DIRECT TESTIMONY

OF ARNE OLSON

ON BEHALF OF NORTHWESTERN ENERGY

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Witness Information

Q. Please provide your name, employer, and title.

A. My name is Arne Olson. My business address is 44 Montgomery Street, Suite 1500, San Francisco, CA 94104. I am employed by Energy + Environmental Economics Inc. ("E3"), where I am a Senior Partner.

Q. Please describe your relevant experience and education.

A. I have over 30 years of experience in the electric utility business in consulting and state government. Since joining E3 in 2002, I have worked extensively in the areas of resource planning, asset valuation, transmission, market design, and energy policy. I currently lead E3's Integrated System Planning practice and contribute frequently to projects across many practice areas. Prior to joining E3 in 2002, I served for six years as an energy policy specialist at the Washington Department of Commerce.

I received a Master of Science degree in International Energy Management & Policy from the University of Pennsylvania and Bachelor of Science degrees in Mathematical Sciences and Statistics from the University of Washington. The attached résumé (Exhibit AO-1) further describes my qualifications, experience, and publications.

I have served as the lead investigator in developing integrated resource plans ("IRP") for utilities and state agencies across North America. Much of my resource planning work has focused on helping utilities analyze the impacts of higher penetrations of variable renewable resources on their operations and investment decisions. Some examples of current and past projects include:

- I am a co-author of the 2016 Report Number 6 of the Lawrence Berkeley National Laboratory's “Future Electric Utility Regulation Series,” entitled “The Future of Integrated Resource Planning.”
- I led a team that supported Nova Scotia Power's IRP focusing on the recently established provincial goal of achieving net zero carbon emissions by 2050.
- For the Sacramento Municipal Utilities District (“SMUD”), I led the development of their 2018 IRP which considered scenarios and resource portfolios for meeting California’s and SMUD’s own renewables goals including 100% renewables by 2040, as well as a 2020 study of resource portfolios for achieving the utility’s net zero carbon emissions goal by 2030.
- For Xcel Energy, I led an effort to support development of Northern States Power’s 2018-2019 IRP examining high renewable scenarios within the context of the company’s stated goal of completely decarbonizing its electric resource portfolio by 2050.
- For a group of utilities in the Pacific Northwest, I led studies in 2017 and 2018 that examined scenarios achieving 50% renewables and up to 100% carbon reductions across the region, focusing on policy mechanisms to achieve the goals at least cost and on the nature and

quantity of complementary resources that are needed to maintain reliable electric service.

- I have led several studies examining the means to ensure resource adequacy under high renewable power systems, including: a 2020 study of the New England system, undertaken in partnership with former U.S. Energy Secretary Dr. Ernest Moniz, entitled “Net Zero New England: Ensuring Electric Reliability in a Low-Carbon Future”; a 2019 study of the California system entitled “Long-Run Resource Adequacy under Deep Decarbonization Pathways Scenarios for California”, funded by the Calpine Corporation; and a 2018 study entitled “Resource Adequacy in the Pacific Northwest” funded by a coalition of 13 publicly-owned and investor-owned utilities including NorthWestern Energy. In 2019, I also supported the Northwest Power Pool’s effort to develop a regional resource adequacy program in the Pacific Northwest, which later became the Western Resource Adequacy Program (WRAP).
- In 2018, I led a study of the value of partially- and fully-dispatchable solar and solar + storage power plants on the Tampa Electric Company (“TECO”) system. The study was funded by First Solar, but it involved extensive participation by a wide range of TECO staff and included detailed TECO power system data. First Solar and TECO jointly received a “2018 Top Innovators” award from Public Utilities Fortnightly in conjunction with the study, and TECO was selected as a

finalist for a 2019 Platts Global Energy Award in the "Grid Edge" category.

- For a group comprising the five largest utilities in California (Los Angeles Department of Water and Power, Pacific Gas and Electric Company, Sacramento Municipal Utilities District, San Diego Gas & Electric Company, and Southern California Edison), I led a landmark 2014 study of the feasibility, cost implications, and complementary measures for achieving 50% renewables by 2030.
- I have participated in several other E3 resource planning studies of achieving very high renewable penetrations for the Hawaiian Electric Company, the New York State Energy Research and Development Authority, and Arizona Public Service Company.
- Since 2017, I have led a team at E3 that supports the California Public Utilities Commission staff in developing a Reference System Plan for California and designing and implementing IRP standards for California load-serving entities.

Q. Have you previously testified in front of the Montana Public Service Commission ("Commission")?

A. No, I have not. However, I was invited by Commission staff to present to the Commission in June 2017 regarding "Resource Adequacy and Planning Reserve Margins." I also presented results of our study "Resource Adequacy in the Pacific Northwest" to the Commission in April

2019. I have provided expert witness testimony to the California Public Utilities Commission, the California Energy Commission, the Oregon Public Utility Commission, the Colorado Public Utilities Commission, the New Mexico Public Regulation Commission, the Georgia Public Service Commission, the South Carolina Public Service Commission, the Alberta Energy and Utilities Board, the Nova Scotia Utility and Review Board, Colorado Superior Court, and the Ontario Superior Court of Justice.

Purpose of Testimony

Q. What is the purpose of your testimony in this docket?

A. The purpose of my testimony is to describe the methods and results of E3's incremental Effective Load Carrying Capability ("ELCC") studies conducted for NorthWestern and used by NorthWestern in its 2020 Supplement to its 2019 Electricity Supply Resource Procurement Plan ("2020 Supplement") and January 2020 Request for Proposals for long-term capacity resources ("RFP"). NorthWestern evaluated the resources proposed in response to the RFP based in part on the amount of effective capacity each resource could be expected to contribute toward meeting the utility's resource adequacy needs, which is often referred to as the resource's "capacity contribution."

