Meeting—and Exceeding—the Clean Power Plan in Virginia

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Technical Appendix

Union of Concerned Scientists

UCS uses the National Renewable Energy Laboratory's (NREL) Regional Energy Deployment System (ReEDS) to analyze the technical and economic feasibility of clean energy policies. This document describes the methodology and assumptions that were used for *How Virginia Can Secure a Clean Energy Future: A Robust Plan for Meeting and Exceeding the Clean Power Plan.*

ReEDS is a capacity planning model for the deployment of electric power generation technologies in the contiguous United States through 2050. ReEDS is designed to analyze the impacts of state and federal energy policies, such as clean energy and renewable energy standards or requirements for reducing carbon emissions. ReEDS provides a detailed representation of electricity generation and transmission systems and specifically addresses issues related to renewable energy technologies, such as transmission, resource supply and quality, variability, and reliability (NREL 2015).

UCS used the 2015.2 version of ReEDS for our analysis (see Cole et al. 2015 for NREL's description of this version). We made a few adjustments to NREL's assumptions for renewable and conventional energy technologies based on project-specific data and estimates from recent studies, as described in more detail below. Our assumptions for the policies that are being tested for this analysis are described in the section, Policy Assumptions for Scenarios, later in this document.

Overall Model Assumptions

UCS regularly reviews data and research on the technologies and systems that are simulated in ReEDS. Information on the assumptions and methodology in ReEDS is available on the NREL website (NREL 2015). Our updated assumptions in ReEDS are described here.

Cost and performance for electric generating technologies:
The cost and performance assumptions for electric generating technologies that UCS used in ReEDS are shown in Tables 1-3 below. We compare our key assumptions to Energy Information Administration's (EIA) Annual Energy Outlook (AEO) 2015 assumptions (EIA 2015), since the AEO assumptions are widely used for energy policy analysis and provide a well-recognized industry benchmark.

We made several changes to NREL's capital cost assumptions. NREL uses EIA's AEO 2015 cost assumptions for conventional plants; our revisions are based on project specific data for recently installed and proposed projects and mid-range estimates from recent studies. We did not make any changes to the assumptions for operating and maintenance (O&M) costs and heat rates. Tables A-2 through A-5 show the cost and performance assumptions for electricity generating technologies we use in ReEDS, and compare these assumptions with EIA's AEO 2015 assumptions.

NREL provides a set of projections for future cost and performance assumptions for renewable energy technologies that users can easily select. Our choices for these projections are consistent with the assumptions that were developed for the DOE Wind Vision report (DOE 2015) and the SunShot Vision report (DOE 2012).

The changes we made include:

- **Learning**. Unlike NREL, 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 2015). EIA's 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 costs for emerging technologies decline over time using a trajectory that is independent of technology penetration in a particular scenario.

- **Coal**. For new integrated gasification and combined cycle (IGCC) and supercritical pulverized coal plants, we use NREL's assumptions, which are based on EIA's higher costs for a single unit plant (600-650 MW) instead of dual unit plants (1200-1300 MW). For plants with carbon capture and sequestration (CCS), we use the same assumptions as NREL and EIA.

- **Natural Gas**. For new plants, we use NREL's assumptions, which are based on the average of EIA's assumptions for conventional and advanced plants in 2015. We do not include EIA's projected cost reductions due to learning because we assume these are mature technologies. 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 2014), 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 use EIA's assumed costs for 2015, but 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. To date, no existing plant has received or applied for an operating license extension beyond 60 years.

- **Onshore and Offshore Wind**. Current cost and performance assumptions are benchmarked to data from actual onshore wind projects in the U.S., the global offshore wind industry, and recent development activity off the Atlantic Coast of the U.S. (Wiser and Bolinger 2015, Tegen et al. 2012). We use NREL's cost and performance projections from their median cost reduction case, as described in the DOE Wind Vision (DOE 2015). These cost and performance projections are based on NREL's estimate of median values from their review of recent literature.

- **Utility-scale solar photovoltaics (PV)**. Current costs are based on data from actual projects (Bolinger and Seel 2015, SEIA/GTM 2015). We use NREL's cost and performance projections from the ReEDS case with 62.5 percent cost reductions (from 2010 levels) by 2020 and 75 percent cost reductions by 2030 based on scenarios developed for the DOE Sunshot Vision Study. (DOE 2012).

- **Distributed solar photovoltaics (PV).** ReEDS does not endogenously simulate the uptake of distributed PV systems (those typically installed on-site by residential or commercial customers). Instead, users must select the appropriate projections for uptake of these systems as an exogenous input to the model based on projections from NREL's Solar DS model (Denholm et al. 2009). For our reference case, we use NREL projections based on the DOE Sunshot Vision Study's 62.5 percent cost reduction (from 2010 levels) by 2020 case with no further cost decrease after 2020. For policy cases that support more distributed solar, we use NREL projections from the Sunshot 62.5 percent cost reduction by 2020 case, with costs declining to reach the Sunshot 75% cost reduction case by 2040. (DOE 2012).

