User Guide for the State and Utility Pollution Reduction Calculator Version 2 (SUPR 2)

Compliance Tool for Clean Power Plan Final Rule

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About This Report

The SUPR 2 calculator is an update to the State and Utility Pollution Reduction (SUPR) Calculator and accompanying user guide originally released by ACEEE in April 2015. Revisions reflect the new data and requirements in the US Environmental Protection Agency's (EPA) Clean Power Plan final rule, released August 3, 2015.

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Introduction

On October 23, 2015, the US Environmental Protection Agency (EPA) published the Clean Power Plan (CPP), a rule to regulate greenhouse gas emissions from existing power plants (EPA 2015a). The rule establishes nationally uniform, subcategorized emission performance rates and individual state targets for carbon dioxide (CO_2) emissions based on a host of pollution-reducing technologies and allows states flexibility to pick from even more technologies and policies when designing their compliance plans. As states design plans to comply with the CPP and other air regulations, they must evaluate the costs of their compliance options. Quantifying the emissions benefits and costs of these strategies is not straightforward. Utilities and power plant owners are making decisions about air emission controls amid uncertainties including anticipated future pollution regulations, technology costs and availability, and the price of natural gas.

Policymakers, state governments, utility and power plant owners, advocates, and other stakeholders are beginning to weigh their options for reducing carbon dioxide emissions from the power sector. To assist states in understanding the cost and amount of pollution reduction available from different options, ACEEE has created the State and Utility Pollution Reduction Calculator Version 2 (SUPR 2). Its purpose is to give policymakers and stakeholders a rough estimate of some of the costs and benefits of various policies and technologies that could help an individual state meet its air quality goals.

The tool allows the user to select up to 10 policies and technologies, including energy efficiency, renewable energy, nuclear power, emission control options, and natural gas. The *Results* section of the tool gives users an idea of the magnitude of the costs and the impacts of selected options on energy use and pollution. The results provided by this tool are high-level estimates and are not intended to replace the more detailed modeling process that states will have to complete to create their CPP compliance plans, as well as criteria-pollutant state implementation plans (SIPs).

The SUPR 2 calculator provides users with detailed energy efficiency results for several policies. While other calculators and models include energy efficiency as an option, users are often required to know how much savings can be achieved through efficiency measures. SUPR 2 estimates energy and emission savings from an energy savings standard as compared with building energy codes and behavior programs. This specificity helps users understand the range of energy efficiency options that a state can use to achieve its CPP goal, relative to other options.

For the SUPR 2 calculator we selected a suite of policy options that states can use to build a plan that complies with the CPP (with the exception of selective catalytic reduction and fuel-gas desulfurization). Any of these options can be selected in any combination to create a compliance scenario. For example, under the rule, South Carolina is required to reduce its emissions by 28%, relative to its 2012 adjusted emissions baseline. If a user selects *Annual 1.0% energy savings target*, *Building codes (low)*, *Combined heat and power (medium)*, and *Utility-scale solar PV (high)*, the results show that those policies together can achieve a 25% reduction in 2012 emissions.

APPROACH AND LIMITATIONS OF THIS TOOL

The results provided by this tool depend on assumptions about costs, power plant sizes, and efficiency potential, among other things. We have tried to use rigorous, reasonable, and conservative assumptions to give the user an approximate comparison of the multiple impacts of different compliance options. However this tool provides a first-order estimate; states considering any of the measures or policies addressed by the SUPR 2 calculator should go on to obtain more accurate estimates of their impacts. Synapse Energy Economics' Clean Power Plan Planning Tool (CP3T) provides a greater level of specificity and allows users to compare CPP compliance options (for instance, rate-based versus mass-based compliance) within a given state (Synapse 2015). The results provided by SUPR can be used as inputs to CP3T. We provide additional references and resources in the bibliography.

Our goal in developing this tool was to make a fair comparison of the costs and benefits of various approaches to reducing emissions from the power sector during a finite time period. Therefore we have estimated the pollution, economic, and energy impacts over a 15-year period (2016–2030).

While we provide the results for individual states, the assumptions are often based on national- or regional-level data. For example, we provide estimates of NOx and SO_2 emission reductions by state for each of the energy efficiency measures. However these estimates come from Electricity Market Module (EMM) regions (part of the National Energy Modeling System, or NEMS) and are not based on state boundaries (EIA 2009). We discuss the assumptions and data sources relied on by SUPR 2 later in this user guide.

The SUPR 2 calculator is not a dispatch model that optimizes the implementation of the selected policies based on the lowest cost to meet electric load, nor do we account for future demand growth in the electric load each state has to meet. Instead, users select policy options and the calculator displays the emission reductions, benefits, and costs of implementing those specific policies in the state.

A number of real-world factors can impact the costs and benefits of the options included in this tool. We have tried to provide reasonable estimates that reflect likely real-world scenarios, but, as circumstances change over time, SUPR 2's assumptions will need to be updated so that the results remain as accurate as possible. For example, once states adopt building energy codes, their enforcement can vary widely. State officials should consider these and other factors to more accurately evaluate their policy options.

ENERGY EFFICIENCY AND CLEAN POWER OPTIONS

The SUPR 2 calculator includes a suite of policies that states can use to comply with the CPP (with the exception of selective catalytic reduction and fuel-gas desulfurization). Users can choose any of these policies in any combination to create a compliance scenario. The energy efficiency policies included in SUPR 2 are:

- *Annual 1.5% energy savings target*. A statewide energy efficiency savings goal of 1.5% electricity savings per year through 2030.

- *Annual 1% energy savings target*. A statewide energy efficiency savings goal of 1% electricity savings per year through 2030.

- *Building energy codes (low)*. Reflects state adoption of codes equivalent to the 2015 IECC for homes and ASHRAE Standard 90.1-2013 for commercial buildings, the current versions of the national model energy codes.

- *Building energy codes (high)*. Reflects the adoption of the national models as they are updated on three-year cycles. States adopt codes equivalent to the 2015 IECC for homes and ASHRAE Standard 90.1-2013 for commercial buildings in 2017, the 2018 IECC and ASHRAE Standard 90.1-2015 in 2020, and improved codes every three years through 2030. This option also assumes better compliance rates.