NorthWestern used E3's ELCC studies to assess the capacity contribution from stand-alone wind, solar, energy storage, and hybrid resources of various configurations. In NorthWestern's 2020 Supplement, ELCC values were used for hydro, wind, solar and storage; forced outage de-rates were used for the capacity contributions of coal, natural gas, and thermal QFs.

Q. What was the scope of E3's ELCC study for NorthWestern?

A. NorthWestern retained E3 to calculate ELCC values for dispatch-limited resources for the purpose of evaluating those resources in its 2020 Supplement and RFP, as described in the Direct Testimony of Michael S. Babineaux. The resources considered in E3's analysis included stand-alone storage (ranging from 3 hours to 10 hours in duration), solar photovoltaic (PV), wind, and solar plus storage and wind plus storage hybrid resources of various configurations, including specific offers received by NorthWestern. E3 tested a range of penetration levels across those resources to determine incremental ELCCs for various levels of potential resource additions.

Capacity Contribution of Intermittent Renewables and Energy Storage

Q. How do dispatch-limited resources differ from firm resources in their ability to contribute to resource adequacy?

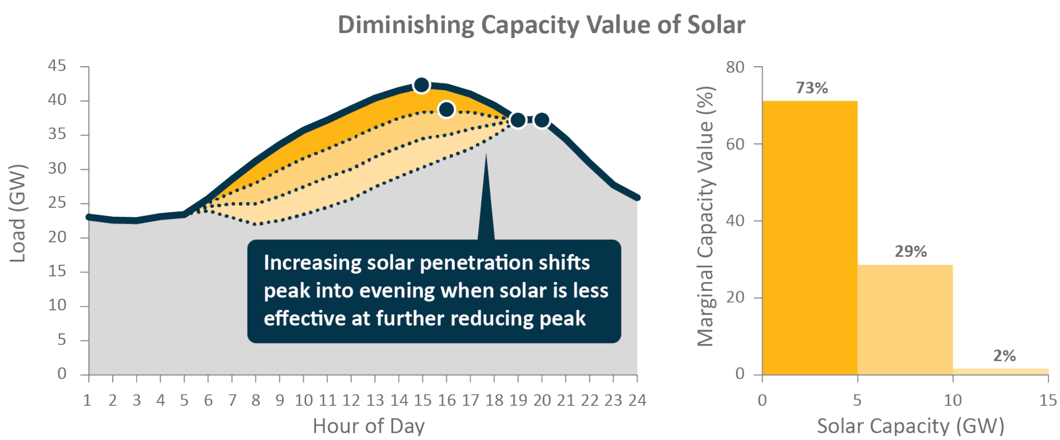
A. Unlike conventional firm resources, dispatch-limited resources have physical limitations that prevent them from being operated continuously at full capacity to meet demand. These constraints may take multiple forms: for intermittent renewable resources like wind and solar, the availability of generation is a function of underlying meteorological conditions and will vary by time of day and from season to season; for energy storage, the resource's "duration" – the number of hours of stored energy – limits the amount of time it can be operated at full capacity. Energy storage may also be limited by the availability of energy for charging.

Due to these limitations, the contributions of dispatch-limited resources to reliability are often lower than the resource's rated maximum or "nameplate" capacity (contributions to reliability for conventional resources are also lower than nameplate capacity due to the potential for forced outages). Another consequence of these limitations is that dispatch-limited resources tend to exhibit diminishing returns with scale due to saturation effects. That is, each increment of a specific dispatch-limited resource will tend to have a lower contribution to resource adequacy than the prior increment.

Q. How do these concepts apply to the capacity contribution of intermittent renewables?

A. The output of intermittent renewable resources varies through time due to factors outside of the control of utilities – namely, as a function of underlying weather conditions. Because their output is often lower than their rated capacities during the periods in which energy is most needed, the contribution of intermittent resources to resource adequacy is typically lower than their rated (maximum) capacities. This dynamic is readily apparent for solar PV in a summer-peaking system. The first increment of solar PV projects added to the system provides moderate capacity value due to its coincidence with system peak loads, but it also has the effect of shifting the "net peak demand" – demand less intermittent renewables – towards the evening, when solar produces less. As a result, subsequent increments of solar PV will produce lower and lower contributions to resource adequacy. These dynamics are shown in Figure 1 below, which is not a model result but illustrates these dynamics conceptually. Similar dynamics would occur on NorthWestern's system and could be amplified by the fact that NorthWestern's peaks often occur in winter evenings.

Figure 1: Solar Capacity Contribution Dynamics (illustrative)



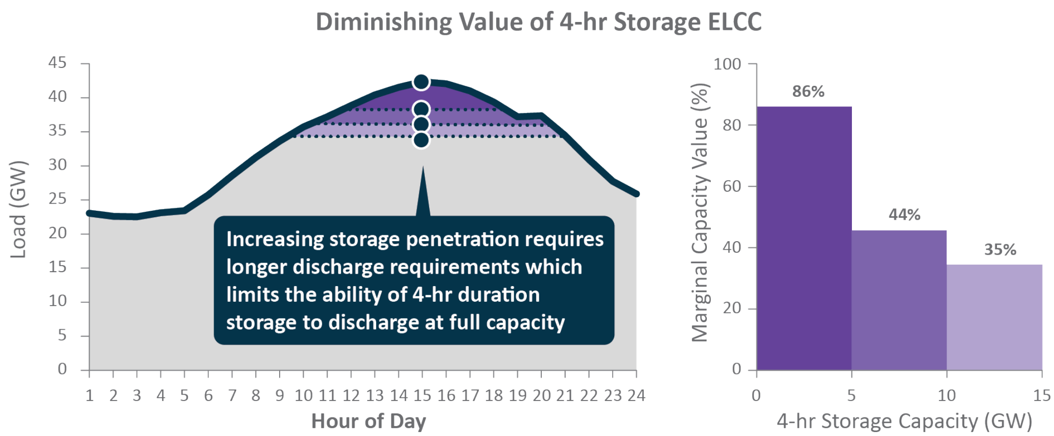
Similar dynamics as described for solar PV occur for wind generation capacity contribution as well.

