# Climate Game Changer
## How A Carbon Standard Can Cut Power Plant Emissions in Half by 2030

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## Methodology and Assumptions
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### UCS Analysis of a Power Plant Carbon Standard

New modeling analysis was performed by UCS to demonstrate how the U.S. electricity sector can make sharp reductions in carbon emissions. This modeling effort provides an analysis of possible energy pathways under different carbon and clean energy policy scenarios. Our core policy scenario indicates that the U.S. can cut electricity sector emissions in half from current levels by 2030. In this core scenario, a diversified generation mix that includes renewable electricity generation from technologies that are currently commercially available can, in combination with energy efficiency, affordably meet U.S. electricity demand.

The analysis uses the National Energy Modeling System (NEMS) model developed by the Energy Information Administration (EIA) of the U.S. DOE. NEMS is a computer-based, energy-economy system of the United States. EIA develops baseline projections with NEMS that are published annually in the Annual Energy Outlook (AEO). AEO reference case projections are policy-neutral, based on currently in-legislation federal, state and local laws and regulations. UCS uses the AEO2013 version of NEMS as the basis of our analysis. However, we did make some changes to EIA's AEO2013 model assumptions. The specific changes, based on project-specific data and mid-range estimates from recent studies, are outlined in detail in the attached Appendix.

### Scenario Summary

To analyze the impacts of a carbon standard, we focused on three scenarios: a reference case, a carbon standard only case, and a carbon standard complemented by additional renewable energy and energy efficiency policies.

*Reference Case*
The Reference Case is based on a modified NEMS version of the AEO2013 "reference case". The Reference Case assumes no new state or federal policies beyond those which existed at the end of 2012. This case establishes a baseline for the analysis using project-specific technology cost and performance assumptions benchmarked to recent studies. We did not make any changes to AEO2013's assumptions for electricity demand growth, natural gas and coal prices, fixed and

variable O&M costs, and heat rates, with a few exceptions noted in the Appendix below. We did make several changes to AEO2013's capital cost assumptions and capacity factors for wind and solar technologies based on project specific data for recently installed and proposed projects, supplemented with estimates from recent studies, when project data was limited or unavailable.

### *Carbon Standard Case*

The Carbon Standard Case analyzes the impacts of a possible carbon standard on the U.S. electricity sector assuming existing renewables and efficiency policies in place at the end of 2012. As a proxy for constraining carbon in the electric sector, a federal carbon price was developed to achieve a 50% emissions reduction from 2005 levels in 2030, and a 60% emissions reduction from 2005 levels in 2040. In addition, we also included a credit for coal retirements in 2018. We modeled this credit as 25% of the total 2011 emissions of coal plants that are over 50 years of age in 2018 and 40 years of age in 2020. The carbon price for this scenario was assumed to increase from $5/metric ton in 2018 to $35 in 2030, and $61 in 2040.

### *Carbon Standard plus Renewables and Efficiency Case*

We also modeled a federal Carbon Standard with strengthened state and federal renewable energy and energy efficiency policies (our core policy case) to show the benefits of a more diversified energy portfolio. This scenario complements a carbon standard with renewable energy and energy policies that drive a higher penetration of these resources, especially in the 2015-2025 timeframe. The renewable energy and efficiency policies considered in this scenario include:

- An full extension of the federal production tax credit (PTC) through 2016, with a gradual ramp-down through 2018
- An extension and ramp-down solar investment tax credit (ITC) from 30% in 2016 to 10% in 2020,
- Adoption of lower cost financing mechanisms such as master limited partnerships (MLPs) and real estate investment trusts (REITs)
- A federal renewable electricity standard (RES) of 25% by 2025 and energy efficiency resource standard (EERS) of 15% by 2025 patterned on S. 1627 (the American Renewable Energy and Efficiency Act)
- Updated residential and commercial building codes and equipment efficiency standards, and an extension of the federal ITC for combined heat and power (CHP) based on EIA's "extended policies" case for AEO 2013.

