore Oil and Gas Supply Submodules; 3. the Oil Shale Supply Submodule; 4. the Alaska Oil and Gas Supply Submodule. The regions for this module are West Coast, Rocky Mountains, Midcontinent, Southwest, Gulf Coast and Northeast.

Key Assumptions:

- **Domestic Resources:** Domestic technically recoverable resources consist of proved and unproved resources. Resource levels are predicted based on estimates from the U.S. Geological Survey (USGS) and the Department of Interior's Bureau of Ocean Energy Management. EIA also includes some plays that are not assessed by USGS. As of 2010, NEMS assumes 220 billion barrels of technically recoverable crude, of which 22.3 billion barrels are proved and 197.9 barrels are unproved. As of 2010, NEMS assumes 2203 trillion cubic feet of technically recoverable natural gas, of which 273 trillion cubic feet are proved reserves and 1931 trillion cubic feet are unproved resources. A full list of the plays is available. Discovery of new fields follows historical patterns.

- **Domestic Supply and Production:** OLOGGS assesses supply from the lower 48 at the play level. The model considers the nature of the resource, available technologies, existing and expected infrastructure and financial constraints for various prospects to predict development.

  For currently producing fields, 20 percent exponential decline is projected for most fields, and 30 percent exponential decline for natural gas production from fields in shallow water. Fields that started production after 2008 remain at their peak level for two years before they begin declining. For fields expected to produce oil and gas, 70 percent is assumed to be oil and 30 percent assumed to be gas.

  NEMS assumes that leasing in the mid and south Atlantic starts in 2018, in the south Pacific in 2023, and after 2035 in remaining markets.

  Alaska has a variety of specific assumptions concerning new field developments, reserves and supply via the pipeline system.

- **Technology:** NEMS models improved drilling and completion practices, advanced production and processing operations and other technology advances to determine impacts on reserves and supplies. The 16 technology adoption curves represent the probability that technology performance improves and is adopted, and can be convex, concave, sigmoid or linear (though none are projected to be convex). The curve is based on the market penetration curve, which represents the economic attractiveness of technology.

IV. Natural Gas Transmission and Distribution Module:

The Natural Gas Transmission and Distribution Module (NGTDM), using the OGSM as an input, projects natural gas production, prices and pipeline flows for peak and off-peak annual periods. NEMS solves for these outputs by finding market equilibrium across the supply, demand and transmission and distribution (T&D) network.

Key Assumptions:

- **Supply, Demand and Flow Determinations:** Based on historical data and data from the previous period. Other outputs are based on the multi-component equilibrium process.

- **T&D:** In the next two years, highly likely announced pipeline and storage capacity is assumed. Subsequently, capacity increases as consumption and price increases warrant. Pricing reflects modeled tariffs and T&D costs.

- **Other NG sources:** Synthetic natural gas from liquids production is projected to continue at current levels. Supplemental supplies, such as coke oven gas, biomass gas, etc. are also held constant. Plants to produce synthetic natural gas from coal are built if high natural gas prices warrant it.

- **Natural Gas Trade:** Natural gas trade with Mexico and Canada are determine through a combination of endogenous and exogenous features.

V. Coal Market Module:

The Coal Market Module (CMM) projects domestic coal production, consumption, distribution, prices and trade.

Key Assumptions:

- **Production:** CMM generates a set of 41 supply curves for each year of the projection, including for 14 regions, nine coal types and two mine types. The curves are constructed using a regression that relates minemouth prices of coal for each region and coal type to independent variables such as mining capacity, labor productivity, cost of inputs, capacity utilization of mines, etc. These 41 curves are each subject to a set of assumptions.

VI. Renewable Fuels Module:

The NEMS Renewable Fuels Module (RFM) uses submodules to represent biomass, geothermal, conventional hydroelectricity, landfill gas, solar thermal, solar photovoltaics and wind power. Each of the submodules has specific assumptions. The final outputs are largely dependent on the EMM, and for biomass, the PMM.

Key Assumptions:

- **Capital Costs:** Costs are assumed to be dependent on quality, accessibility, T&D access, permitting, construction and other site-specific features. Limits on infrastructure and increasing construction costs are expected to impact all fuels.

DEMAND MODULES

VII. Residential Demand Module:

The Residential Demand Module uses projected number of households and expectations about associated energy-consuming equipment to predict residential energy demand. The residential module is based on the nine Census divisions.

Key Assumptions:

- **Technology and Consumer Behavior:** Assumes no major changes in consumer behavior or technology.

- **Housing Stock:** Models growth in number of households at the Census region level using interaction with the MAM.

  Inputs to Housing Stock:

    - **Projected Fuel Consumption:** Based on housing stock and type and location of stock.