Q. How do these concepts apply to energy storage?

A. While energy storage resources can be operated flexibly in response to system conditions, they are unable to generate continuously at maximum output for long periods of time. The "duration" – a measure of the amount of time a storage resource can discharge at full capacity before its state of charge is exhausted – may limit the ability of energy storage resources to produce power when needed. For example, a peak load event may require some energy storage resources to discharge continuously for four hours, but if the resources have a duration less than four hours, then the storage resources either run out of energy before the event is over or must operate at partial output over the full period to lower the peak demand across the entire timespan. Once an energy storage resource is depleted, it is unavailable to discharge to help meet system needs until it is able to re-charge. For example, on a particular day, an energy storage resource may discharge during the late afternoon to help meet peak demand, but if an outage occurs at a thermal power plant in the evening when energy demand is still very high, the energy storage resource would be unavailable to respond.

Like other dispatch-limited resources, the capacity contribution of energy storage resources tends to diminish with increasing levels of penetration. The capacity contribution of storage declines because, as successive tranches of storage reduce peak demand, the next tranche of storage must reduce the peak over a longer period. These dynamics are shown in Figure 2 below, which is not a model result but illustrates these concepts.

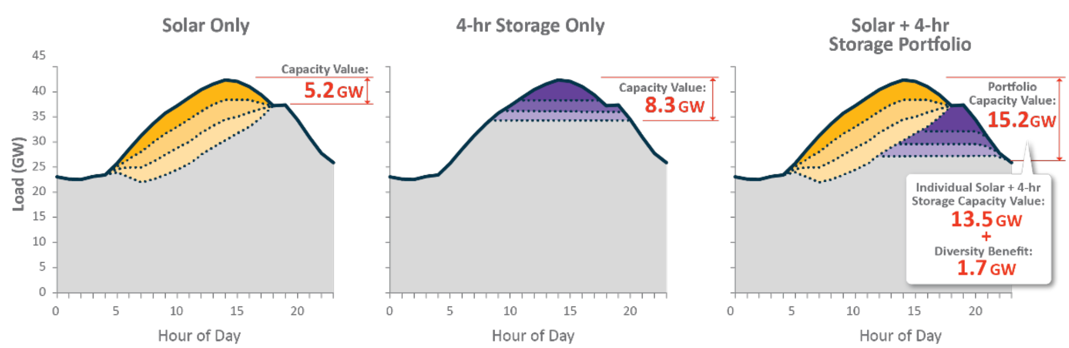
Figure 2: Energy Storage Capacity Contribution Dynamics (illustrative)



Q. Are there interactive effects between different types of dispatch-limited resources?

A. Yes. The contribution of a resource toward resource adequacy depends on the characteristics of the other resources in the portfolio; that is, resources have interactive effects with one another such that a portfolio of resources may provide a capacity contribution that is greater than (or smaller than) the sum of its parts. The combination of solar PV and battery storage is a useful example. These two resources tend to have a positive interactive effect when added to a portfolio. The solar PV generation during the day shifts and compresses the net peak period into a few evening hours, enabling the battery storage to more effectively meet the net peak demand. Thus, the solar PV resource helps to satisfy daytime energy demand while the energy storage resource can help to meet evening energy demand. This dynamic is shown in Figure 3 below, which is not a model result but illustrates this concept. Other resource combinations may produce similar interactive effects.

Figure 3: Capacity Contribution Dynamic of Adding Solar and Energy Storage (illustrative)



Q. How do utilities evaluate the contribution of dispatch-limited resources toward resource adequacy?

A. No single method is used to evaluate the contribution of dispatch-limited resources toward resource adequacy, and historically, many system planners have relied upon relatively simple heuristic methods to estimate capacity contributions such as average output during a 2-6 p.m. time window. However, as more dispatch-limited resources are added to the system, these methods become increasingly inaccurate and fail to capture how the addition of dispatch-limited resources will cause the timing of supply constraints to shift to other times of the day (or year). Further, they do not capture significant interactive effects between different types of technologies. When renewables make up a significant portion of a utility's portfolio, it is important to use an accurate method for calculating the contribution of these resources toward resource adequacy, and the ELCC method has emerged as the industry "best-practice" for estimating the contribution of dispatch-limited resources toward resource adequacy.

Q. How is the ELCC of a resource defined?

A. The ELCC is a robust measure of a resource's contribution to a utility's reliability standard, defined as the quantity of "perfect" capacity[1] that could be displaced by a resource while providing equivalent system reliability. For example, if a resource has an ELCC of 50 megawatts ("MW") that means that it could displace 50 MW of perfect capacity with no impact on system reliability. The ELCC can also be expressed in percentage terms by dividing by the nameplate capacity; if the resource in this example has a nameplate rating of 100 MW, its ELCC would be 50%.

Quantifying ELCC values requires the use of a Loss-of-Load Probability ("LOLP") model. An LOLP model simulates the balance of demand and available supply across a broad range of weather conditions to measure the performance of resources during periods of system stress,

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[1] A "perfect" capacity resource is a resource that can dispatch on demand at full capacity and is always available.

incorporating the effects of any correlations (positive or negative) that might exist between dispatch-limited resource production and load. While the ELCC method considers a resource's performance across all hours and under all possible conditions, the resulting ELCC is a measure of the resource's contribution to system needs during the periods in which it is needed most.