Many of the federal policies were modeled as a proxy for what states could achieve by adopting their own enhanced renewable energy and energy efficiency policies.
For a discussion of the analysis results and our recommendations, see Rachel Cleetus' blog at http://blog.ucsusa.org/cut-power-plant-carbon-by-50-percent-new-epa-climate-rules-real-global-warming-solutions-552 and accompanying PowerPoint slide deck at http://www.ucsusa.org/assets/documents/global_warming/Carbon-Standards-Analysis-Union-of-Concerned-Scientists.pdf.

## Appendix

*UCS Assumptions for AEO 2013 version of NEMS*

The cost and performance assumptions for electric generating technologies that UCS used in the Annual Energy Outlook (AEO) 2013 version of EIA's National Energy Modeling System (NEMS) are shown in Tables 1-3 below, compared to EIA's AEO 2013 assumptions (EIA 2013a). We also describe our cost assumptions for energy efficiency investments that were not included in the model. We did not make any changes to EIA's assumptions for electricity demand growth, natural gas and coal prices, fixed and variable O&M costs, and heat rates, with a few exceptions noted below (EIA 2013a). However, we did make several changes to EIA's capital cost assumptions and wind and solar capacity factors based on project specific data for recently installed and proposed projects, supplemented with estimates from recent studies, when project data was limited or unavailable. These changes include:

- Commodity costs. We do not include EIA's projected changes in commodity costs that results in a 9 percent reduction in capital costs by 2040 for all technologies because of the high level of uncertainty in projecting these costs (EIA 2013a).

- Learning. We do not use EIA's learning assumptions that lower the capital costs of different technologies over time as the penetration of these technologies increase in the U.S. (EIA 2013a). This approach does not adequately capture growth in international markets and potential technology improvements from research and development (R&D) that are important drivers for cost reductions. Instead, we assume costs for mature technologies stay fixed over time and we hard wire cost reductions for emerging technologies.

- Natural gas and coal. For plants without carbon capture and storage (CCS), we use EIA's initial capital costs, but do not include EIA's projected cost reductions due to learning because we assume they are mature technologies. For new IGCC and supercritical pulverized coal plants, we use EIA's higher costs for a single unit plant (600-650 MW) instead of dual unit plants (1200-1300 MW), which is more consistent with data from proposed and recently built projects (SNL 2013). For plants with CCS, we assume: 1) higher initial capital costs than EIA based on mid-range estimates from recent studies (Black & Veatch 2012, Lazard 2013, NREL 2012, EIA 2013), 2) no cost reductions through 2020 as very few plants will be operating by then, and 3) EIA's projected cost reductions by 2040 will be achieved by 2050 (on a percentage basis).

- Nuclear. We assume higher initial capital costs than EIA for new plants based on mid-range estimates from recent studies and announced cost increases at projects in the U.S. that are proposed or under construction (Black & Veatch 2012, Henry 2013, Lazard 2013, Penn 2012, SNL 2013, Vukmanovic 2012, Wald 2012). We did not include EIA's projected capital cost reductions, given the historical and recent experience of cost increases in the U.S. We also assume existing plants will receive a 20-year license extension, allowing them to operate for 60 years and will then be retired due to safety and economic issues. In addition, we include 4.7 GW of retirements at five existing plants (Vermont Yankee, Kewaunee, Crystal River, San Onofre, Oyster Creek) based on recent announcements, and 5.5 GW of planned additions (Vogtle, V.C. Summer, and Watts Bar).

- Onshore Wind. We assume lower initial capital costs than EIA based on data from a large sample of recent projects from DOE's 2012 Wind Technologies Market Report (Wiser 2013). While this report shows that installed capital costs have declined 13 percent since 2009 for U.S. projects, we conservatively assume capital costs will stay fixed over time as the wind industry invests in technology improvements that result in increases in capacity factors. Current capacity factors are based on data from recent projects and studies that reflect recent technology advances (Wiser 2012).

We assume capacity factors will increase over time to achieve a reduction in the overall cost of electricity based on mid-range projections from 13 independent studies and 18 scenarios (Lantz 2013). We also assume higher fixed O&M costs than EIA based on mid-range estimates (EIA 2013, Wiser 2012, Black & Veatch 2012, NREL 2012).

