Memorandum

To: Board of Directors

From: Steve Kern, System Planning Committee Chair

Date: April 28, 2011

Subject: Report Completed – Capabilities of Electric Power Resources

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PNUCC's System Planning Committee has been plumbing the depths of a significant resource planning issue that has emerged in the Northwest. We recently completed the attached report entitled *Capabilities of Electric Power Resources*, which explains how *capacity* and *flexibility* have become major concerns in planning for new generation. The report also clarifies a vocabulary of terms that is growing up around the issue.

The Northwest's power system was traditionally anchored by hydroelectricity, which provided an abundance of both energy and capacity to meet loads. Hydroelectricity also supplied flexibility, enabling the system to adjust quickly in response to shifts in load. But things have changed.

There has been a huge shift over the past several decades in the region's resource mix. And the recent addition of large quantities of wind power, a variable and non-dispatchable resource that uses system capacity and flexibility, has underscored the need for a new perspective on planning to assure reliability.

Not all resources are created equal when it comes to providing energy, capacity, and flexibility, all of which are key ingredients for reliability. Today, as utilities consider adding new resources to meet load, they are increasingly concerned about the operating characteristics of the available choices and how each would affect the mix on their systems.

I encourage you to take the time to read this report. It is interesting and insightful work that will contribute to the region's discussion and response to significant changes in the planning environment.

Capabilities of Electric Power Resources

PNUCC

System Planning Committee

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Acknowledgements

This paper was developed and reviewed by members of the PNUCC System Planning Committee. However several members contributed significant time and effort.

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Capabilities of Electric Power Resources

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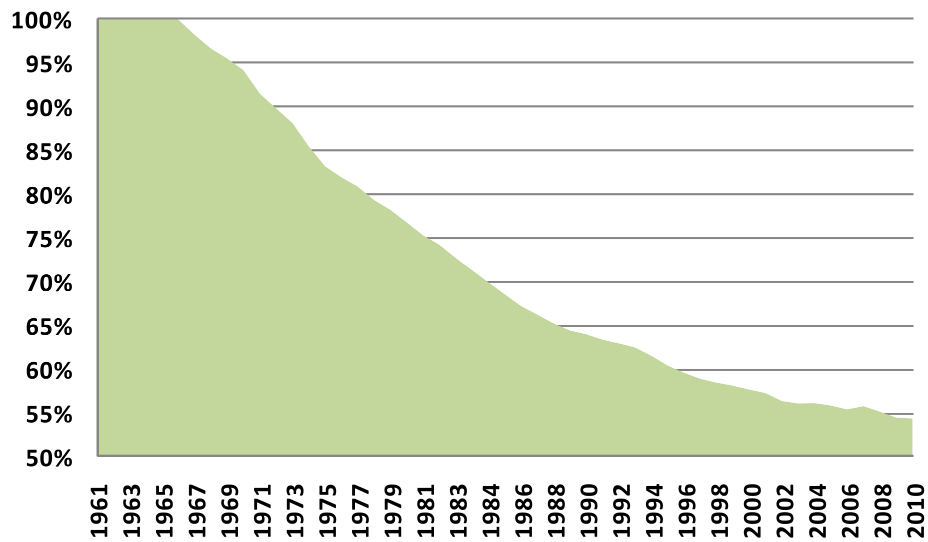
Introduction and Background

The Pacific Northwest [1] traditionally has benefitted from a large hydroelectricity generation portfolio. Forty years ago, 90% of northwest energy came from these facilities. With an average capacity factor of approximately 40%, the projects' capabilities greatly exceeded regional needs for decades.[2] The following chart presents a history of hydroelectricity generation as a percentage of total Northwest electricity generation, taken from PNUCC *Northwest Regional Forecasts*.

Hydro Generation as Percent of Total NW Generation – 5-Year Moving Average



Today on a planning basis the energy contribution of the Northwest hydroelectricity system has fallen significantly, from one-hundred percent, to near fifty-five percent. This reduction reflects the construction of nuclear, natural gas-fired and wind generation resources to meet growing regional loads, as well as new limitations placed on hydroelectricity facilities to benefit anadromous fish survival.

Non-hydro generating resource additions have very different operating characteristics and abilities (or inabilities) to provide on-peak and other energy, capacity and flexibility products essential to system reliability. Generally, the flexibility of these new resources is much more limited than hydroelectricity facilities, though many have an advantage over hydroelectricity in that they are not limited by fuel availability.