Q. Why is the ELCC method preferred over other methods?

A. The ELCC method is preferred for three primary reasons:

1. It captures a wide range of system conditions by simulating electric system operations over hundreds or even thousands of simulation years. This ensures that the estimation of capacity contributions is robust across a wide distribution of potential outcomes, including infrequent "tail" events (e.g. higher load and lower renewable output than expected combined with forced generator outages) that are the primary drivers of reliability challenges.
2. It naturally accounts for both the saturation effects that occur as a particular resource type is added to the system in increasing quantities and the interactive effects between different types of technologies to provide an accurate measurement of the contribution of dispatch-limited resources to the system.
3. As a result of the first two characteristics listed above, the ELCC method ties the capacity contribution of a resource directly to its ability

to help satisfy the reliability target. This ensures that its deemed capacity contribution corresponds one-for-one to its contribution toward resource adequacy. This approach therefore creates a common metric that ensures an “apples-to-apples” comparison among resources with very different characteristics. A resource with an ELCC of 1 MW has the same contribution toward resource adequacy, regardless of whether that capacity contribution comes from solar PV, wind, energy storage, etc. This makes ELCC a suitable metric for comparing capacity contributions of different resources in capacity procurement solicitations.

<u>E3’s Incremental Effective Load Carrying Capability Study</u>

Q. How did E3 quantify the ELCC for dispatch-limited resources?

A. The ELCC for dispatch-limited resources was quantified using E3’s proprietary Renewable Energy Capacity Planning (“RECAP”) model with input data on NorthWestern’s loads and resources. RECAP is a LOLP model that has been used extensively to test the resource adequacy of electric systems across North America and to measure the contribution of dispatch-limited resources towards resource adequacy. E3 developed RECAP specifically to address the needs of a changing electricity system by incorporating the unique characteristics of dispatch-limited resources into the traditional reliability framework.

Q. Please describe, at a high level, how RECAP functions.

A. RECAP calculates the loss-of-load expectation ("LOLE") of a portfolio by simulating the availability of generation to supply load on an hourly basis across a wide range of possible system conditions. The range of conditions simulated captures load and renewable variability (based on an underlying record of weather data from 1970-2018) as well as stochastic outages of generating resources. Correlations among load and renewable generation are maintained within the model to ensure appropriate statistical relationships among load, weather, and renewable generation conditions, based on historical observations. Hourly simulations are completed for hundreds of years of potential conditions to ensure a robust result; this ensures that RECAP captures a wide distribution of potential outcomes, including tail events.

To determine the LOLE of a portfolio, RECAP compares demand with available generation in each hour of the simulation. A loss-of-load event is recorded each time the supply of resources is inadequate to meet the load requirement. RECAP determines the frequency of loss-of-load events across all simulation years and then calculates the LOLE as the count of loss-of-load events per year.

Q. How is the ELCC for dispatch-limited resources determined in RECAP?

A. The steps followed to calculate the ELCC of a particular resource (or combination of resources) in RECAP are as follows:

1. RECAP is first used to calculate the LOLE for the electric system without the specified resource. If the resulting LOLE does not match the specified reliability target, the system is calibrated to meet the target reliability standard (e.g. 0.1 days/yr.) by adding or removing perfect capacity.[2]
2. The specified dispatch-limited resource is added to the system and the LOLE is recalculated. This will result in a reduction in the system's LOLE, as the amount of available generation has increased and the reliability of the system has improved.[3]
3. Perfect capacity resources are removed from the system until the LOLE is restored to the specified reliability target. The amount of perfect capacity removed from the system represents the ELCC of the specified resource (measured in MW) added in step 2; this metric can be translated to a percentage value by dividing by the installed capacity of the specified resource.

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[2] A reliability target can be based on reliability metrics other than LOLE. This is an area of emerging research for systems with high penetrations of dispatch-limited resources. For this study, E3 utilized a 0.1 days/yr. LOLE reliability metric.

[3] E3's method for this study was to use the Expected Unserved Energy ("EUE") equivalent to the 2020 NorthWestern system reaching 0.1 day/yr. LOLE, which was 5 MWh/yr. EUE. This EUE value was used in calculating ELCCs due to its greater granularity compared to the relatively less granular event metric used to define LOLE.

Q. Has RECAP been used to quantify the ELCC of resources in other jurisdictions?

A. Yes. E3 initially developed RECAP for the CAISO in 2011 to facilitate studies of renewable integration and it has since been adapted for use in many jurisdictions across North America. Multiple utilities have used RECAP for some aspect of resource adequacy planning, including the Los Angeles Department of Water and Power, the Sacramento Municipal Utilities District, Portland General Electric, Xcel Energy, NV Energy, El Paso Electric, Hawaiian Electric, New Brunswick Power, and Nova Scotia Power. The California PUC has also used RECAP for a variety of resource planning proceedings, and E3 worked with the CAISO to use RECAP to examine the ELCC of demand response and energy storage. Finally, RECAP has been used in several of E3's long-term resource planning studies of decarbonized electricity systems, including studies in

California,[4] the Pacific Northwest,[5] the Upper Midwest,[6] and the Northeast.[7]

Q. Does E3's ELCC study consider or evaluate resource economics?

A. No. E3's study evaluates the capacity contribution of resources, which is necessary for evaluating system reliability. E3 did not use RECAP to evaluate resource economics or provide an economic comparison between different resources. The evaluation of the resources proposed in response to the RFP is explained in the Direct Testimony of Scott A. Leigh.