- **Technology Choice:** Based on regional fuel prices and technology characteristics, such as cost, efficiency, etc. There are a variety of assumptions related to efficiency of appliances, energy use in new vs. existing units, etc.

VIII. Commercial Demand Module:

The Commercial Demand Module projects commercial energy demand, mostly in commercial buildings but also for privately operated public services such as lighting or pumps. Transportation and manufacturing are not included. The commercial module is based on ten end-use services and eleven building categories in the nine Census divisions.

The commercial module projects floorspace based on existing data, then projects energy use for that floorspace, then projects onsite generation, then projects end-use energy demand for the sector. Each of these steps includes a variety of assumptions about use of space by the commercial sector.

IX. Industrial Demand Module:

The Industrial Demand Module projects energy consumption, by energy source, across 21 manufacturing and non-manufacturing industries. Petroleum refining is included in the Petroleum Market Module rather than this module. Energy consumption is calculated for the four Census Regions than attributed to the nine Census Divisions based on fixed shares. Each industry has an individual set of assumptions.

Key Assumptions:

- **Per Unit Consumption:** Uses the 2006 baseline Unit Energy Consumption (UEC) estimates from the Manufacturing Energy Consumption Survey (MECS), which indicate the per unit energy use to produce one unit of output across the various industries. The module also uses Technology Possibility Curves (TPC), which estimate the change in energy intensity in the manufacturing process or end-use.

X. Transportation Demand Module:

The Transportation Demand Module estimates transportation energy use for over ten fuel types across eight transport mode for the nine Census divisions. The eight transport modes are light-duty vehicles, commercial light trucks, freight trucks, buses, freight and passenger aircraft, freight and passenger rail, freight shipping, miscellaneous transport (such as recreational boating). Each mode has an individual set of assumptions, for example:

- **Light-duty vehicles:** Uses the Manufacturers Technology Choice Model (MTCM), including 58 technology inputs to model expectations. Holds manufacturers shares constant and projects size class sales based on variables such as income, fuel prices, etc. Automakers evaluate parameters based on need to meet CAFE standards vs. meet consumer willingness to pay. EIA assumes fleetwide fuel economy meets 35 miles per gallon in 2020 and then holds them constant through the end of 2035.

CONVERSION MODULES

XI. Electricity Market Module (EMM):

The EMM uses the 22 regions and subregions defined by the North American Electric Reliability Corporation (NERC) and represents the planning, dispatching and pricing of electricity. It consists of four submodules: 1. Electricity capacity planning, 2. Electricity fuel dispatching, 3. Electricity load and demand, 4. Electricity finance and pricing. The EMM determines the least-cost way to supply electricity, within constraints. The EMM includes 24 types of generating capacity, plus 32 types of existing coal plants within the coal plant type.

Key Assumptions:

- **New Plant Characteristics:** Heat rates for fossil fuels are expected to decline linearly through 2025. Base overnight plant costs are estimated for a typical region, and then have regional multipliers applied. The first plants for new technologies have higher costs associated with assumed underestimation for new technologies' costs. Each technology is subject to a learning function with a learning rate, which contributes to cost reductions.

- **Retirements:** Fossil-fuel and nuclear plants are assumed to retire when it is not cost efficient to continue running them.

- **Biomass Co-Firing:** Assumes will co-fire if economical.

- **Nuclear uprates:** Anticipating higher levels of uprates, EIA estimates 7.3 GW of nuclear uprates through 2035.

- **Pricing:** Prices include generation, T&D and taxes. NEMS assumes T&D remains regulated, and accommodates competitive, partially competitive and regulated electricity markets. In competitive regions, customers can compete for better rates using a model algorithm. In regulated markets, the price includes utility costs for each rate class.

XII. Petroleum Market Module:

The NEMS Petroleum Market Module (PMM) projects supply sources and prices for petroleum products, and capacity growth at domestic refineries. The PMM is based on the five Petroleum Administration for Defense Districts (PADDs), essentially the West, Rockies, Gulf Coast, Midwest and East.

Key Assumptions:

- **Products:** PMM models the following petroleum products: motor gasoline, jet fuel, distillates, residual fuels, liquefied petroleum gases, petrochemical feedstocks and others. Each of these fuels is broken out into several specific products, each with their own assumptions. NEMS assumes that current State and

Federal specifications for these fuels remain constant, except with lower sulfur requirements for gasoline and diesel and lower benzene content in gasoline.

- **Prices:** End-use petroleum prices are based on marginal production costs, fixed costs, distribution costs and taxes. State and Federal taxes are also included where applicable. State taxes are held constant in real dollars throughout the projection, while Federal taxes are deflated.
- **Alternative Fuels:** PMM models fuels that are not petroleum-based, including biochemical and thermocatalytic fuels. For unproven technologies, costs for the first five plants are higher than the overall new plant projection for these fuel types.

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