- *Behavior programs*. Reflects a residential feedback program saving 2% from program participants, assuming a 50% participation rate in each state.

- *Energy service company (ESCO) programs*. Reflects energy performance contracts with energy service companies in municipal buildings, universities, schools, and hospitals (commonly known as the MUSH market), as well as entities in the private commercial sector. The size of the programs in each state is based on historic ESCO market growth trends of 8.3% annually.

- *Combined heat and power (low)*. A total of 40 megawatts (MW) of combined heat and power (CHP) are installed evenly split between the commercial and industrial sector.

- *Combined heat and power (medium)*. A total of 100 MW of CHP are installed evenly split between the commercial and industrial sector.

- *Combined heat and power (high)*. A total of 500 MW of CHP are installed evenly split between the commercial and industrial sector.

You may also select new energy generation technologies that do not emit CO_2:

- *Nuclear power*. Construction and operation of a 1,000 MW nuclear power plant operating at 85% capacity factor.

- *Onshore wind power (low)*. Construction and operation of 100 MW of onshore wind power operating at 30% capacity factor.

- *Onshore wind power (high)*. Construction and operation of 500 MW of onshore wind power operating at 30% capacity factor.

- *Rooftop photovoltaic (PV) solar power.* Construction and operation of 100 MW of distributed rooftop solar PV at 23% capacity factor.

- *Utility-scale PV solar power (low)*. Construction and operation of 100 MW of solar PV at 25% capacity factor.

- *Utility-scale PV solar power (high)*. Construction and operation of 500 MW of solar PV at 25% capacity factor.

The tool also allows you to select from a series of modifications that can be made or installed on a 500 MW coal-fired power plant operating at 85% capacity, with selective catalytic reduction and fuel-gas desulfurization reducing criteria pollutants:

- *Fuel switching from coal to natural gas*. A retrofit of an existing coal-fired power plant to burn natural gas.

- *Selective catalytic reduction*. Installation of an emission control technology used to reduce emissions of nitrogen oxide (NOx) from an uncontrolled facility by 90%.

- *Flue-gas desulfurization*. Installation of an emission control technology used to reduce emissions of sulfur dioxide (SO_2) from an uncontrolled plant by 95%.

- *Carbon sequestration*. Installation of a post-combustion carbon dioxide (CO_2) capture and storage technology that reduces CO_2 emissions by 90%.

Instructions

The workbook tab labeled *Introduction* gives a general overview of SUPR 2 and includes the steps below.

Step 1. Begin in the tab labeled *Start*. Click on the cell next to *Select state* at the top of the page and then choose the desired state from the drop-down menu.

Step 2. Select between 1 and 10 energy efficiency, pollution control, and clean power–generating measures from the drop-down menus in the boxes labeled 1–10. When you select a measure, the blue box to the right will display a brief description of it. You may select a measure multiple times and the results will be additive. For example, if you select *Onshore wind* once, the results will reflect the installation of 100 MW of onshore wind power. If you select *Onshore wind* twice, the results will reflect the installation of 200 MW of onshore wind power.

Step 3. Click on the *Results* → button and the tool will take you to the *Results* tab. The *Results* tab includes a summary of the emissions reduced (NOx, SO_2, and CO_2), net cost, and energy saved in 2020, 2025, and 2030 for the selected measures. The *Results* tab also generates a figure displaying the CPP emission rate target for your state (column on left) and the contribution of the selected measure(s) toward the achievement of your state's overall CO_2 emissions mass target (column on right).[1] The tab also displays the associated annual emission reductions in 2030 and shows some equivalents of the cumulative results, including cumulative cost savings from energy purchases avoided by the selected measures.

[1] Alaska, Hawaii, Washington, DC, and Vermont do not have emission targets under the CPP, so this figure will not be generated for those states.

It also converts the energy savings from efficiency to the number of avoided 100 MW power plants running at 70% capacity factor.

Step 4. Click on the *Detailed results* → button to go to the *Detailed results* tab. This tab breaks out the cumulative emissions reduced (NOx, SO_2, and CO_2), net cost, and energy saved in 2020, 2025, and 2030 for each selected measure. It also lists a summary of all the results for every measure. This includes a box with a list of definitions to help clarify the meaning of the results, including the associated costs and energy savings.

Step 5. Click on the *Visual results* → button, which will bring you to the *Visual results* page. This page includes several figures illustrating the costs and emission reductions from the selected measures.

Assumptions and Data Sources

This section outlines the assumptions and data sources used to develop SUPR 2, beginning with the efficiency policies and continuing with the other emission control measures. The associated emission reductions, energy savings, and costs of all policies and program options are reported in several forms in the *Results* section of SUPR 2. ACEEE defines *annual savings* as the savings in a given year from all the measures that have been installed under a policy or program in that year and in prior years that are still saving energy (and CO_2, NOx, and SO_2). *Cumulative savings* are all of the savings under a policy or program up through a given year, i.e., the sum of annual savings through that year. *Cumulative net costs* are defined as all of the spending on a policy or program up through a given year, minus all of the savings (avoided spending) that result from that policy or program through the same year. Programs and policies may generate savings beyond 2030; however those additional benefits are not captured here. The annual and cumulative savings definitions may vary from similar terminology seen within EPA's CPP documentation. Compliance with the CPP is based on what ACEEE calls annual savings.

We have tried to be as clear and transparent as possible with our assumptions and data sources. If you have questions about the assumptions or data sources used in the tool, please contact Cassandra Kubes at ckubes@aceee.org.

EMISSION REDUCTIONS

Emission reductions for all policies for CO_2, NOx, and SO_2 rely on the EPA's eGRID data (EPA 2015c). Since the eGRID does not abide by state boundaries, data for electricity consumption, emissions, and electricity generation are often broken out by utility or aggregated into regions. For analysis purposes, the US Energy Information Administration (EIA) aggregates multiple utility service areas into Electricity Market Module (EMM) regions based on the North American Electric Reliability Corporation (NERC) regions and subregions (EIA 2015a).