- **Solar CSP**. We assume concentrating solar plants will include six hours of storage and use the capital and O&M cost projections from DOE Sunshot Study's 62.5 percent by 2020 and 75 percent by 2030 cost reduction scenarios (DOE 2012).

- **Biomass**. We use EIA's initial capital costs for new fluidized bed combustion plants and for biomass co-firing with coal, but do not include EIA's projected cost reductions due to learning because we assume it's a mature technology. We also use a slightly different biomass supply curve than EIA and NREL 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). And we limit the coal capacity that can be retrofit to co-fire biomass to 10 percent of a plant's capacity, compared with the 15 percent maximum used in NREL assumptions.

- **Geothermal, landfill gas and storage technologies**. We didn't make any changes to NREL's assumptions for these technologies.

- **Hydro.** We restricted the construction of large hydro dams until after 2019 to reflect the long lead times for planning, permitting and building such facilities. NREL's assumptions in ReEDS are based on a 2006 report and research indicates that future costs will likely be higher than those assumptions. We increased the cost assumptions for non-powered dams to be twice the NREL assumptions based on the *2014 Hydropower Market Report* (Cohen 2015, ORNL 2015). We didn't make any other changes to NREL's assumptions for the hydro supply curves, which are site specific.

Electricity sales and energy efficiency projections. ReEDS does not endogenously model electricity sales or efficiency; instead users provide assumptions of future use. As a default, electricity sales are taken from the EIA's AEO 2015 projections. ReEDS starts with the 2010 electricity sales for each state, then projects future electricity sales using the growth rate for the appropriate census region from the AEO 2015 reference case. UCS adjusts these projections to account for reductions in load growth resulting from currently-enacted state energy efficiency resource standards (EERS) that are not included in the AEO 2015. Our adjustments follow the approach used by the Environmental Protection Agency in *Projected Impacts of State Energy Efficiency and Renewable Energy Policies* (EPA 2014). We assume full compliance with EERS policies that had been enacted as of end of October 2015.

Accounting for recent or planned changes to generating resource or transmission availability. We reviewed ReEDS assumptions for expected changes in power plant capacity and transmission lines in the near term and compared that with our understanding, based on SNL data and industry reports/projections, of real-world conditions. Our updates to ReEDS included:

- accounting for prescribed builds of newly constructed or under-construction generating resources (including natural gas, nuclear, coal, wind and utility-scale solar facilities) using a combination of SNL and industry association data published as of May 7, 2015 and including plants expected to be on-line by 2016;
- accounting for recent or recently-announced coal-plant retirements based on data published as of July 2015;
- updating assumptions for transmission projects based on data published as of August 2015; and
- adding California's storage mandate.

Calculation of energy efficiency costs and savings. In a separate analysis from our use of ReEDS, we estimate the costs and electricity savings resulting from implementing a mandatory EERS in Virginia reaching 9 percent of statewide sales by 2022 (see Assumptions for Scenarios below). We calculate the electricity savings by adjusting the EIA's electricity sales projection to account for the EERS. We also estimate the investment and program costs of achieving these savings, based on recent studies by the American Council for Energy Efficiency Economy (ACEEE) (Hayes et al. 2014; Molina 2014). For Virginia, we assume average first-year costs of \$0.62 per kWh (based on Hayes et al. 2014). We split these costs between utilities (55 percent) and consumers (45 percent), with 20 percent of the utility costs allocated to administering the programs and 80 percent allocated to investment in more efficient technologies and measures. We also assume that 20 percent of utility and consumer investment costs and 100 percent of utility administration costs are financed over an average measure lifetime of 11 years. We then add the total annual costs of efficiency investments to the electricity sector compliance costs. The utility energy efficiency costs are also included in consumer electricity bills in the policy brief.

Calculation of the monetary value of carbon dioxide (CO_2) reduction benefits. To calculate the monetary value of CO_2 reductions, we use the U.S. Government's estimates for the social costs of carbon (SCC). The SCC is an estimate of the dollar damages resulting from adding a metric ton of CO_2 to the atmosphere in a given year. We multiply the tons of CO_2 reduced in our scenarios by the SCC to derive the CO_2 reduction benefits, or avoided damages.

We use the updated SCC values reported in the EPA's Regulatory Impact Assessment for the Final CPP rule (EPA 2015), see Table A-1. We use the average values applying a 3-percent discount rate.

