2020 Renewable Resources Assessment

PacifiCorp

2020 Renewable Resources Assessment
Project No. 125017

Revision 1
August 2020

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prepared for

PacifiCorp
2020 Renewable Resources Assessment
Salt Lake City, Utah

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Revision 1
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prepared by

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1.0 INTRODUCTION

PacifiCorp (Owner) retained Burns & McDonnell Engineering Company (BMcD) to evaluate various renewable energy resources in support of the development of the Owner's 2020 Integrated Resource Plan (IRP) and associated resource acquisition portfolios and/or products. The 2020 Renewable Resources Assessment (Assessment) is screening-level in nature and includes a comparison of technical capabilities, capital costs, and O&M costs that are representative of renewable energy and storage technologies listed below.

It is the understanding of BMcD that this Assessment will be used as preliminary information in support of the Owner's long-term power supply planning process. The level of detail in this study is sufficient to provide screening level data required for the IRP planning process. Past the IRP modeling and selection, technologies of interest to the Owner should be further investigated in order to refine design, major equipment selection, value engineering, and specific project scope adjustments.

1.1 Evaluated Technologies

- Single Axis Tracking Solar
- Onshore Wind
- Energy Storage
  - Pumped Hydro Energy Storage (PHES)
  - Compressed Air Energy Storage (CAES)
  - Lithium Ion Battery
  - Flow Battery
- Solar + Energy Storage
- Wind + Energy Storage

1.2 Assessment Approach

This report accompanies the Renewable Resources Assessment spreadsheet files (Summary Tables) provided by BMcD. The Summary Tables are broken out into three separate files for Solar, Wind, and Energy Storage options. The costs are expressed in mid-2020 dollars for a fixed price, turn-key resource implementation. The Summary Tables can be found in Appendix A: Summary Tables.

This report compiles the assumptions and methodologies used by BMcD during the Assessment. Its purpose is to articulate that the delivered information is in alignment with PacifiCorp's intent to advance its resource planning initiatives.

1.3 Statement of Limitations

Estimates and projections prepared by BMcD relating to performance, construction costs, and operating and maintenance costs are based on experience, qualifications, and judgment as a professional consultant. BMcD has no control over weather, cost and availability of labor, material and equipment, labor productivity, construction contractor's procedures and methods, unavoidable delays, construction contractor's method of determining prices, economic conditions, government regulations and laws (including interpretation thereof), competitive bidding and market conditions or other factors affecting such estimates or projections. Actual rates, costs, performance ratings, schedules, etc., may vary from the data provided.

2.0 STUDY BASIS AND ASSUMPTIONS

2.1 Scope Basis

Scope and economic assumptions used in developing the Assessment are presented below. Key assumptions are listed as footnotes in the summary tables, but the following expands on those with greater detail for what is assumed for the various technologies.

2.2 General Assumptions

The assumptions below govern the overall approach of the Assessment:

- All estimates are screening-level in nature, do not reflect guaranteed costs, and are not intended for budgetary purposes. Estimates concentrate on differential values between options and not absolute information.
- All information is preliminary and should not be used for construction purposes.
- All capital cost and O&M estimates are stated in mid-2020 US dollars (USD). Escalation is excluded.
- Estimates assume an Engineer, Procure, Construct (EPC) fixed price contract for project execution.
- Unless stated otherwise, all wind and solar options are based on a generic site with no existing structures or underground utilities and with sufficient area to receive, assemble and temporarily store construction material. Battery options are assumed to be located on existing Owner land.
- Sites are assumed to be flat, with minimal rock and with soils suitable for spread footings.
- Wind and solar technologies were evaluated across five states within Owner’s service areas: Washington, Oregon, Idaho, Utah, and Wyoming. The specific locations within each state for potential wind/solar sites were determined by Owner.
- All performance estimates assume new and clean equipment. Operating degradation is excluded.
- Electrical scope is assumed to end at the high side of the generator step up transformer (GSU) unless otherwise specified in the summary table (most notably for CAES and PHES).
- Demolition costs were included for technology options with a shorter life cycle (Li-Ion, Solar, and Wind). Costs were developed based on Burns & McDonnell experience as well as published information. Recycling costs are included in the demolition figures; however, re-sale value of materials is excluded as that can vary significantly depending on metals pricing and competition in the currently expanding recycling market.

The current market is being impacted by various trade tariffs on materials as well as on solar modules. Predicting future trends or impacts of these tariffs is beyond the scope of this study. This 2020 study has based costs on recent bids that have accounted for the additional costs associated with current tariffs when available. While these costs are intended to represent a snapshot of 2020 pricing, additional volatility could occur when looking at future pricing of these options. These factors may also change the declining costs curves presented in the appendices.

Energy storage technologies evaluated in this assessment are expected to take advantage of less expensive, off-peak power to charge the system to later be used for generation during periods of higher demand. These storage options provide the ability to optimize the system for satisfying monthly, or even seasonal, energy needs. Energy stored off-peak and delivered on-peak can help reduce on-peak prices and is therefore beneficial to consumers. Additionally, energy storage has a direct benefit to renewable resources as it is able to absorb excess energy that otherwise would need to be curtailed due to transmission constraints. This could increase the percentage of power generated by clean technologies and delivered during peak hours. Costs and options shown in this assessment represent storage technologies that are designed for one full cycle per day in a scheduled use case. Other use cases such as frequency regulation, voltage regulation, renewable smoothing, renewable firming, and black starting are not accounted for in the options presented in this study. Different use cases will impact the capital cost, O&M, and performance of the various technologies. EPC Project Indirect Costs

The following project indirect costs are included in capital cost estimates:

- Construction/startup technical service
- Engineering and construction management
- Freight
- Startup spare parts
- EPC fees & contingency

2.3 Owner Costs

Allowances for Owner’s costs are included in the pricing estimates. The cost buckets for Owner’s costs varies slightly by technology but is broken out in the summary tables in Appendix A: Summary Tables.

2.4 Cost Estimate Exclusions

The following costs are excluded from all estimates:

- Financing fees

- Interest during construction (IDC)
- Escalation
- Performance and payment bond
- Sales tax
- Property taxes and insurance
- Off-site infrastructure
- Utility demand costs
- Salvage values

2.5 Operating and Maintenance Assumptions

Operations and maintenance (O&M) estimates are based on the following assumptions:

- O&M costs are based on a greenfield facility with new and clean equipment.
- O&M costs are in mid-2020 USD.
- Property taxes allowance included for solar and onshore wind options.
- Land lease allowance included for PV and onshore wind options.
- Li-Ion battery O&M includes costs for additional cells to be added over time.

3.0 SOLAR PHOTOVOLTAIC

This Assessment includes 100 MW, and 200 MW single axis tracking photovoltaic (PV) options evaluated at two locations within the PacifiCorp services area.

3.1 PV General Description

The conversion of solar radiation to useful energy in the form of electricity is a mature concept with extensive commercial experience that is continually developing into a diverse mix of technological designs. PV cells consist of a base material (most commonly silicon), which is manufactured into thin slices and then layered with positively (i.e. Phosphorus) and negatively (i.e. Boron) charged materials. At the junction of these oppositely charged materials, a "depletion" layer forms. When sunlight strikes the cell, the separation of charged particles generates an electric field that forces current to flow from the negative material to the positive material. This flow of current is captured via wiring connected to an electrode array on one side of the cell and an aluminum back-plate on the other. Approximately 15% of the solar energy incident on the solar cell can be converted to electrical energy by a typical silicon solar cell. As the cell ages, the conversion efficiency degrades at a rate of approximately 2% in the first year and 0.5% per year thereafter. At the end of a typical 30-year period, the conversion efficiency of the cell will still be approximately 80% of its initial efficiency.

3.2 PV Performance

BMcD pulled Typical Meteorological Year (TMY) weather data for each site to determine expected hourly irradiance. BMcD then ran simulations of each PV option using PVSYST software. The resultant capacity factors for single axis tracking systems are shown in the Summary Tables. Inverter loading ratios (ILR) for each base plant nominal output at the point of electrical interconnect are indicated in Table 3-1.

Table 3-1: Inverter Loading Ratios in Assessment

Nominal Output	Single-Axis Tracking (SAT) DC/AC Ratio
100 MW	1.30
200 MW	1.30

There are different panel technologies which may exhibit different performance characteristics depending on the site. This assessment assumes poly-crystalline panels. The alternative, thin film technologies, are typically cheaper per panel, but they are also less energy dense, so it’s likely that more panels would be required to achieve the same output. In addition, the two technologies respond differently to shaded conditions. The two technologies are also impacted differently by current solar tariffs which has also impacted availability of the two.

Appendix B: Solar PVSYST Model Output (5MW) shows the PVSYST model output for a 4.2 MW block with the input assumptions, losses, and output summary. Appendix C: Solar Output Summary shows an additional output summary page unique for each solar option size and location. TMY data for each site as well as PVSYST 8760 outputs are provided to accompany this report outside of the formal report appendices.

3.3 PV Cost Estimates

Cost estimates were developed using in-house information based on BMcD project experience as an EPC contractor as well as an Owner's Engineer for EPC solar projects. Cost estimates assume an EPC project plus typical Owner's costs. A typical solar project cash flow is included in Appendix F: Generation Cash Flows.

PV cost estimates for the single axis tracking systems are included in the Summary Tables. Costs are based on the DC/AC ratios in Table 4-1 above, and $/kW costs, based on the nominal AC output, are shown in Appendix A: Summary Tables. The project scope assumes a high voltage interconnection for both the 100 and 200 MW options. Owner's costs include a switchyard allowance for the larger scale options, but no transmission upgrade costs or high voltage transmission interconnect line costs are included.

PV installed costs have steadily declined for years. The main drivers of cost decreases include substantial module price reductions, lower inverter prices, and higher module efficiency. However, recent US tariffs have had an impact on PV panels and steel imports. Pricing in the summary table is based on actual competitive EPC market quotes since these tariffs have been in place to take into account this impact. The panel tariffs only impact crystalline solar modules, however the availability of CdTe is limited for the next couple years, so it is prudent to assume similar cost increases for thin film panels until the impacts of the tariff are clearer.

Demolition costs for PV are included in the IRP Inputs and are meant to reflect the end of life decommissioning efforts. PV recycling in the U.S. is led by the Solar Energy Industries Association (SEIA), which has developed a national PV recycling program. This program works with several recycling companies along with regulators in order to abide by the Federal Resource Conservation and Recovery Act (RCRA), which is the governing legislation for the disposal of PV equipment. SEIA advises system owners to consider reuse and refurbishment when possible. However, when demolition and recycling is required, PV panels contain several materials that can be recovered. By weight, 80% of the panel consists of glass and aluminum. Other valuable materials include copper, silver, and semiconductor materials. Similar to the Li-Ion storage industry, many PV sites have not yet reached their end of useful life and therefore the recycling and materials resale market is still in its infancy.

The 2020 Assessment excludes land costs from capital and Owner costs. It is assumed that all PV projects will be on leased land with allowances provided in the O&M costs.

3.4 PV O&M Cost Estimate

O&M costs for the PV options are shown in the Summary Tables. O&M costs are derived from BMcD project experience and vendor information. The 2020 Assessment includes allowances for land lease and property tax costs.

The following assumptions and clarifications apply to PV O&M:

- O&M costs assume that the system is remotely operated and that all O&M activities are performed through a third-party contract. Therefore, all O&M costs are modeled as fixed costs, shown in terms of $MM per year.
- Land lease and property tax allowances are included based on in house data from previous projects.
- Equipment O&M costs are included to account for inverter maintenance and other routine equipment inspections.
- BOP costs are included to account for monitoring & security and site maintenance (vegetation, fencing, etc.).
- Panel cleaning and snow removal are not included in O&M costs.
- The capital replacement allowance is a sinking fund for inverter replacements, assuming they will be replaced once during the project life. It is a 15-year levelized cost based on the current inverter capital cost.

3.5 PV Plus Storage

The PV plus storage options combine the PV technology discussed in section 3.0 with the lithium ion batteries described in section 9.0. The battery storage size is set at approximately 50% of the total nominal output of the base solar options, with four hours of storage duration.

The storage system is assumed to be electrically coupled to the PV system on the AC side, meaning the PV and storage systems have separate inverters. However, there are use cases such as PV clipping that may be better served by a DC-DC connection. In a DC coupled system, the storage side would have a DC-DC voltage converter and connect to the PV system upstream of the DC-AC inverters. For a clipping application, a DC-DC connection allows the storage system to capture the DC output from the PV modules that may have otherwise been clipped by the inverters. Further study beyond the scope of this assessment would be required to determine the best electrical design for a particular application or site, but at this level of study, the capital costs provided are expected to be suitable for either AC or DC coupled systems.

Capital costs are show as add-on costs, broken out as project and owner's costs. These represent the additional capital above the PV base cost, intended to capture modest savings to account for shared system costs such as transformer(s) and switchgear. In addition, overlapping owner costs are eliminated or reduced. Finally, a line for O&M add-on costs is also included which can be added with the base PV O&M costs to determine overall facility O&M.

As with the Li-Ion battery options, the co-located storage option assumes an operation profile of one cycle per day, which is used for calculating the O&M costs.

4.0 ON-SHORE WIND

4.1 Wind Energy General Description

Wind turbines convert the kinetic energy of wind into mechanical energy, which can be used to generate electrical energy that is supplied to the grid. Wind turbine energy conversion is a mature technology and is generally grouped into two types of configurations:

- Vertical-axis wind turbines, with the axis of rotation perpendicular to the ground.
- Horizontal-axis wind turbines, with the axis of rotation parallel to the ground.

Over 95 percent of turbines over 100 kW are horizontal-axis. Subsystems for either configuration typically include the following: a blade/rotor assembly to convert the energy in the wind to rotational shaft energy; a drive train, usually including a gearbox and a generator; a tower that supports the rotor and drive train; and other equipment, including controls, electrical cables, ground support equipment and interconnection equipment.

Wind turbine capacity is directly related to wind speed and equipment size, particularly to the rotor/blade diameter. The power generated by a turbine is proportional to the cube of the prevailing wind, that is, if the wind speed doubles, the available power will increase by a factor of eight. Because of this relationship, proper siting of turbines at locations with the highest possible average wind speeds is vital.

Appendix D: Wind Performance Information includes NREL wind resource maps for Idaho, Oregon, Utah, Washington, and Wyoming with the locations of interest marked as provided by Owner.

4.2 Wind Performance

This Assessment includes 200 MW onshore wind generating facilities in Idaho, Oregon, Utah, Washington, and Wyoming service areas. BMcD relied on publicly available data and proprietary computational programs to complete the net capacity factor characterization. Generic project locations were selected within the area specified by Owner.

The Vestas V150-4.0 wind turbine model were assumed for this analysis. The respective nameplate capacity, rotor diameter, and a hub height are provided in the Table 4-1. The maximum tip height of this package is under 500 feet, which means there are less likely to be conflicts with the Federal Aviation Administration (FAA) altitudes available for general aircraft. A generic power curve at standard atmospheric conditions for each of the sites was assumed for the V150-4.0. Note that this turbine is intended only to be representative of a typical International Electrotechnical Commission wind turbine.

Because this analysis assumes generic site locations, the turbine selection is not optimized for a specific location or condition. Actual turbine selection requires further site-specific analysis.

Table 4-1: Summary of Wind Turbine Model Information

	Vestas V150-4.0
Name Plate Capacity, MW	4.0
Rotor Diameter, meters	150
Hub Height, meters	105

Using the NREL wind resource maps, the mean annual hub height wind speed at each potential project location was estimated and then extrapolated using the wind profile power law for the appropriate hub height to determine a representative wind speed. Using a Rayleigh distribution and power curve for the turbine technology described above, a gross annual capacity factor (GCF) was subsequently estimated for each site for both turbine types.

Annual losses for a wind energy facility were estimated at approximately 17 percent, which is a common assumption for screening level estimates in the wind industry. This loss factor was applied to the gross capacity factor estimates to derive a net annual capacity factor (NCF) for each potential site. Ideally, a utility-scale generation project should have an NCF of 30 percent or better. The NCF estimates for the PacifiCorp service areas are shown in the Summary Tables and represent an average of the two evaluated technologies.

4.3 Wind Cost Estimate

The wind energy cost estimate is shown in the Summary Tables. A typical cash flow for a wind project is included in Appendix F: Generation Cash Flows. Cost estimates assume an EPC project plus typical Owner's costs. Costs are based on a 200 MW plant with 4.0 MW turbines (50 total turbines) and 105-meter hub heights.

- Equipment and construction costs are broken down into subcategories per PacifiCorp's request. These breakouts represent the general scale of a 200 MW wind project but are not intended to indicate the expected scope for a specific site.
- The EPC scope includes a GSU transformer for interconnection at 161 kV.

- Land costs are excluded from the EPC and Owner's cost. For the 2020 Study, it is assumed that land is leased, and those costs are incorporated into the O&M estimate. Cost estimates also exclude escalation, interest during construction, financing fees, off-site infrastructure, and transmission.

Demolition costs shown on the IRP Input Table are meant to represent the efforts to return the project site back to native conditions (i.e. re-grading the site to achieve suitable drainage and seeding disturbed areas consistent with surrounding areas). This includes the decommissioning and demolition of all wind turbines as well as the associated infrastructure (i.e. buildings, turbine foundations, access roads, transmission lines, etc.). Also included is the transportation cost associated with moving the turbines off-site to recycling or landfill locations. Demolishing turbine blades can be a difficult as they are made of tough resin and fiberglass. One method of decommissioning is to cut the blades up into 3 or more parts to make them easier to transport to landfills. Another method involves grinding the blades into small pellets that can used for decking, pallets, and piping. Along with PV and li-ion storage, wind turbines contain valuable components such as steel, copper, and other metals that ideally can be resold as part of the recycling process.

4.4 Wind Energy O&M Estimates

O&M costs in the Summary Tables are derived from in-house information based on BMcD project experience and vendor information. Wind O&M costs are modeled as fixed O&M, including all typical operating expenses including:

- Labor costs
- Turbine O&M
- BOP O&M and other fixed costs (G&A, insurance, environmental costs, etc.)
- Property taxes
- Land lease payments

A summary of the suggested planned maintenance activities for a utility-scale wind energy facility are presented in Table 4-2 below. These represent the minimum activities that Burns & McDonnell suggests to be performed on a recurring basis and represent a minimum standard of performance if high availability and/or extended useful life are required. For the avoidance of doubt, the frequencies noted in Table 4-2 represent a minimum recurrence interval; trending results, condition-based monitoring data, supplier recommendations, or other similar items may necessitate more frequent planned maintenance.

Table 4-2: Minimum Wind Farm Planned Maintenance Activities

Component	Activity	Min. Frequency
General	Visual inspection of exterior components (e.g., nacelle, tower, blades)	Semi-annual
	Tower weld inspections	3-year rotation
	External paint touch-up	As required
	Fastener inspections and re-torque	3-year rotation
	Condition monitoring system set-point review	Annual
	Supplier-recommended semi-annual maintenance	Semi-annual
	Monitoring via SCADA	24/7
Nacelle	Visual inspection of internal components	Per supplier manuals
	Functional tests of major components	Per supplier manuals
	Gearbox borescope inspections	3-year rotation
	Gearbox oil sampling and trending	Annual
	Gearbox oil and filter replacement	Per supplier manuals
	Bearing grease sampling and trending (e.g., main bearing, yaw bearings, blade bearings)	Per supplier manuals
	Lubrication flush and filter replacement	Per supplier manuals
	Inspection of emergency equipment	Annual
Foundations	Visual inspection of exterior components (including bolts, nuts, washers, concrete, and surroundings)	Semi-annual
	Re-application of anti-corrosion protective coating	As required
BOP	Visual inspection of infrastructure (e.g., roads, collection routes, gen-tie routes, substation)	Annual
	Visual inspection of electrical equipment (e.g., transformers, breakers)	Semi-annual
	Maintain drainage away from foundations / structures	As required
	Transformer oil testing and trending	Annual
	Infrared scanning on all transformers	Annual
	De-energized substation maintenance	3 years
	Revenue meter test / calibration	Semi-annual
	Visual inspection of met towers (including tower, instruments, and guys)	Annual
	Met tower instrument calibration	Bi-annual

An allowance for capital replacement costs is not included within the annual O&M estimate in the Summary Table. A capital expenditures budget for a wind farm is generally a reserve that is funded over the life of the project that is dedicated to major component failures. An adequate capital expenditures budget is important for the long-term viability of the project, as major component failures are expected to occur, particularly as the facility ages.

If a capital replacement allowance is desired for planning purposes, Table 4-3 shows indicative budget expectations as a percentage of the total operating cost. As with operating expenses, however, these costs can vary with the type, size, or age of the facility, and project-specific considerations may justify deviations in the budgeted amounts.

Table 4-3: Summary of Indicative Capital Expenditures Budget by Year

Operational Years	Capital Expenditure Budget
0 – 2	None (warranty)
3 – 5	3% – 5%
6 – 10	5% – 10%
11 – 20	10% – 15%
21 – 30	15% – 20%
31 – 40	20% – 25%

4.5 Wind Energy Production Tax Credit

Tax credits such as the production tax credit (PTC) and investment tax credit (ITC) are not factored into the cost or O&M estimates in this Assessment, but an overview of the PTC is included below for reference.

To incentivize wind energy development, the PTC for wind was first included in the Energy Policy Act of 1992. It began as a $15/MWh production credit and has since been adjusted for inflation, currently worth approximately $25/MWh.

The PTC is awarded annually for the first 10 years of a wind facility’s operation. Unlike the ITC that is common in the solar industry, there is no upfront incentive to offset capital costs. The PTC value is calculated by multiplying the $/MWh credit times the total energy sold during a given tax year. At the end of the tax year, the total value of the PTC is applied to reduce or eliminate taxes that the owners would normally owe. If the PTC value is greater than the annual tax bill, the excess credits can potentially go unused unless the owner has a suitable tax equity partner.

Since 1992, the changing PTC expiration/phaseout schedules have directly impacted market fluctuations, driving wind industry expansions and contractions. The PTC is currently available for projects that begin construction by the end of 2020, but with a phaseout schedule that began in 2017. Projects that started construction in 2015 and 2016 will receive the full value of the PTC, but those that start(ed) construction in later years received reduced credits:

- 2017: 80% of the full PTC value
- 2018: 60% of the full PTC value
- 2019: 40% of the full PTC value
- 2020: 40% of the full PTC value (extended through Dec 31st, 2020)

To avoid receiving a reduction in the PTC, a "Safe Harbor" clause allowed for developers to avoid the reduction through an upfront investment in wind turbines by the end of 2016. The Safe Harbor clause allowed for wind projects to be considered as having begun construction by the end of the year if a minimum of 5% of the project's total capital cost was incurred before January 1st, 2017.

Many wind farms were planned for construction and operation when it was assumed they would receive 100% of the PTC. However, with the reduction in the PTC, some of these projects are no longer financially viable for developers to operate. This may result in renegotiated or canceled PPAs, or transfers to utilities for operation.

4.6 Wind Plus Storage

The wind plus storage options combine the wind technology discussed in section 4.0 with the lithium ion batteries described in section 9.0. The battery storage size is set at approximately 50% of the total nominal output of the base solar options, with four hours of storage duration. The storage system is assumed to be electrically coupled to the wind system on the AC side, meaning the storage system has its own inverter.

Capital costs are shown as add-on costs, broken out as project and owner's costs. These represent the additional capital above the wind base cost, intended to capture modest savings to account for shared system costs such as transformer(s) and switchgear. In addition, overlapping owner costs are eliminated or reduced. Finally, a line for O&M add-on costs is also included which can be added to the base wind O&M costs to determine overall facility O&M. As with the Li-Ion battery options, the co-located storage option assumes an operation profile of one cycle per day, which is used for calculating the O&M costs.