In order to apportion average emissions rates to states based on those found in eGRID data, we assigned states to the eGRID region where the majority of their electricity might be expected to be consumed. In most cases, we were able to assign entire states to a particular eGRID region. However we made assumptions regarding nine states.[2]

We used eGRID's total output emission rate to calculate emissions reduced from energy saved or alternative generation. We did so to avoid presuming which fuels or generation loads would be replaced by any particular measure. We assumed a 5% transmission and distribution loss and factored that into emission savings for all energy efficiency measures.[3]

We also used the methodology in EPA's *Clean Power Plan Final Rule Technical Support Document: Goal Computation* (EPA 2015b) to calculate rate adjustments for selected measures as seen in the figure on the *Results* tab.

On the *Results* tab, we list the impacts of selected measures on a state's rate- and mass-based goals for the CPP.[4] We used different assumptions when calculating the impact of a scenario on the calculated rate and the avoided emissions for a given state. For one, in the rate-based approach we assumed that selected energy efficiency measures avoid generation and emissions only from in-state power plants covered under the rule. In the mass-based approach we used the 2012 eGRID data to project emission impacts through 2030. In addition, in order to measure the reduction in emissions achieved by selected measures in 2030, we calculated the avoided CO_2 short tons as a percentage of the EPA's adjusted 2012 CO_2 baseline. This adjusted baseline modifies the 2012 historical emission data to take into account under-construction fossil steam and natural gas combined cycle (NGCC) capacity and adjusts for hydro generation (EPA 2015b).

EFFICIENCY POLICIES

This subsection describes the assumptions and data sources relied on for the estimated energy and cost savings of the energy efficiency policies included in SUPR 2. We used the aggregated total output emission rate for the EPA eGRID to estimate SO_2 and NOx emission reductions from energy efficiency policies. CO_2 savings are based on EPA's *Clean Power Plan Final Rule Technical Support Document: Goal Computation* (EPA 2015b).

Annual Energy Savings Targets

POLICY

There are two options that represent implementation of an annual energy savings target: an annual savings target of 1.5% per year through 2030 and an annual savings target of 1% per year through 2030. Since it can take time to design, approve, and implement efficiency programs, our analysis assumes that efficiency savings ramp up gradually. In this analysis,

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[2] Alaska, Hawaii, Illinois, Mississippi, Missouri, Nevada, New York, Pennsylvania, and Wyoming are each split among multiple EMM regions, so we assigned portions of these states to different regions. Portions were based on utility electricity sales in the state.

[3] A 5% transmission and distribution loss is a conservative estimate. A typical loss can be 6–7%, and on peak days the loss can be up to 20%.

[4] SUPR 2 calculates the impacts of selected measures against a state's mass goal for existing units only (instead of a state's mass goal for existing units plus new source complement), along with the state-specific emission rate goal.

we assume that each state adopts a savings target that ramps up at a rate of 0.25% of electricity sales per year. Policies are assumed to begin in 2016, and energy savings are projected through 2030. The 2016 starting point is based on actual statewide 2011 or 2012 (as available) electricity savings levels. You may vary these goals by selecting the *Annual energy savings target* option multiple times from the drop-down menus in the *Start* tab (e.g., if you select the 1.5% option for Step 2a and the 1% option for Step 2b, you will be effectively selecting a 2.5% savings target). States may have energy efficiency measures installed after 2013 that will continue to generate savings beyond the start of CPP compliance. The energy savings and emission reductions associated with these measures can count toward a state's compliance starting in 2022 and beyond.

Annual savings targets generally require programs to promote a variety of measures. Some common examples include air sealing and insulation for residential and commercial buildings, appliance rebate programs, partnerships with business to reduce energy costs, and upgrades to factories and public buildings. The annual target option in this calculator assumes that all savings are achieved outside of any additional programs or policies that are selected by you such as behavior programs and ESCO programs. For example, if you select the *Annual energy savings target* option in box 1 and then select the *Behavior* option for box 2, the behavior programs will be additional to the annual energy savings target.[5]

Many states have energy savings targets in place. As shown in table 1, four states now have incremental savings targets of 2% or more of sales per year, and five other states have targets of 1.5% or more of sales per year. For states that have energy savings targets in place, SUPR 2 estimates cost and savings of your selected policies, disregarding energy savings targets that may already be in place.

Table 1. State savings targets

Approximate annual savings target in 2015	Number of states	States
2% or greater	4	Arizona, Massachusetts, Rhode Island, Vermont
1.5–1.99%	4	Illinois, Maine, Maryland, Minnesota
1.0–1.49%	11	California, Colorado, Connecticut, Iowa, Hawaii, Michigan, New Mexico, New York, Ohio, Oregon, Washington
0.1–0.9%	6	Arkansas, Pennsylvania, Wisconsin, Nevada, North Carolina, Texas

Source: Gilleo and Molina, 2015

[5] Behavior programs are typically included within utility program offerings for an annual savings target. However in the SUPR 2 calculator we have made behavioral programs an additional option to select because of the availability of program data for this tool.

ENERGY SAVINGS

This analysis is taken largely verbatim from Hayes et al. 2014 with the exception of the 1.0% scenario. Unlike the scenario in that earlier report, the 1.0% scenario caps annual savings at 1% of sales.

Each state adopts a statewide savings target that ramps up to either 1.5% or 1%. Savings are based on sales per year relative to the forecasted sales for that state in the previous year. This means that each year the state will achieve new savings equal to 1.5% or 1% of demand for the previous year.

For all states, we start ramping up in 2016 using a start point equal to actual statewide 2011 or 2012 (as available) electricity savings levels. If 2011 savings levels are below 0.25%, we assume the state begins at 0.25%. If a state is currently achieving less than 1.5% or 1%, we assume a ramp-up of 0.25% per year until 1.5% or 1% is achieved; 1.5% or 1% then remains the constant annual savings through 2030. If you select the 1.5% policy, a state that is currently achieving 1% savings per year would achieve 1% in 2016, 1.25% in 2017, and 1.5% in 2018 and each year thereafter through 2030 in the standard scenario.

State-specific energy savings are based on annual forecasted retail electricity sales by state for the residential, commercial, and industrial sectors in 2012. Annual sector-specific growth rates are applied to estimate forecasted sales (EIA 2013).