Q. How was RECAP configured for modeling NorthWestern's system?

A. E3 took the following steps to set up the NorthWestern RECAP model:

1. **Load shape development**: E3 developed a neural network model that generates hourly load shapes for the NorthWestern system across

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[4] *Long-Run Resource Adequacy for California Under Deep Decarbonization*, available at: https://www.ethree.com/wp-content/uploads/2019/06/E3_Long_Run_Resource_Adequacy_CA_Deep-Decarbonization_Final.pdf

[5] *Resource Adequacy in the Pacific Northwest*, available at: https://www.ethree.com/wp-content/uploads/2019/03/E3_Resource_Adequacy_in_the_Pacific-Northwest_March_2019.pdf

[6] *Xcel Energy Low Carbon Scenario Analysis,* available at: https://www.ethree.com/wp-content/uploads/2020/01/E3_Xcel_MN_IRP_Report_2019-07_FINAL.pdf

[7] *Net-zero New England: Ensuring Electric Reliability in a Low Carbon Future*, available at: https://www.ethree.com/wp-content/uploads/2020/11/E3-EFI_Report-New-England-Reliability-Under-Deep-Decarbonization_Full-Report_November_2020.pdf.

multiple years. The model was trained on historical 2010-2018 NorthWestern loads, and the trained parameters were used to generate load shapes for 1970-2018 based on historical temperature data. Load shapes used in this analysis were those of the NorthWestern retail electricity supply function customers and captured the dual-peak (i.e. both summer and winter) nature of the system.

2. **Resource shape development**: E3 used historical wind and solar data provided by NorthWestern for existing resource output. RECAP's algorithm calculates hourly renewable output shapes across the full range of simulated years using A) historical renewable output in similar seasons (+/- 15 calendar days to the simulated day) to capture inter-annual variations in renewable energy output, B) historical correlations with load to capture any positive or negative correlations between load and renewable energy output, and C) correlations with the previous day's renewable generation to capture the frequency of multi-day sequences of extreme heat, extreme cold, or extremely low renewable energy output. This algorithm is applied stochastically for each Monte Carlo simulation.

3. **Add the existing resources in NorthWestern's supply portfolio**: NorthWestern's existing resources were added to RECAP, and their operations were simulated in the model runs used to develop the incremental ELCCs.

4. **Adding perfect capacity to NorthWestern's system to meet a LOLE of 1 day in 10 years**: Per standard practice, the system was "tuned" to 0.1 LOLE by adding perfect capacity resources, prior to calculating the incremental ELCCs.
5. **Adding renewable generation shapes for new resources**: For new wind incremental ELCCs, historical NorthWestern wind output shapes (over 2014-2018) were used as the basis for modeling wind output in RECAP. For new solar incremental ELCCs, simulated output shapes (over 2014-2018) were used to better represent the best-in-class tracking PV technologies expected from solicitation proposals. Simulated solar shapes were derived by using the National Renewable Energy Laboratory's ("NREL") National Solar Radiation Database and NREL's System Advisor Model. Figure 5 and Figure 6 show the month-hour average wind and solar profiles modeled in RECAP.

Figure 4:Wind Output Data used in E3's ELCC Calculations (Month/Hour averages)

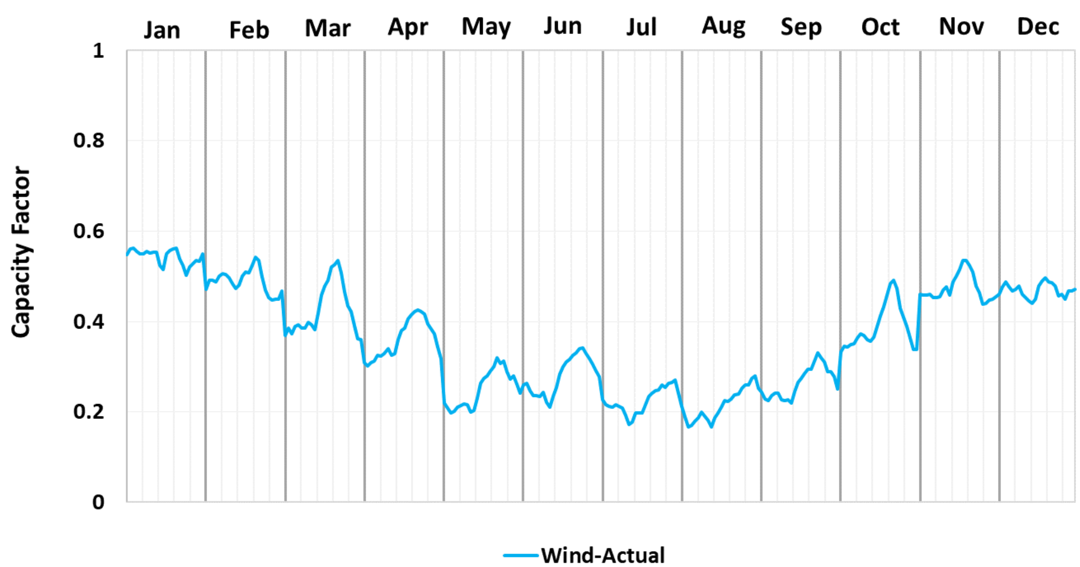
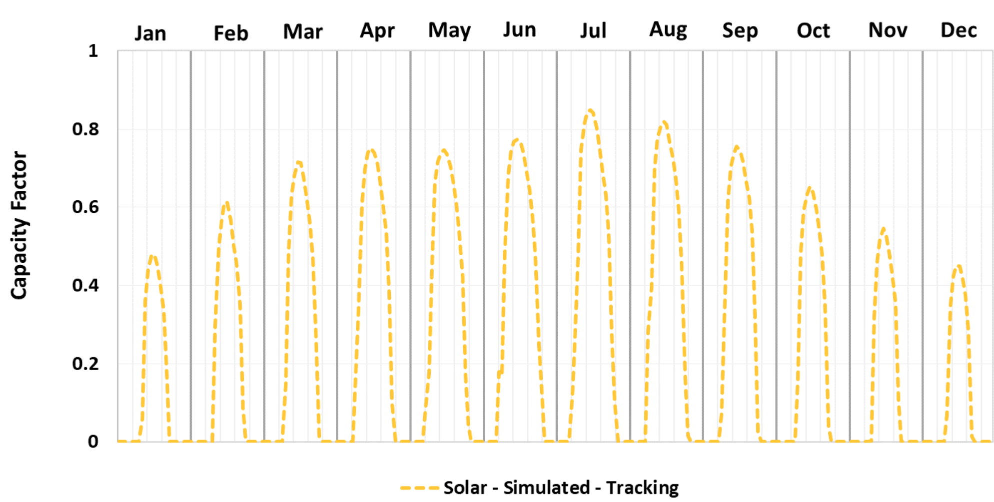