5.0 PUMPED HYDRO ENERGY STORAGE

5.1 General Description

Pumped-hydro Energy Storage (PHES) offers a way of storing off peak generation that can be dispatched during peak demand hours. This is accomplished using a reversable pump-turbine generator-motor where water is pumped from a lower reservoir to an upper reservoir using surplus off-peak electrical power. Energy is then recaptured by releasing the water back through the turbine to the lower reservoir during peak demand. To utilize PHES, locations need to be identified that have suitable geography near high-voltage transmission lines.

PHES provides the ability to optimize the system for satisfying monthly or even seasonal energy needs and PHES can provide spinning reserve capacity with its rapid ramp-up capability. Energy stored off-peak and delivered on-peak can help reduce on-peak prices and is therefore beneficial to consumers. PHES is well suited for markets where there is a high spread in day-time and night-time energy costs, such that water can be pumped at a low cost and used to generate energy when costs are considerably higher.

PHES also has the ability to reduce cycling of existing generation plants. Additionally, PHES has a direct benefit to renewable resources as it is able to absorb excess energy that otherwise would need to be curtailed due to transmission constraints. This could increase the percentage of power generated by clean technologies and delivered during peak hours.

5.2 PHES Cost Estimate

The PHES cost estimate was based on information provided by developers with limited scope definition. The costs were aligned as closely as possible based on the information provided. The reason information from developers was used versus using a generic site for PHES is due to the significant importance of geographical location for this type of energy storage. The cost estimate is shown in the Summary Tables. PHES can see life cycle benefits as their high capital cost is offset by long lifespan of assets.

6.0 COMPRESSED AIR ENERGY STORAGE

6.1 General Description

Compressed air energy storage (CAES) offers a way of storing off peak generation that can be dispatched during peak demand hours. CAES is a proven, utility-scale energy storage technology that has been in operation globally for over 30 years. CAES has two primary application methods: diabatic and adiabatic. To utilize CAES, the project needs a suitable storage site, either a salt cavern or mined hard-rock cavern. Salt caverns are the most preferred due to the low cavern construction costs, however mined hard-rock caverns are now a viable option in areas that do not have salt formations with the use of hydrostatic compensation to increase energy storage density and reduce the cavern volume required. CAES facilities use off-peak electricity to power a compressor train that compresses air into an underground reservoir at approximately 850 psig. Energy is then recaptured by releasing the compressed air, heating it, and generating power as the heated air travels through an expander.

6.1.1 Diabatic CAES

The difference between diabatic and adiabatic compressed air energy storage is in the method that the air is heated during generation. Diabatic CAES uses natural gas firing during generation via a gas turbine expansion train. Expansion train technology is also currently allowing for 30% H2 co-firing today and there are plans to develop the technology to support 100% H2. Round-trip efficiencies for diabatic CAES plants account for the energy input of the compressors as well as the energy input of the gas turbine. The energy input of the compressors is a design choice that will be made to balance cost and benefit. The round-trip efficiencies represented in this technology assessment are the efficiencies that can be reached at the cost that is shown. The heat input of the gas turbine during generation takes into account the heat rate of the turbine. The total energy output of the CAES plant is divided by the combination of these two figures (compressor energy and natural gas heat input) to calculate the round-trip efficiency. There have been two commercial CAES plants built and operated in the world. The first plant began commercial operations in 1978 and was installed near Huntorf, Germany. This 290 MW facility included major equipment by Brown, Boveri, and Company (BBC). The second is located near McIntosh, Alabama and is currently owned and operated by PowerSouth (originally by Alabama Electric Cooperative). This 110 MW facility began commercial operations in 1991 and employs Dresser Rand (DR) equipment. BMcD served as the Owner’s engineer for this project. Diabatic CAES was removed from the evaluated options due to a shift in focus from developers to adiabatic CAES, which offers zero emissions storage.

6.1.2 Adiabatic CAES

A second application of compressed air energy storage is adiabatic, which uses no natural gas firing. Heat is recovered in a Thermal Energy Storage (TES) system while air is being compressed and this energy is released to heat the air during expansion and generation. During compression, air temperatures can reach up to 1000°F. The use of a TES (with oil, molten salt, etc..) to capture and release this heat allows the adiabatic CAES technology to work free of any fuel. This trait can decrease operating and construction costs. The absence of a gas turbine makes the calculation for round-trip efficiency the total energy output of the plant divided by the energy input of the compressors. Again, the size and energy requirements of the compressors is a design choice and the efficiencies represented in the technology assessment table are in conjunction with the costs also represented for each option. This technology is currently in service or in construction at 3 plants in Canada and Australia that total 25 MWh of storage capacity.

6.2 CAES Cost Estimates

The CAES cost estimates are shown in the Summary Tables. The costs were developed using generic Siemens and Hydrostor information that includes the power island, balance of plant and reservoir. Cost estimates assume an EPC project plus typical Owner’s costs.

6.3 CAES Emissions Control

A Selective Catalytic Reduction (SCR) system is utilized in the diabatic CAES design along with demineralized water injection in the combustor to achieve NOx emissions of 2 parts per million, volumetric dry (ppmvd). A carbon monoxide (CO) catalyst is also used to control CO emissions to 2 ppmvd at the exit of the stack.

The use of an SCR and a CO catalyst requires additional site infrastructure. An SCR system injects ammonia into the exhaust gas to absorb and react with the exhaust gas to strip out NOx. This requires onsite ammonia storage and provisions for ammonia unloading and transfer. Adiabatic CAES is an emissions-free operation and does not require an emissions control system.

7.0 LIQUID AIR ENERGY STORAGE

7.1 General Description

Liquid air energy storage (LAES) uses electricity to drive a compression/refrigeration system that cools ambient air to approximately -320 °F, at which point it becomes a liquid. Liquefying air is advantageous because it achieves a volume reduction of approximately 700:1, meaning that large quantities of air can be stored in a significantly smaller volume. The liquid air is stored is until it is ready for use. Energy is then recaptured by re-vaporizing the liquid air and generating power as the heated air travels through a series of heat exchangers and expanders. The overall system is optimized by taking advantage of waste heat and "waste cold" in the process to reduce the amount of power required to liquefy the air.

LAES is a relatively new application in the energy storage market, however, the major equipment components and technologies used to liquefy, store, and re-vaporize the air have been widely used in many other industry applications for decades. Highview Power is one of the major LAES technology licensors in the market, having completed a LAES pilot plant in Heathrow, UK in 2011. This operational facility uses 350 kW to liquefy the air and provides 2.5 MWh of energy storage.

One of the major similarities between LAES and CAES is that the LAES technology also offers the ability to take advantage of off-peak power to charge the system that can then be later discharged during peak demand hours as described in Section 6.1.

Another similarity LAES shares with adiabatic CAES is a zero emissions process. When coupled with a renewable energy source to provide power for the system, LAES is considered a completely green technology, meaning that it does not have any emissions associated with the process. The system utilizes motor-driven equipment, as opposed to a gas turbine, for the main air compressors and other auxiliary equipment, so there are no emissions generated from combustion. Additionally, there are no hydrocarbons used in the process at all – only air – so fugitive emissions are also non-existent.

The LAES technology can be broken down into three (3) major systems; system charging (air liquefaction), energy storage (liquid air storage), and system discharge (power generation). Each of these systems are relatively independent of one another and therefore can be designed for different amounts of capacity, depending on the specific application and use case. For example, the charging section of the facility (air liquefaction) could be designed to produce liquid air at a rate sufficient enough to utilize any excess energy generated from renewable sources that otherwise would need to be curtailed due to transmission constraints. However, the discharge system could be designed to generate power at the rate required to meet the demand during peak times; this rate may or may not be the same as the charging rate.

The number of hours of available storage can be easily modified by adding additional liquid air storage tanks.

The following sections describe each of these three systems in more detail.

7.1.1 System Charging – Air Liquefaction

Ambient air is used as the source of air for the process. The air is sent through a series of compressors and heat exchangers to increase the pressure from atmospheric to approximately 850 psig. This initial air compression requires the largest amount of power usage for the entire process; there are other users within the process, but they are significantly smaller the main air compressor.

Contaminants in the air such as carbon dioxide, water, and particulates must be removed prior to the liquefaction process. Carbon dioxide and water will freeze at the cryogenic temperatures and could clog the piping, valves, or equipment. The air flows through a set of molecular-sieve beds that adsorb the water and CO_2 from the air – this technology is very similar to the process used in liquefied natural gas (LNG) facilities. Once saturated, the molecular-sieve is regenerated with dry air and ready to be used again.

A common process used to liquefy air is the Claude cycle. In the Claude cycle, the air acts as the process fluid to be cooled as well as the refrigerant. The high pressure air is let-down across an expander and/or valve to low pressure. This rapid reduction in pressure creates a cooling effect, known the Joule-Thompson (JT) effect, and a portion of the air becomes the liquid air product. Any air that is not liquefied is used as a refrigerant to further cool the system and is recycled to go through the process again. This is a well-known and widely industry-recognized process for liquefying air.

7.1.2 Energy Storage – Liquid Air Storage

Once the air is liquefied, it must be stored until ready for use. A benefit that LAES provides over CAES is that a specialized storage site, such as a salt cavern, is not required. Liquid air is stored in field-erected, insulated, cryogenic, storage tanks. These tanks are very similar to the storage tanks used to store other cryogenic liquids (such as liquid nitrogen or liquefied natural gas) and are widely utilized the in the oil, gas, and chemicals industry. By not depending on the geological formations of the site for storage, LAES facilities can be built in any location in which sufficient space is available.

Although the tanks are very well insulated, there will be some amount of the liquid air that "boils-off" as the system sits stagnant. Fortunately, since the contents of the storage system are only air (nitrogen, oxygen, argon, etc.), this "boil-off" vapor can be vented directly to atmosphere with no additional handling equipment required.

Depending on the amount of storage duration desired (i.e. hours of storage), the volume and quantities of storage tanks can be modified. Additional storage duration requires additional storage volume. When determining the size/capacity of the charging system, it is important to consider how long it will take to fill the storage tanks. If the charging duration is too long, it may be advantageous to increase the charging system capacity.

7.1.3 System Discharge – Power Generation

When ready to use to generate power, the liquid air is pumped from the storage tanks to a heat exchanger in which it is re-vaporized. The warm air then flows through series of heat exchangers and expanders, similar to CAES, in order to generate power via the expander. The rate in which power is generated is determined by the pumping capacity and the expander capacity. The higher discharge rate required, the larger the expander required.

Once the air is fully expanded, it is released back into the atmosphere.

8.0 GRAVITY ENERGY STORAGE

8.1 General Description

Gravity energy storage (GES) offers a technique of storing off peak generation that can be dispatched during peak demand hours. Like Pumped Hydro Storage, GES takes advantage of kinetic and potential energy via mass transfer between different elevations. This developing storage technology presents unique advantages in performance with round-trip efficiencies of approximately 80-90%. GES's largest competing technology is pumped-hydro storage due to similarities in fundamental design. However, GES has little to no site restrictions and can be integrated into any high voltage transmission grid while maintaining an insignificant environmental impact over the storage system's lifespan. Currently, storage capabilities range from 6-14 hours. In addition, gravity storage caries a small land footprint per kWh, thus increasing storage capability per acre.

GES technology is currently in small-scale international operation but is not yet available on a commercial scale. However, due to the growing global demand for large-scale storage options, there is burgeoning interest in the use of GES as a commercial storage solution. CapEx for GES depends on the design of the system and is customizable to balance the economic and performance goals of the project. GES has a large upfront capital cost but does not require as much ongoing CapEx throughout the life of the project due to minimal degradation. The future success of GES systems will depend on their ability to compete with other emerging energy storage methods in the long term.

8.1.1 Vertical Shaft Gravity Energy Storage

Vertical shaft (VS) GES systems consist of a shaft of large diameter, a piston, and other common operational components such as a pump-turbine, generator, etc. The water that fills the large shaft below the piston serves as a medium for energy transfer. The system operates on the simple function of pumping water to hydraulically lift a piston fitted within the large shaft. The steel piston is filled with reinforced rock and concrete materials. A reversible pump-turbine essentially creates a closed-circuit and converts grid power to potential energy by pumping water into the large shaft to raise the piston. During peak demand, the stored potential energy can be converted back into electrical energy by the descending piston that then allows the water under pressure to transfer back through the turbine, and ultimately back onto the grid.

In 2013 a Santa Barbara, California based company, Gravity Power, planned to construct its first commercial GES demonstration in Penzberg, Germany designed with a power shaft depth of 500-m and a 30-m diameter. These parameters produce an equivalence of 160 MWh (40 MW for 4 hours of bulk energy storage and requires a power consumption of 40 MW for a charge time of approximately 5 hours). This project is expected to have a lifetime of at least 50 years. The total cost estimate of this system was estimated at $1,100/kWh or $4,400 kW. Because general planning for a GES can take 2+ years with an additional 3-4 years of construction, this GES project is expected to be operational within the next few years.

8.1.2 Crane-Lift Gravity Energy Storage

A second application of GES employs the elevation of rock or concrete masses by crane to create a tower where potential energy is stored via elevation gain. Electric motors power the lifting of blocks to various levels that then create a tower. The total allowable energy storage is relative to tower height mass of the blocks, and the quantity of the blocks that can fit under the cranes. Energy from the grid is used to lift blocks and during hours of peak demand, energy is returned to the grid when the cranes lower the blocks. The force of gravity pulls the blocks downward, maintaining a constant speed of descent which creates kinetic energy that is converted to electrical energy by turning the electric generator. Since the mass of the blocks affects the CapEx of the cranes, the most cost effective way to increase power and energy capacity for this system is to increase the height of the tower and the velocity at which the blocks descend.

Energy Vault, a Swiss-based company specializing in utility-scale gravity-based energy storage, partnered with Indian energy provider, Tata Power, to deploy a 35-MW system in 2018. Energy Vault has developed a six-arm crane with capability to lift 35T (5,000 concrete blocks) to a height of ~30 stories. The system holds a round-trip efficiency between 80-90%. The storage system’s capability maintains ranges of 20-35-80 MWh storage capacity and a 4-8MW of power discharge for 8-16 hours. A 30+ year lifespan is expected for this size GES system. Though this system is small-scale when considering the possible capabilities of its technology, its appeal has propelled Energy Vault and other companies to push the boundaries of crane-lift GES systems. This GES system may be more commonly utilized in the coming years due to large storage capacities, efficiency, low O&M costs, and sparse site restrictions. However, the technology is new, and the concern of its ability to compete with other new storage proposals produced in the long term remains.

8.1.3 Rail Energy Storage

Rail energy storage (RES) similarly takes advantage of potential energy to store and kinetic energy to discharge energy like Pumped Hydro Storage and the other GES technologies, with a simpler approach and less infrastructure. RES does not require water as a working fluid like pumped hydro and does not involve intensive extraction of materials during the construction process. RES has the potential to have lower CapEx and O&M expenses than other current energy storage options in certain topographical areas. RES storage facilities perform at approximately 80% round-trip operating efficiency while continuously delivering energy for up to 8 hours.

This storage solution utilizes rail cars that haul large masses (typically concrete or rock masses) back and forth between storage yards to store excess energy in times of low demand and easily disperse that energy during peak demand. RES uses surplus electrical energy from nearby renewable plants to power the increase in elevation of rail cars during hours of low demand, which creates potential energy. During hours of peak demand, the rail cars descend back downhill via gravity. This process converts the stored potential energy back into kinetic energy through regenerative braking, a technology commonly seen in electric vehicles. Regenerative braking utilizes the motor as a generator and converts lost kinetic energy from deceleration back into electrical that can be returned to the grid.

In April of 2016, Advanced Rail Energy Storage (ARES), a Santa-Barbara, California based energy startup had its first commercial-scale project approved on behalf of the Bureau of Land Management. The small-scale project, called ARES Nevada, planned for development on ~100 acres of public land near Pahrump, Nevada, has a 50-MW power capacity and can produce 12.5 MWh of energy. The estimated cost of the project is $55 million (at approximately $4,400/kWh) with an expected lifespan of 40 years. Though the project was scheduled to be in operation by late 2019 to early 2020, its success is still in question as it has not been in commercial use for an extended period. ARES is currently working on new designs to enable the storage system to perform on much steeper slopes along shorter distances which would allow the technology to be operable in more densely populated regions.

9.0 BATTERY STORAGE TECHNOLOGY

This Assessment includes standalone battery options for both lithium ion (Li-Ion) and flow battery technologies. Li-Ion options included 1 MW output with 30-minute, 1-hour, 4-hour, and 8-hour storage capacities as well as a 50 MW option with 4-hours of storage. A 1 MW, 1-hour, 4-hour, and 8-hour flow cell battery options were also included, along with a 20MW, 8-hour option. Additionally, the solar and wind summary tables include optional costs for adding Li-Ion battery capacity of 50% of the nominal renewable output to the site with 4-hours of storage.

9.1 General Description

Electrochemical energy storage systems utilize chemical reactions within a battery cell to facilitate electron flow, converting electrical energy to chemical energy when charging and generating an electric current when discharged. Electrochemical technology is continually developing as one of the leading energy storage and load following technologies due to its modularity, ease of installation and operation, and relative design maturity. Development of electrochemical batteries has shifted into three categories, commonly termed “flow,” “conventional,” and “high temperature” battery designs. Each battery type has unique features yielding specific advantages compared to one another.

9.1.1 Flow Batteries

Vanadium Redox batteries (VRB) and Zinc-Bromide (ZnBr) batteries are representative of commercially available flow battery technologies, but other technologies, such as iron flow batteries, are also available. Generally, flow batteries have lower round-trip efficiencies than Li-Ion batteries, however their theoretical performance does not degrade. This allows flow batteries to exhibit longer life spans than Li-Ion batteries without augmentation.

Developed in the early 1990’s by the University of New South Wales in Australia, VRBs employ a two tank, two pump system that contains vanadium-based electrolyte solutions on each side. Electrons are passed between the two solutions via an ion-permeable membrane to charge and discharge the battery. VRBs may be attractive for grid-scale applications due to their long lifetime and potential to scale power and energy capacity independently as needed for a given application. However, commercially available VRBs are generally modular in design, so the electrolyte volumes and discharge durations are limited by the form factor. As products and markets develop further, decoupled designs may arrive with greater design flexibility. The vanadium in the electrolyte does not degrade, so it can be reused/recycled after the useful life of the battery.

Zinc-Bromide batteries were developed in the 1970's by Exxon and are often referred to as "hybrid" flow batteries. ZnBr batteries use pumped liquid electrolyte in a single pump, single tank system. During charging, energy is stored by plating electrode surfaces with zinc. Discharging causes the zinc to oxidize and dissolve into the aqueous solution, which releases electrons to do work in the external circuit. The capacity of ZnBr batteries (and other plating style technologies) is dependent on electrode area as well as electrolyte volume. Commercially available units are modular designs with fixed power and energy ratings

9.1.2 Conventional Batteries

A conventional battery contains a cathodic and an anodic electrode and an electrolyte sealed within a cell container that can be connected in series to increase overall facility storage and output. During charging, the electrolyte is ionized such that when discharged, a reduction-oxidation reaction occurs, which forces electrons to migrate from the anode to the cathode thereby generating electric current. Batteries are designated by the electrochemicals utilized within the cell; the most popular conventional batteries are lead acid and Li-Ion type batteries.

Lead acid batteries are the most mature and commercially accessible battery technology, as their design has undergone considerable development since conceptualized in the late 1800s. The Department of Energy (DOE) estimates there is approximately 110 MW of lead acid battery storage currently installed worldwide. Although lead acid batteries require relatively low capital cost, this technology also has inherently high maintenance costs and handling issues associated with toxicity, as well as low energy density (yields higher land and civil work requirements). Lead acid batteries also have a relatively short life cycle at 5 to 10 years, especially when used in high cycling applications.

Li-Ion batteries contain graphite and metal-oxide electrodes and lithium ions dissolved within an organic electrolyte. The movement of lithium ions during cell charge and discharge generates current. Li-Ion technology has seen a resurgence of development in recent years due to its high energy density, low self-discharge, and cycling tolerance. Many Li-Ion manufacturers currently offer 20-year warranties or performance guarantees. Consequently, Li- Ion has gained traction in several markets including the utility and automotive industries.

Li-Ion battery prices are trending downward, and continued development and investment by manufacturers are expected to further reduce production costs. While there is still a wide range of project cost expectations due to market uncertainty, Li-Ion batteries are anticipated to expand their reach in the utility market sector.

9.1.3 High Temperature Batteries

High temperature batteries operate similarly to conventional batteries, but they utilize molten salt electrodes and carry the added advantage that high temperature operation can yield heat for other applications simultaneously. The technology is considered mature with ongoing commercial development at the grid level. The most popular and technically developed high temperature option is the Sodium Sulfur (NaS) battery. Japan-based NGK Insulators, the largest NaS battery manufacturer, installed a 4 MW system in Presidio, Texas in 2010 following operation of systems totaling more than 160 MW since the project's inception in the 1980s.

The NaS battery is typically a hermetically sealed cell that consists of a molten sulfur electrolyte at the cathode and molten sodium electrolyte at the anode, separated by a Beta-alumina ceramic membrane and enclosed in an aluminum casing. The membrane is selectively permeable only to positive sodium ions, which are created from the oxidation of sodium metal and pass through to combine with sulfur resulting in the formation of sodium polysulfides. As power is supplied to the battery in charging, the sodium ions are dissociated from the polysulfides and forced back through the membrane to re-form elemental sodium. The melting points of sodium and sulfur are approximately 98ºC and 113ºC, respectively. To maintain the electrolytes in liquid form and for optimal performance, the NaS battery systems are typically operated and stored at around 300ºC, which results in a higher self-discharge rate of 14 percent to 18 percent. For this reason, these systems are usually designed for use in high-cycling applications and longer discharge durations.

NaS systems are expected to have an operable life of around 15 years and are one of the most developed chemical energy storage technologies. However, unlike other battery types, costs of NaS systems have historically held, making other options more commercially viable at present.

9.2 Battery Emissions Controls

No emission controls are currently required for battery storage facilities. However, Li-Ion batteries can release large amounts of gas during a fire event. While not currently an issue, there is potential for increased scrutiny as more battery systems are placed into service.

9.3 Battery Storage Performance

This assessment includes performance for multiple Li-Ion options as well as one flow battery option. Li-Ion systems can respond in seconds and exhibit excellent ramp rates and round-trip cycle efficiencies. Because the technology is rapidly advancing, there is uncertainty regarding estimates for cycle life, and these estimates vary greatly depending on the application and depth of discharge. The systems in this

Assessment are assumed to perform one full cycle per day, and capacity factors are based on the duration of full discharge for 365 days. OEMs typically have battery products that are designed to suit different use-cases such as high power or high energy applications. The power to energy ratio is commonly shown as a C-ratio (for example, a 1MW / 4 MWh system would use a 0.25C battery product). However, the 8-hour battery option is based on a 0.25C system that is sized for twice the power and discharged for eight hours instead of four. While the technology continues to advance, commercially available, high energy batteries for utility scale applications are generally 0.25C and above.

Flow batteries are a maturing technology that is well suited for longer discharge durations (>4 hours, for example). Flow batteries can provide multiple use cases from the same system and they are not expected to exhibit performance degradation like lithium ion technologies. However, they typically have lower round trip efficiency than Li-Ion batteries. Storage durations are currently limited to commercial offerings from select vendors but are expected to broaden over the next several years. Performance guarantees of 20 years are expected with successful commercialization, but there is not necessarily a technical reason that original equipment manufacturer (OEM) and/or balance of plant (BOP) designs could not accommodate 30+ year life.

9.4 Regulatory Trends

Two (2) Federal Energy Regulatory Commission (FERC) Orders released in 2018 provide clarity on the role of storage in wholesale markets, and potentially drive continued growth. FERC Order 841 requires RTOs and ISOs to develop clear rules regulating the participation of energy storage systems in wholesale energy, capacity, and ancillary services markets. Prior to the final release of FERC 841, the California Public Utilities Commission introduced 11 rules to determine how multi-use storage products participate in California Independent System Operator (CAISO). FERC Order 842 addresses requirements for some generating facilities to provide frequency response, including accommodations for storage technologies. In addition, the Internal Revenue Service (IRS) is considering new guidance for the ITC that will impact projects combining storage with renewables.