Savings reported are the total cumulative savings that would be obtained from this policy.

COST

Cost assumptions for this analysis are taken largely verbatim from Hayes et al. 2014.

Utility program costs/kWh is based on total program costs per kWh for a utility. These costs vary by state. For this analysis, we divide states into two tiers. Tier 1 states have been implementing energy efficiency programs for at least a decade, while Tier 2 states are new to comprehensive efficiency programs or are still ramping up from lower levels. First-year cost for Tier 1 states is $0.32 per first-year kWh. First-year cost for Tier 2 states is $0.17 per first-year kWh. Beginning in 2021, we assume that all Tier 2 states' first-year costs increase to Tier 1 levels; i.e., the first-year costs for all states are set at Tier 1 levels beginning in 2021. Cost assumptions are based on data from Molina (2014).

Tier 1 is the average of Vermont, Oregon, California, Massachusetts, Rhode Island, Minnesota, Iowa, and Connecticut, and Tier 2 is the average of Arizona, Colorado, Illinois, Michigan, New Mexico, Nevada, Texas, and Utah.

From 2016 to 2021, Tier 2 states are Alabama, Alaska, Arizona, Arkansas, Colorado, Delaware, DC, Florida, Georgia, Idaho, Illinois, Indiana, Kansas, Kentucky, Louisiana, Maine, Maryland, Michigan, Mississippi, Missouri, Montana, Nebraska, Nevada, New Hampshire, New Jersey, New Mexico, North Carolina, North Dakota, Ohio, Oklahoma, Pennsylvania, South Carolina, South Dakota, Tennessee, Texas, Utah, Virginia, Washington, West Virginia, and Wyoming.

Utility program incentive costs/kWh is the amount of money the utility invests in customer incentives per kWh of electricity saved. We assume that 80% of total program costs are incentives paid to customers for technologies or services. For Tier 1 states this is $0.26/kWh ($0.32/kWh*80%). For Tier 2 states these costs are $0.14/kWh.

Utility program admin costs/kWh is the amount of money a utility invests in program administration per unit of electricity saved. We assume that program administrative costs are 20% of total program costs. For Tier 1 states this is $0.06/kWh. For Tier 2 states this is $0.03/kWh.

Customer cost/kWh is the amount of money that customers invest when they participate in a utility-run energy efficiency program. We assume that utilities and customers split technology costs evenly, so that customers contribute the same amount as utility program incentives. For Tier 1 states this is $0.26/kWh. For Tier 2 states this is $0.14/kWh.

Building Codes

Policy

Building codes establish minimum requirements for the design and construction of new and renovated residential and commercial buildings. States have the authority to adopt building codes, which are generally based on model codes developed by national consensus standards organizations. The International Code Council develops the International Energy Conservation Code (IECC), the national residential model code, and updates it every three years. The American Society of Heating, Refrigerating, and Air-Conditioning Engineers (ASHRAE) updates model commercial codes (ASHRAE Standard 90.1) every three years. The most recent national model codes date from 2015 and 2012 for residential and commercial buildings respectively. While many states have been leaders, not all states have adopted model building codes, and almost all of them are several years behind in adopting the most recent codes.

Savings and cost numbers for both the low and the high building code scenarios are taken largely verbatim from Hayes, Ungar, and Herndon 2015.

The low savings case assumes that states adopt codes equivalent to the 2015 IECC for homes and ASHRAE Standard 90.1-2013 for commercial buildings, the current versions of the national model energy codes. These model codes were issued after extensive review under the IECC and ASHRAE consensus processes, respectively. The 2015 IECC is very similar to the 2012 IECC, which is already being implemented in several states (the largest difference is a new optional compliance pathway). The analysis counts savings under these codes starting with construction in 2017.

Both of the national models are updated on three-year cycles. The high savings case assumes that state codes are updated on the same schedule. Based on the Pacific Northwest National Laboratory (PNNL) analysis, in the last three code cycles the residential IECC achieved an estimated 33% average total savings in covered energy costs, and Standard 90.1 achieved an estimated 28% average total savings in whole-building energy costs (the codes do not cover plug loads and some other energy uses) (PNNL 2013). The high savings case assumes 5% savings in each code cycle in residential covered energy costs and 5% savings in each cycle in commercial whole-building energy costs, a somewhat slower, but still ambitious, rate of improvement. The exception is 90.1-2016, for which we assume the ASHRAE committee will meet its goal of additional savings of 10% of 90.1-2004 energy use (about 14% savings compared to the current standard) (Misuriello 2014). For comparison, the default assumptions in the PNNL estimator (see below) are for 5% residential and 7% commercial savings in each code cycle.

ENERGY SAVINGS

The following analysis is taken largely verbatim from Hayes, Ungar, and Herndon 2015.

Energy use estimates under different codes are based on PNNL building energy simulations done for DOE. PNNL has recently prepared estimators intended to allow utilities and states to estimate savings due to improved compliance with codes (DOE 2014). The methodology was developed for impact estimates PNNL did for DOE's Building Energy Code Program (Livingston et al. 2014). PNNL simulated electricity and natural gas/oil use in each state (in some cases in multiple climate zones) in model single-family and multifamily homes under the 2006, 2009, and 2012 IECC, and in 13 types of commercial buildings under 90.1-2004, -2007, and -2010. They aggregated these results in each state using weightings for each building type and climate zone to obtain an average energy use per home and per square foot of commercial building space.

For the 2015 IECC and 90.1-2013, PNNL has estimated an overall percentage energy savings nationwide (0.9% and 8.7%, respectively, in energy costs). In the absence of state-level estimates, we applied these uniformly to all states and energy sources. The potential savings from future model codes described above were applied similarly.

We assumed that the lifetime of all savings would be 30 years. Although buildings typically last for many decades and some equipment is replaced after a few years, this is a period frequently used in building life-cycle cost analysis and is appropriate for a building-level average (DOE 2015a and 2015b). Thus there is no degradation of savings by 2030; the lifetime only applies to the life-cycle cost analysis.