Figure 5: Solar Output Data used in E3's ELCC Calculations (Month/Hour averages)

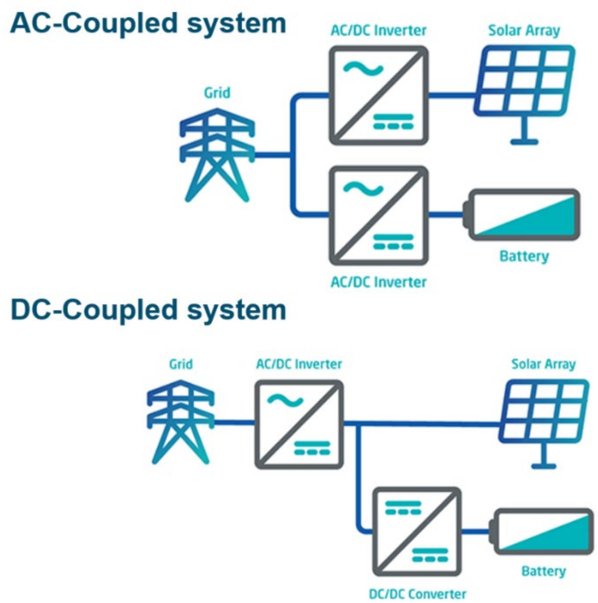


Q. How were hybrid resource ELCCs modeled?

A. Both hybrid wind and hybrid solar resources were modeled in various project configurations. E3 modeled some configurations of hybrid resources that could charge from the grid, enabling the storage to charge sufficiently using grid electricity to provide their full reliability benefit. E3 also modeled some configurations of hybrid resources that could only charge from their co-located solar or wind resource, which limits their ability to sufficiently charge the storage during loss-of-load events modeled in RECAP. This limitation means that variable energy resource ("VER")-only charging hybrids had lower ELCCs than hybrid resources that could charge from the grid. However, some developers may choose to limit grid charging to enable capturing of the full investment tax credit for both the solar and storage components of their project.

Hybrid resources were modeled in various ratios of VER capacity to storage capacity. All hybrid resources were modeled with 4-hour battery durations, and all hybrid resource ELCCs were limited by their joint interconnection capacity limit. Solar hybrid resources were modeled in both AC-coupled and DC-coupled conditions. As shown in the chart below, AC-coupled systems feature two AC-to-DC inverters, one for the solar array and another for the battery system, while DC-coupled systems site both the solar array and the battery behind a single inverter. E3 modeled a 1.3 inverter loading ratio for AC-coupled hybrids and a 1.7 inverter loading ratio for DC-coupled hybrids.[8]

Figure 6:AC-Coupled vs. DC-Coupled Hybrid System Configurations (source: Fluence Energy[9])



<u>ELCC Calculation Results</u>

Q. What were the results of E3's incremental ELCC calculations?

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[8] Inverter loading ratio ("ILR") describes the ratio of DC capacity behind the AC-to-DC inverter to the final AC output from that inverter. A 1.3 ILR means that there are 130 MW_DC of solar PV behind a 100-MW inverter. DC-coupled hybrid systems often feature higher ILRs because the energy that would have been "clipped" due to the inverter capacity limits can instead be stored in the battery behind the same inverter. A 1.7 ILR means that there are 170 MW_DC of solar PV behind a 100-MW inverter, which allows additional energy that can be used to charge the storage device.

[9] https://blog.fluenceenergy.com/energy-storage-ac-dc-coupled-solar

A. E3 calculated incremental ELCCs for the resource types, resource penetrations, and resource configurations shown in the tables below. Table 1 and Table 2 below contain the final set of incremental ELCC MW and ELCC percentage values across the resources studied that E3 provided to NorthWestern in July 2020.These final results are presented in Exhibit AO-2.

Table 1: E3's Effective Capacity and Incremental ELCC of Standalone Resources Results from July 2020 Study (ELCC MW and Incremental ELCC vs. Nameplate MW additions)[10]

Effective Capacity Provided by Different Resources, 2020									
Incremental Nameplate Capacity (MW)		Charging From	25 MW	50 MW	100MW	200MW	300MW	400MW	500MW
Standalone Battery	4hr	Grid	25	50	100	181	217	243	263
Pumped Storage	10hr	Grid			100	200	290	323	343
Solar PV	Simulated			2	4	6	7		
Wind	Historical			3	5	10	14		

Incremental ELCC Provided by Different Resources, 2020									
Incremental Nameplate Capacity (MW)		Charging From	25 MW	50 MW	100MW	200MW	300MW	400MW	500MW
Standalone Battery	4hr	Grid	100%	100%	100%	91%	72%	61%	53%
Pumped Storage	10hr	Grid			100%	100%	97%	81%	69%
Solar PV	Simulated			5%	4%	3%	2%		
Wind	Historical			6%	5%	5%	5%		

[10] These results are shown as the ELCC MW for the capacity being added, e.g. 200 MW of 4-hr standalone battery storage provides 181 MW of ELCC (i.e. the equivalent perfect capacity)..