- Offshore wind. Initial capital costs are based on data from recent and proposed projects located in shallow water in Europe and the U.S. from NREL's offshore wind database (Schwartz 2010). We assume capital costs decline and capacity factors increase over time based on mid-range projections from several studies (Lantz 2013, EIA 2013, NREL 2012, Black & Veatch 2012, BVG 2012, Prognos 2013). We also assume higher fixed O&M costs than EIA based on mid-range estimates (EIA 2013, Wiser 2012, Black & Veatch 2012, NREL 2012).

- Solar photovoltaics (PV). We assume lower initial capital costs than EIA based on data from a large sample of recent utility scale and rooftop PV projects installed in the U.S. through the third quarter of 2013 (SEIA 2013). We assume future solar PV costs for utility scale, residential, and commercial systems will decline over time based on mid-range projections from several studies and scenarios (DOE 2012, EIA 2013, NREL 2012, Black & Veatch 2012). The mid-range projections are roughly consistent with the DOE Sunshot Vision Study 62.5 percent price scenario and the NREL Renewable Electricity Futures study Evolution Technology Improvement (ETI) scenario. This results in lower costs for utility scale systems than EIA. Because EIA's projections for residential and commercial systems are consistent with these mid-range projections, we don't make any changes to those assumptions. In addition, we use slightly lower capacity factors for solar PV based on NREL data (NREL 2012).

- Solar CSP. We assume concentrating solar plants will include six hours of storage and include higher costs and capacity factors than EIA to account for this based on data developed by Black & Veatch for NREL's Renewable Electricity Futures study (Black & Veatch 2012). EIA assumes CSP plants without storage.

- Biomass plants. We use EIA's initial capital costs new fluidized bed combustion plants, but do not include EIA's projected cost reductions due to learning because we assume it's a mature technology. However, we assume the technology transitions to more efficient integrated gasification combined cycle plants over time, resulting in a gradual decline in the heat rate from 13,500 Btu/kWh to 9,500 Btu/kWh by 2035. For biomass co-firing in coal plants, we reduce EIA's co-firing limit from 15 percent to 10 percent to reflect potential resource supply constraints near clusters of coal plants, and assume higher capital costs based on data from Black & Veatch (2012). We also use a slightly different biomass supply curve than EIA based on a UCS analysis of data from DOE's Updated Billion Ton study that includes additional sustainability criteria, resulting in a potential biomass supply of 680 million tons per year by 2030 (UCS 2012, ORNL 2011).

- Geothermal and hydro. We didn't make any changes to EIA's assumptions for geothermal and hydro, which are site specific. EIA's geothermal supply curve is based on a 2010 NREL assessment.

- Energy efficiency. We estimated the costs and electricity savings from implementing a federal energy efficiency resource standard (EERS) of 15 percent by 2025 (based on S. 1627: The American Renewable Energy and Efficiency Act) outside of the NEMS model. We calculated the electricity savings by multiplying EIA's electricity sales projection by the annual EERS targets, which were adjusted to remove small utilities and to account for existing state EERS policies. We also estimated the investment and program costs of achieving these savings based on recent studies by the American Council for Energy Efficiency Economy (Molina 2014, Hayes 2014). We assumed national average first-year costs of 46 cents/kWh based on ACEEE's survey of utility energy efficiency programs. These costs were split equally between utilities and consumers, with 20 percent of the utility costs allocated to administering the programs and the other 80 percent allocated to investing in more efficient technologies and measures. We also assumed 50 percent of utility and consumer investment costs and 100 percent of utility program costs would be financed over an average measure lifetime of 11 years. In addition, we included the costs of replacing half of the efficiency measures after their average lifetime and assumed customers would replace the other half without utility incentives. We then added the total annual costs of efficiency investments to the electricity sector compliance costs and consumer electricity bills projected by the NEMS model.

- Calculation of the monetary value of $CO_2$ reduction benefits. To calculate the monetary value of CO2 reductions, we used the U.S. Government's estimates for the social costs of carbon (SCC). The SCC is an estimate of the dollar damages from an additional metric ton of $CO_2$ in a given year. We multiplied the metric tons of CO2 reduced in our scenarios by the SCC to derive the CO2 reduction benefits, which are equal to the avoided climate damages from reducing a metric ton of CO2.