Tariffs are a popular concern in the solar and storage market. With recent tariffs, uncertainty of how manufacturing abroad and nationally will be affected has crept into the industry. The “Section 301” tariffs are comprised of four lists of Chinese products that have been selected for tariffs between 15% and 30%. Raw materials used to create Li-Ion batteries and solar modules are already impacted by the Section 301 tariffs in affect and were set to increase from 25% to 30% in late Fall 2020 but has since been delayed. While these tariffs are beginning to increase, manufacturers in China have started to react and move production of solar and storage products outside of China to Mexico and India to avoid paying some of the tariffs.

9.5 Battery Storage Cost Estimate

The estimated costs of the Li-Ion and flow battery systems are included in the Summary Tables, based on BMcD experience and vendor correspondence. The key cost elements of a Li-Ion battery system are the inverter, the battery cells, the interconnection, and the installation. The capital costs reflect recent trends for overbuild capacity to account for short term degradation. The battery enclosures include space for future augmentation, but the costs associated with augmentation are covered in the O&M costs. It is assumed that land is available at an existing PacifiCorp facility and is therefore excluded from the cost estimate. These options assume the battery interconnects at medium voltage.

Flow battery estimates for the 1 MW options are based on iron flow battery technology. This is a modular design in which the OEM scope includes the tanks, electrolyte storage, and associated pumps and controls in a factory assembled package. The EPC scope includes the inverters, switchgear, MV transformer, and installation.

Demolition costs are meant to reflect the end of life decommissioning efforts. This includes discharging the batteries to the greatest extent possible, shutting the system down, final inspections, and physically disconnecting all electrical equipment. Following this, battery modules will need to be removed from the racks and placed on pallets for shipment to a recycling facility. Lithium-ion batteries are considered Class 9 hazardous waste and is currently treated like e-waste. Once at the recycling facility, a dissembler will break the module down into major subcomponents like steel, cells, copper, printed circuit boards, plastics, etc. The cells are then sent through either a shredding or smelting process to recover valuable metals. Once the cells go through this process, any remaining waste is not considered hazardous. Battery recycling costs vary significant depending on chemistry. Cobalt-based battery chemistries have higher recovery value and because they are more energy dense, typically involve handling less material. In all cases, the cost of disassembly and freight to the recycling facility is estimated to account for 70-90% of the total cost for recycling. Estimates, though, can vary significantly depending on metals pricing and competition in the battery recycling market.

9.6 Battery Storage O&M Cost Estimate

O&M estimates for the Li-Ion and flow battery systems are shown in the Summary Tables, based on BMcD experience and recent market trends. The battery storage system is assumed to be operated remotely.

The technical life of a Li-Ion battery project is expected to be 20 years, but battery performance degrades over time, and this degradation is considered in the system design. Systems can be "overbuilt" by including additional capacity in the initial installation, and they can also be designed for future augmentation. Augmentation means that designs account for the addition of future capacity to maintain guaranteed performance.

Overbuild and augmentation philosophies can vary between projects. Because battery costs are expected to continue falling, many installers/integrators are aiming for lower initial overbuild percentages to reduce initial capital costs, which means guarantees and service contracts will require more future augmentation to maintain capacity. Because costs should be lower in the future, the project economics may favor this approach. This assessment assumes minimal overbuild beyond system efficiency losses, and the O&M estimates include allowances for augmentation.

Battery storage O&M costs are modeled to represent the portions of performance guarantees and augmentation from recent BMcD project experience. The O&M cost for the Li-Ion systems include a nominal fixed cost to administer and maintain the O&M contract with an OEM/integrator, plus an allowance for calendar degradation fees. Calendar degradation represents performance degradation and subsequent augmentation expected to occur regardless of the system's operation profile, even if the batteries sit unused. Because calendar degradation is not tied to system operation or output, it is modeled as part of the fixed O&M.

Previously represented as variable O&M, estimates for Li-ion options account for cycling degradation fees are now also included in the fixed O&M section due to how the industry is now utilizing service agreements. Cycling the batteries increases performance degradation, so the performance guarantees provided by the OEM and/or integrator are commonly modeled to account for augmentation based on the expected operating profile. The augmentation O&M estimates in this assessment are based on an operation profile of one charge/discharge cycle per day and may not be valid for increased cycling.

Flow battery O&M costs are modeled around an annual service contract from the OEM or a factory trained third party. Costs are based on correspondence with manufacturers and are subject to change as the technology achieves greater commercialization and utilization in the utility sector. Unlike Li-Ion technologies, flow batteries generally do not exhibit calendar or cycle degradation, so there is not an augmentation O&M component per cycle. There is mechanical equipment that requires service based on an OEM recommended schedule, which is modeled as a levelized annual cost for the life of the system.

10.0 CONCLUSIONS

This Renewable Energy Resource Technology Assessment provides information to support PacifiCorp's power supply planning efforts. Information provided in this Assessment is screening level in nature and is intended to highlight indicative, differential costs associated with each technology. BMcD recommends that PacifiCorp use this information to update production cost models for comparison of renewable resource alternatives and their applicability to future resource plans. For specific project development efforts beyond IRP planning, PacifiCorp should pursue additional engineering studies to define project scope, budget, and timeline.

Renewable options include PV and wind systems. PV is a proven technology for daytime peaking power and a viable option to pursue renewable goals. PV capital costs have steadily declined for years, but recent import tariffs on PV panels and foreign steel may impact market trends. Wind energy generation is a proven technology and turbine costs dropped considerably over the past few years.

Utility-scale battery storage systems are being installed in varied applications from frequency response to arbitrage, and recent cost reduction trends are expected to continue. While PHES currently has the most installed capacity for energy storage as a whole, Li-Ion technology is achieving the greatest market penetration in the battery storage sector. This is aided in large part by its dominance in the automotive industry, but other technologies like flow batteries should be monitored, as well.

PacifiCorp's region has several geological sites that can support large scale storage options including PHES and CAES. This gives PacifiCorp flexibility in terms of energy storage. Smaller applications will be much better suited for battery technologies, but if a larger need is identified PHES or CAES could provide excellent larger scale alternatives. Both of these technologies benefit from economies of scale in regard to their total kWh of storage, allowing them to decrease the overall $/kWh project costs.

APPENDIX A – SUMMARY TABLES

APPENDIX B – SOLAR PVSYST MODEL OUTPUT (5MW)

APPENDIX C – SOLAR OUTPUT SUMMARY

APPENDIX D – WIND PERFORMANCE INFORMATION

APPENDIX E – DECLINING COST CURVES

APPENDIX F – GENERATION CASHFLOWS

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PACIFICORP RENEWABLE TECHNOLOGY ASSESSMENT SUMMARY TABLE
ENERGY STORAGE

PROJECT TYPE	Pumped Hydro								
BASE PLANT DESCRIPTION	**Swan Lake**	**Goldendale**	**Seminoe**	**Badger Mountain**	**Owyhee**	**Flat Canyon**	**Utah PS2**	**Utah PS3**	**Banner Mountain**
Nominal Output, MW	400	400	750	500	600	300	500	600	400
Nominal Output, MWh	3800	3800	7500	4000	4800	1800	4000	4800	3400
Capacity Factor (%)	31%	39%	40%	32%	32%	24%	32%	32%	34%
Startup Time (Cold Start), minutes	1.5	1.5	1.8	1.8	1.8	1.8	1.8	1.8	1.5
Full Pumping to Full Gen, minutes	4	4	3.5	3.5	3.5	3.5	3.5	3.5	0.67
Transition Time from Charging to Discharging, minutes	6	6	3.5	3.5	3.5	3.5	3.5	3.5	N/A
Availability Factor, %	90%	90%	95%	95%	95%	95%	95%	95%	95%
Technology Rating	Mature	Mature	Mature	Mature	Mature	Mature	Mature	Mature	Mature
Life Cycle, yrs	60	60	80	80	80	80	80	80	50+
Permitting & Construction Schedule, year (note 1)	6	10	8	6	8	8	6	8	7
ESTIMATED PERFORMANCE									
Base Load Performance @ (Annual Average)									
Net Plant Output, kW	400,000	400,000	750,000	500,000	600,000	300,000	500,000	600,000	400,000
Total Plant Storage, kWh (note 2)	3,800,000	4,800,000	7,500,000	4,000,000	4,800,000	1,800,000	4,000,000	4,800,000	3,400,000
Time for Full Discharge, hours	9.5	12.0	10	8	8	6	8	8	8.5
Time for Full Charge, hrs	9.5	14.0	12	9.5	9.5	7.2	9.5	9.5	10
Compression Power, MW (note 11)	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Round-Trip Efficiency (%) (note 3)	78%	78%	80%	80%	80%	80%	80%	80%	81%
ESTIMATED CAPITAL AND O&M COSTS (Note 8)									
EPC Project Capital Costs, 2020 MM$ (w/o Owner's Costs)	**$814**	**$2,146**	**$1,625**	**$897**	**$1,203**	**$760**	**$1,108**	**$1,266**	**$900**
Owner's Costs, 2020 MM$	**$163**	**$429**	**$249**	**$137**	**$184**	**$116**	**$169**	**$194**	**$77**
Owner's Project Development	Included	Included	Included	Included	Included	Included	Included	Included	Included
Owner's Engineer	Included	Included	Included	Included	Included	Included	Included	Included	Included
Owner's Project Management	Included	Included	Included	Included	Included	Included	Included	Included	Included
Owner's Legal Costs	Included	Included	Included	Included	Included	Included	Included	Included	Included
Permitting and Licensing Fees	Included	Included	Included	Included	Included	Included	Included	Included	Included
Generation Switchyard (note 4)	Included in Project Costs	Included in Project Costs	Included in Project Cost	Included in Project Cost	Included in Project Cost	Included in Project Cost	Included in Project Cost	Included in Project Cost	Included
Transmission to Interconnection Point (note 4)	Included in Project Costs	Included in Project Costs	Included in Project Cost	Included in Project Cost	Included in Project Cost	Included in Project Cost	Included in Project Cost	Included in Project Cost	Included
Training/Testing	Included in Project Costs	Included in Project Costs	Included in Project Cost	Included in Project Cost	Included in Project Cost	Included in Project Cost	Included in Project Cost	Included in Project Cost	Included in O&M
Land (note 6)	Included in Project Costs	Included in Project Costs	Included in Project Cost	Included in Project Cost	Included in Project Cost	Included in Project Cost	Included in Project Cost	Included in Project Cost	Included
Permanent Plant Equipment and Furnishings	Included	Included	Included	Included	Included	Included	Included	Included	Included in Project Cost
Builders Risk Insurance (0.45% of Project Cost)	$3.7	$9.7	$7.3	$4.0	$5.4	$3.4	$5.0	$5.7	$4.1
Owner's Contingency (5% of Total Project Cost)	$40.9	$107.8	$88.9	$49.0	$65.8	$41.5	$60.6	$69.2	$46.3
Total Screening Level Project Costs, 2020 MM$	**$977**	**$2,575**	**$1,874**	**$1,034**	**$1,387**	**$876**	**$1,277**	**$1,460**	**$977**
EPC Project Costs, 2020 $/kWh	**$214**	**$447**	**$217**	**$224**	**$251**	**$422**	**$277**	**$264**	**$265**
Total Screening Level Project Costs, 2020 $/kWh	**$257**	**$536**	**$250**	**$259**	**$289**	**$487**	**$319**	**$304**	**$287**
Demolition Costs (end of life cycle) 2020$/kWh (note 10)	**N/A**	**N/A**	**N/A**	**N/A**	**N/A**	**N/A**	**N/A**	**N/A**	**N/A**
O&M Cost, 2020 MM$/yr									
Fixed O&M Cost, 2020 MM$/yr	$5	$15	$12	$14	$12	$16	$14	$12	$11.4
Variable O&M Cost, 2020 $/MWh	$0	$0	$0.37	$0.37	$0.37	$0.37	$0.37	$0.37	$0

PROJECT TYPE	ADIABATIC CAES								
BASE PLANT DESCRIPTION	**Hydrostor**								
Nominal Output, MW	150	150	150	300	300	300	500	500	500
Nominal Output, MWh	600	1200	1800	1200	2400	3600	2000	4000	6000
Capacity Factor (%)	16%	32%	24%	16%	32%	24%	16%	32%	24%
Startup Time (Cold Start), minutes	5	5	5	5	5	5	5	5	5
Full Pumping to Full Gen, minutes	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Transition Time from Charging to Discharging, minutes	10	10	10	10	10	10	10	10	10
Availability Factor, %	95%	95%	95%	95%	95%	95%	95%	95%	95%
Technology Rating	Developing	Developing	Developing	Developing	Developing	Developing	Developing	Developing	Developing
Life Cycle, yrs	50+	50+	50+	50+	50+	50+	50+	50+	50+
Permitting & Construction Schedule, year (note 1)	2.5	2.5	2.5	2.5	2.5	3.0	3.0	3.5	3.5
ESTIMATED PERFORMANCE									
Base Load Performance @ (Annual Average)									
Net Plant Output, kW	150,000	150,000	150,000	300,000	300,000	300,000	500,000	500,000	500,000
Total Plant Storage, kWh (note 2)	600,000	1,200,000	1,800,000	1,200,000	2,400,000	3,600,000	2,000,000	4,000,000	6,000,000
Time for Full Discharge, hours	4	8	12	4	8	12	4	8	12
Time for Full Charge, hrs	7	13	20	7	13	20	7	13	20
Compression Power, MW (note 11)	90	90	90	180	180	180	300	300	300
Round-Trip Efficiency (%) (note 3)	60%	60%	60%	60%	60%	60%	60%	60%	60%
ESTIMATED CAPITAL AND O&M COSTS (Note 8)									
EPC Project Capital Costs, 2020 MM$ (w/o Owner's Costs)	**$235**	**$261**	**$290**	**$374**	**$402**	**$439**	**$572**	**$644**	**$700**
Owner's Costs, 2020 MM$	**$39**	**$46**	**$53**	**$63**	**$73**	**$84**	**$98**	**$118**	**$135**
Owner's Project Development	Included	Included	Included	Included	Included	Included	Included	Included	Included
Owner's Engineer	Included	Included	Included	Included	Included	Included	Included	Included	Included
Owner's Project Management	Included	Included	Included	Included	Included	Included	Included	Included	Included
Owner's Legal Costs	Included	Included	Included	Included	Included	Included	Included	Included	Included
Permitting and Licensing Fees	Included	Included	Included	Included	Included	Included	Included	Included	Included
Generation Switchyard (note 4)	Included in Project Cost	Included in Project Cost	Included in Project Cost	Included in Project Cost	Included in Project Cost	Included in Project Cost	Included in Project Cost	Included in Project Cost	Included in Project Cost
Transmission to Interconnection Point (note 4)	Included in Project Cost	Included in Project Cost	Included in Project Cost	Included in Project Cost	Included in Project Cost	Included in Project Cost	Included in Project Cost	Included in Project Cost	Included in Project Cost
Training/Testing	Included in Project Cost	Included in Project Cost	Included in Project Cost	Included in Project Cost	Included in Project Cost	Included in Project Cost	Included in Project Cost	Included in Project Cost	Included in Project Cost
Land (note 6)	Included in Project Cost	Included in Project Cost	Included in Project Cost	Included in Project Cost	Included in Project Cost	Included in Project Cost	Included in Project Cost	Included in Project Cost	Included in Project Cost
Permanent Plant Equipment and Furnishings	Included in Project Cost	Included in Project Cost	Included in Project Cost	Included in Project Cost	Included in Project Cost	Included in Project Cost	Included in Project Cost	Included in Project Cost	Included in Project Cost
Builders Risk Insurance (0.45% of Project Cost)	$1	$1	$1	$2	$2	$2	$3	$3	$3
Owner's Contingency (5% of Total Project Cost)	$11.8	$13.1	$14.6	$18.8	$20.2	$22.0	$28.7	$32.3	$35.2
Total Screening Level Project Costs, 2020 MM$	**$274**	**$307**	**$343**	**$437**	**$475**	**$523**	**$670**	**$762**	**$835**
EPC Project Costs, 2020 $/kWh	**$392**	**$218**	**$161**	**$312**	**$168**	**$122**	**$286**	**$161**	**$117**
Total Screening Level Project Costs, 2020 $/kWh	**$457**	**$256**	**$191**	**$364**	**$198**	**$145**	**$335**	**$191**	**$139**
Demolition Costs (end of life cycle) 2020$/kWh (note 10)	**N/A**	**N/A**	**N/A**	**N/A**	**N/A**	**N/A**	**N/A**	**N/A**	**N/A**
O&M Cost, 2020 MM$/yr									
Fixed O&M Cost, 2020 MM$/yr	$1.9	$1.9	$1.9	$2.8	$2.8	$2.8	$3.3	$3.3	$3.3
Variable O&M Cost, 2020 $/MWh	$6.50	$6.50	$6.50	$6.50	$6.50	$6.50	$6.50	$6.50	$6.50

PROJECT TYPE	Li-Ion Battery					Flow Battery			
BASE PLANT DESCRIPTION									
Nominal Output, MW	1	1	1	1	50	1	1	1	20
Nominal Output, MWh	0.5	1	4	8	200	1	4	8	160
Capacity Factor (%)	2%	4%	16%	32%	16%	4%	16%	32%	32%
Startup Time (Cold Start), minutes	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Full Pumping to Full Gen, minutes	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Transition Time from Charging to Discharging, minutes	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Availability Factor, %	97%	97%	97%	97%	97%	97%	97%	97%	97%
Technology Rating	Mature	Mature	Mature	Mature	Mature	Commercial	Commercial	Commercial	Commercial
Life Cycle, yrs	20	20	20	20	20	20	20	20	20
Permitting & Construction Schedule, year (note 1)	1.5	1.5	1.5	1.5	2	1.5	1.5	1.5	2
ESTIMATED PERFORMANCE									
Base Load Performance @ (Annual Average)									
Net Plant Output, kW	1,000	1,000	1,000	1,000	50,000	1,000	1,000	1,000	20,000
Total Plant Storage, kWh (note 2)	500	1,000	4,000	8,000	200,000	1,000	4,000	8,000	160,000
Time for Full Discharge, hours	0.5	1	4	8	4	1	4	8	8
Time for Full Charge, hrs	0.6	1.2	4.6	9.2	4.6	1.3	5.2	10.4	10.4
Compression Power, MW (note 11)	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Round-Trip Efficiency (%) (note 3)	85%	85%	85%	85%	85%	70%	70%	70%	70%
ESTIMATED CAPITAL AND O&M COSTS (Note 8)									
EPC Project Capital Costs, 2020 MM$ (w/o Owner's Costs)	**$1.1**	**$1.2**	**$2.2**	**$3.5**	**$68.0**	**$3.6**	**$3.9**	**$5.9**	**$70.0**
Owner's Costs, 2020 MM$	**$0.8**	**$0.8**	**$0.8**	**$0.9**	**$13.7**	**$0.9**	**$0.9**	**$1.0**	**$13.8**
Owner's Project Development	$0.1	$0.1	$0.1	$0.1	$0.1	$0.1	$0.1	$0.1	$0.1
Owner's Engineer	$0.1	$0.1	$0.1	$0.1	$0.2	$0.1	$0.1	$0.1	$0.2
Owner's Project Management	$0.1	$0.1	$0.1	$0.1	$0.2	$0.1	$0.1	$0.1	$0.2
Owner's Legal Costs	$0.1	$0.1	$0.1	$0.1	$0.5	$0.1	$0.1	$0.1	$0.5
Permitting and Licensing Fees	$0.1	$0.1	$0.1	$0.1	$0.3	$0.1	$0.1	$0.1	$0.3
Generation Switchyard (note 4)	$0.1	$0.1	$0.1	$0.1	$4.6	$0.1	$0.1	$0.1	$4.6
Transmission to Interconnection Point (note 4)	N/A	N/A	N/A	N/A	$3.5	N/A	N/A	N/A	$3.5
Training/Testing	$0.1	$0.1	$0.1	$0.1	$0.1	$0.1	$0.1	$0.1	$0.1
Land (note 6)	Assumes Co-located	Assumes Co-located	Assumes Co-located	Assumes Co-located	Assumes Co-located	Assumes Co-located	Assumes Co-located	Assumes Co-located	Assumes Co-located
Permanent Plant Equipment and Furnishings	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Builders Risk Insurance (0.45% of Project Cost)	$0.00	$0.01	$0.01	$0.02	$0.31	$0.02	$0.02	$0.03	$0.32
Owner's Contingency (5% of Total Project Cost)	$0.1	$0.1	$0.1	$0.2	$3.9	$0.2	$0.2	$0.3	$4.0
Total Screening Level Project Costs, 2020 MM$	**$1.9**	**$2.0**	**$3.0**	**$4.4**	**$82**	**$4**	**$5**	**$7**	**$84**
EPC Project Costs, 2020 $/kWh	**$2,200**	**$1,200**	**$550**	**$438**	**$340**	**$3,600**	**$975**	**$738**	**$438**
Total Screening Level Project Costs, 2020 $/kWh	**$3,706**	**$1,959**	**$753**	**$548**	**$408**	**$4,490**	**$1,202**	**$864**	**$524**
Demolition Costs (end of life cycle) 2020$/kWh (note 10)	**$110**	**$110**	**$110**	**$110**	**$110**	**N/A**	**N/A**	**N/A**	**N/A**
O&M Cost, 2020 MM$/yr									
Fixed O&M Cost, 2020 MM$/yr	$0.04	$0.05	$0.07	$0.10	$1.38	$0.013	$0.013	$0.027	$0.61
Variable O&M Cost, 2020 $/MWh	Included in FOM	Included in FOM	Included in FOM	Included in FOM	Indluded in FOM	Included in FOM	Included in FOM	Included in FOM	Indluded in FOM

Notes

Note 1. Permitting & Construction Schedule is based on earliest COD date for some of the pumped hydro options
Note 2. CAES storage is based on full charge. Typical operation is to not fully discharge, but rather to discharge only a portion of the capacity to maintain cavern pressure.
Note 3. Round trip efficiency for CAES is based on the electric energy input to compress air plus the energy in the gas input compared to the electrical output.
Note 4. 1MW battery options (Li-Ion and Flow) assume interconnection at distribution voltage and therefore excludes GSU and switchyard. Larger options include GSU and switchyard costs as well as a standalone transmission cost. Also assumes co-located with existing asset and therefore excludes land costs.
Note 5. Battery O&M assumes the site is remotely controlled and that batteries cycle once per day. Capital costs assume the system is slightly oversized initially to accommodate normal degradation at the start of the project life, and then degradation supplement cost throughout the project life. O&M accounts for the parasitic power draw of the system, including HVAC and efficiency losses.
Note 6. Pumped Hydro O&M excludes major maintenance cost items, like generator rewinds, that are viewed as end of life repairs to extend the intended life of the asset.
Note 7. Battery capacity factor and annual O&M is based on one full cycle per day.
Note 8. EPC and Owner's Cost estimates exclude AFUDC, Sales Tax, Insurance and Property Tax During Construction
Note 9. Compression Capacity Ratio is defined as the relationship of the MWh of charging to the MWh of generation.
Note 10. Demolition costs are not shown for longer life cycle storage options (pumped hydro, CAES, and flow batteries). Li-Ion storage includes the cost to recycle the modules but does not include any resale of raw materials.
Note 11. Compressors can be sized to meet most charging duration requirments. A representative size has been chosen for the options shown.

