Advancing Minnesota's Clean Energy Economy
Building on a History of Leadership and Success

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Methodology and Assumptions
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UCS used the National Renewable Energy Laboratory's (NREL) Regional Energy Deployment System (ReEDS) model to analyze the technical and economic feasibility of Minnesota pursuing a 40 percent by 2030 renewable energy standard (RES). This document describes the methodology and assumptions that were used for that analysis. The ReEDS modeling of the 40 percent by 2030 RES in Minnesota shows that this level of renewable energy penetration is achievable while maintaining reliable and affordable electricity, driving significant economic benefits, and positioning the state to make meaningful reductions in carbon dioxide (CO_2) emissions.

ReEDS is a computer-based, long-term capacity-expansion model for the deployment of electric power generation technologies in the United States. ReEDS is designed to analyze the impacts of state and federal energy policies, such as clean energy and renewable energy standards or reducing carbon emissions, in the U.S. electricity sector. ReEDS provides a detailed representation of electricity generation and transmission systems and specifically addresses issues related to renewable energy technologies, such as transmission, resource quality, variability, and reliability. UCS used the 2014 version of ReEDS for our analysis. However, we did make some changes to NREL's assumptions for renewable and conventional energy technologies based on project-specific data and mid-range estimates from recent studies, as described in more detail below.

Scenarios

To analyze the impacts of Minnesota adopting a strengthened RES, we compared the state's energy future under a 40 percent by 2030 RES (Strengthened RES case) to a business as usual (Reference case) scenario. The Reference case assumes no new state or federal policies beyond those which existed at the end of 2013. This includes Minnesota's currently-enacted 25 percent by 2025 RES (30 percent by 2020 for Xcel Energy - the state's largest investor-owned utility) and energy efficiency resource standard that achieves a 1.5 percent reduction in electricity sales per year. This scenario establishes a baseline for the analysis.

UCS' Strengthened RES case analyzes the impacts of a stronger state renewable energy standard that would go above and beyond Minnesota's current RES to achieve 40 percent by 2030. We assume that the strengthened RES maintains the same policy design elements as the current RES, including the resources eligible for compliance, any geographic limitations on eligible resources, etc. We also assume the state's current RES remains in effect as enacted through 2025, including current renewable energy ramp up rates to achieve the 25 percent by 2025 requirement. We then assume the strengthened RES takes effect beginning in 2026 and that the required ramp-up schedule to ultimately achieve 40 percent renewable energy in 2030 takes a linear trajectory - adding approximately 2.5 percent additional renewable energy each year through 2030. After 2030, we assume that Minnesota's utilities are required to maintain 40 percent renewable energy each year.

Assumptions

Cost and performance for electric generating technologies:

The cost and performance assumptions for electric generating technologies that UCS used in the 2014 version of NREL's ReEDS model are shown in Tables 1-3 below, compared to EIA's AEO 2014 assumptions (EIA 2014). We also describe our assumptions for energy efficiency investments that were not included in the model. For conventional technologies, NREL uses EIA's AEO 2014 cost and performance assumptions. We did not make any changes to EIA's assumptions for natural gas and coal prices, fixed and variable O&M costs, and heat rates, with a few exceptions noted below (EIA 2014). 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. The cost and performance assumptions for renewable energy technologies are mostly consistent with the assumptions that were developed for the forthcoming DOE Wind Vision report (DOE 2014). These changes we made include:

- **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 2014). 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 costs for emerging technologies decline over time at the same levels for all scenarios.

- **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 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 assume higher initial capital costs than EIA for new nuclear 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. To date, no existing plant has received or applied for an operating license extension beyond 60 years. 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 closures, 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 *2013 Wind Technologies Market Report* (Wiser and Bolinger 2014). This report shows that capacity-weighted installed capital costs for U.S. projects declined 13 percent from $2,262/kW (in 2013$) in 2009 to $1,960/kW in 2012. While costs dropped again to $1,630/kW in 2013 and are expected to average $1,750/kW in 2014, these projects are heavily weighted toward lower cost projects in the interior region of the U.S. Thus, we conservatively assume that average U.S. installed costs will stay fixed at 2012 levels over time based on a larger sample of projects, and assume 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 2014). We also assume higher fixed O&M costs than EIA based on mid-range estimates (EIA 2014, 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 2014, 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 2014, 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 second quarter of 2014 (SEIA 2014). We assume future solar PV costs for utility scale systems and residential and commercial rooftop systems will decline over time based on mid-range projections from the DOE Sunshot Vision Study's 62.5 percent and 75 percent cost reduction (relative to 2010 costs) scenarios. In addition, we use slightly lower capacity factors for solar PV than EIA based on NREL data (NREL 2012).

- **Solar CSP**: We assume concentrating solar plants will include six hours of storage and used the price projection and O&M costs from the DOE Sunshot Vision Study's 62.5 percent and 75 percent cost reduction scenario.