  We used the November 2013 updated SCC values. The SCC values are available in 2007$/metric ton CO2 in 5-year increments and different discount rates. We used the values assuming a 3% discount rate.

| Year | SCC (in 2007$ per metric ton of CO2) 3% discount rate |
|---|---|
| 2010 | 32 |
| 2015 | 37 |
| 2020 | 43 |
| 2025 | 47 |
| 2030 | 52 |

Source: http://www.whitehouse.gov/sites/default/files/omb/assets/inforeg/technical-update-social-cost-of-carbon-for-regulator-impact-analysis.pdf
Finally, we converted the dollar amounts to 2013$ for the sake of consistency with all our results.

- Calculation of the monetary value of $SO_2$ and NOx reduction benefits.To value the $SO_2$ and NOx emissions reductions, we used data from an EPA technical support document that calculates the dollar value of the health benefits per ton of $SO_2$ and NOX reduced for different sectors, including the power sector (EPA 2013).
  http://www.epa.gov/airquality/benmap/models/Source_Apportionment_BPT_TSD_1_31_13.pdf
  In particular, for the 2020 emissions reductions from our modeling results, we used the values in table 7 for Electric Generating Units or EGUs (the Krewski et al. estimates): $37,000/ton SO2 and $5,400/ton NOx. These values are in 2010$ using a 3% discount rate. We converted them to 2013$ to be consistent with the other results of our analysis.
  For 2030, we used the values in table 11 for EGUs (again the Krewski et al. estimates): $43,000/ton $SO_2$ and $6,200/ton NOx. These values are in 2010$ using a 3% discount rate. Again, we converted them to 2013$ to be consistent with the other numbers.

|  | UCS 2013 |  |  |  |  | EIA AEO 2013 |  |  |  |
|---|---|---|---|---|---|---|---|---|---|
| Technology | 2010 | 2020 | 2030 | 2040 | 2050 | 2010 | 2020 | 2030 | 2040 |
| Natural Gas CC | 1,000 | 1,000 | 1,000 | 1,000 | 1,000 | 1,006 | 1,000 | 882 | 797 |
| Natural Gas-CC-CCS | n/a | 2,900 | 2,628 | 2,425 | 2,323 | n/a | 1,980 | 1,715 | 1,504 |
| Natural Gas CT | 665 | 665 | 665 | 665 | 665 | 664 | 647 | 555 | 497 |
| Coal-Supercritical PC | 3,190 | 3,190 | 3,190 | 3,190 | 3,190 | 2,883 | 2,944 | 2,704 | 2,472 |
| Coal-IGCC | n/a | 4,325 | 4,325 | 4,325 | 4,325 | n/a | 3,694 | 3,292 | 2,960 |
| Coal-PC-CCS | n/a | 5,950 | 5,604 | 5,354 | 5,184 | n/a | 5,087 | 4,570 | 4,083 |
| Nuclear | n/a | 6,300 | 6,300 | 6,300 | 6,300 | n/a | 4,733 | 4,223 | 3,697 |
| Biomass | 4,040 | 4,040 | 4,040 | 4,040 | 4,040 | 4,041 | 3,727 | 3,370 | 3,003 |
| Solar PV-Utility | 4,150 | 2,100 | 1,900 | 1,835 | 1,835 | 3,805 | 3,217 | 2,859 | 2,533 |
| Solar PV-Residential | 7,368 | 3,715 | 2,724 | 2,724 | 2,724 | 7,368 | 3,715 | 2,724 | 2,724 |
| Solar PV-Commercial | 6,316 | 3,406 | 2,848 | 2,477 | 2,477 | 6,316 | 2,848 | 2,477 | 2,477 |
| Solar CSP-No Storage | 5,083 | 4,702 | 4,321 | 3,939 | 3,558 | 4,979 | 3,732 | 3,293 | 2,884 |
| Solar CSP-With Storage | 7,318 | 6,768 | 5,502 | 4,871 | 4,871 | n/a | n/a | n/a | n/a |
| Wind-Onshore | 2,200 | 1,900 | 1,900 | 1,900 | 1,900 | 2,175 | 2,220 | 2,039 | 1,864 |
| Wind-Offshore | n/a | 5,142 | 4,458 | 4,100 | 3,432 | 6,121 | 6,108 | 5,411 | 4,759 |