Of growing concern is a power station's ability (or inability) to adjust its generation level on very short notice in response to changes in loads or variable generating resource output. Electric systems always have needed flexibility to follow load, but the growing prevalence of variable, non-dispatchable resources has dramatically increased the need for resources with flexibility adequate to manage these

[1] Defined as the states of Idaho, Oregon, Montana west of the Continental Divide, and Washington.
[2] Capacity factor is calculated as the average hourly generation level across the year divided by the capacity level.

changes. Therefore, planners must now evaluate resources for at least three characteristics, namely energy, capacity and flexibility (or dispatchability). Utilities today are planning to requirements beyond energy production, the traditional Northwest metric of adequacy. The new metrics require fresh analytical tools and processes to ensure that all potential resource options are evaluated on an "apples-to-apples" basis, considering the energy, capacity and flexibility characteristics of each option.

System operators and planners must value the operating characteristics of a variety of new generation options to ensure grid reliability. Additionally, they can no longer take for granted that new generation resources will provide the same high level of intra-hour operational flexibility as exists in many hydroelectricity facilities. Absent such recognition, grid reliability could be compromised and later investments in more flexible resources necessary. Further, industry consensus explains that system planners no longer can target the traditional one-hour resource peaking capacity metric. Evaluating sustained peaking capacity and flexibility metrics are essential to ensuring future grid reliability.

The intent of this paper is to help system planners and operators as they think about how new resource additions and market opportunities can assist in ensuring a flexible and reliable resource portfolio. It strives to clarify and standardize terms and their usage in the industry when referring to various resources and their capabilities. The authors also intend that readers, after reviewing this paper, understand that using the term "capacity" generically can be confusing and can lead to misunderstandings. A descriptor (e.g., "nameplate" capacity) is essential to avoid confusion when referring to the various capabilities of the electricity system. In some cases the term capacity is used incorrectly to describe a flexibility product. For example, "regulating capacity" is better termed "regulating capability" or "regulating flexibility" because it is not a measure of how much a resource can generate, but instead describes the rate at which the resource can change its operating level.

This paper first provides standardized definitions to familiarize the reader with terms that have presented some confusion or have been misused in the industry. It then describes how electricity power stations are used in operating a power system. The final focus provides a generic description of the production capabilities of the predominant generation options available to utilities today. A table illustrating these capabilities is provided at the end of the paper as a starting point for evaluating new and existing resources.

Definitions and Terms

The following terms help frame a discussion about resources and their capabilities. In many cases it is an industry standard to label each type of capability as a "capacity" measurement. However, the term capacity is too broad without additional description. Capacity does explain the level of production that can be achieved by a resource, or, alternatively, "how high it can go" such as a nameplate rating. But it is more accurate to describe many resource capabilities in a manner representing their inherent flexibility or ability to change output over time.

Base Load Capacity

Base load capacity generally is efficient (i.e., low heat rate or fuel cost) and controllable generation scheduled evenly over a scheduling period or periods. Some base load resources have a limited ability to change their output, but still can provide some of the other capabilities described in this paper. Base load resources typically are fired by coal, nuclear, natural gas, geothermal, or biomass fuels. Some hydroelectricity facilities with restrictions on their operations may also act as base load generation, with output remaining constant over extended periods.

Busbar Capacity

Busbar capacity is the aggregate rating of all generating units at a station or plant at the common point of interconnection to the electricity grid.[3] Busbar capacity is gross capacity minus station service. Usually it is defined as measured at the point of metering.

Capacity

Capacity is the ability to produce power to meet system load requirements. The electrical unit of power is the volt-ampere, or watt.[4] Power traditionally has been measured in watts, even though vars are necessary to meet certain load requirements.[5] While the power consumption of small end use appliances and some distributed generation equipment is measured in watts, the larger metrics of kilowatt (kW, or $1x10^3$ watt), megawatt (MW, or $1x10^6$ watt) and gigawatt (GW, or $1x10^9$ watt) are normally employed when describing power station ratings and capabilities.

Dispatchability

Dispatchability refers to the ability to direct changes in power station output on hourly as well as intra-hour and intra-minute time scales. Most traditional resources respond to a signal from the balancing authority to generate within an operating range. Dispatchable power stations are able to follow a dispatch signal, increasing or decreasing output when load rises or falls. Some power stations have low to near-zero operating cost and/or other operating constraints that make it financially or operationally impractical or impossible to dispatch for load.