PACIFICORP RENEWABLE TECHNOLOGY ASSESSMENT SUMMARY TABLE
SOLAR GENERATION

PROJECT TYPE				
PROJECT LOCATION	**Lakeview, OR**		**Milford, UT**	
BASE PLANT DESCRIPTION	**100 MW**	**200 MW**	**100 MW**	**200 MW**
Nominal Output, MW	100	200	100	200
Annualized Energy Production, MWh (Yr 1)	242,000	484,000	264,900	529,700
AC Capacity Factor at POI (%) (Note 1)	27.6%	27.6%	30.2%	30.2%
Availability Factor, % (Note 2)	99%	99%	99%	99%
Assumed Land Use, Acres	800	1600	800	1600
PV Inverter Loading Ratio (DC/AC)	1.30	1.30	1.30	1.30
PV Degradation, %/yr (Note 3)	1st year: 2% After 1st Year: 0.5% per year	2nd year: 2% After 1st Year: 0.5% per year	1st year: 2% After 1st Year: 0.5% per year	2nd year: 2% After 1st Year: 0.5% per year
Technology Rating	Mature	Mature	Mature	Mature
Permitting & Construction Schedule, year	2	2	2	2
ESTIMATED PERFORMANCE				
Base Load Performance @ (Annual Average)				
Net Plant Output, kW	100,000	200,000	100,000	200,000
ESTIMATED CAPITAL AND O&M COSTS (Note 7)				
EPC Project Capital Costs, 2020 MM$ (w/o Owner's Costs)	**$113**	**$222**	**$111**	**$216**
Modules	$48	$91	$48	$91
Racking w/ Piles	$16	$31	$16	$31
Inverter & MV Transformer	$4	$8	$4	$8
Labor, Materials, and BOP Equiment	$29	$59	$27	$53
Project Indirects, Fee, and Contingency	$16	$33	$16	$33
Owner's Costs, 2020 MM$	**$24**	**$31**	**$24**	**$31**
Owner's Project Development	$0.3	$0.3	$0.3	$0.3
Owner's Project Management	$0.1	$0.1	$0.1	$0.1
Owner's Legal Costs	$0.3	$0.3	$0.3	$0.3
Permitting and Licensing Fees	$0.5	$0.6	$0.5	$0.6
Interconnection Switchyard (Note 5)	$2.0	$2.0	$2.0	$2.0
Transmission Interconnection (Note 8)	$3.5	$3.5	$3.5	$3.5
Transmission Interconnection Application and Upgrades (Note 9)	$9.8	$9.8	$9.8	$9.8
Land (Note 4)	$0.0	$0.0	$0.0	$0.0
Operating Spare Parts	$0.8	$1.6	$0.8	$1.6
Builders Risk Insurance (0.45% of Project Cost)	$0.5	$1.0	$0.5	$1.0
Owner's Contingency	$6.5	$12.1	$6.4	$11.8
Total Screening Level Project Costs, 2020 MM$	**$137**	**$253**	**$135**	**$247**
EPC Project Costs, 2020 $/kW	**$1,130**	**$1,110**	**$1,110**	**$1,080**
Total Screening Level Project Costs, 2020 $/kW	**$1,372**	**$1,266**	**$1,351**	**$1,234**
Demolition Costs (end of life cycle) 2020$/kW	**$35**	**$35**	**$35**	**$35**
O&M Cost, 2020 MM$/yr	**$1.7**	**$3.2**	**$1.9**	**$3.5**
Third Party LTSA, 2020$MM/Yr	$0.7	$1.3	$0.7	$1.3
BOP and Other Cost, 2020$MM/Yr	$0.2	$0.3	$0.2	$0.3
Land Lease Allowance, 2020$MM/Yr	$0.4	$0.8	$0.6	$1.1
Capital Replacement Allowance, 2020$/MWh (Notes 3-5)	$0.4	$0.8	$0.4	$0.8
O&M Cost, 2020 $/kWac-yr	**$16.20**	**$16.10**	**$17.60**	**$17.60**
Co-Located Energy Storage - 4 hr Capacity				
Add-On Costs				
Capital Costs, 2020 MM$	$70	$133	$68	$130
Owner's Costs, 2020 MM$	$6.9	$10.3	$6.8	$10.1
Incremental O&M Cost, 2020 MM$/Yr	$1.38	$2.57	$1.38	$2.57
Co-Located Energy Storage - 4 hr Capacity + 200MW Wind				
Add-On Costs				
Capital Costs, 2020 MM$	N/A	$365	N/A	$361
Owner's Costs, 2020 MM$	N/A	$34	N/A	$33
Incremental O&M Cost, 2020 MM$/Yr	N/A	$13.37	N/A	$12.77

Notes

Note 1. Solar capacity factor accounts for typical losses. 100 and 200 MW options have AC capacity overbuilt for high voltage losses.
Note 2. Availability estimates are based on vendor correspondence and industry publications.
Note 3. PV degradation based on typical warranty information for polycrystalline products. Assuming factory recommended maintenance is performed, PV performance is estimated to degrade ~2% in the first year and 0.5% each
Note 4. PV projects assume that land is leased and therefore land costs are included in O&M, not capital costs. Assumes eight acres per MW for tracking.
Note 5. Solar project substation included in EPC cost. Interconnection switchyard assumes additional position on existing ring bus.
Note 6. Oregon cost estimates assume union labor.
Note 7. EPC and Owner's Cost estimates exclude AFUDC, Sales Tax, Insurance and Property Tax During Construction
Note 8. Transmission interconnect allowance assumes 3 miles of transmission line at 161 kV. Land costs are excluded.
Note 9. Transmission interconnect application costs and upgrade costs are representative only. These costs can vary greatly depending on the site location and existing infrastructure.

PACIFICORP RENEWABLE TECHNOLOGY ASSESSMENT SUMMARY TABLE
WIND GENERATION

PROJECT TYPE	Onshore Wind				
PROJECT LOCATION	**Pocatello, ID**	**Arlington, OR**	**Monticello, UT**	**Medicine Bow, WY**	**Goldendale, WA**
BASE PLANT DESCRIPTION	**200 MW**	**200 MW**	**200 MW**	**200 MW**	**200 MW**
Nominal Output, MW	200	200	200	200	200
Number of Turbines	50 x 4 MW	50 x 4 MW	50 x 4 MW	50 x 4 MW	50 x 4 MW
Capacity Factor (Note 1)	43.0%	43.0%	36.1%	48.6%	43.0%
Availability Factor, % (Note 2)	95%	95%	95%	95%	95%
Assumed Land Use, Acres	56	56	56	56	56
Technology Rating	Mature	Mature	Mature	Mature	Mature
Permitting & Construction Schedule, year	2.5	2.5	2.5	2.5	2.5
ESTIMATED PERFORMANCE					
Base Load Performance @ (Annual Average)					
Net Plant Output, kW	200,000	200,000	200,000	200,000	200,000
ESTIMATED CAPITAL AND O&M COSTS (Note 6)					
Project Capital Costs, 2020 MM$ (w/o Owner's Costs)	**$231**	**$232**	**$231**	**$231**	**$232**
Wind Turbine Generators	$155	$156	$155	$155	$156
Roads	$5	$5	$5	$5	$5
O&M Building	$2	$2	$2	$2	$2
Collection System	$8	$8	$8	$8	$8
Other BOP, Materials, Labor, Indirects	$61	$61	$61	$61	$61
Owner's Costs, 2020 MM$	**$73**	**$73**	**$72**	**$72**	**$73**
Project Development (Note 3)	$24.4	$24.4	$23.4	$23.4	$24.4
Wind Resource Assessment	$1.0	$1.0	$1.0	$1.0	$1.0
Land Control	$2.4	$2.4	$2.4	$2.4	$2.4
Permitting and Licensing Fees	$3.2	$3.2	$3.2	$3.2	$3.2
Generation Switchyard	$2.0	$2.0	$2.0	$2.0	$2.0
Transmission Interconnection (Note 7)	$3.5	$3.5	$3.5	$3.5	$3.5
Transmission Interconnection Application and Upgrades (Note 8)	$9.8	$9.8	$9.8	$9.8	$9.8
Land (Note 4)	$0.0	$0.0	$0.0	$0.0	$0.0
Operating Spare Parts	Included in O&M	Included in O&M	Included in O&M	Included in O&M	Included in O&M
Temporary facilities and Construction Utilities	$12.0	$12.0	$12.0	$12.0	$12.0
Builders Risk Insurance (0.45% of Project Cost)	Included in Project Costs	Included in Project Costs	Included in Project Costs	Included in Project Costs	Included in Project Costs
Owner's Contingency (5% of Total Project Cost)	$14.5	$14.5	$14.4	$14.4	$14.5
Total Screening Level Project Costs, 2020 MM$	**$304**	**$305**	**$303**	**$303**	**$305**
EPC Project Costs, 2020 $/kW	**$1,155**	**$1,160**	**$1,155**	**$1,155**	**$1,160**
Total Screening Level Project Costs, 2020 $/kW	**$1,519**	**$1,524**	**$1,513**	**$1,513**	**$1,524**
Demolition Costs (end of life cycle) 2020$/kW	**$13**	**$13**	**$13**	**$13**	**$13**
O&M Cost, 2020 MM$/yr	$10.6	$10.8	$10.2	$9.6	$10.8
O&M Cost, 2020 $/kW-yr	$53.0	$54.0	$51.0	$48.0	$54.0
Co-Located Energy Storage - 4 hr Capacity					
Add-On Costs					
Capital Costs, 2020 MM$	$130	$133	$130	$130	$133
Owner's Costs, 2020 MM$	$11.2	$11.3	$11.2	$11.2	$11.3
Incremental O&M Cost, 2020 MM$/Yr	$2.57	$2.57	$2.57	$2.57	$2.57

Notes

Note 1. Wind capacity factor based on NREL 80 meter wind speed maps used to convert wind speeds to 105 meter hub height.
Note 2. Availability estimates are based on vendor correspondence and industry publications.
Note 3. Development costs include legal costs, developer costs prior to COD, Owner project management, engineering, and interconnect studies.
Note 4. Wind projects assume that land is leased and therefore land costs are included in O&M, not capital costs. Assumes one acre per turbine.
Note 5. Oregon and Washington cost estimates assume union labor.
Note 6. EPC and Owner's Cost estimates exclude AFUDC, Sales Tax, Insurance and Property Tax During Construction
Note 7. Transmission interconnect allowance assumes 3 miles of transmission line at 161 kV. Land costs are excluded.
Note 8. Transmission interconnect application and upgrade costs are representative only. These costs can vary greatly depending on the site location and existing infrastructure.

Grid-Connected System: Simulation parameters

Project : **Pacificorp20-LakeviewOR**

Geographical Site	**Lakeview**		Country	**United States**
Situation	Latitude	42.17° N	Longitude	-120.40° W
Time defined as	Legal Time	Time zone UT-8	Altitude	1441 m
	Albedo	0.20		
Meteo data:	**Lakeview**	NREL: TMY3 hourly DB (1991-2005) - TMY		

Simulation variant : **PC20_VC0_LakeviewOR_SAT**

Simulation date 30/06/20 10h33

Simulation parameters	System type	**Trackers single array, with backtracking**		
Tracking plane, tilted axis	Axis Tilt	0°	Axis azimuth	0°
Rotation Limitations	Minimum Phi	-60°	Maximum Phi	60°
	Tracking algorithm	Irradiance optimization		
Backtracking strategy	Nb. of trackers	100	Single array	
	Tracker Spacing	10.00 m	Collector width	4.26 m
Inactive band	Left	0.02 m	Right	0.02 m
Backtracking limit angle	Phi limits	+/- 79.9°	Ground Cov. Ratio (GCR)	42.6%
Models used	Transposition	Perez	Diffuse	Imported
			Circumsolar	separate
Horizon	Average Height	2.4°		
Near Shadings	Linear shadings			
User's needs :	Unlimited load (grid)			

PV Array Characteristics

PV module Si-poly	Model	**CS3W-400P HE**		
Custom parameters definition	Manufacturer	Canadian Solar Inc.		
Number of PV modules	In series	28 modules	In parallel	488 strings
Total number of PV modules	nb. modules	13664	Unit Nom. Power	400 Wp
Array global power	Nominal (STC)	**5466 kWp**	At operating cond.	4961 kWp (50°C)
Array operating characteristics (50°C)	U mpp	982 V	I mpp	5049 A
Total area	Module area	**30186 m²**	Cell area	27114 m²
Inverter	Model	**Solar Ware 840 - PVU-L0840ER(PRERELEASE)**		
Custom parameters definition	Manufacturer	TMEIC		
Characteristics	Unit Nom. Power	**840 kWac**	Oper. Voltage	915-1300 V
Inverter pack	Total power	**4200 kWac**	Pnom ratio	1.30
	Nb. of inverters	5 units		
Total	Total power	**4200 kWac**	Pnom ratio	1.30

PV Array loss factors

Array Soiling Losses			Loss Fraction	2.0 %
Thermal Loss factor	Uc (const)	25.0 W/m²K	Uv (wind)	1.2 W/m²K / m/s
Wiring Ohmic Loss	Global array res.	3.2 mΩ	Loss Fraction	1.5 % at STC
LID - Light Induced Degradation			Loss Fraction	2.0 %
Module Quality Loss			Loss Fraction	-0.5 %
Module mismatch losses			Loss Fraction	2.0 % at MPP
Strings Mismatch loss			Loss Fraction	0.10 %

Grid-Connected System: Simulation parameters

Incidence effect (IAM): User defined profile

10°	20°	30°	40°	50°	60°	70°	80°	90°
1.000	1.000	1.000	0.990	0.990	0.970	0.920	0.760	0.000

System loss factors

AC wire loss inverter to transfo — Inverter voltage 630 Vac tri

Wires: 3 x 4000 mm² 1 m — Loss Fraction 0.0 % at STC

MV transfo — Grid Voltage 34.5 kV

One MV transfo

Operating losses at STC — Iron loss (24/24 Connexion) 10.70 kW — Loss Fraction 0.2 % at STC

Copper (resistive) loss 3 x 1.03 mΩ — Loss Fraction 1.4 % at STC

Grid-Connected System: Horizon definition

Project : **Pacificorp20-LakeviewOR**

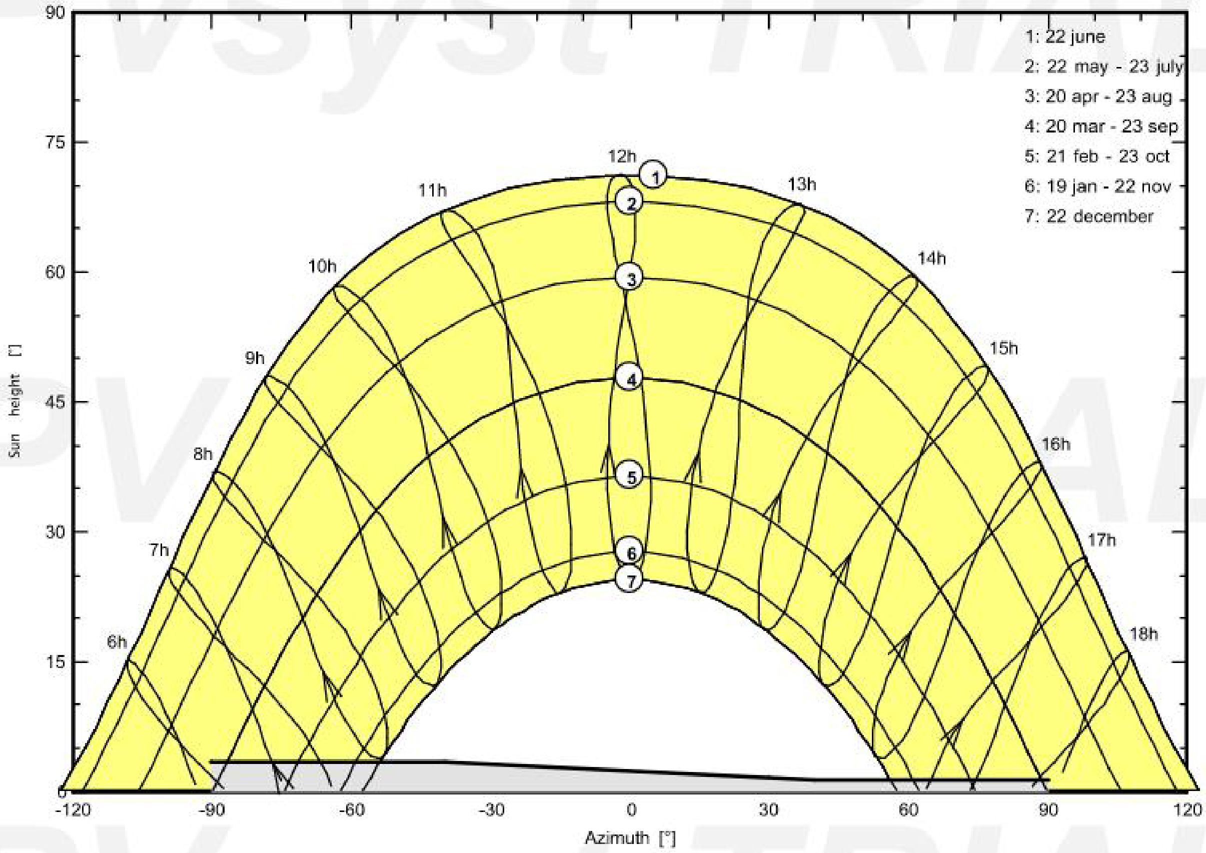
Simulation variant : **PC20_VC0_LakeviewOR_SAT**

Main system parameters	System type	**Trackers single array, with backtracking**		
Horizon	Average Height	2.4°		
Near Shadings	Linear shadings			
PV Field Orientation	tracking, tilted axis, Axis Tilt	0°	Axis azimuth	0°
PV modules	Model	CS3W-400P HE	Pnom	400 Wp
PV Array	Nb. of modules	13664	Pnom total	**5466 kWp**
Inverter	Solar Ware 840 - PVU-L0840ER(PRERELEASE)		Pnom	840 kW ac
Inverter pack	Nb. of units	5.0	Pnom total	**4200 kW ac**
User's needs	Unlimited load (grid)			

Horizon	Average Height	2.4°	Diffuse Factor	0.99
	Albedo Factor	100%	Albedo Fraction	0.96

Height [°]	3.4	3.4	1.4	1.4
Azimuth [°]	-90	-40	40	90

Horizon line at LakeviewOR_NSRDB



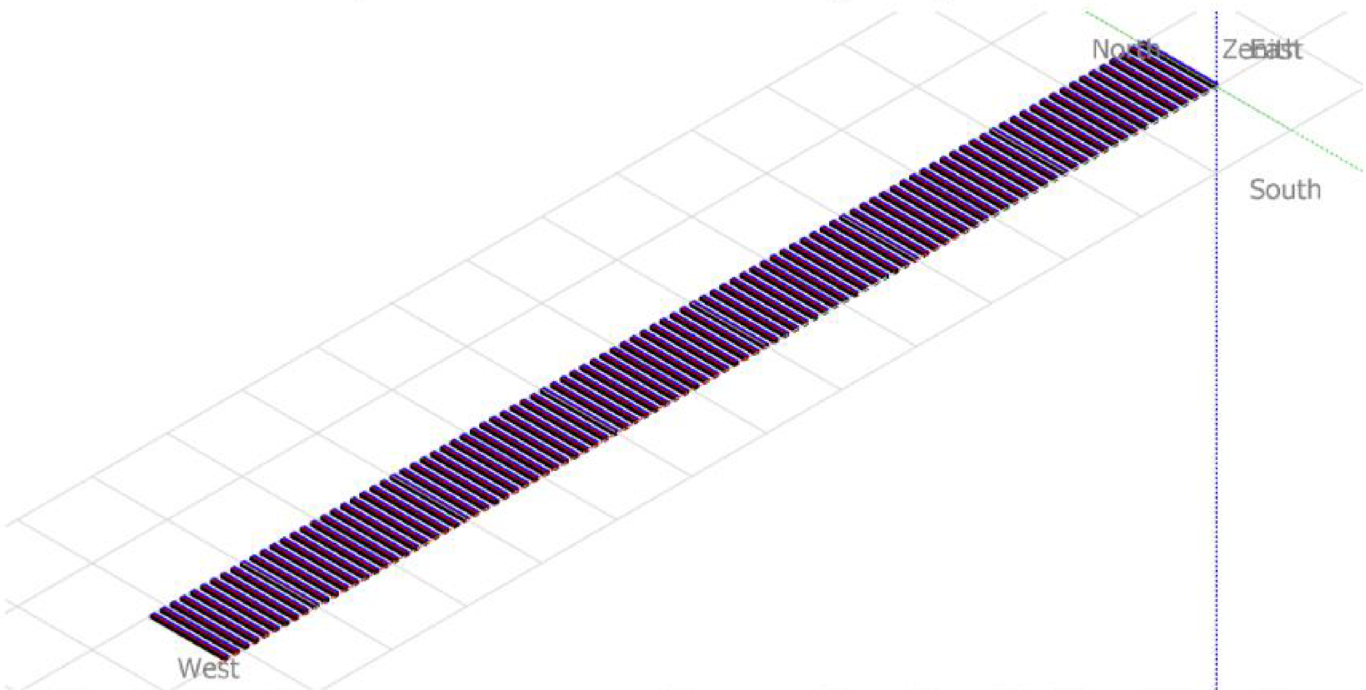
Grid-Connected System: Near shading definition

Project : **Pacificorp20-LakeviewOR**

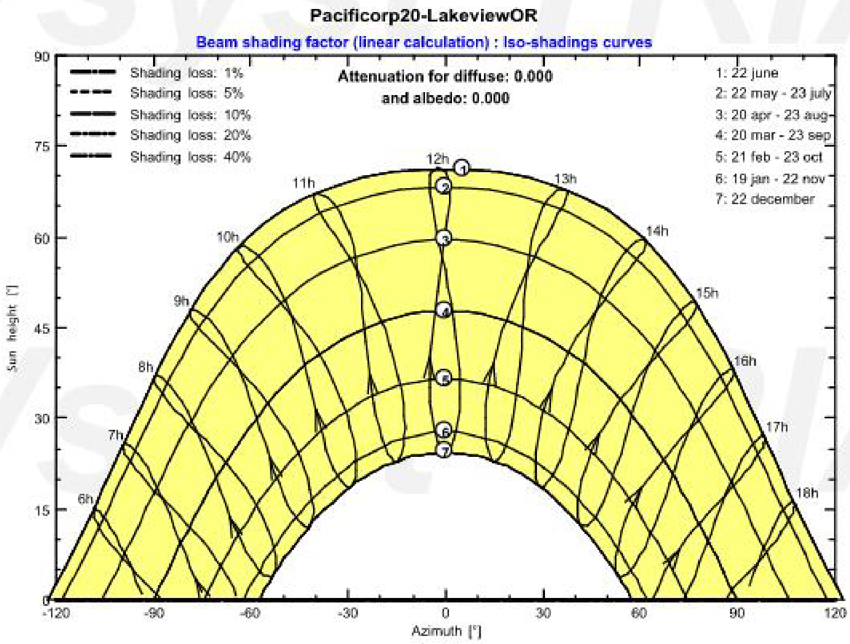
Simulation variant : **PC20_VC0_LakeviewOR_SAT**

Main system parameters	System type	**Trackers single array, with backtracking**		
Horizon	Average Height	2.4°		
Near Shadings	Linear shadings			
PV Field Orientation	tracking, tilted axis, Axis Tilt	0°	Axis azimuth	0°
PV modules	Model	CS3W-400P HE	Pnom	400 Wp
PV Array	Nb. of modules	13664	Pnom total	**5466 kWp**
Inverter	Solar Ware 840 - PVU-L0840ER(PRERELEASE)		Pnom	840 kW ac
Inverter pack	Nb. of units	5.0	Pnom total	**4200 kW ac**
User's needs	Unlimited load (grid)			