Not all buildings fully comply with energy codes, and it is widely recognized that noncompliance can reduce energy savings. In recent years there has been much more focus on increasing and measuring compliance. However few studies have tried to measure the energy impacts of noncompliance or the change in compliance levels as codes become more stringent, and those studies have used different metrics and methodologies. Studies have found energy use of up to about 20% above what it would be with full compliance, and as low as 11% *below* the code level (NYSERDA 2014; DNV KEMA, Energy & Resource Solutions, and APPRISE 2012; KEMA et al. 2010; NMR et al. 2012). After reviewing the literature, a recent study assumed two possible cases for an initial starting point on compliance, one with 11% and one with 4% excess energy use, and modeled achieving 100% compliance (Stellberg 2013).

For our analysis in the lower savings case we used a conservative assumption that 25% of the expected energy savings would be lost due to noncompliance. We can convert to the metric used above: With the baseline at the code level (not adjusted for compliance), this corresponds to average energy use in homes 12% above the 2015 IECC level, and energy use in commercial buildings 10% above the 90.1-2013 level.

In the higher savings case we assume 5% of the energy savings would be lost, corresponding to about 2% excess energy use on average for residential and commercial buildings. As compliance is likely to become more difficult as codes become more stringent, achieving this level of savings would likely require greater compliance efforts.

For this analysis we excluded energy savings associated with natural gas. We only display electricity savings from the implementation of building energy codes.

COST

The following is taken largely verbatim from Hayes, Ungar, and Herndon 2015.

The added cost to meet the codes was also based on PNNL estimates. PNNL has estimated the cost of meeting the 2012 IECC and in some cases the 2009 IECC for roughly 40 states and has estimated the cost of meeting 90.1-2010 in about 20 states (PNNL 2013; DOE 2012). These costs are based on the prescriptive pathways in the codes and on the model buildings used in the energy simulations (for commercial buildings, a subset of five of the building types). PNNL took the component and labor costs from RS Means data and various studies, taking into account regional variation.[6]

For states without PNNL estimates of cost, we estimated residential costs based on the same code climate zone requirements, state-level building mix from PNNL, and construction cost multiplier used by PNNL; therefore, these estimates should be very close to those of PNNL. We did not have the same data for commercial buildings and took weighted averages of the PNNL estimates by census region, adjusted with the same construction cost multiplier used in the residential analysis. Although this is a somewhat rough approximation, it should be sufficient to look at the cost effectiveness. We used census rather than climate regions because of better correlation with PNNL's costs, which for commercial buildings vary at least as much with building type as with climate.

For future codes, it is difficult to know the cost because the specific code changes have not been determined. (For the 2015 IECC and 90.1-2013 there are not yet good cost estimates, but the costs and savings are relatively small.) Thus the cost estimates for the higher savings case must be regarded as somewhat speculative. We assumed that in each state the cost per percentage energy savings for each code update would remain constant. But as the codes improve, the energy savings decrease for a given percentage change. Thus the cost per unit of energy saved as well as the time required for simple payback slowly increase.

In addition to the building costs, we also include implementation costs for the codes: $100 per home and $0.015 per square foot for commercial buildings. A recent PNNL survey (though not of a representative sample) found average enforcement costs of $49 per home and $139 per commercial building (for the average commercial building of 19,100 square feet, this would be $0.007 per square foot), not including fringe pay, travel, or training

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[6] RS Means is a widely recognized source of construction cost data. More information can be found at www.rsmeans.com/product.aspx?zpid=1002.

(Williams 2014). Higher spending may be needed to improve compliance, but the effect on this analysis would be small, as enforcement accounts for a small part of overall costs.

Combined Heat and Power (CHP)

POLICY

CHP is the concurrent generation of electric power and thermal energy. CHP is not a single technology, but rather a particular application of a suite of different technologies, including engines and turbines. Natural gas, coal, biomass, biofuels, and other resources fuel CHP units. Due to the concurrent generation of power and thermal energy, the overall combined electric and thermal efficiency of CHP units can exceed 80%, whereas the current electric generation fleet is only about 35% efficient.

The SUPR 2 calculator provides three CHP policy options: low, medium, and high. The low option represents construction and operation of 40 MW of CHP facilities (20 MW in the commercial sector and 20 MW in the industrial sector) in the selected state. Medium represents 100 MW of CHP installed, and high represents 500 MW of CHP. All options are evenly split between the commercial and industrial sectors. We have assumed that an equal amount of CHP is installed each year starting in 2016 such that the full amount is installed by 2030. If you believe your state has more potential, you may select the CHP policy multiple times (e.g., selecting CHP [low] in Step 2 in box 1 *and* box 2 will estimate costs and benefits for 80 MW of CHP in the results).

ACEEE estimated the amount of CHP that states could install cost effectively without any new policy incentives in Hayes et al. 2014. These amounts vary widely by state, with the lowest estimate finding no potential and the highest estimate finding approximately 4,500 MW. To provide better guidance, we have included these amounts per state in the description box in the calculator.

When using this guidance, it is important to note that amounts per state reflect a certain set of assumptions that constrain the scope of savings that CHP can contribute to CPP compliance. For example, only *new* CHP capacity is considered in Hayes et al. 2014, but *existing* CHP capacity may also contribute to a state's overall emission reductions. Keep in mind that potential savings from additional state policy commitments or changes to regulatory models could result in substantially higher levels of new CHP implementation. Modeling these activities was beyond the scope of this analysis.

ENERGY SAVINGS

Energy savings is based on CHP operating characteristics from Hayes at al. 2014 and the accounting method described in the CPP (EPA 2015a).[7] CHP units are low-emitting electric-generating resources that can replace higher-emitting generation from centralized power plants. In the CPP, the amount of electrical output from a CHP unit that can be considered emissions free is determined by calculating the CHP unit's "incremental CO_2 emission rate" and comparing it with a "reference CO_2 emission rate."

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[7] See 80 Fed. Reg. at 64902.

This accounting methodology determines a discounted portion (%) of electrical output that should be attributed to a CHP measure as "avoided generation" from the grid. Although highly efficient, CHP systems still generate some carbon dioxide emissions. Rather than credit 100% of the MWh generated as avoided generation, the following steps prorate the amount of electricity generated by CHP for crediting purposes.