Energy

Power stations creating electrical power create energy, or "useful work." Energy therefore measures the quantity of electrical power (i.e., flow) over time. The basic unit of electrical power is the watt. The amount of energy produced by one thousand watts of rated capacity operating over a one-hour period in the context of power generation and transmission is defined as one kilowatt-hour (kWh, $1x10^3$ watt-hour). Larger energy quantities are expressed as megawatt-hours (MWh, $1x10^6$ watt-hour) and gigawatt-hours (GWh, $1x10^9$ watt-hour). This definition is not used only to measure consumption over a full hour. For example, a customer who has used 10 MWh of energy may have consumed power at a rate well above 10 megawatts for a period of time less than one hour. Alternatively, the customer might have consumed power at a rate below 10 megawatts for a period of time exceeding one hour.

An alternative measure of energy used in the Pacific Northwest is the average megawatt (aMW or MWa). Where a power station has generated energy at a rate of exactly 1 MW, and did so continuously for 1 full year, it would produce 8,760 MWhs of energy in a 365-day year, or one average megawatt. As

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[3] Some definitions of busbar capacity are at the low-voltage side of the main transformers.
[4] One watt is equal to one volt-ampere at unity power factor.
[5] Vars are required to serve magnetic loads (e.g., alternating-current motors) operating outside of unity power factor. Resistive loads such as incandescent light bulbs and electric resistance heating operate at unity power factor and do not require vars.

with kWh, the average megawatt concept also can describe consumption or production during varying periods of time. For example, a customer who consumed electrical power at a rate of 10 megawatts for a month could be described as having used 10 aMW for the month. The same description of usage could be used if the customer used 20 megawatts for half of a month and consumed no electricity for the second half of the month. The combinations to arrive at an average megawatt are numerous but in fact define average energy delivery rates over a specific timeframe.

Gross Capacity

Gross capacity is the maximum power output of a generating unit measured at the power station terminals, after deducting auxiliary electrical loads used in the generation process ("station service"). Gross capacity can also be referred to as busbar capacity.

Maximum Continuous Capacity Rating

The maximum continuous capacity rating is the largest value of electrical load at which a generating station will operate successfully and continuously. It is affected by external conditions including ambient weather and river flow that generally are beyond operator control.

Nameplate Capacity

Nameplate capacity, also sometimes referred to as a nameplate rating, is the maximum rated output of a power station, prime mover or other electric power production equipment under specific conditions designated by the manufacturer. Power station nameplate capacity is commonly expressed in megavolt-amperes ("MVA"), and sometimes in megawatts.[6] The nameplate capacity rating usually is displayed on a metal plaque or tag physically attached to the equipment being rated, and contains information including brand name, serial number, voltage, power ratings under specified conditions and other manufacturer-supplied data. Because nameplate capacity typically is associated with a specific piece of equipment (e.g., prime mover or electrical generator), limitations elsewhere in the plant (boiler, turbine, etc.) can constrain the equipment to operate below its full nameplate rating. In some cases, particularly with hydroelectricity facilities that have been upgraded over time, plant output can exceed the nameplate rating.

Net (Maximum) Available Capacity

Net or net maximum available capacity is the full power output of a generating unit less station service. Net available capacity is another term for busbar capacity.

Net Dependable Capacity

Net dependable capacity is the maximum power a generating unit, power plant, or system can supply under specified conditions for a given time interval without exceeding approved limits of temperature and stress. The value is stated net of station service. Net dependable capacity is equivalent to rated capacity when rated capacity is stated as net of station service.

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[6] As noted elsewhere in this paper, generators providing reactive support cannot convert all of their MVA rating into real power (MW). Megawatt ratings on generators assume the generator is providing no var support, i.e., unity power factor.

Net Summer Capacity

Net summer capacity is the maximum output that generating equipment can supply to meet system load, as demonstrated by a multi-hour test, at the time of summer peak demand. Net summer capacity is affected by high temperature and other ambient conditions that can substantially affect (generally reduce) output levels on many power stations.

Net Winter Capacity

Net winter capacity is the maximum output that generating equipment can supply to meet system load, as demonstrated by a multi-hour test, at the time of peak winter demand. Net winter capacity is affected by low temperature and other ambient conditions that can substantially affect output levels on many power stations.

Nominal Capacity

Nominal capacity is the rated, or expected, output of a power station under specified standard conditions such as voltage, ambient temperature, pressure and frequency. The nominal capacity rating generally appears in product catalogs as a gross figure, though certain auxiliary loads such as lube oil pumps may be accounted for.