Perspective of the PV-field and surrounding shading scene



Iso-shadings diagram



Grid-Connected System: Main results

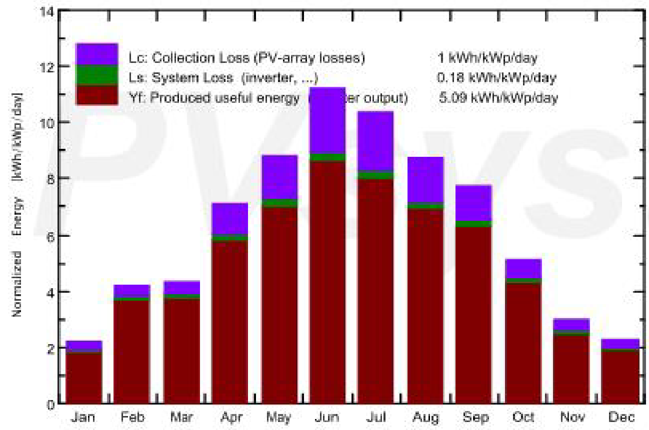
Project : **Pacificorp20-LakeviewOR**

Simulation variant : **PC20_VC0_LakeviewOR_SAT**

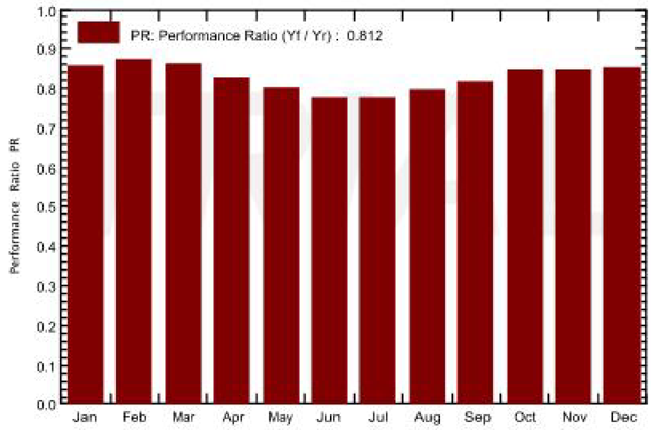
Main system parameters	System type	**Trackers single array, with backtracking**		
Horizon	Average Height	2.4°		
Near Shadings	Linear shadings			
PV Field Orientation	tracking, tilted axis, Axis Tilt	0°	Axis azimuth	0°
PV modules	Model	CS3W-400P HE	Pnom	400 Wp
PV Array	Nb. of modules	13664	Pnom total	**5466 kWp**
Inverter	Solar Ware 840 - PVU-L0840ER(PRERELEASE)		Pnom	840 kW ac
Inverter pack	Nb. of units	5.0	Pnom total	**4200 kW ac**
User's needs	Unlimited load (grid)			

Main simulation results				
System Production	**Produced Energy**	**10146 MWh/year**	Specific prod.	1856 kWh/kWp/year
	Performance Ratio PR	81.15 %		

Normalized productions (per installed kWp): Nominal power 5466 kWp



Performance Ratio PR



PC20_VC0_LakeviewOR_SAT

Balances and main results

	GlobHor kWh/m²	DiffHor kWh/m²	T_Amb °C	GlobInc kWh/m²	GlobEff kWh/m²	EArray MWh	E_Grid MWh	PR ratio
January	52.8	28.22	-1.22	67.9	62.0	334	317	0.854
February	85.1	27.99	-0.46	118.6	109.9	587	565	0.872
March	106.7	50.37	2.86	135.8	126.4	665	640	0.862
April	163.1	61.22	5.42	212.8	200.2	994	960	0.825
May	209.3	67.48	9.94	273.8	258.5	1235	1195	0.799
June	251.2	49.77	16.42	336.8	319.7	1471	1425	0.774
July	242.7	54.01	20.83	321.4	304.8	1404	1360	0.774
August	198.5	46.36	17.73	270.3	256.0	1215	1176	0.796
September	167.3	37.18	14.61	232.3	218.7	1069	1035	0.815
October	114.2	35.81	6.91	158.2	147.4	759	733	0.847
November	63.8	22.84	1.73	89.2	81.8	432	413	0.847
December	49.6	20.66	-0.87	70.4	64.1	344	328	0.851
Year	1704.3	501.91	7.87	2287.5	2149.6	10512	10146	0.812

Legends:				
	GlobHor	Global horizontal irradiation	GlobEff	Effective Global, corr. for IAM and shadings
	DiffHor	Horizontal diffuse irradiation	EArray	Effective energy at the output of the array
	T_Amb	T amb.	E_Grid	Energy injected into grid
	GlobInc	Global incident in coll. plane	PR	Performance Ratio

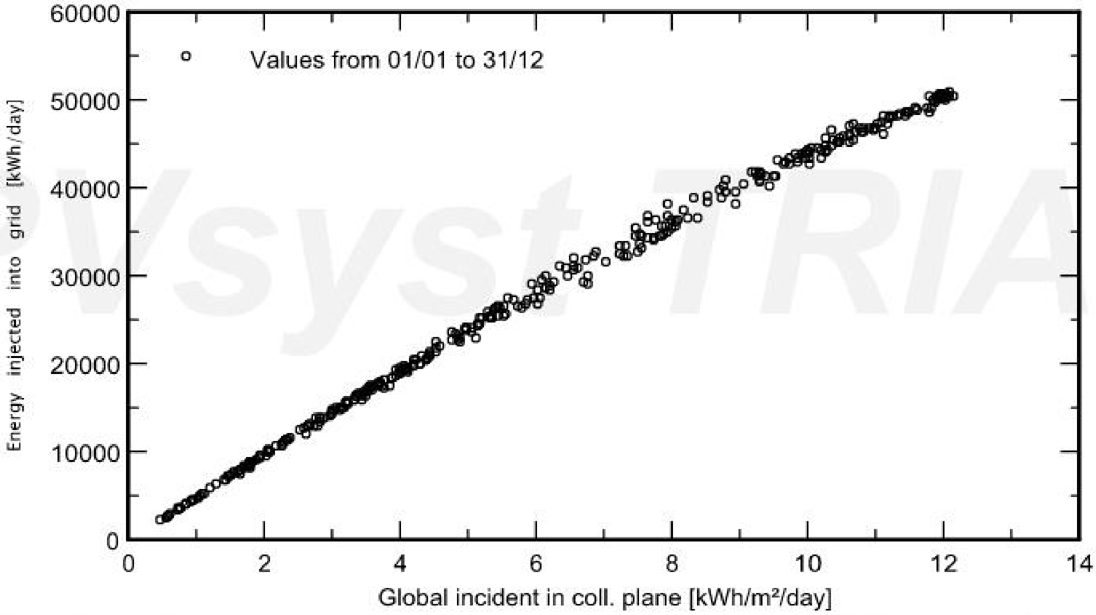
Grid-Connected System: Special graphs

Project : **Pacificorp20-LakeviewOR**

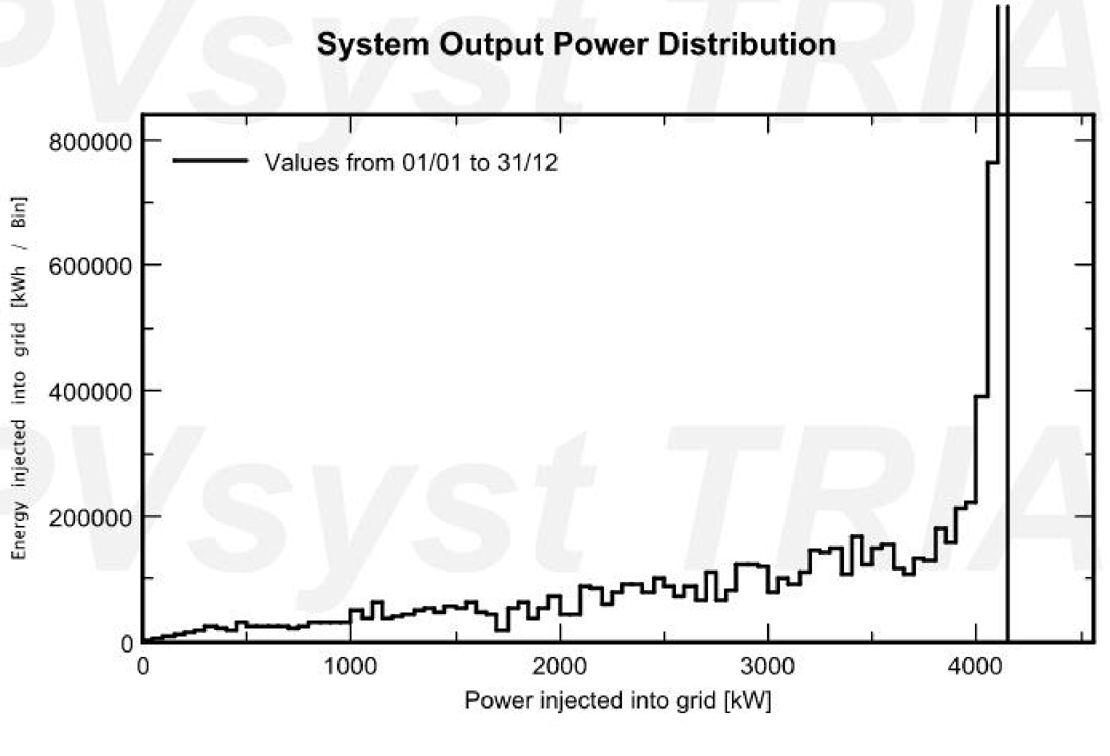
Simulation variant : **PC20_VC0_LakeviewOR_SAT**

Main system parameters	System type	**Trackers single array, with backtracking**		
Horizon	Average Height	2.4°		
Near Shadings	Linear shadings			
PV Field Orientation	tracking, tilted axis, Axis Tilt	0°	Axis azimuth	0°
PV modules	Model	CS3W-400P HE	Pnom	400 Wp
PV Array	Nb. of modules	13664	Pnom total	**5466 kWp**
Inverter	Solar Ware 840 - PVU-L0840ER(PRERELEASE)		Pnom	840 kW ac
Inverter pack	Nb. of units	5.0	Pnom total	**4200 kW ac**
User's needs	Unlimited load (grid)			

Daily Input/Output diagram



System Output Power Distribution



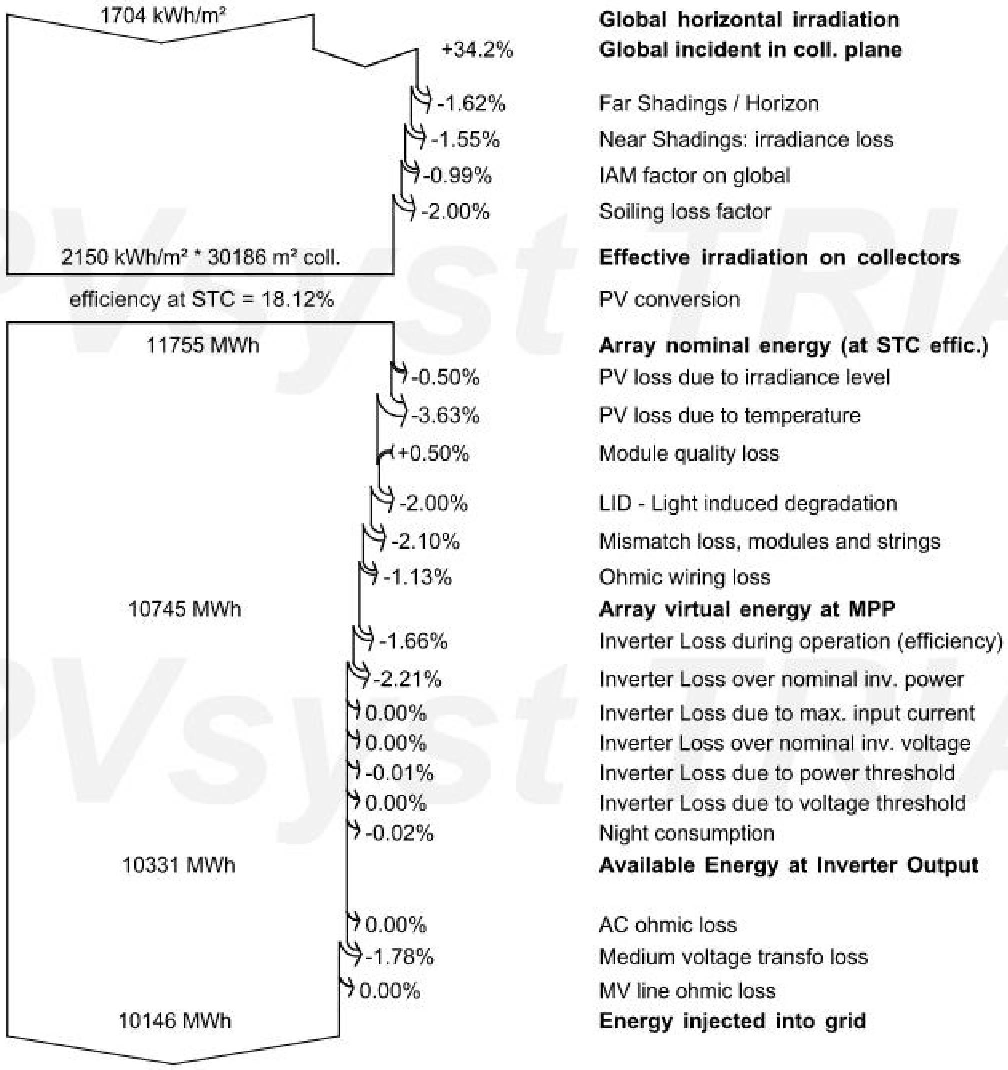
Grid-Connected System: Loss diagram

Project : **Pacificorp20-LakeviewOR**

Simulation variant : **PC20_VC0_LakeviewOR_SAT**

Main system parameters	System type	**Trackers single array, with backtracking**		
Horizon	Average Height	2.4°		
Near Shadings	Linear shadings			
PV Field Orientation	tracking, tilted axis, Axis Tilt	0°	Axis azimuth	0°
PV modules	Model	CS3W-400P HE	Pnom	400 Wp
PV Array	Nb. of modules	13664	Pnom total	**5466 kWp**
Inverter	Solar Ware 840 - PVU-L0840ER(PRERELEASE)		Pnom	840 kW ac
Inverter pack	Nb. of units	5.0	Pnom total	**4200 kW ac**
User's needs	Unlimited load (grid)			

Loss diagram over the whole year



Grid-Connected System: Simulation parameters

Project :	**Pacificorp20-MilfordUT**			
Geographical Site	**MilfordUT_NSRDB**		Country	**United States**
Situation	Latitude	38.41° N	Longitude	-113.02° W
Time defined as	Legal Time	Time zone UT-7	Altitude	0 m
	Albedo	0.20		
Meteo data:	**MilfordUT_NSRDB**	NREL: TMY3 hourly DB (1991-2005) - TMY		

Simulation variant :	**MilfordUT_SAT**			
	Simulation date	23/06/20 14h56		

Simulation parameters	System type	**Trackers single array, with backtracking**		
Tracking plane, tilted axis	Axis Tilt	0°	Axis azimuth	0°
Rotation Limitations	Minimum Phi	-60°	Maximum Phi	60°
	Tracking algorithm	Irradiance optimization		
Backtracking strategy	Nb. of trackers	100	Single array	
	Tracker Spacing	10.00 m	Collector width	4.26 m
Inactive band	Left	0.02 m	Right	0.02 m
Backtracking limit angle	Phi limits	+/- 79.9°	Ground Cov. Ratio (GCR)	42.6%
Models used	Transposition	Perez	Diffuse	Imported
			Circumsolar	separate
Horizon	Average Height	3.0°		
Near Shadings	Linear shadings			
User's needs :	Unlimited load (grid)			

PV Array Characteristics					
PV module	Si-poly	Model	**CS3W-400P HE**		
Custom parameters definition		Manufacturer	Canadian Solar Inc.		
Number of PV modules		In series	28 modules	In parallel	488 strings
Total number of PV modules		nb. modules	13664	Unit Nom. Power	400 Wp
Array global power		Nominal (STC)	**5466 kWp**	At operating cond.	4961 kWp (50°C)
Array operating characteristics (50°C)		U mpp	982 V	I mpp	5049 A
Total area		Module area	**30186 m²**	Cell area	27114 m²
Inverter		Model	**Solar Ware 840 - PVU-L0840ER(PRERELEASE)**		
Custom parameters definition		Manufacturer	TMEIC		
Characteristics		Unit Nom. Power	**840 kWac**	Oper. Voltage	915-1300 V
Inverter pack		Total power	**4200 kWac**	Pnom ratio	1.30
		Nb. of inverters	5 units		
Total		Total power	**4200 kWac**	Pnom ratio	1.30

PV Array loss factors				
Array Soiling Losses			Loss Fraction	2.0 %
Thermal Loss factor	Uc (const)	25.0 W/m²K	Uv (wind)	1.2 W/m²K / m/s
Wiring Ohmic Loss	Global array res.	3.2 mΩ	Loss Fraction	1.5 % at STC
LID - Light Induced Degradation			Loss Fraction	2.0 %
Module Quality Loss			Loss Fraction	-0.5 %
Module mismatch losses			Loss Fraction	2.0 % at MPP
Strings Mismatch loss			Loss Fraction	0.10 %

Grid-Connected System: Simulation parameters

Incidence effect (IAM): User defined profile

10°	20°	30°	40°	50°	60°	70°	80°	90°
1.000	1.000	1.000	0.990	0.990	0.970	0.920	0.760	0.000

System loss factors

AC wire loss inverter to transfo	Inverter voltage	630 Vac tri		
	Wires: 3 x 4000 mm²	1 m	Loss Fraction	0.0 % at STC

MV transfo	Grid Voltage	34.5 kV		
One MV transfo				
Operating losses at STC	Iron loss (24/24 Connexion)	10.73 kW	Loss Fraction	0.2 % at STC
	Copper (resistive) loss	3 x 1.03 mΩ	Loss Fraction	1.4 % at STC

Grid-Connected System: Horizon definition

Project : **Pacificorp20-MilfordUT**

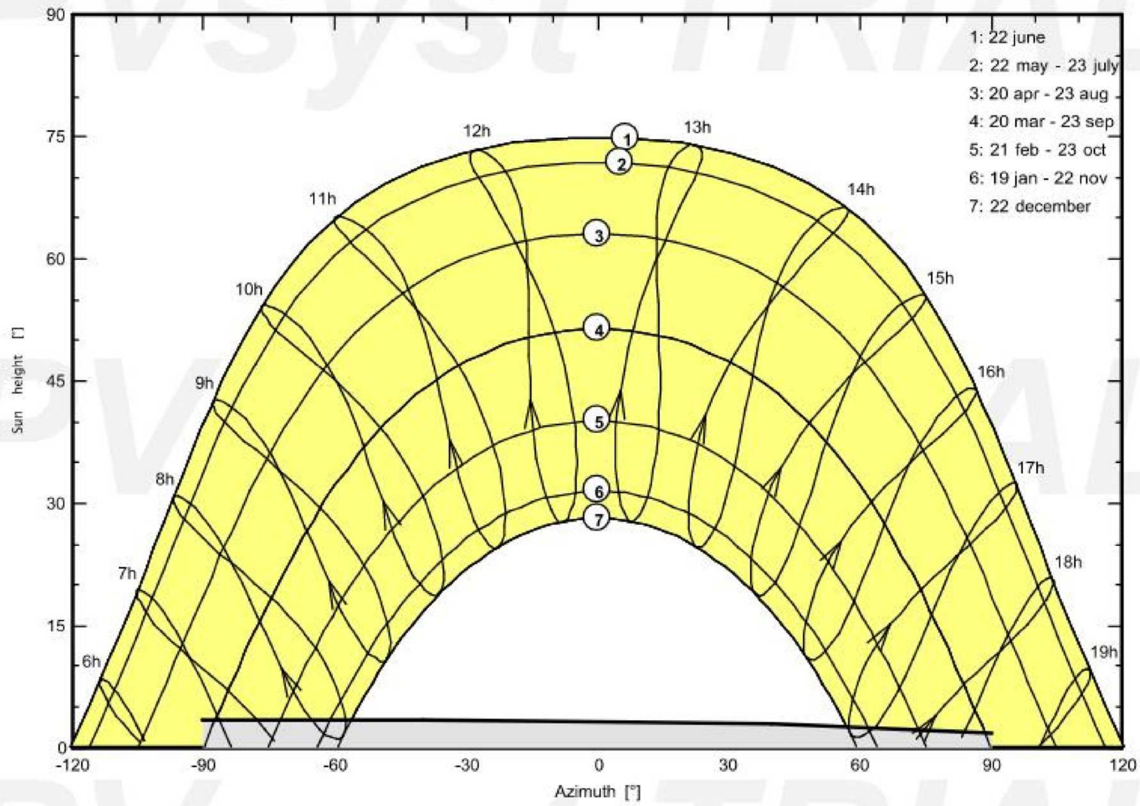
Simulation variant : **MilfordUT_SAT**

Main system parameters	System type	**Trackers single array, with backtracking**		
Horizon	Average Height	3.0°		
Near Shadings	Linear shadings			
PV Field Orientation	tracking, tilted axis, Axis Tilt	0°	Axis azimuth	0°
PV modules	Model	CS3W-400P HE	Pnom	400 Wp
PV Array	Nb. of modules	13664	Pnom total	**5466 kWp**
Inverter	Solar Ware 840 - PVU-L0840ER(PRERELEASE)		Pnom	840 kW ac
Inverter pack	Nb. of units	5.0	Pnom total	**4200 kW ac**
User's needs	Unlimited load (grid)			

Horizon	Average Height	3.0°	Diffuse Factor	0.98
	Albedo Factor	100%	Albedo Fraction	0.94

Height [°]	3.4	3.4	2.9	1.8
Azimuth [°]	-90	-40	40	90

Horizon line at MilfordUT_NSRDB



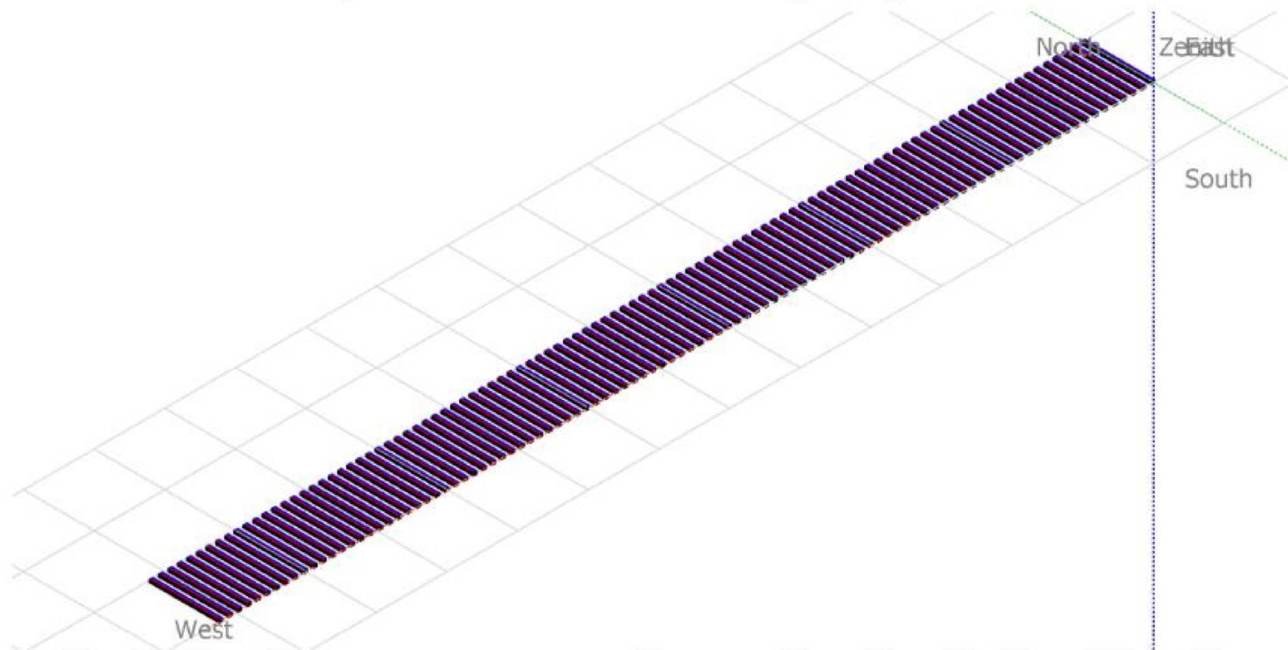
Grid-Connected System: Near shading definition