TABLE A-1. **Social Costs of Carbon Values**

Year	Social Cost of Carbon (2015$ per ton of CO_2)[1]
2015	37
2020	43
2025	47
2030	51

1 Assuming a 3 percent discount rate.

SOURCE: EPA 2015, TABLE 4-2.

Calculation of the monetary value of sulfur dioxide (SO_2) and nitrogen oxides (NOx) reduction benefits. To value SO_2 and NO_x emissions reductions, we also use estimates from the EPA Regulatory Impact Assessment for the CPP Final Rule of the dollar value of the health benefits per ton of SO_2 and NO_x reduced by different sectors, including the electricity sector (EPA 2015).

In particular, for the 2020 emissions reductions generated in our models, we use the values in Table 4-7: $30,000 per ton of SO2 and $2,800 per ton of NO_x. These values are in 2011$ using a 7-percent discount rate for the East region. We convert them to 2015$ to be consistent with other dollar values in our analysis. For 2025 and 2030, we use the values in Tables 4-8 and 4-9: $33,000 per ton of SO_2 and $3,000 per ton of NO_x in 2025 and $36,000 per ton of SO_2 and $3,200 per ton of NO_x in 2030. These values are also in 2011$ using a 7-percent discount rate. Again, we convert them to 2015$ for consistency.

Assumptions for scenarios

For this analysis, we compared two cases, the Reference Case and the Clean Energy Compliance Pathway (which we also refer to as the "Clean Path") Case. For each case we ran the ReEDS model for the contiguous U.S. with a consistent set of assumptions across all states. Our analysis then focused on the impacts in Virginia.

The Reference Case includes

- state and federal policies in place at the end of 2014 and assumes no additional policies have been or will be implemented,
- electricity demand, natural gas prices and coal prices from reference case of the AEO2015,
- state energy efficiency standards through October 2015 as calculated by UCS based on data from DSIRE and state utility information using a calculation methodology developed by EPA for state analyses
- state renewable energy standards as enacted through October 2015 based on information calculated by Lawrence Berkeley National Laboratory (LBNL) or NREL as part of ReEDs assumptions, and
- the model revisions described in the previous section.

The reference case assumptions did not require state compliance with the Clean Power Plan (CPP).

The Clean Path Case includes

- Compliance with the CPP mass-based targets including the new source complement, which includes both new and existing fossil-fired power plants. The CPP offers a number of options for each state to develop an implementation plan most suited to its own electricity mix, resource availability, and policy objectives. For this case, we apply one set of compliance options for all states.
- All states have the option to meet their CPP targets by trading carbon allowances with any other state.
- A full extension of the federal production tax credit through 2016, with a gradual ramp-down through 2018
- An extension and ramp-down of the current federal solar investment tax credit from 30 percent in 2016 to 10 percent in 2020 and thereafter
- For Virginia we have assumed that the state implements mandatory Energy Efficiency Resource standard (EERS) with energy efficiency savings equivalent to 9 percent of statewide electricity sales in 2022 and continuing at this level through 2030. Virginia set a voluntary goal for energy efficiency in SB 1416 of 10 percent of 2006 sales (Virginia Acts of Assembly, 2007). For the mandatory EERS in our analysis, we used the voluntary goal for a base and calculated the equivalent electricity savings requirement in 2022 (9 percent of sales in that year). Additionally, we assume that the policy maintains the requirement at this level through 2030.
- We also assumed Virginia implements a Renewable Portfolio standard (RPS) policies in 2018 with renewable generation (including hydro generation) meeting 8 percent of sales in 2025 expands to meet 16 percent of sales in 2030. Virginia's current voluntary RPS has a goal for investor owned utilities to meets 15 percent of adjusted 2007 sales in 2025 from renewable energy resources (Virginia Acts of Assembly 2013, Chapter 2). We used this goal as a base for the mandatory RPS policy assuming that the policy will require that the goals are met with renewable generation without any additional credits provided for wind, solar. We also assume that utilities will not be permitted to meet any portion of the RPS goal through expenses on research and development activity related to renewable energy and alternative energy sources. We recalculated the goals relative to state-wide sales in 2025. The extension of the RPS is based on meeting the 2030 renewable electricity targets described in our previous analysis of renewable energy in the proposed CPP (Cleetus et al. 2014). The mandatory RPS has the same resources eligibility criteria as the voluntary RPS.

The CPP includes a Clean Energy Incentive Program (CEIP), which offers states incentives for early development of renewable energy and energy efficiency. The CEIP offers credits for renewables generation in the years 2020 and 2021 from wind and solar projects that start construction after a state's compliance plan is finalized. Energy efficiency investments in low-income communities also qualify. A portion of the generation that meets the RPS and EERS requirements may qualify for the CEIP but our analysis does not attempt to estimate this portion.