Peaking Capacity

Peaking capacity is generation which is particularly suited to be dispatched for limited periods of time during the day when the power system is experiencing its highest demand levels, or to stand in temporarily for base load units which are otherwise unavailable. While many resources have the potential to provide peaking capacity, including base load plants, most commonly this concept refers to units that do not operate for extended periods of time (days, weeks, months), or ones that rarely operate at their peak output levels, due to fuel availability limitations or high operating costs. Base load plants, gas-fired peaking units and hydroelectricity power stations all have the ability to provide peaking capacity. Generally, peaking capacity resources must be able to respond quickly in order to be of value in this role.

Ramping Capability

Ramping capability is the ability of a power station to change its output over time. It is sometimes referred to as “ramping capacity,” “step-change dynamic capacity,” “load following” or “generation following,” and is used for slower (i.e., greater than 10 minute) load and generation changes within an hour. This flexibility often is represented as a number of megawatts of change over a one-minute period.

Ramping capabilities are often tied to then-current operating levels. For example, a 300 MW combined-cycle combustion turbine starting up from being offline could take five or more hours to reach nominal capacity. Though start-ups are not thought of as ramping in the pure sense, this rate equates to one MW per minute. Once online, and after having gone through a portion or full start-up cycle, the same resource likely would have a ramping rate of 5 MW or more per minute. Resources designed for regulating capability in most cases can provide ramping capability, but lower-cost alternatives often are available. Among resources with ramping capability are online base loaded gas- and coal-fired plants, many off-line natural gas-fired peaking units and on- and off-line hydroelectricity power stations.

Rated Capacity

Rated capacity, also called maximum available capacity, is the maximum power a generating unit, power plant, or system can supply under specified conditions for a given time interval without exceeding approved limits of temperature and stress. Rated capacity is stated as a gross or net figure. If stated as net, rated capacity is also termed "net dependable capacity."

Regulating Capability

Regulating capability, also sometimes called "regulating reserve capability," "fast-acting dynamic capacity," or "regulating capacity," is used for fast response needed to provide regulation-like services. It is comprised of flexible generation units able to respond instantaneously to supply requests. Regulating capability can be provided by online natural gas peaking units, most hydroelectricity power stations unless constrained by non-power requirements, and fast-acting storage technology (e.g., pumped hydro, fly-wheel, battery), among others. In regions outside the Northwest base-load gas and coal plants provide system regulating capability as well.

Site-Rated Capacity

Similar to nominal capacity, site-rated capacity is the expected power output of a power plant or generator unit at site-specific conditions such as voltage, ambient temperature and pressure and frequency. Site rating may be stated as net of station service, or as a gross figure.

Sustained Peaking Capacity

Sustained peaking capacity is the maximum load that a power station, turbine, transmission circuit, apparatus, station or system can supply for a given peak load period. As an example, the Pacific Northwest Resource Adequacy Forum has defined a sustained peaking period for the Pacific Northwest regional adequacy standard as the highest six load hours in each of three consecutive days. The peak load period hours are not necessarily consecutive.

Volt-Amps-Reactive (var)

Volt-ampere reactive measures reactive power in alternating current power systems. Reactive power exists in an alternating current circuit when current and voltage are not changing in synchronization with one another. The existence of reactive power in a circuit reduces the useful energy that can be produced or transferred. Some components, including some types of generators, can be operated in a way that reduces reactance on the system. However, providing reactive support reduces the ability of a generator to produce other services such as meeting peak demand. Given the importance of providing reactive support, var capabilities should be considered when planning for future power needs. See the definition of Reactive Power in the next section for a more detailed definition of this power concept.

Watt

One watt is a measure of power, the rate at which work is done when one ampere of current flows through an electrical potential difference of one volt. It is also equal to the conversion rate of one joule per second.

Uses of Generating Resources

The abilities of a generation resource to change and sustain its power flow define the energy, and capacity and flexibility products it may provide to a utility system. The primary products of interest in the Northwest are discussed below. Many of the definitions provided rely on a June 2010 paper published by the Pacific Northwest Utilities Conference Committee.[7]

Energy

Power is the rate at which energy is generated, delivered, or used. A basic unit of electrical energy, the watt-hour, illustrates the time relationship between energy and power. An energy quantity of one watt-hour could be realized by operating at a power of one watt for a period of one hour. It also could be realized by operating at two watts for one half of one hour, etcetera.

Regulating Capability

Regulating capability is spinning reserve capability immediately responsive to automatic generation control. It is used to meet moment-to-moment variations in energy demand or power station output. Regulation is required in both the upward and downward directions, and is deployed to accommodate variability during a scheduling period.