Project : **Pacificorp20-MilfordUT**

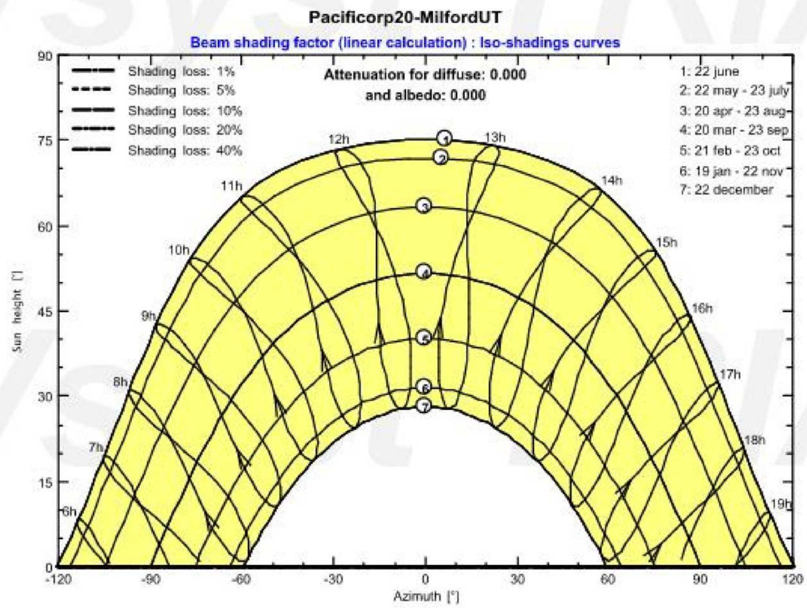
Simulation variant : **MilfordUT_SAT**

Main system parameters	System type	**Trackers single array, with backtracking**		
Horizon	Average Height	3.0°		
Near Shadings	Linear shadings			
PV Field Orientation	tracking, tilted axis, Axis Tilt	0°	Axis azimuth	0°
PV modules	Model	CS3W-400P HE	Pnom	400 Wp
PV Array	Nb. of modules	13664	Pnom total	**5466 kWp**
Inverter	Solar Ware 840 - PVU-L0840ER(PRERELEASE)		Pnom	840 kW ac
Inverter pack	Nb. of units	5.0	Pnom total	**4200 kW ac**
User's needs	Unlimited load (grid)			

Perspective of the PV-field and surrounding shading scene



Iso-shadings diagram



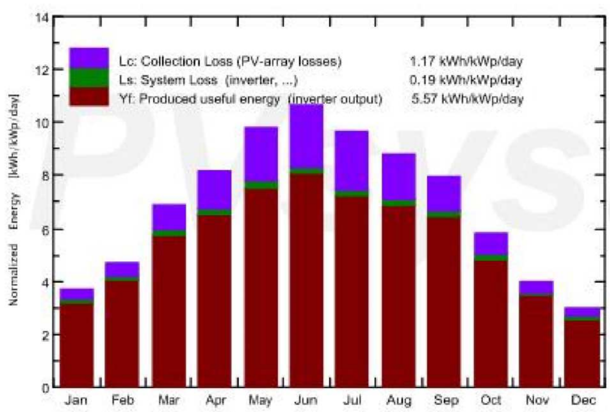
Grid-Connected System: Main results

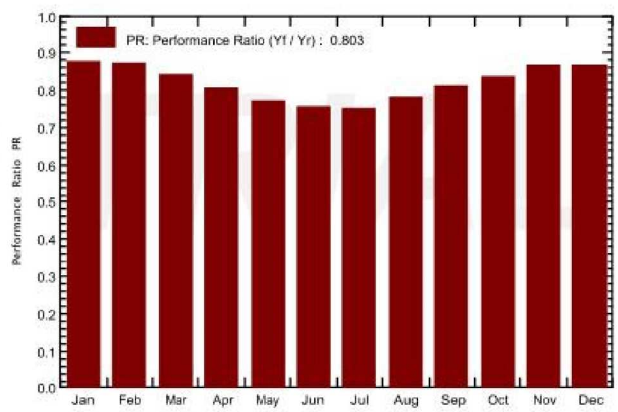
Project : **Pacificorp20-MilfordUT**

Simulation variant : **MilfordUT_SAT**

Main system parameters	System type	**Trackers single array, with backtracking**		
Horizon	Average Height	3.0°		
Near Shadings	Linear shadings			
PV Field Orientation	tracking, tilted axis, Axis Tilt	0°	Axis azimuth	0°
PV modules	Model	CS3W-400P HE	Pnom	400 Wp
PV Array	Nb. of modules	13664	Pnom total	**5466 kWp**
Inverter	Solar Ware 840 - PVU-L0840ER(PRERELEASE)		Pnom	840 kW ac
Inverter pack	Nb. of units	5.0	Pnom total	**4200 kW ac**
User's needs	Unlimited load (grid)			

Main simulation results				
System Production	**Produced Energy**	**11113 MWh/year**	Specific prod.	2033 kWh/kWp/year
	Performance Ratio PR	80.32 %		





MilfordUT_SAT

Balances and main results

	GlobHor kWh/m²	**DiffHor** kWh/m²	**T_Amb** °C	**GlobInc** kWh/m²	**GlobEff** kWh/m²	**EArray** MWh	**E_Grid** MWh	**PR** ratio
January	83.0	25.95	-1.63	114.6	105.9	571	549	0.876
February	97.2	34.43	0.96	130.7	122.0	647	623	0.872
March	158.1	47.64	2.97	213.0	200.6	1014	980	0.841
April	188.5	62.38	7.14	244.2	231.0	1113	1076	0.806
May	233.1	62.75	15.67	303.5	288.3	1323	1281	0.772
June	243.9	56.57	19.11	320.3	304.5	1365	1322	0.755
July	230.2	57.42	23.97	299.1	284.3	1269	1229	0.752
August	207.6	52.71	23.16	274.0	260.1	1204	1166	0.778
September	175.2	38.23	15.35	238.3	225.7	1093	1057	0.812
October	132.0	32.68	11.70	180.3	168.9	851	822	0.835
November	86.8	26.42	1.58	120.3	111.6	591	568	0.865
December	67.8	23.58	-1.75	93.4	85.6	461	442	0.865
Year	1903.4	520.77	9.92	2531.7	2388.6	11502	11113	0.803

Legends:			
GlobHor	Global horizontal irradiation	GlobEff	Effective Global, corr. for IAM and shadings
DiffHor	Horizontal diffuse irradiation	EArray	Effective energy at the output of the array
T_Amb	T amb.	E_Grid	Energy injected into grid
GlobInc	Global incident in coll. plane	PR	Performance Ratio

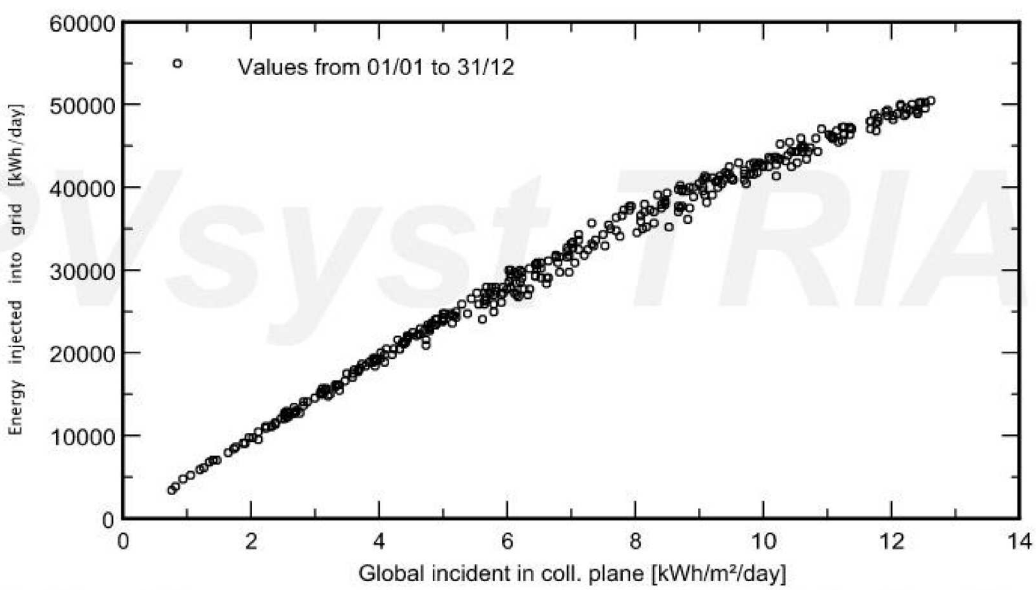
Grid-Connected System: Special graphs

Project : **Pacificorp20-MilfordUT**

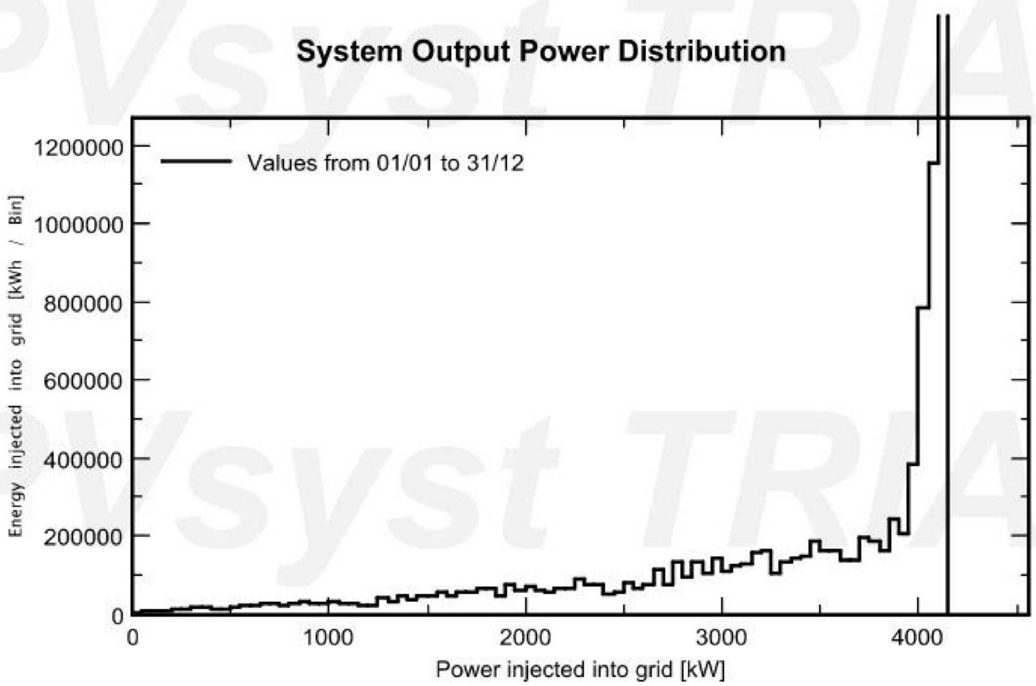
Simulation variant : **MilfordUT_SAT**

Main system parameters	System type	**Trackers single array, with backtracking**		
Horizon	Average Height	3.0°		
Near Shadings	Linear shadings			
PV Field Orientation	tracking, tilted axis, Axis Tilt	0°	Axis azimuth	0°
PV modules	Model	CS3W-400P HE	Pnom	400 Wp
PV Array	Nb. of modules	13664	Pnom total	**5466 kWp**
Inverter	Solar Ware 840 - PVU-L0840ER(PRERELEASE)		Pnom	840 kW ac
Inverter pack	Nb. of units	5.0	Pnom total	**4200 kW ac**
User's needs	Unlimited load (grid)			

Daily Input/Output diagram



System Output Power Distribution



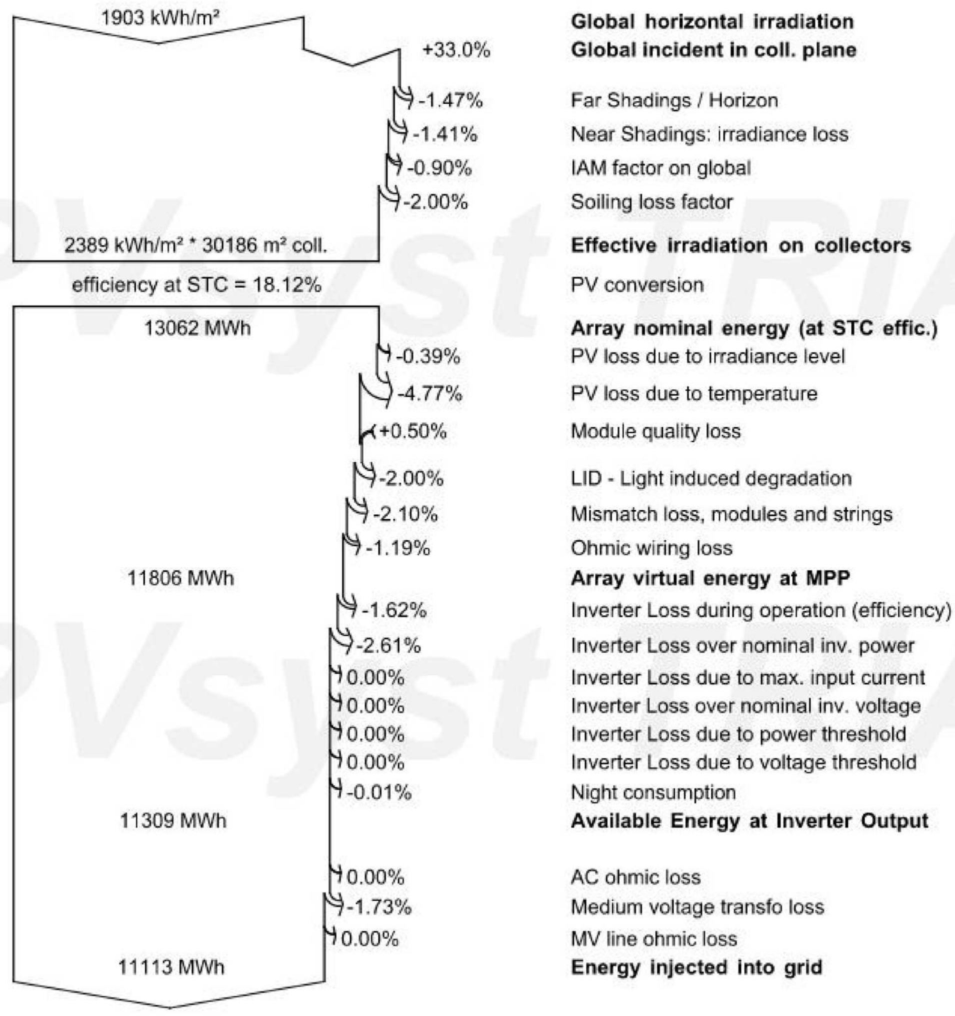
Grid-Connected System: Loss diagram

Project : **Pacificorp20-MilfordUT**

Simulation variant : **MilfordUT_SAT**

Main system parameters	System type	**Trackers single array, with backtracking**		
Horizon	Average Height	3.0°		
Near Shadings	Linear shadings			
PV Field Orientation	tracking, tilted axis, Axis Tilt	0°	Axis azimuth	0°
PV modules	Model	CS3W-400P HE	Pnom	400 Wp
PV Array	Nb. of modules	13664	Pnom total	**5466 kWp**
Inverter	Solar Ware 840 - PVU-L0840ER(PRERELEASE)		Pnom	840 kW ac
Inverter pack	Nb. of units	5.0	Pnom total	**4200 kW ac**
User's needs	Unlimited load (grid)			

Loss diagram over the whole year



BURNS & McDONNELL

Energy Production Summary

Burns & McDonnell, Energy Division

Project Name: **Pacificorp 2020 Renewables Technology Assessment**

Variant: VC0

Date: 26-Jun-20

Site Information	
City / State:	Lakeview, OR
Latitude (N):	42.17 °
Longitude (W):	-120.4 °
Altitude	1441 m
ASHRAE Cooling DB Temp.	32.2 °C
ASHRAE Extreme Mean Min. Temp.	-22.6 °C

Estimated Annual Energy Production	
P50 net production (yr-1)	241986.6 MWh
AC capacity factor - Inv Rating	27.62%
AC capacity factor - POI Rating	27.62%
DC capacity factor	21.23%
Specific Production	1860 kWh/kWp/yr
Performance Ratio PR	81.15%
Night time losses	-407.2 MWh
Plant Output Limitations	0.00%

Design Parameters	
System DC Voltage	1500 VDC
GCR	42.6 %
Row spacing	10 m
Mounting	Tracker
Tilt angle or rotation limits	60 °
Azimuth	0 °
Tracking strategy	TRUE
Availability	100.0 %
Degradation	0.5 %/yr

Facility Level Information	
Nameplate Capacity	**130.13 MWDC**
Number of modules	325333
Nameplate Capacity	**100.00 MWAC**
Number of arrays	24
Interconnection Limit	**100.00 MWAC**
Inteconnection Voltage	34.5 kV
DC/AC ratio - POI Rating	1.301

Array Level Information	
Module rating	400 W
# Modules per string	28
Strings in parallel	488
Total number of modules	13664
DC capacity	5466 kW
Inverter rating	4200 kW
DC/AC ratio - Inv Rating	1.301

Weather	
Source	TMY3
GHI	1704.3 kWh/m2
DHI	kWh/m2
Global POA	2287.5 kWh/m2
Average Temp.	7.87 °C
Average Temp. (Generation)	12.45 °C
Average Wind	3.33 m/s
Average Wind (Generation)	3.61 m/s

PVsyst Input Parameters	
Transposition model	Perez
Constant thermal loss factor (Uc)	25.0 W/m2-K
Wind loss factor (Uv)	1.2 W/m2-K/m/s
Soiling losses	2.2 %
Light induced degradation	2.0 %
DC wiring loss	1.5 %
Module quality loss	-0.4 %
Module mismatch loss	1.0 %
DC health loss	1.0 %

AC System Losses	
MV transformer no-load losses	0.00%
MV transformer full load losses	0.00%
MV collection system	1.30%
HV transformer no-load losses	0.07%
HV transformer full load losses	0.48%
HV line	0.05%
Auxiliary	0.01%

Energy Production Summary

Burns & McDonnell, Energy Division

Project Name: **Pacificorp 2020 Renewables Technology Assessment**

Variant: VC0 Date: 26-Jun-20

Site Information	
City / State:	Lakeview, OR
Latitude (N):	42.17 °
Longitude (W):	-120.4 °
Altitude	1441 m
ASHRAE Cooling DB Temp.	32.2 °C
ASHRAE Extreme Mean Min. Temp.	-22.6 °C

Design Parameters	
System DC Voltage	1500 VDC
GCR	42.6 %
Row spacing	10 m
Mounting	Tracker
Tilt angle or rotation limits	60 °
Azimuth	0 °
Tracking strategy	TRUE
Availability	100.0 %
Degradation	0.5 %/yr

Array Level Information	
Module rating	400 W
# Modules per string	28
Strings in parallel	488
Total number of modules	13664
DC capacity	5466 kW
Inverter rating	4200 kW
DC/AC ratio - Inv Rating	1.301

PVsyst Input Parameters	
Transposition model	Perez
Constant thermal loss factor (Uc)	25.0 W/m2-K
Wind loss factor (Uv)	1.2 W/m2-K/m/s
Soiling losses	2.2 %
Light induced degradation	2.0 %
DC wiring loss	1.5 %
Module quality loss	-0.4 %
Module mismatch loss	1.0 %
DC health loss	1.0 %

Estimated Annual Energy Production	
P50 net production (yr-1)	483973.1 MWh
AC capacity factor - Inv Rating	27.62%
AC capacity factor - POI Rating	27.62%
DC capacity factor	21.23%
Specific Production	1860 kWh/kWp/yr
Performance Ratio PR	81.15%
Night time losses	-814.4 MWh
Plant Output Limitations	0.00%

Facility Level Information	
Nameplate Capacity	**260.27 MWDC**
Number of modules	650667
Nameplate Capacity	**200.00 MWAC**
Number of arrays	48
Interconnection Limit	**200.00 MWAC**
Inteconnection Voltage	34.5 kV
DC/AC ratio - POI Rating	1.301

Weather	
Source	TMY3
GHI	1704.3 kWh/m2
DHI	kWh/m2
Global POA	2287.5 kWh/m2
Average Temp.	7.87 °C
Average Temp. (Generation)	12.45 °C
Average Wind	3.33 m/s
Average Wind (Generation)	3.61 m/s

AC System Losses	
MV transformer no-load losses	0.00%
MV transformer full load losses	0.00%
MV collection system	1.30%
HV transformer no-load losses	0.07%
HV transformer full load losses	0.48%
HV line	0.05%
Auxiliary	0.01%

BURNS & McDONNELL

Energy Production Summary

Burns & McDonnell, Energy Division

Project Name: **Pacificorp 2020 Renewables Technology Assessment**

Variant: VC0 Date: 26-Jun-20

Site Information		
City / State:	Milford, UT	
Latitude (N):	38.41	°
Longitude (W):	-113.02	°
Altitude	0	m
ASHRAE Ext. Max Mean Temp	38.1	°C
ASHRAE 99.6% Heating DB	-19.8	°C

Estimated Annual Energy Production		
P50 net production (yr-1)	264852.0	MWh
AC capacity factor - Inv Rating	30.23%	
AC capacity factor - POI Rating	30.23%	
DC capacity factor	23.23%	
Specific Production	2035	kWh/kWp/yr
Performance Ratio PR	80.39%	
Night time losses	-398.3	MWh
Plant Output Limitations	0.00%	

Design Parameters		
System DC Voltage	1500	VDC
GCR	42.6	%
Row spacing	10	m
Mounting	Tracker	
Tilt angle or rotation limits	60	°
Azimuth	0	°
Tracking strategy	TRUE	
Availability	100.0	%
Degradation	0.5	%/yr

Facility Level Information		
Nameplate Capacity	**130.13**	**MWDC**
Number of modules	325333	
Nameplate Capacity	**100.00**	**MWAC**
Number of arrays	24	
Interconnection Limit	**100.00**	**MWAC**
Inteconnection Voltage	34.5	kV
DC/AC ratio - POI Rating	1.301	

Array Level Information		
Module rating	400	W
# Modules per string	28	
Strings in parallel	488	
Total number of modules	13664	
DC capacity	5466	kW
Inverter Rating	4200	kW
DC/AC ratio - Inv Rating	1.301	

Weather		
Source	TMY3	
GHI	1903.4	kWh/m2
DHI		kWh/m2
Global POA	2531.7	kWh/m2
Average Temp.	9.92	°C
Average Temp. (Generation)	14.87	°C
Average Wind	2.11	m/s
Average Wind (Generation)	2.81	m/s

PVsyst Input Parameters		
Transposition model	Perez	
Constant thermal loss factor (Uc)	25.0	W/m2-K
Wind loss factor (Uv)	1.2	W/m2-K/m/s
Soiling losses*	2.0	%
Light induced degradation	2.0	%
DC wiring loss	1.5	%
Module quality loss	-0.5	%
Module mismatch loss	1.0	%
DC health loss	1.0	%
Albedo*	1.0	%

AC System Losses	
MV transformer no-load losses	0.00%
MV transformer full load losses	0.00%
MV collection system	1.30%
HV transformer no-load losses	0.07%
HV transformer full load losses	0.48%
HV line	0.05%
Auxiliary	0.01%