Table 2: E3's Effective Capacity and Incremental ELCC of Hybrid Resources Results from July and November 2020 Studies (ELCC MW and Incremental ELCC vs. Nameplate MW additions)[11]

Capacity Value of a 100MW Incremental Paired Hybrid, 2020	4-Hr Storage Hybrid Configuration	Charging From:	Effective Capacity (ELCC MW)	Incremental ELCC (%)
	25 MW (AC-coupled)	Grid	29	29%
	50 MW (AC-coupled)	Grid	54	54%
	100 MW (DC-coupled)[¥]	Grid	100	100%
100 MW Solar +	***200 MW (AC-coupled)****	***Grid***	***196***	***196%***
4-Hr Storage	***25 MW (AC-coupled)***	***Solar Only***	***24***	***24%***
	50 MW (AC-coupled)	***Solar Only***	***43***	***43%***
	100 MW (DC-coupled)[¥]	Solar Only	66	66%
	125 MW (AC-coupled)*	***Solar Only***	***58***	***58%***
	200 MW (AC-coupled)*	***Solar Only***	***65***	***65%***
	25 MW	Grid	30	30%
	50 MW	Grid	54	54%
100 MW Wind +	***100 MW***	***Grid***	***100***	***100%***
4-Hr Storage	***25 MW***	***Wind Only***	***25***	***25%***
	50 MW	Wind Only	46	46%
	100 MW	***Wind Only***	***56***	***56%***
	125 MW*	***Wind Only***	***60***	***60%***

Values in blue represent hybrids with ability to charge from the grid

[¥]DC-coupled Solar resources assumed to have an inverter loading ratio of 1.7

*Interconnection limit is assumed to be matched with the capacity of the largest resource

Bold and Italicized Values denotes additional hybrid configurations from Nov 2020 Study

[11] Hybrid resources were modeled at various storage sizes relative to the 100 MW_AC addition of co-located wind or solar. Hybrid resources were subject to an interconnection limit based on the larger of the resources. For instance, the "200% of solar PV" project assumes 100 MW_AC solar PV and 200 MW of energy storage, subject to a maximum 200 MW output based on the assumed interconnection limit.

Observations from ELCC Calculation Results

Q. What dynamics were observed in the incremental ELCC modeling results?

A. E3 observed the following dynamics for the incremental ELCCs:

- **Energy storage**: NorthWestern has no utility-scale energy storage (except for a small amount of water storage within the hydro system) on its system currently and the first 100 MW of 4-hr and 10-hr storage additions provide essentially 100% of their capacity in ELCC MW. By 200 MW of storage additions, incremental ELCCs begin to decline, for instance adding 200 MW of 4-hour storage provides only 181 MW of ELCC. This dynamic continues as the MW of storage penetrations increases, but is mitigated to an extent if storage of longer duration is also added.
- **Solar PV**: Driven by the fact that solar output is quite low during NorthWestern's winter peaks, solar provides very low incremental ELCC MW for new additions. Saturation effects are also present in these results, with 100 MW providing 4 MW ELCC (4%) and 300 MW of additions providing 7 MW ELCC (2%).
- **Wind**: Given the significant penetration of wind already in NorthWestern's supply portfolio, incremental wind additions tend to provide low ELCC MW (5-6%) to NorthWestern's system. Historical shapes were used for calculating incremental ELCCs since they

captured actual performance of wind on NorthWestern's system (including cold temperature cut outs, maintenance outages, etc.).

- **Hybrid resources**: Hybrid resources were all tested at 100 MW-AC of either wind or solar additions, with varying levels of 4-hour battery storage and either grid or VER-only charging configurations. The configurations that allowed grid charging showed ELCCs similar to the sum of the stand-alone VER and the stand-alone storage device. However, when added as a hybrid resource, there is also a "diversity benefit" that the resources may provide. Solar and storage hybrid additions provide slightly more than the sum of the stand-alone systems for this reason. Hybrid resources that limit charging to the VER resource and do not allow grid charging tend to show lower ELCC values than the equivalent grid-charging hybrid. This is because the storage may not be able to fully charge with only VER energy before a loss-of-load event. DC-coupled solar hybrid configurations are less impacted by this dynamic than AC-coupled solar hybrid configurations, though the impact still exists. This is because DC-coupled solar hybrids were modeled with a higher inverter loading ratio of 1.7 (vs. 1.3 for AC-coupled solar hybrids), which provides more solar DC capacity behind the shared inverter that can be used for charging the storage device.

Q. What are the differences between the July ELCC results, the November ELCC results?

A. E3 first performed an incremental ELCC study for NorthWestern that was delivered in July 2020. NorthWestern subsequently asked E3 to update the study in November 2020 with additional hybrid configuration types. The ELCC study results dated November 2020 contain the same ELCCs as the July 2020 study, except for the VER-only charging hybrid resources and additional hybrid configurations added to the study. The updated November 2020 vintage study is provided as Exhibit AO-3.

Q. In addition to the generic ELCC resources presented, were calculations done on specific proposals received by NorthWestern?