1. Calculate an incremental CHP emission rate for the CHP system (or fleet of systems).

*Incremental CHP emission rate = ((CHP fuel input * Fuel emission factor – (Useful thermal output/Boiler efficiency) * Fuel emission factor))/(CHP electricity output (MWh))*

Where

- CHP fuel input (MMBtu) = CHP electricity output (MWh) * CHP heat rate (MMBtu/MWh)
- CHP electricity output (MWh) = CHP capacity (MW) * Estimated 7,500 hours of operation
- Fuel emission factor is 116.9 lbs/MMBtu for natural gas
- Useful thermal output (MMBtu) = CHP fuel input (MMBtu) * CHP system efficiency (%) – CHP electricity output (MWh) * 3.412 (MMBtu/MWh)[8]
- Displaced boiler efficiency is 80%

2. Calculate MWh output eligible for credit by comparing the incremental CHP emission rate with the reference CO_2 emission rate.

Prorated MWh = (1 – (Incremental CHP electrical emission rate/reference CO_2 emission rate))/(1 – T&D losses)

Where

- Reference CO_2 emission rate is 1,305 lbs/MWh
- Avoided transmission and distribution losses (T&D) are 6%.

The result is the percentage of CHP electric output that is eligible for credit. Multiplying total CHP electricity output (MWh) by the prorated MWh percentage yields electricity savings that should be credited to CHP.

The CPP does not define or establish a value for the "reference CO_2 emission rate." We applied a single reference rate of 1,305 lbs/MWh in all states and in all compliance years. This reference rate is based on the final national performance rate for steam generating units in 2030 finalized in the CPP and is the simplest approach with the most reasonable results of the options we considered. States may choose different and more complex approaches to determining an appropriate reference rate that may provide a more accurate estimate of emission-free electricity generated by CHP. For example, states could use as the reference rate the average emission rate of affected EGUs for the eGRID subregion in which the CHP unit is located. This approach is more accurate than the single-rate approach used in SUPR 2

[8] Conversion factor of 1 MWh = 3.412 MMBtu.

because it is based on actual emissions (rather than a performance target) and accounts for generation that is imported and exported across state lines. EPA has suggested a different reference rate in its proposed model rule, and the appropriate reference rate is the subject of ongoing debate (EPA 2015d).

COST

The cost of CHP for this analysis is taken largely verbatim from Hayes et al. 2014. CHP entails costs (other than fuel costs) including installation and operations and maintenance (O&M).

- Installation cost = CHP capacity installed in a given year * Average CHP capital cost per kW
- Annual operating cost = Electric load * Average CHP O&M costs per kWh

Our analysis assumes that the manufacturing and commercial entities installing CHP pay 15% of the installation cost up front and finance the rest over a 15-year period. We assume that each year utility programs spend an amount equal to about 2% of CHP investments either on sharing best practices and providing technical assistance or on managing a state-level CHP resource standard.

Behavior Programs

POLICY

The *Behavior programs* option models an enhanced billing program that provides residential customers with additional energy usage data as an addendum to their monthly utility bills, often referred to as a residential feedback program.

When selected, we assume a behavior program occurs independent of any other energy efficiency policies selected. Often utilities will run a behavior program to help them meet their annual energy savings target. For the purpose of this tool, if you select *Annual 1.5% energy savings targets* and *Behavior programs*, the two policies will be implemented in the state separately and will be added together.[9]

ENERGY SAVINGS

Estimated savings assume that 50% of residential customers participate in the program by state (based on participation numbers provided by Opower) and that they achieve 2% annual savings every year between 2016 and 2030.

These savings are calculated as a percentage of current forecasted consumption by state, using the same methodology that was used for the *Annual savings target* options.

COST

The kilowatt-hour saving per dollar invested in such a program was provided by Opower, based on an average of the programs they have operated in each state (Harry Godfrey,

[9] In the SUPR 2 calculator we have made behavior programs an additional option to select because of the availability of program data for this tool.

manager of national policy and partnerships, Opower, pers. comm., November 25, 2014). These costs range from 15 to 36 kWh/$ depending on the state.

Energy Service Company (ESCO) Programs

POLICY

An ESCO, or energy service company, is a business that develops, installs, and arranges financing for projects designed to improve the energy efficiency and maintenance costs for facilities. Typically, ESCOs develop, design, and arrange financing for energy efficiency projects; install and maintain the energy-efficient equipment involved; and measure, monitor, and verify the project's energy savings. These services are bundled into the project owner's cost, and the ESCO is repaid through the dollar savings generated via reduced energy costs.

ESCO projects can be comprehensive, with ESCOs employing financing for a wide array of cost-effective measures to achieve energy savings. In this calculator, the ESCO programs policy reflects energy savings performance contracts (ESPCs) with ESCOs.

Historically, ESCO projects have focused on municipal buildings, schools, universities, and hospitals. However there is potential for ESCO programs to expand to other parts of the commercial sector, which would increase potential savings beyond what has already been demonstrated.

ENERGY SAVINGS

State-specific energy savings are based on an analysis prepared by AJW for comment on the CPP (AJW 2014). The analysis uses Lawrence Berkeley National Laboratory's (Berkeley Lab) estimates of the size of the US ESCO market (Stuart et al. 2013). Berkeley Lab estimated three scenarios of growth in its paper. We chose low growth to give a conservative estimate of the potential savings from the ESCO market. The low-growth scenario assumes 8.3% growth in the ESCO market annually. This is based on actual 2008–2011 ESCO industry growth rates collected in the Berkeley Lab US ESCO project database (Larsen et al. 2012).

Berkeley Lab provides estimates of the cost of saving a megawatt-hour through ESCO services (Carvallo et al. 2014). Electricity savings from ESCO projects came from Berkeley Lab's ESCO database, which contains information on actual (reported) electricity savings in millions of British thermal units (MMBtu) or kilowatt-hours (kWh) or, in its absence, reported guaranteed electricity savings. Its estimate of electricity savings per dollar invested was applied to the total US market to get a national energy savings estimate.

The national estimate was broken out by state based on EIA total electricity consumption data (EIA 2013).

COST

The total economic size of the ESCO market comes from Berkeley Lab's analysis (Stuart et al. 2013). For the purpose of this tool we do not include any additional financing and we use the average cost spent by ESCOs per MWh saved (Carvallo et al. 2014). We assume a 15-year measure life and a 0% discount rate.