Table 1. Comparison of Overnight Capital Costs for Electric Generation Technologies (2011$/kW). Abbreviations are as follows: combined-cycle (CC), combustion turbine (CT), carbon capture and storage (CCS), pulverized coal (PC), integrated gasification and combined-cycle (IGCC) and photovoltaic (PV).

| Technology | Fixed O&M ($/kW-yr) | Variable O&M ($/MWh) | Heat Rate (Btu/kWh) | |
|---|---|---|---|---|
| | | | 2010 | 2050 |
| Natural Gas-CC | 15.10 | 3.21 | 6430 | 6333 |
| Natural Gas-CC-CCS | 31.23 | 6.66 | 7525 | 7493 |
| Natural Gas CT | 6.92 | 10.19 | 9750 | 8550 |
| Coal-Supercritical PC | 30.64 | 4.39 | 8800 | 8740 |
| Coal-IGCC | 50.49 | 7.09 | 8700 | 7450 |
| Coal-IGCC-CCS | 65.31 | 4.37 | 10700 | 8307 |
| Nuclear | 91.65 | 2.10 | 10452 | 10452 |
| Biomass | 103.79 | 5.17 | 13500 | 9500 |
| Solar PV-utility | 21.37 | 0.00 | n/a | n/a |
| Solar PV-Residential | 32.47 | 0.00 | n/a | n/a |
| Solar PV-Commercial | 7.62 | 0.00 | n/a | n/a |
| Solar CSP-No Storage | 66.09 | 0.00 | n/a | n/a |
| Solar CSP-With Storage | 66.09 | 0.00 | n/a | n/a |
| Wind-Onshore | 50.00 | 0.00 | n/a | n/a |
| Wind-Offshore | 100.00 | 0.00 | n/a | n/a |

Table 2. Operation and Maintenance (O&M) and Heat Rate Assumptions. Abbreviations are as follows: Combined-cycle (CC), combustion turbine (CT), carbon capture and storage (CCS), pulverized coal (PC), photovoltaic (PV), integrated gasification and combined-cycle (IGCC).

| Technology | UCS2013 | EIA AEO 2013 |
|---|---|---|
| Solar PV-utility | 16-28% | 21-32% |
| Solar CSP-No Storage | 19-29% | 5-26% |
| Solar CSP-With Storage | 27-54% | n/a |

Table 3. Comparison of Solar Capacity Factors.

|  | UCS 2013 |  |  |  |  | EIA AEO 2013 |  |  |  |
|---|---|---|---|---|---|---|---|---|---|
| Technology | 2012 | 2020 | 2030 | 2040 | 2050 | 2010 | 2020 | 2030 | 2040 |
| **Wind-Onshore Class 3** | 31% | 35% | 37% | 39% | 40% | 28% | 29% | 29% | 29% |
| **Wind-Onshore Class 4** | 35% | 39% | 41% | 43% | 45% | 32% | 33% | 33% | 33% |
| **Wind-Onshore Class 5** | 40% | 45% | 48% | 50% | 51% | 39% | 39% | 39% | 39% |
| **Wind-Onshore Class 6** | 44% | 50% | 53% | 53% | 53% | 45% | 46% | 46% | 46% |
|  |  |  |  |  |  |  |  |  |  |
| **Wind-Offshore Class 5** | 36% | 38% | 40% | 42% | 44% | 27% | 27% | 27% | 27% |
| **Wind-Offshore Class 6** | 45% | 47% | 49% | 51% | 53% | 34% | 34% | 34% | 34% |
| **Wind-Offshore Class 7** | 52% | 52% | 53% | 53% | 53% | 40% | 40% | 40% | 40% |

Table 4. Comparison of Wind Capacity Factors.

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