A. Yes, In January 2021, E3 also calculated specific ELCCs for a limited set of proposals, per NorthWestern's request. The results of this analysis are captured in Table 3 and are described in more detail in E3's memo, attached as Exhibit AO-4.

Table 3: E3's Effective Capacity of Hybrid Proposals Calculated in January 2021

Project ID	Type	Configuration	Coupling	ILR	Project Export Capability (MW)	VER-Only Charging	Grid-Charging
012-1.4	*Wind + ESS*	*60 MW + 20 MW/5-hr*	*AC*	*-*	*60*	36	36
014-1.3	*Solar + ESS*	*80 MW + 30 MW/5-hr*	*DC*	*1.75*	*80*	32	33
014-2.3	*Solar + ESS*	*300 MW + 150 MW/5-hr*	*DC*	*1.75*	*300*	151	154
020-3.4	*Wind + ESS*	*100 MW + 100 MW/5-hr*	*AC*	*-*	*105*	102	105
053-1.1	*Solar + ESS*	*100 MW + 30 MW/5-hr*	*AC*	*1.2*	*130*	33	33
053-1.2	*Solar + ESS*	*200 MW + 200 MW/5-hr*	*AC*	*1.2*	*200*	197	200

Q. How were specific proposals received by NorthWestern modeled in RECAP?

A. Consistent with the July and November 2020 ELCC studies, E3 calculated specific ELCCs using RECAP. To represent specific bids, E3 used bid-specific energy output profiles provided by NorthWestern. Figure 8 and Figure 9 show the month-hour average wind and solar profiles used in the January 2021 analysis.

Figure 7: Bid-Specific Wind Output Data used in January 2021 ELCC Calculations (Month/Hour averages)

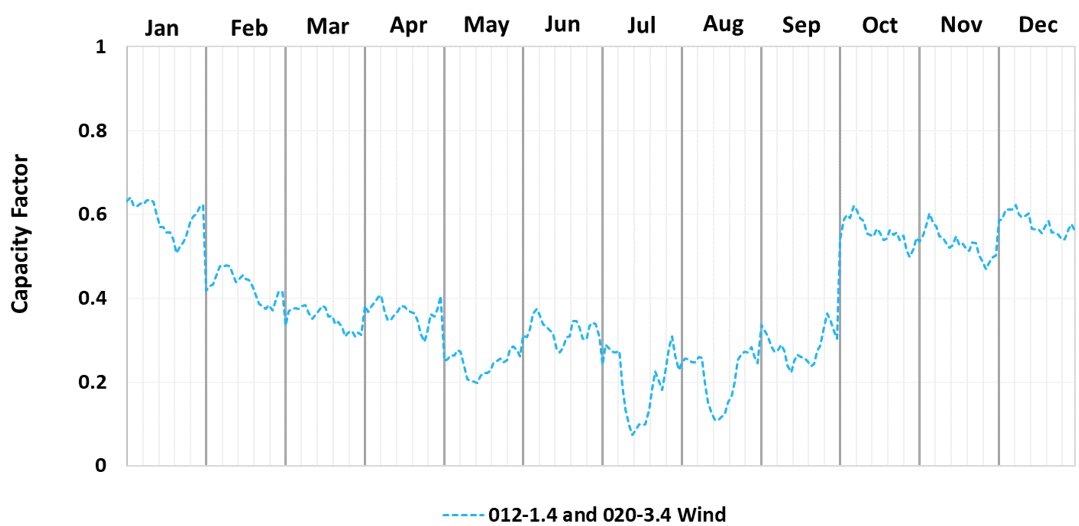
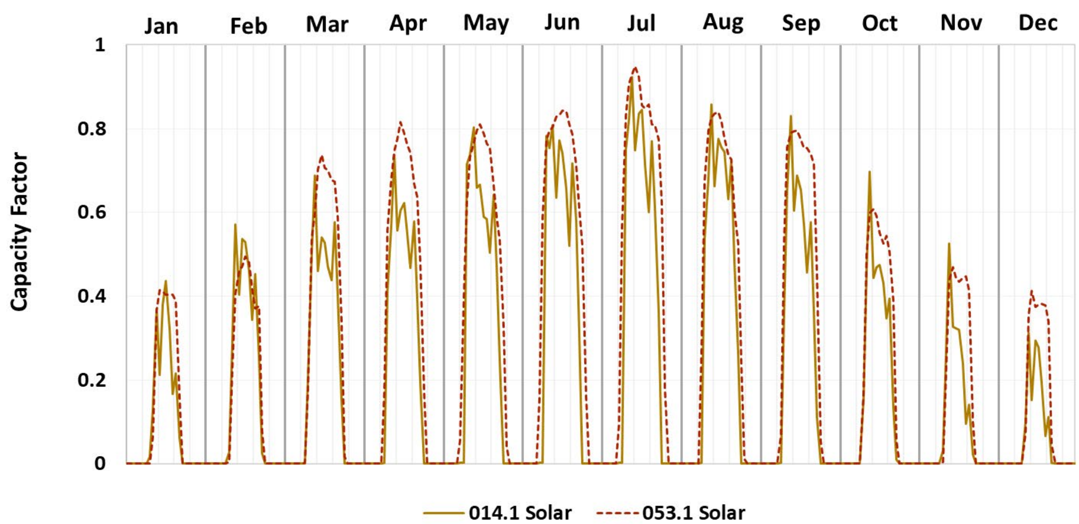


Figure 8: Bid-Specific Solar Output Data used in January 2021 ELCC Calculations (Month/Hour averages)



Q. Does this conclude your direct testimony?

A. Yes, it does.

VERIFICATION

This Direct Testimony of Arne Olson is true and accurate to the best of my knowledge, information, and belief.

Arne Olson