BURNS & McDONNELL

Energy Production Summary

Burns & McDonnell, Energy Division

Project Name: **Pacificorp 2020 Renewables Technology Assessment**

Variant: VC0 Date: 26-Jun-20

Site Information	
City / State:	Milford, UT
Latitude (N):	38.41 °
Longitude (W):	-113.02 °
Altitude	0 m
ASHRAE Ext. Max Mean Temp	38.1 °C
ASHRAE 99.6% Heating DB	-19.8 °C

Design Parameters	
System DC Voltage	1500 VDC
GCR	42.6 %
Row spacing	10 m
Mounting	Tracker
Tilt angle or rotation limits	60 °
Azimuth	0 °
Tracking strategy	TRUE
Availability	100.0 %
Degradation	0.5 %/yr

Array Level Information	
Module rating	400 W
# Modules per string	28
Strings in parallel	488
Total number of modules	13664
DC capacity	5466 kW
Inverter Rating (Max Temp & 95% pf)	4200 kW
DC/AC ratio - Inv Rating	1.301

PVsyst Input Parameters	
Transposition model	Perez
Constant thermal loss factor (Uc)	25.0 W/m2-K
Wind loss factor (Uv)	1.2 W/m2-K/m/s
Soiling losses*	2.0 %
Light induced degradation	2.0 %
DC wiring loss	1.5 %
Module quality loss	-0.5 %
Module mismatch loss	1.0 %
DC health loss	1.0 %
Albedo*	1.0 %

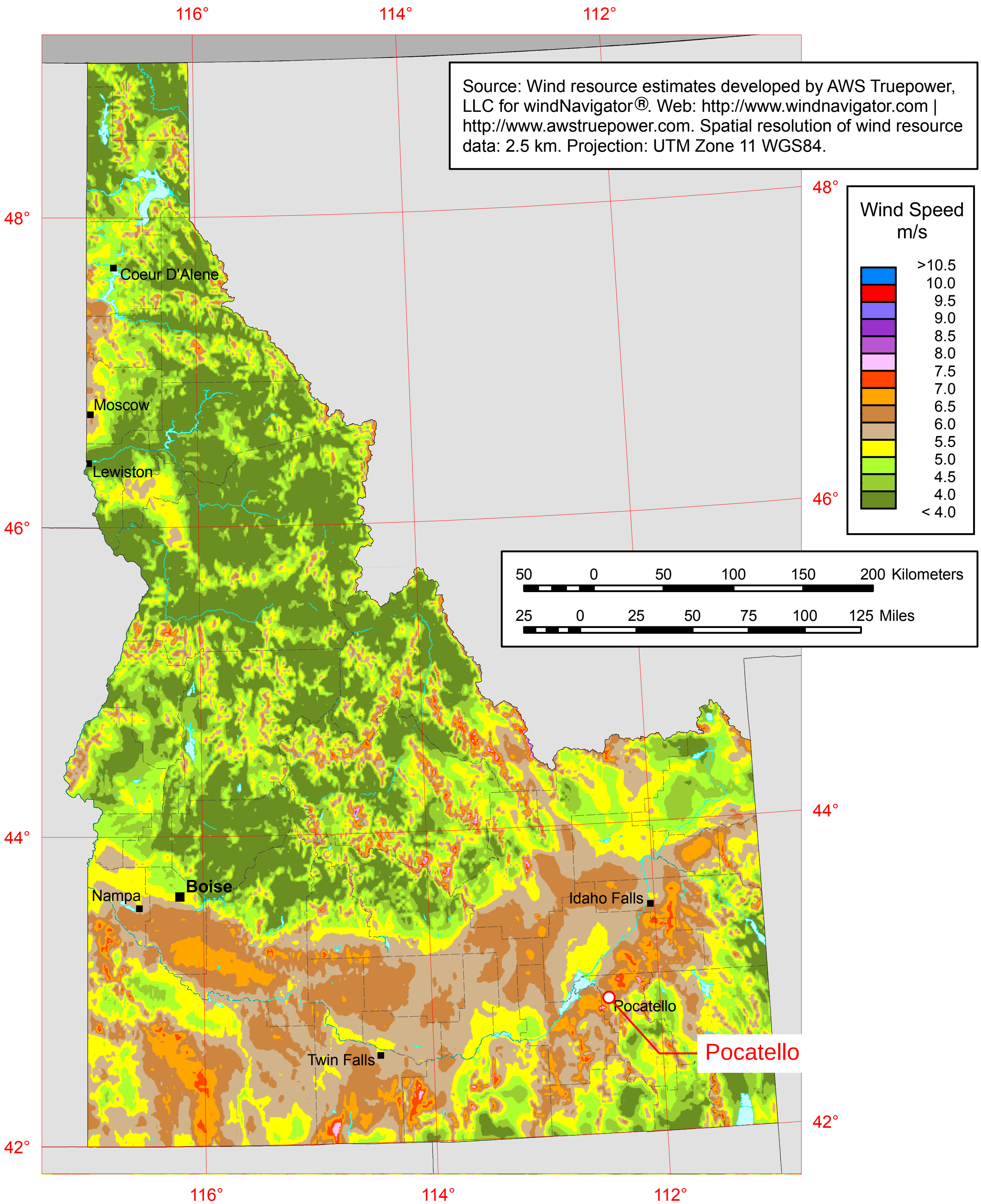
Estimated Annual Energy Production	
P50 net production (yr-1)	529704.0 MWh
AC capacity factor - Inv Rating	30.23%
AC capacity factor - POI Rating	30.23%
DC capacity factor	23.23%
Specific Production	2035 kWh/kWp/yr
Performance Ratio PR	80.39%
Night time losses	-796.6 MWh
Plant Output Limitations	0.00%

Facility Level Information	
Nameplate Capacity	**260.27 MWDC**
Number of modules	650667
Nameplate Capacity	**200.00 MWAC**
Number of arrays	48
Interconnection Limit	**200.00 MWAC**
Inteconnection Voltage	230 kV
DC/AC ratio - POI Rating	1.301

Weather	
Source	TMY3
GHI	1903.4 kWh/m2
DHI	kWh/m2
Global POA	2531.7 kWh/m2
Average Temp.	9.92 °C
Average Temp. (Generation)	14.87 °C
Average Wind	2.11 m/s
Average Wind (Generation)	2.81 m/s

AC System Losses	
MV transformer no-load losses	0.00%
MV transformer full load losses	0.00%
MV collection system	1.30%
HV transformer no-load losses	0.07%
HV transformer full load losses	0.48%
HV line	0.05%
Auxiliary	0.01%

Idaho - Annual Average Wind Speed at 80 m



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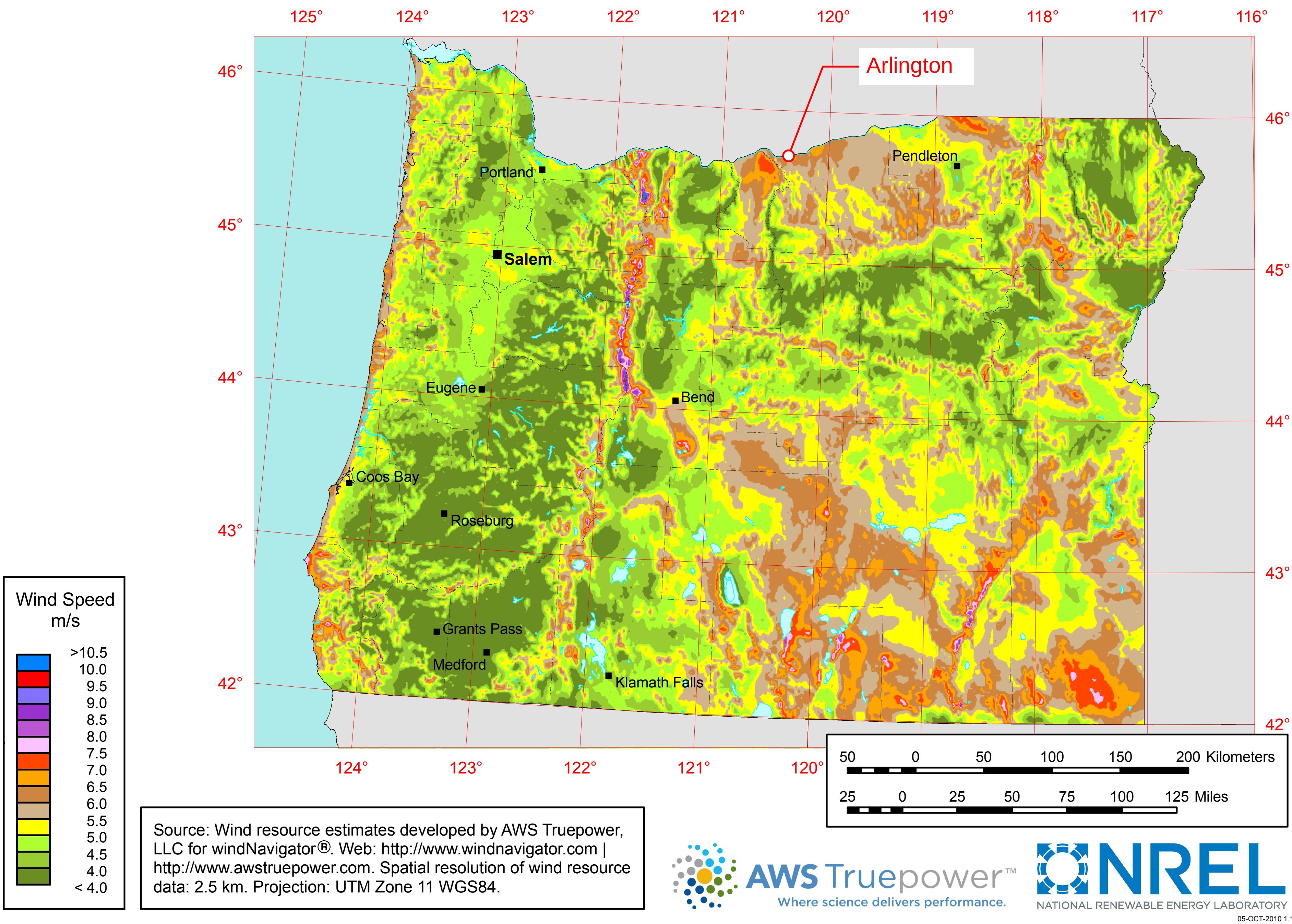
NREL
NATIONAL RENEWABLE ENERGY LABORATORY

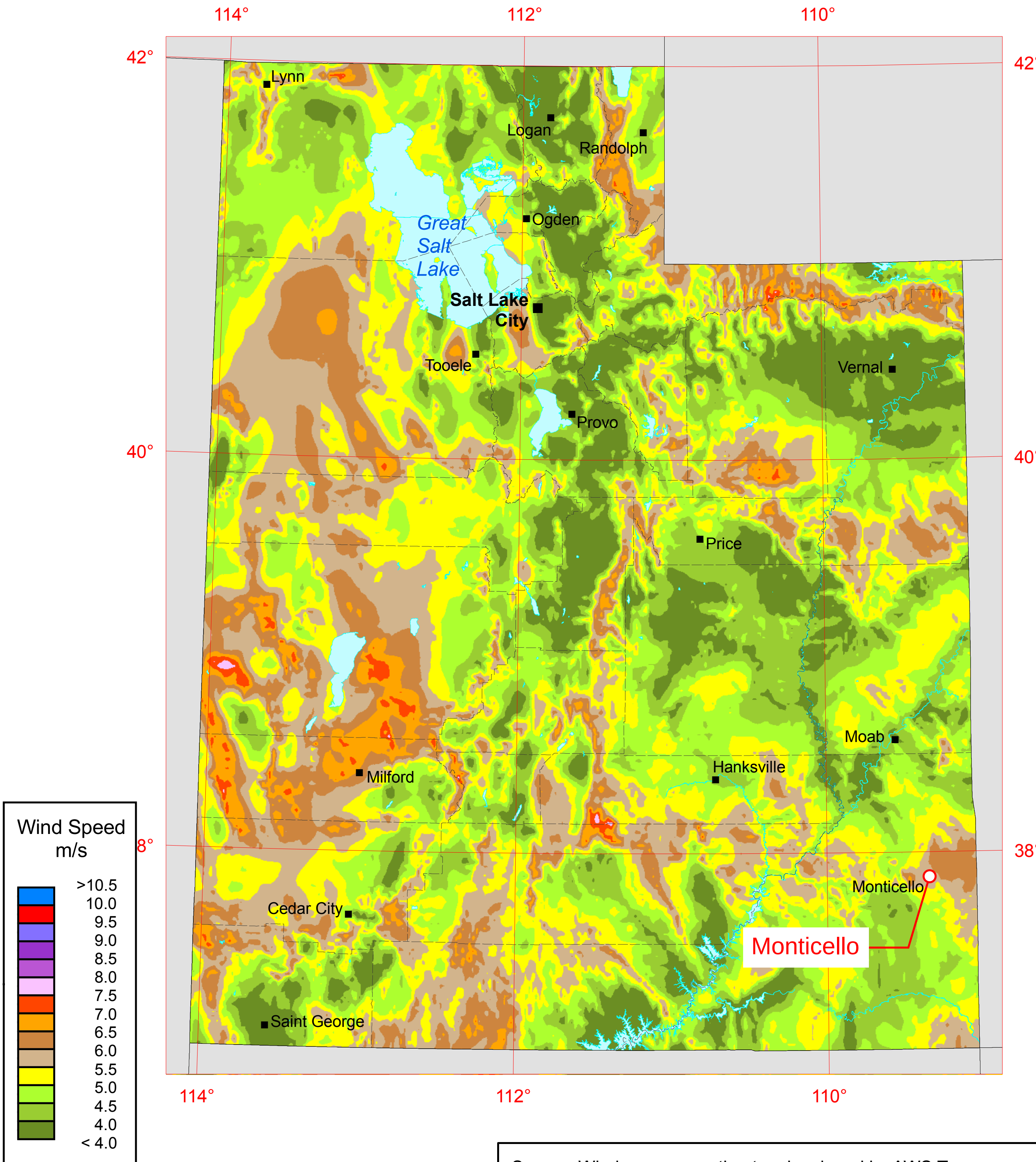
06-OCT-2010 1.1.1

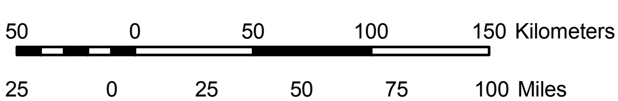
Oregon - Annual Average Wind Speed at 80 m



Source: Wind resource estimates developed by AWS Truepower, LLC for windNavigator®. Web: http://www.windnavigator.com | http://www.awstruepower.com. Spatial resolution of wind resource data: 2.5 km. Projection: UTM Zone 11 WGS84.

Utah - Annual Average Wind Speed at 80 m





Source: Wind resource estimates developed by AWS Truepower, LLC for windNavigator®. Web: http://www.windnavigator.com | http://www.awstruepower.com. Spatial resolution of wind resource data: 2.5 km. Projection: UTM Zone 12 WGS84.

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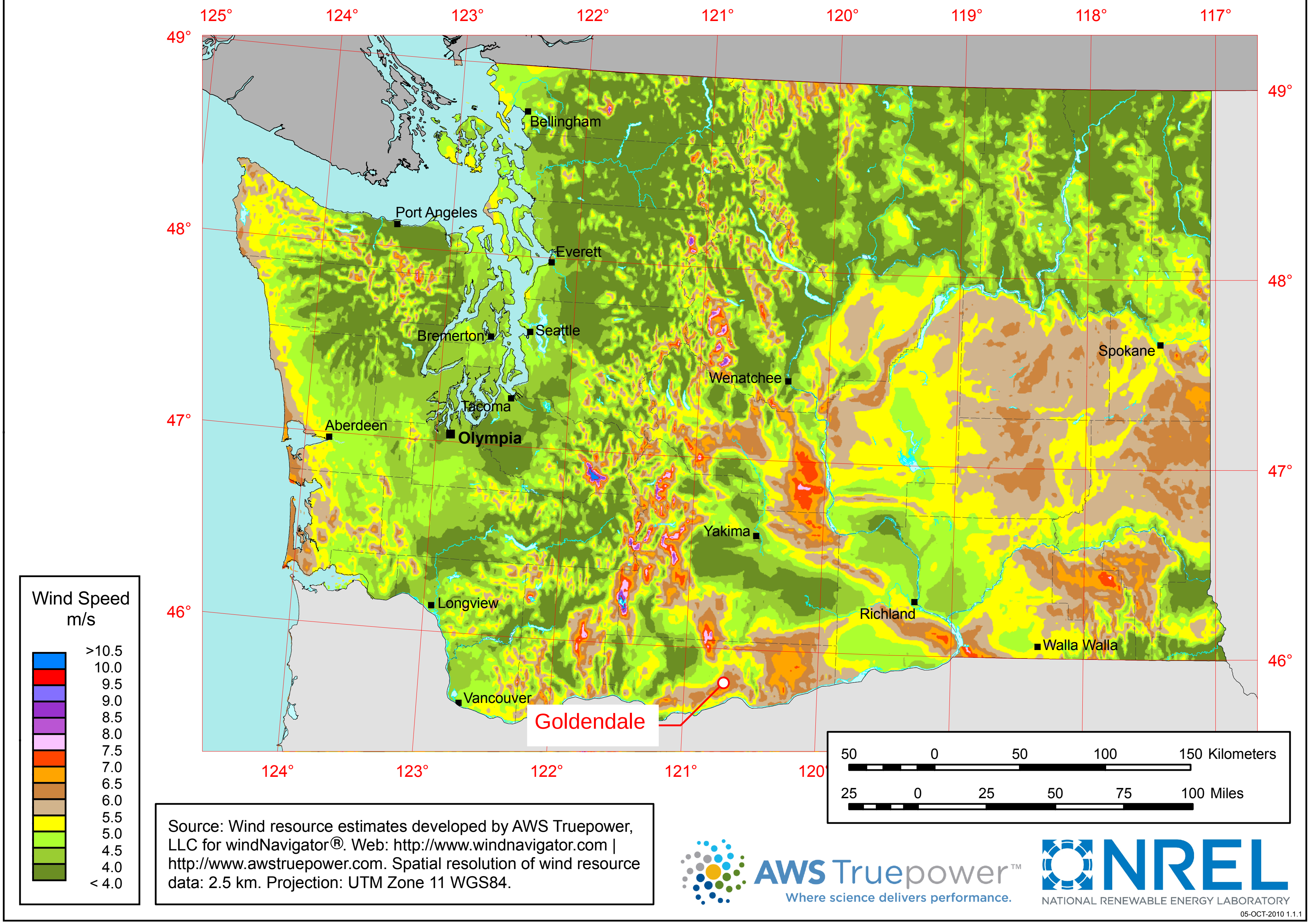
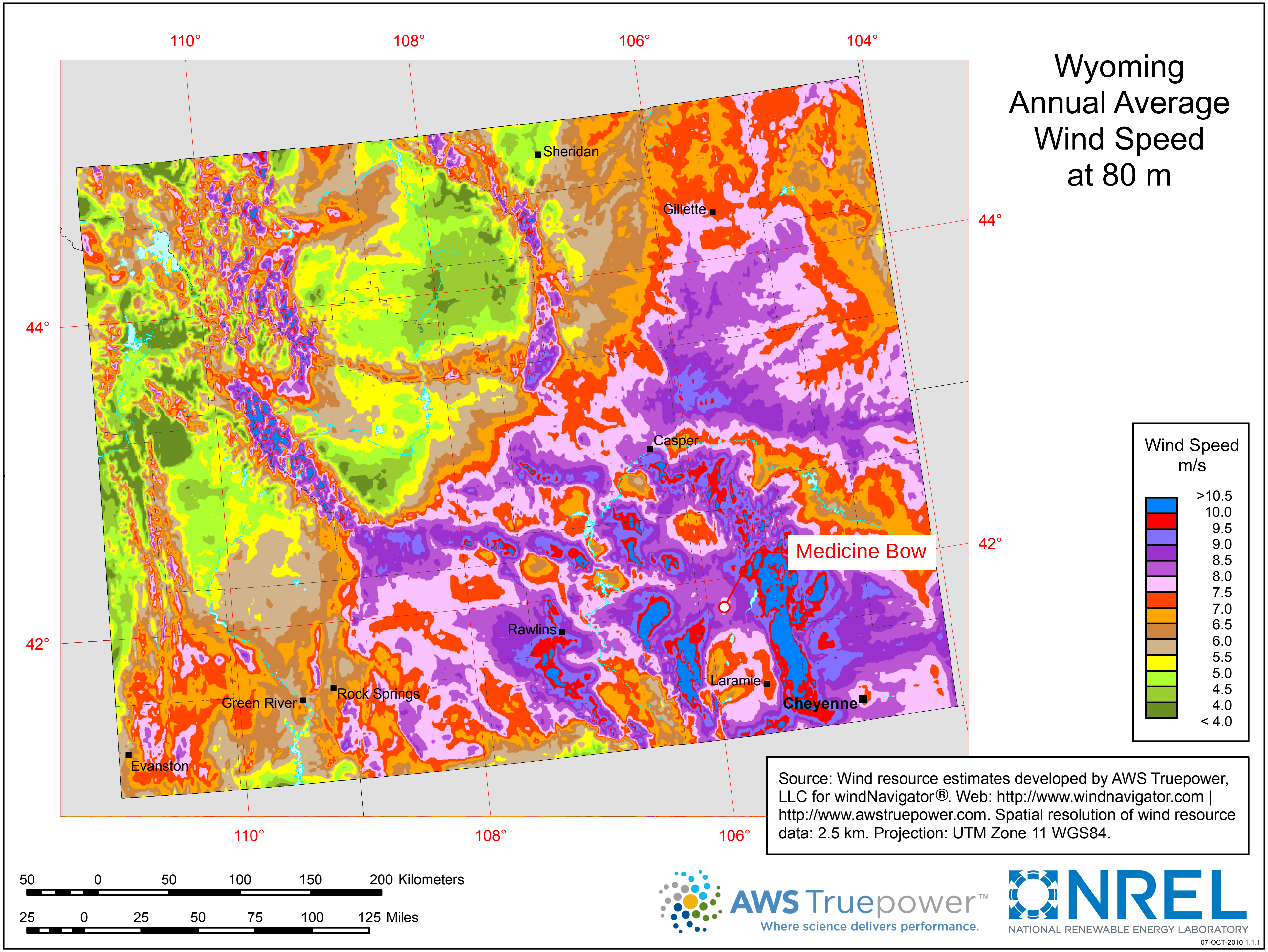
Washington - Annual Average Wind Speed at 80 m



Source: Wind resource estimates developed by AWS Truepower, LLC for windNavigator®. Web: http://www.windnavigator.com | http://www.awstruepower.com. Spatial resolution of wind resource data: 2.5 km. Projection: UTM Zone 11 WGS84.