- **Biomass**: We use EIA's initial capital costs for 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 that biopower 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 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).

- **Geothermal and hydro**: We didn't make any changes to NREL's assumptions for geothermal and hydro, which are site specific.

Load growth and energy efficiency projections. Load growth projections are taken from the Energy information Administration's Annual Energy Outlook (AEO) 2014 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 2014 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 2014. 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.

Accounting for recent or planned changes to generating resource or transmission availability
To ensure the ReEDS model has an accurate accounting of the current and near-term electricity system, we undertook a thorough review of the model's depiction of the electricity system (across the contiguous United States) in 2012 and 2014 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 within the model to accurately reflect newly constructed or under-construction generating resources (including natural gas, nuclear, coal, wind and utility-scale solar facilities);
- Accounting for recent or recently-announced coal-plant retirements to ensure these resources are not available to the model;
- Ensuring the model accurately reflects under-construction transmission projects and making adjustments to certainty of the project or anticipated completion dates based on industry or regional transmission operator progress reports.

Technology	UCS 2014					EIA AEO 2014			
	2010	2020	2030	2040	2050	2010	2020	2030	2040
Natural Gas CC	1,036	1,036	1,036	1,036	1,036	1,043	1,036	914	826
Natural Gas-CC-CCS	n/a	3,005	2,885	2,752	2,645	n/a	2,052	1,777	1,559
Natural Gas CT	689	689	689	689	689	688	670	575	515
Coal-Supercritical PC	3,306	3,306	3,306	3,306	3,306	2,988	3,051	2,802	2,562
Coal-IGCC	n/a	4,482	4,482	4,482	4,482	n/a	3,828	3,412	3,067
Coal-PC-CCS	n/a	6,166	5,971	5,756	5,581	n/a	5,272	4,736	4,231
Nuclear	n/a	6,529	6,529	6,529	6,529	n/a	4,905	4,376	3,831
Biomass	4,187	4,187	4,187	4,187	4,187	4,188	3,862	3,492	3,112
Solar PV-Utility	4,350	1,835	1,660	1,603	1,603	3,943	3,334	2,963	2,625
Solar PV-Residential	Used NREL's Sunshot scenarios, 62.5% by 2020 and 75% by2040					7,636	3,850	2,823	2,823
Solar PV-Commercial	Used NREL's Sunshot scenarios, 62.5% by 2020 and 75% by2040					6,545	2,951	2,567	2,567
Solar CSP-With Storage	4,060	2,797	2,457	2,116	2,116	n/a	n/a	n/a	n/a
Wind-Onshore	2,280	1,969	1,969	1,969	1,969	2,254	2,301	2,113	1,932
Wind-Offshore	n/a	5,329	4,620	4,249	3,557	6,343	6,330	5,608	4,932

Table 1. Comparison of Overnight Capital Costs for Electric Generation Technologies (2013$/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	15.65	3.33	6430	6333
Natural Gas-CC-CCS	32.36	6.90	7525	7493
Natural Gas CT	7.17	10.56	9750	8550
Coal-Supercritical PC	31.75	4.55	8800	8740
Coal-IGCC	52.32	7.35	8700	7450
Coal-IGCC-CCS	67.68	4.53	10700	8307
Nuclear	94.98	2.18	10452	10452
Biomass	107.56	5.36	13500	9500
Solar PV-utility	16.30	0.00	n/a	n/a
Solar PV-Residential	NREL	0.00	n/a	n/a
Solar PV-Commercial	NREL	0.00	n/a	n/a
Solar CSP-With Storage	68.49	0.00	n/a	n/a
Wind-Onshore	51.82	0.00	n/a	n/a
Wind-Offshore	103.63	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	UCS2014	EIA AEO 2014
Solar PV-utility	16-28%	21-32%
Solar CSP-With Storage	27-54%	n/a

Table 3. Comparison of Solar Capacity Factors.

	UCS 2014					EIA AEO 2014			
Technology	2012	2020	2030	2040	2050	2010	2020	2030	2040
Wind-Onshore Class 3	31%	32%	32%	32%	32%	28%	29%	29%	29%
Wind-Onshore Class 4	37%	38%	38%	38%	38%	32%	33%	33%	33%
Wind-Onshore Class 5	43%	44%	44%	44%	44%	39%	39%	39%	39%
Wind-Onshore Class 6	46%	47%	47%	47%	47%	45%	46%	46%	46%
Wind-Offshore Class 4	n/a	35%	38%	38%	38%	27%	27%	27%	27%
Wind-Offshore Class 5	n/a	41%	44%	44%	44%	34%	34%	34%	34%
Wind-Offshore Class 6	n/a	44%	47%	47%	47%	40%	40%	40%	40%
Wind-Offshore Class 7	n/a	48%	52%	52%	52%	n/a	n/a	n/a	n/a

Table 4. Comparison of Wind Capacity Factors.

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