TABLE A-2. **Comparison of Assumed Overnight Capital Costs for Electric Generation Technologies (2015$/kW)**

	UCS 2015					EIA AEO 2015			
Technology	**2010**	**2020**	**2030**	**2040**	**2050**	**2010**	**2020**	**2030**	**2040**
Natural Gas CC	1,015	988	988	988	988	1,015	970	935	903
Natural Gas-CC-CCS	N/A	3,087	2,798	2,582	2,472	N/A	2,002	1,863	1,733
Natural Gas CT	862	841	841	841	841	862	821	788	759
Coal-Supercritical PC	3,069	2,995	2,995	2,995	2,995	3,069	2,965	2,899	2,833
Coal-IGCC	3,958	3,816	3,816	3,816	3,816	3,958	3,708	3,539	3,382
Coal-PC-CCS	6,615	6,322	5,941	5,573	5,573	6,615	6,322	5,941	5,573
Nuclear	5,003	5,420	5,420	5,420	5,420	5,003	4,935	4,575	4,283
Hydro*									
Biomass, dedicated	4,302	3,743	3,743	3,743	3,743	4,302	3,656	3,515	3,380
Biomass, cofired with coal**	447	447	447	447	447	294	294	294	294
Solar PV-Utility	4,464	1,647	1,098	1,098	1,098	5,012	3,119	2,826	2,586
Solar PV-Residential	6,697	2,471	2,471	2,471	2,471	10,316	4,880	3,990	3,762
Solar PV-Commercial	5,581	2,059	2,059	2,059	2,059	7,358	4,148	3,268	3,078
Solar CSP-With 6 hour Storage	6,965	4,183	3,164	3,164	3,164	AEO 2015 does not include CSP with storage			
Wind-Onshore***	1,720	1,615	1,560	1,554	1,554	2,410	2,238	2,100	1,940
Wind-Shallow Offshore	5,453	4,652	3,957	3,850	3,729	AEO 2015 does not include shallow offshore wind			
Wind-Deep Offshore	6,021	5,135	4,366	4,248	4,113	6,321	6,119	5,781	5,444
Landfill gas	8,945	8,408	8,220	8,034	8,034	8,945	8,408	8,220	8,034

* Hydro capital costs are too detailed to show in this table; ReEDs uses supply curves with capital cost variation by potential resource capacity. ** The cost for biomass co-firing is per kW of plant capacity, including coal capacity. *** Capital costs for wind represent technologies for class 6 resources.

TABLE A-3. **Operation and Maintenance (O&M) and Heat Rate Assumptions**

Technology	Fixed O&M (2015$/kW-yr)	Variable O&M (2015$/MWh)	Heat Rate (Btu/kWh)	
			2010	2030
Natural Gas-CC	14.6	3.5	6,624	6,567
Natural Gas-CC-CCS	32.6	7.0	7,504	7,493
Natural Gas CT	7.4	13.3	9,756	9,500
Coal-Supercritical PC	32.5	1.7	8,760	8,740
Coal-IGCC	52.8	7.4	7,867	7,450
Coal-PC-CCS	7.5	8.7	9,105	8,307
Nuclear	95.8	2.2	10,479	10,479
Biomass	108.4	5.4	13,500	13,500
Solar PV-utility	22.3	0.0	n/a	n/a
Wind-Onshore	50.75	0	n/a	n/a
Wind-Shallow Offshore	132	0	n/a	n/a

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).

TABLE A-4. **Comparison of Solar Capacity Factors**

Technology	UCS2015
Solar PV-utility	17-28%
Solar CSP-With 6-hour Storage	28-38%

Table A-5. **Comparison of Wind Capacity Factors**

	UCS 2015					EIA AEO 2015			
Technology	2014	2020	2030	2040	2050	2014	2020	2030	2040
Wind-Onshore Class 3	32%	35%	37%	38%	40%	28%	29%	31%	31%
Wind-Onshore Class 4	38%	41%	44%	45.1%	47%	32%	33%	34%	34%
Wind-Onshore Class 5	44%	47%	49%	51%	53%	36%	37%	38%	38%
Wind-Onshore Class 6	47%	49%	52%	53%	55%	40%	41%	30%	42%
Wind-Onshore Class 7	51%	54%	56%	58%	60%	n/a	n/a	n/a	n/a
Wind-Offshore Class 4	43%	44%	47%	48%	48%	32%	33%	35%	35%
Wind-Offshore Class 5	47%	48%	51%	52%	52%	36%	37%	39%	39%
Wind-Offshore Class 6	49%	50%	54%	54%	55%	40%	41%	43%	43%
Wind-Offshore Class 7	42%	43%	46%	46%	47%	44%	44%	45%	45%

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