NON-CO_2-EMITTING ENERGY TECHNOLOGIES

Below is a description of the assumptions that went into the emissions savings and cost calculations for non-CO_2-polluting energy-generation technologies. Renewable energy and nuclear power are both options for compliance under the CPP.

All of the policies are non-emitting, so calculating emission reductions is the same as for energy efficiency policies. Emission reductions for all policies for NOx, SO_2, and CO_2 rely on EPA's eGRID data, broken out based on Electricity Market Module (EMM) regions. We used the eGRID's total output emission rate to calculate emissions reduced from energy saved or alternative generation. We did so not to presume which loads would be offset by any particular measure.

Nuclear Power Plant

TECHNOLOGY

This measure is the construction and operation of a 1,000 MW nuclear power plant operating at 85% capacity. We assume that the nuclear plant would replace other generation sources in the state. States may have more or less capacity for nuclear power depending on the state. We did not try to assess actual technical or economic potential for nuclear power in the state, nor did we account for any planned new plants or plants set for retirement. You are able to select the nuclear power option multiple times; if you select *Nuclear power* for Step 2a and Step 2b it would be equal to 2,000 MW of installed nuclear capacity in the state.

COST

The costs of nuclear power plant energy technology are from Lazard capital cost for electricity plants data (Lazard 2014). The costs include

- Capital costs, estimated at $7,591 per kW
- Fixed operation and maintenance costs at $105 per kW-yr
- Variable operation and maintenance costs at $0.5 per MWh

The costs also include the fuel cost of uranium ($0.0079 per kWh) and money committed to the Nuclear Waste Fund ($0.001 per kWh) (NEI 2015; NEI 2016).

Onshore Wind Power

TECHNOLOGY

There are two onshore wind power options, a low option and a high option. The low option represents the construction and operation of 100 MW of onshore wind power operating at 30% capacity factor. High represents 500 MW of onshore wind power. We assume that the onshore wind power would replace other generation sources in the state. We did not assume which sources would be offset; rather, as we did with energy efficiency measures, we use the grid average emission rate by EMM region to calculate emission reductions. States may have more or less capacity for onshore power depending on the state. We did not try to assess actual technical or economic potential for onshore wind power in each state, nor did we account for any currently planned wind power development whose construction has been initiated. We also recognize that some states may adopt offshore wind power. There are differences in the costs between onshore and offshore wind. However for the purpose of getting a high-level comparison between technologies, we selected onshore wind. (Most wind development in the United States is onshore.)

COST

The costs of onshore wind power energy technology are from Lazard 2014. The costs include

- Capital costs between $1,400 and $1,800 per kW (we selected a middle number of $1,600 per kW)
- Fixed operation and maintenance costs of $37.5 per kW-yr
- Variable operation and maintenance cost of $0

Photovoltaic (PV) Solar Power

TECHNOLOGY

There are three solar PV options: low utility-scale, high utility-scale, and rooftop solar. The low option represents the construction and operation of 100 MW of utility-scale solar PV at 30% capacity factor, high represents 500 MW of utility-scale solar PV, and the rooftop option represents 100 MW of distributed rooftop solar installed in the state at 23% capacity factor.[10] We assume that the PV solar power would replace other generation sources in the state. We did not assume which sources would be offset; rather, as we did with energy efficiency measures, we use the grid-average emission rate by EMM region to calculate emission reductions. States may have more or less capacity for PV power depending on the state. You may select this option multiple times, which will result in additional PV power constructed. We did not try to assess actual technical or economic potential for PV power in each state, nor did we account for any planned PV power.

COST

The costs of PV solar power technology are from Lazard capital cost for electricity plants data (Lazard 2014). The costs include

- Capital costs of utility-scale solar of $1,500 per kW
- Fixed operation and maintenance costs of $7.50 per kW-yr
- Variable operation and maintenance costs of $0

EMISSION CONTROL MEASURES

Below is a description of the assumptions that went into the emission savings and cost calculations for the pollution control measures. These measures are the most common kinds of controls that utilities use to comply with air regulations. In addition, we selected fuel switching as a control option since many power plants are likely to use natural gas instead of coal because of the current low price points and the lower emission rates. The results for all of these options are based on a 500 MW coal-fired power plant operating at 85% capacity factor.[11] The results from the selected policies are cumulative, and you may select the same

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[10] Capacity factors are from Lazard Version 8.0 (Lazard 2014).

[11] The following control technologies are not options for Idaho, Maine, and Rhode Island because these states do not have existing coal-fired power plants.

policy more than once. If you select multiple controls, the controls are assumed to be applied to multiple power plants, not the same one (e.g., if you select *Selective catalytic reduction* for Step 3a and *Flue-gas desulfurization* for Step 3b, the total affected power plants would be two 500 MW plants, or 1,000 MW of power plants).

Fuel Switching from Coal to Natural Gas

TECHNOLOGY

The fuel-switching option reflects a scenario in which a coal-fired plant is retrofitted to burn natural gas.

COST

The costs[12] of this retrofit include

- Capital costs estimated at $128.70 per kW (EPA 2011)[13]
- Variable costs of operating coal plant with no mercury, SO_2, or NOx controls of approximately $0.0032 per kWh ($2012) (EPA 2013). This is reduced to 75% as the incremental variable operation and maintenance (VOM) costs of operating a coal plant retrofit to gas decrease by 25% (EPA 2011).[14]
- Fixed costs of operating a coal plant with no mercury, SO_2, or NOx controls of approximately $24.29 per kW per year ($2011)(EPA 2013).[15] This amount is reduced by 33% if the plant is retrofitted to burn natural gas (EPA 2013).[16]

The cost of constructing new pipeline needed to transport gas to a facility can vary widely depending largely on the location of the facility. In order to provide a reasonable estimate of this, we took the average estimated cost of new pipeline for facilities between 400 and 600 MW in capacity (EPA 2011).

To estimate the difference in fuel costs when burning natural gas instead of coal, we used an average of the forecasted price of coal ($2.40 per MMBtu) and natural gas ($4.90 per MMBtu) (EIA 2012).