Wyoming
Annual Average
Wind Speed
at 80 m
110°
108°
106°
104°
44°
42°
Sheridan
Gillette
Casper
Medicine Bow
Rawlins
Laramie
Cheyenne
Rock Springs
Green River
Evanston
Wind Speed
m/s
>10.5
10.0
9.5
9.0
8.5
8.0
7.5
7.0
6.5
6.0
5.5
5.0
4.5
4.0
< 4.0
Source: Wind resource estimates developed by AWS Truepower, LLC for windNavigator®. Web: http://www.windnavigator.com | http://www.awstruepower.com. Spatial resolution of wind resource data: 2.5 km. Projection: UTM Zone 11 WGS84.
50 0 50 100 150 200 Kilometers
25 0 25 50 75 100 125 Miles
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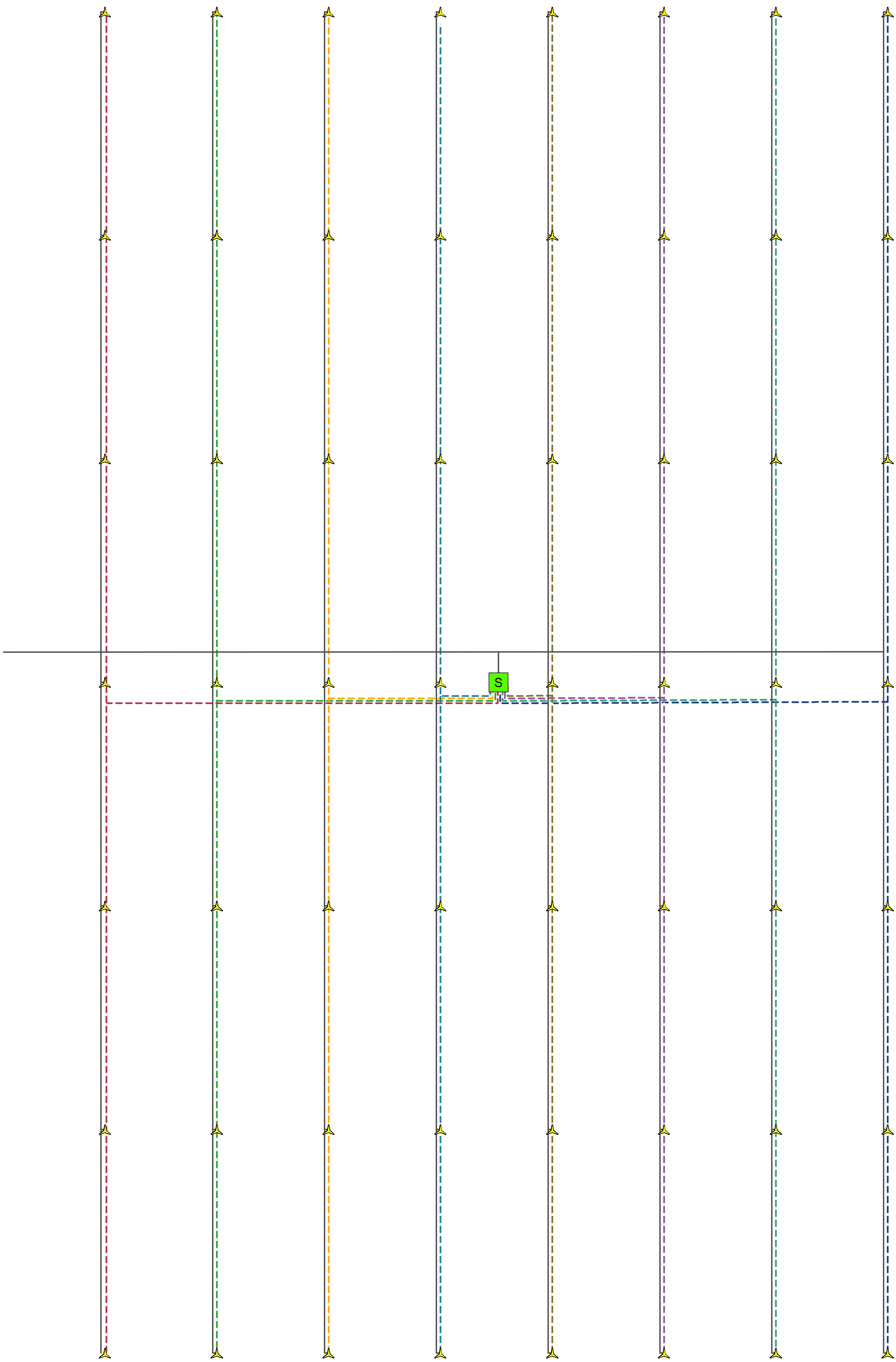
07-OCT-2010 1.1.1



Drawing Notes:
1. Layout is intended to be generic / conceptual and not necessarily representative of a site that would be constructed. Layout based upon generic turbine model with approx. 414m by 828m gridded spacing. Final turbine model, project size, and site conditions will alter layout.

PRELIMINARY
NOT FOR CONSTRUCTION

LEGEND

Proposed Turbine
S Collector Substation
Access Roads

Circuit 1
Circuit 2
Circuit 3
Circuit 4
Circuit 5
Circuit 6
Circuit 7
Circuit 8

REFERENCE

0 500 1,000
Feet

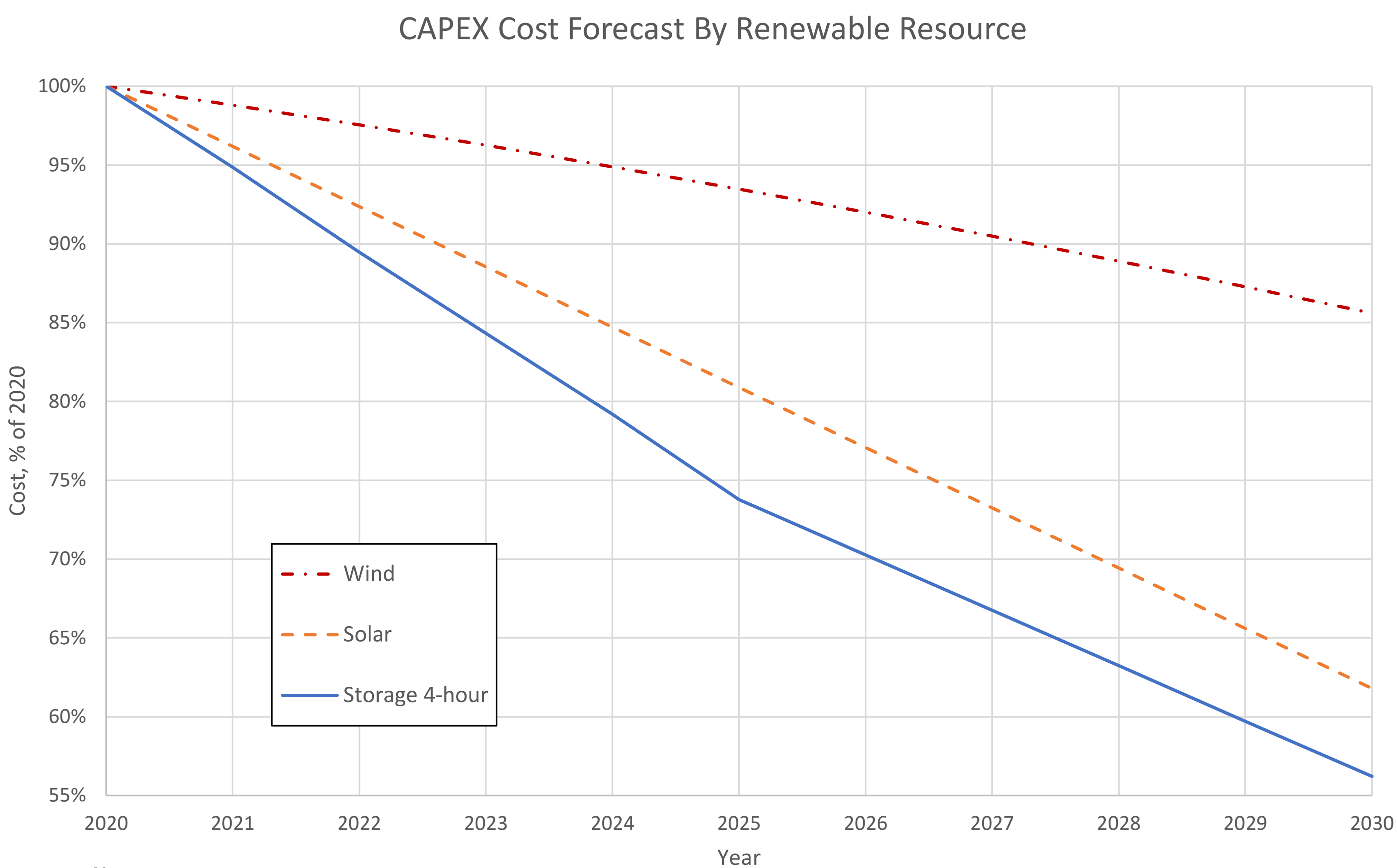
0 100 200
Meters

N

GENERIC SITE LAYOUT
200 MW Wind Farm

LOCATION:	Generic
CLIENT:	Pacificorp
PROJ. NO.:	109571
CREATED:	09/06/2018

BURNS McDONNELL
www.burnsmcd.com



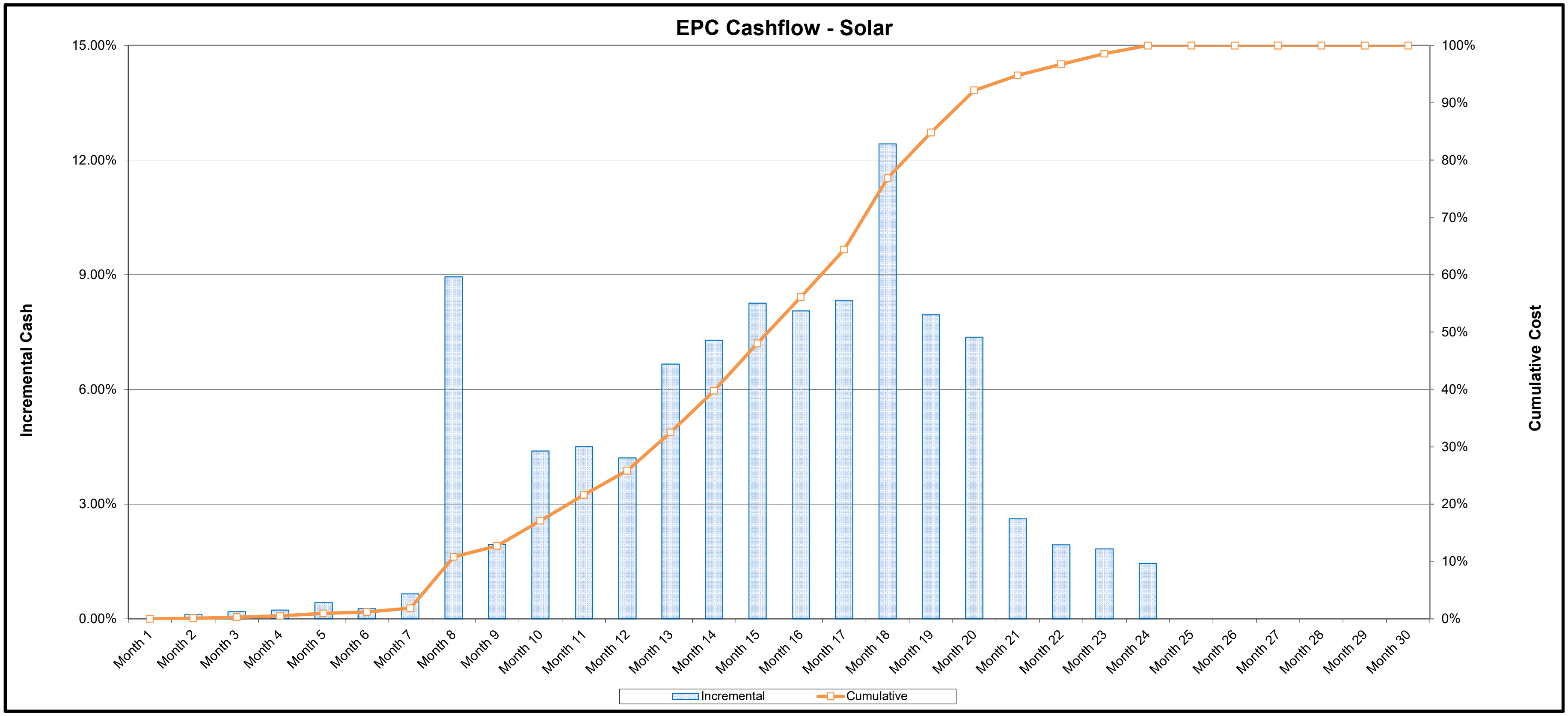
Notes:

1. The declining cost curve for onshore wind was developed using NREL Land-Based Wind Classes (Class) moderate overnight cost inforamtion. The costs for Class 2, Class 6, and Class 8 were averaged to represent the Pacificorp identified sites based on average wind speed.

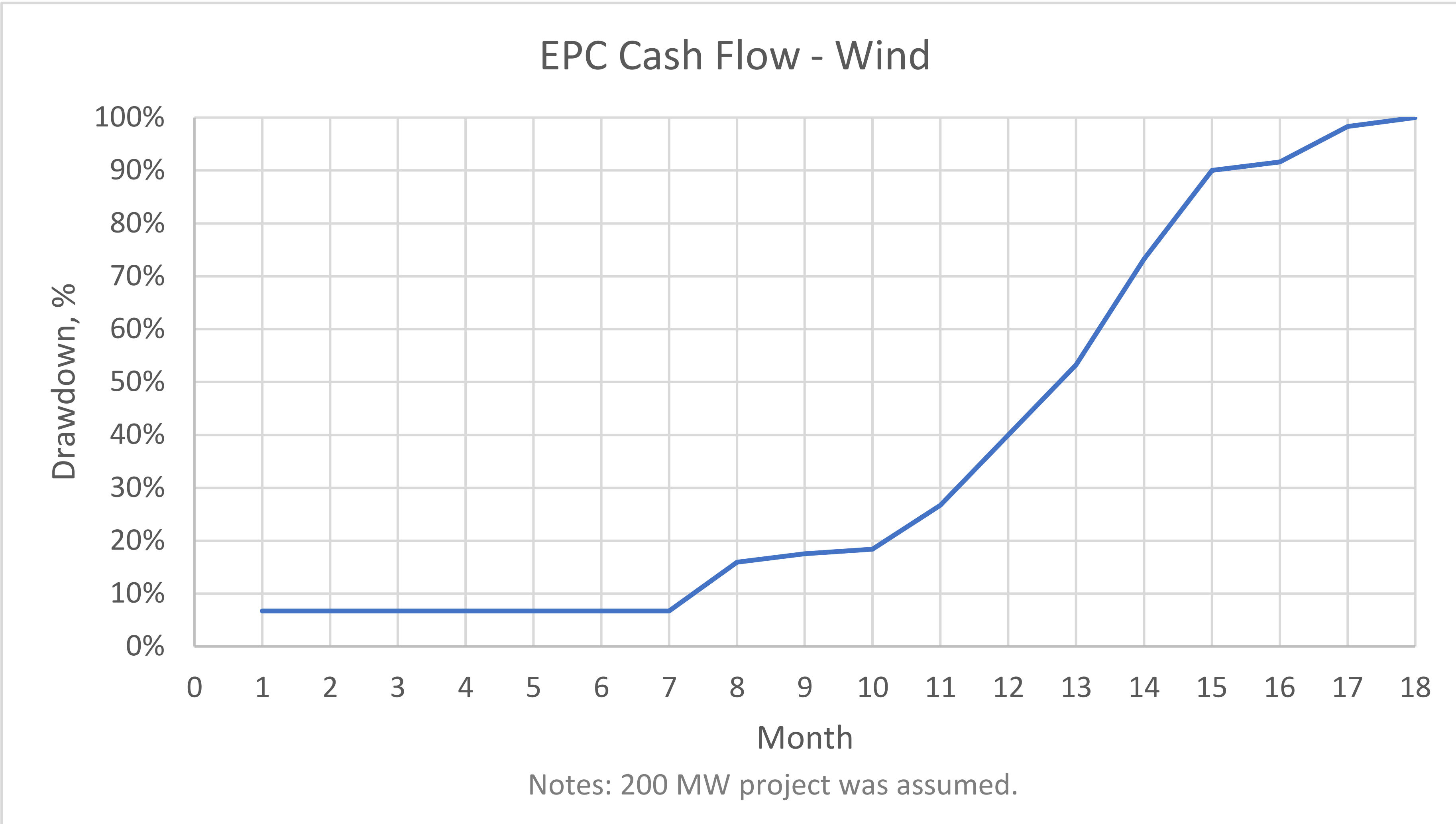
2. The declining cost curve for utility solar photovoltaic was developed using NREL mid overnight cost inforamtion.

3. The declining cost curve for battery storage was developed using NREL mid overnight CAPEX cost information for a storage device with 15-year life and 85% round-trip efficiency for 4- hour storage.

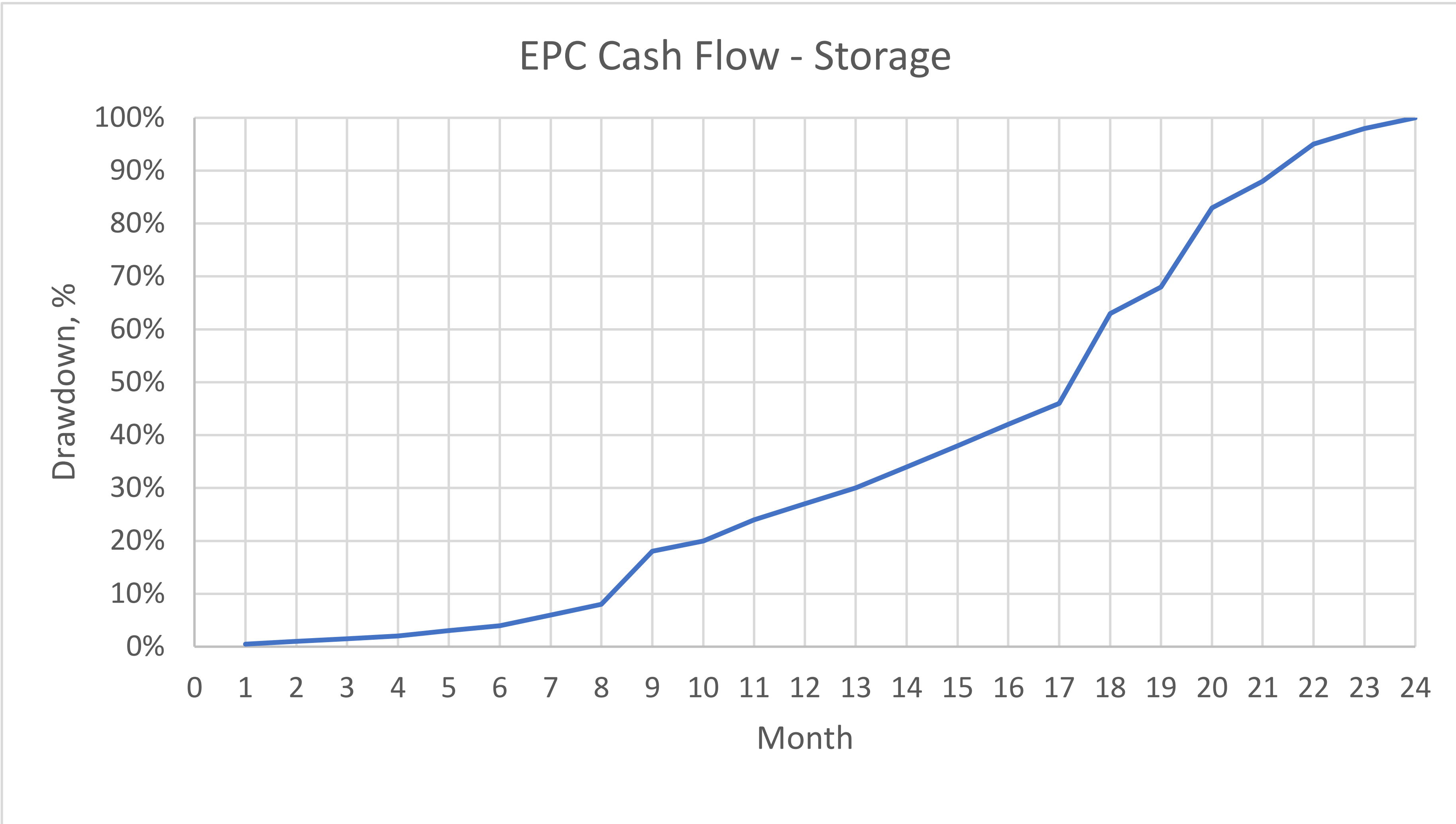
Overnight Cost Forecast ($/kW)											
Technology	**2020**	**2021**	**2022**	**2023**	**2024**	**2025**	**2026**	**2027**	**2028**	**2029**	**2030**
Wind	$1,684.96	$1,664.76	$1,643.66	$1,621.65	$1,598.74	$1,574.92	$1,550.20	$1,524.58	$1,498.05	$1,470.62	$1,442.28
Percentage of 2020	100.00%	98.80%	97.55%	96.24%	94.88%	93.47%	92.00%	90.48%	88.91%	87.28%	85.60%
Solar	$1,324.76	$1,274.15	$1,223.53	$1,172.91	$1,122.30	$1,071.68	$1,021.06	$970.45	$919.83	$869.22	$818.60
Percentage of 2020	100.00%	96.18%	92.36%	88.54%	84.72%	80.90%	77.08%	73.25%	69.43%	65.61%	61.79%
Storage ($/kWh)	$370.00	$351.00	$331.00	$312.00	$293.00	$273.00	$260.00	$247.00	$234.00	$221.00	$208.00
Percentage of 2020	100.00%	94.86%	89.46%	84.32%	79.19%	73.78%	70.27%	66.76%	63.24%	59.73%	56.22%



EPC Cashflow - Solar
Incremental Cash
Cumulative Cost
15.00%
12.00%
9.00%
6.00%
3.00%
0.00%
100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
Month 1
Month 2
Month 3
Month 4
Month 5
Month 6
Month 7
Month 8
Month 9
Month 10
Month 11
Month 12
Month 13
Month 14
Month 15
Month 16
Month 17
Month 18
Month 19
Month 20
Month 21
Month 22
Month 23
Month 24
Month 25
Month 26
Month 27
Month 28
Month 29
Month 30
Incremental
Cumulative



EPC Cash Flow - Wind
Drawdown, %
100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
0
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18
Month
Notes: 200 MW project was assumed.


EPC Cash Flow - Storage
Drawdown, %
100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24
Month

25 - Year Cashflows

200 MW UT Solar

Year:	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25
Capital Cost, $MM:	$ 216.00	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ 11.59	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -
O&M, $MM:	$ -	$ 3.59	$ 3.68	$ 3.77	$ 3.86	$ 3.96	$ 4.06	$ 4.16	$ 4.26	$ 4.37	$ 4.48	$ 4.59	$ 4.71	$ 4.82	$ 4.95	$ 5.07	$ 5.20	$ 5.33	$ 5.46	$ 5.60	$ 5.74	$ 5.88	$ 6.03	$ 6.18	$ 6.33	$ 6.49

200 MW UT Wind

Year:	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25
Capital Cost, $MM:	$ 231.00	$ -	$ -	$ 0.44	$ 0.45	$ 0.46	$ 0.89	$ 0.91	$ 0.93	$ 0.96	$ 0.98	$ 1.67	$ 1.72	$ 1.76	$ 1.80	$ 1.85	$ 1.89	$ 1.94	$ 1.99	$ 2.04	$ 2.09	$ 3.00	$ 3.07	$ 3.15	$ 3.23	$ 3.31
O&M, $MM:	$ -	$ 10.46	$ 10.72	$ 10.98	$ 11.26	$ 11.54	$ 11.83	$ 12.12	$ 12.43	$ 12.74	$ 13.06	$ 13.38	$ 13.72	$ 14.06	$ 14.41	$ 14.77	$ 15.14	$ 15.52	$ 15.91	$ 16.31	$ 16.71	$ 17.13	$ 17.56	$ 18.00	$ 18.45	$ 18.91

50 MW 200 MWh Storage

Year:	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
Capital Cost, $MM:	$ 68.00	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ 4.71	$ -	$ -	$ -	$ -	$ -
O&M, $MM:	$ -	$ 1.41	$ 1.45	$ 1.49	$ 1.52	$ 1.56	$ 1.60	$ 1.64	$ 1.68	$ 1.72	$ 1.77	$ 1.81	$ 1.86	$ 1.90	$ 1.95	$ 2.00	$ 2.05	$ 2.10	$ 2.15	$ 2.21	$ 2.26