There is a 5% penalty for natural gas consumption due to a reduction in efficiency. This penalty appears as an increase in fuel consumed and increased emissions.

EMISSION SAVINGS

Estimated emission reductions of mercury (Hg) and SO_2 assume that emissions of both pollutants are eliminated by burning natural gas. Estimated reductions in SO_2 emissions are

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12 These cost assumptions are for conversion of the boiler of a pulverized coal plant to burn natural gas, not for the addition of a turbine.

13 Table 5-11, Cost and Performance Assumption for Coal-to-Gas Retrofits. The incremental cost formula used is 250*(75/MW)^0.35.

14 Table 5-11, Cost and Performance Assumption for Coal-to-Gas Retrofits.

15 Table 4 -13, Performance and Unit Cost Assumptions for Potential (New) Capacity from Conventional Technologies in EPA Base Case v.5.13.

16 Table 4-9, FOM Assumptions Used in EPA Base Case v.5.13.

based on the average emission rate by NERC subregion of coal-fired plants with a capacity greater than 100 MW (EPA 2015d).

NOx emissions are estimated at 50% of the average emissions of existing coal-fired power plants in the NERC subregion with a capacity greater than 100 MW (EPA 2015d).

To calculate the reductions of CO_2 that would be achieved, we used eGRID to determine the average emission rate by NERC subregion of CO_2 from coal-fired power plants with a capacity greater than 100 MW. In order to compare this with the CO_2 emissions in a power plant retrofitted to burn natural gas, we determined the average efficiency by NERC subregion of coal-fired power plants and applied a 5% efficiency penalty (see above) to determine how many Btus of natural gas would be needed to generate the same amount of electricity.[17] There are typically 117 lbs of CO_2 per million Btu of energy for natural gas (EIA 2015b). Using this information, we were able to determine the CO_2 reductions that would occur if a facility were retrofitted from coal to natural gas.

Selective Catalytic Reduction (SCR)

TECHNOLOGY

The *Selective catalytic reduction* option represents NOx reduction in an SCR system that takes place by injecting ammonia (NH_3) vapor into the flue gas stream where the NOx is reduced to nitrogen (N_2) and water (H_2O) abetted by passing over a catalyst bed typically containing titanium, vanadium oxides, molybdenum, and/or tungsten. The technology is assumed to have an NOx emission capture and control efficiency of 90%.

COST

Capital costs for this technology are $197 per kW (2012 dollars); fixed operating and maintenance costs are $0.87 per kwh (2012 dollars); and variable operating and maintenance costs are $0.001373 ($1.373 mills) per kWh (2012 dollars) (EPA 2010). The technology is assumed to reduce emission of NOx by 90%.

EMISSION SAVINGS

The results for this option are based on a power plant burning bituminous coal in the NERC subregion where the state is located. These reductions are calculated using the average emission rate of coal-fired power plants with greater than 100 MW capacity and an emission rate of at least 0.15 lb per MMBtu operating in the NERC subregion where the selected state is primarily located. The emissions and costs reported reflect a 0.56% capacity penalty incurred by installation of the SCR technology (EPA 2015c).

Flue-Gas Desulfurization (FGD)

TECHNOLOGY

The technology is assumed to have an SO_2 emissions capture and control efficiency of 95%. This efficiency is deducted from the average per megawatt emission rate of coal-fired power plants greater than 100 MW and with an emission rate greater than 0.60 lb/MMBtu operating in the NERC subregion where the selected state is primarily located. Mercury co-benefits are assumed to be 58% removal of mercury from inlet Hg concentrations. Inlet Hg

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[17] In states where an average emission rate or efficiency by NERC subregion is unavailable, we used a national average.

concentrations come from the process described below for the Activated Carbon Injection option.

COST

Capital costs for this technology are $538 per kW (2012 dollars), fixed operation and maintenance costs are $8.68 per kW-yr (2012 dollars), and variable operation and maintenance costs are 1.996 mills (2012 dollars) (EPA 2010). The option assumes limestone forced oxidation—a wet technology—because removal efficiency of the alternative (lime spray dryer) varies considerably depending on the sulfur content of the coal.

The emissions and costs reported reflect a 1.67% capacity penalty incurred by installation of the flue-gas desulfurization technology (EPA 2015c).

Carbon Sequestration

TECHNOLOGY

The *Carbon sequestration* option represents retrofitting an existing pulverized coal-fired power plant with post-combustion technology to capture emissions of CO_2.

COST

The capital cost of this technology is based on an up-front cost of $2,184 (2012 dollars) per kW, fixed operating and maintenance costs assume a cost of $3.32 (2012 dollars) per kW-year, and variable operating and maintenance costs are estimated at 2.60 mills (2012 dollars) per kWh (EPA 2011). The cost of transporting the captured CO_2 is $84,270,894 (2012 dollars) annually, and storage costs are based on a cost of $10.08 (2012 dollars) per ton (a midpoint selected from a wide range of potential storage costs) (EPA 2011). Carbon sequestration has a heat rate penalty of 33%, which has been included as increased emission and fuel costs in the results. Carbon sequestration requires that SO_2 be removed from the flue gas prior to the capture and compression of CO_2. The costs included here assume that FGD technology has already been installed. You may separately select FGD as an additional control measure to get a more accurate estimate of the costs of carbon sequestration on a facility that does not already have FGD installed, and no additional investment is needed. Further, increased fuel costs due to the 33% efficiency penalty assume a price of coal of $2.40 per MMBtu (EIA 2012).

EMISSION SAVINGS

Emission savings are based on the average CO_2 emission rate from coal-fired power plants operating in the NERC subregion where the state is located. Calculations reflect a 33% increase in emissions that would be generated by 500 MW of existing capacity due to the increased energy needed to operate the carbon capture technology (EPA 2011). Estimates reflect a 90% reduction of these total estimated emissions (EPA 2011).

For Further Information

For more information regarding the SUPR Calculator or any of the other related projects mentioned above, see our dedicated web page at aceee.org/topics/section-111d-clean-air-act.

To speak to us directly or provide feedback on the SUPR 2 calculator, please contact Cassandra Kubes at ckubes@aceee.org.

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