Spinning Reserve Capability

Spinning reserve capability is on-line, unloaded or partially loaded, synchronized, and frequency-change responsive, generation capable of meeting system requirements within ten minutes and sustainable for a period of not less than sixty minutes. Oftentimes spinning reserve capability is called on during a generation or transmission contingency, or to compensate for the changing output of variable power stations.

Non-Spinning Reserve Capability

Non-spinning reserve capability is part of the operating reserve required for electrical system contingencies. It is the unloaded portion of a power station or generator capable of being synchronized and ramped to a specified level within a specified timeframe–generally ten minutes–and sustainable for a period of not less than sixty minutes.

Generation and Load Following Capability

Generation and load following capability match anticipated schedules with varying resources and loads up to the end of the prevailing scheduling period (presently sixty minutes in the Northwest). A derivative of regulation, adequate generation and load following capabilities must be retained to provide movement in both the up and down directions. The service generally follows the slower load and generation trends within the scheduling period. The summation of the energy provided by this product over a scheduling time step is termed “generation imbalance” or “energy imbalance.”

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[7] See http://pnucc.org/documents/ReservesinCapacityPlanningFinal.pdf

Reactive Power

According to the Bonneville Power Administration's January 1984 publication "BPA Definitions," reactive power, measured in Volt-Amperes Reactive, or var, is the out-of-phase component of total volt-amperes in an electrical circuit. BPA goes further to state that reactive power represents the power involved in the alternating exchange of stored inductive and capacitive energies in a circuit. Managing reactive power with generators is a primary source of support for system voltage, but it reduces the capability of a power station to provide the other energy, capacity and flexibility services described in this paper.

Electric Power Resources

There are many resource alternatives available to electricity planners and operators for meeting system energy, capacity and flexibility needs. Some resources have very low fuel and operating costs, potentially making them an expensive source of non-energy services because operating away from peak efficiency means losing the opportunity to generate energy at high margins. Alternatively, other resources have fuel and operating costs that together approach the market energy price, enabling them to create non-energy products at comparatively low cost. Finally, some resources have very high operating costs that in most periods exceed the market energy price. These resources have the ability to create energy, and capacity and flexibility products, but at high short-run costs.

Planners need to ensure that a resource obtains its highest value by creating the most valuable energy and capacity and flexibility products at each moment in time. For example, a gas turbine might have an ability to provide 100 MW of either spinning or non-spinning reserves over a given timeframe; however, non-spinning reserves generally are of less value to the electricity grid. This resource in most cases should be valued assuming it generates the higher-valued spinning reserve product to the extent that the system can use the additional spinning reserves or where a market exists to sell spinning reserves services in excess of utility requirements.

A brief description of each major resource type is provided below. The discussion will highlight significant capabilities relative to other resource options. For an illustrative definition of the capabilities of each resource type, refer to the table at the end of this paper.

Hydroelectricity

Hydroelectricity projects in most cases are very flexible resources having the ability to provide most of the energy, and capacity and flexibility products necessary for reliable system operations. However, the physical and license constraints of each hydroelectricity facility differ, sometimes to a great extent. System operators and planners must carefully consider how these facilities contribute to system needs. Given their capabilities, hydroelectricity projects oftentimes can provide the products discussed in this paper across nearly their entire nameplate rating. For example, a 300 MW hydroelectricity facility could have the ability to provide as much as 300 MW of any of the energy, and capacity and flexibility products listed above unless it is subject to ramping rates, fuel limitations or other constraints. This is not the case with most other generation options, as various constraints greatly limit their abilities. The one limitation of most hydroelectricity projects is fuel access. Depending on the project, sustaining output over extended periods of time might not be possible.

Hydroelectricity projects generally fall into one of three categories: reservoir storage, run-of-river and pumped storage. Reservoir storage hydroelectricity projects most often have the greatest ability to provide service because water, or fuel, stored in a reservoir ensures that its capabilities can be sustained for extended periods of time.

Run-of-river hydroelectricity projects are capable of providing smaller amounts of flexibility relative to reservoir storage projects because they oftentimes are the most downstream projects and provide river regulation. Environmental requirements can limit the amount of hour-to-hour and even minute-to-minute flow changes. Because water flow is the fuel for hydroelectricity generation, limiting a project's ability to make flow changes can greatly reduce its flexibility in providing energy, and capacity and flexibility products.

Pumped hydro facilities have the potential to provide many of the services discussed in this paper. However, the major difference is that pumped hydro projects are net energy consumers. In other words, approximately 15% to 25% of the energy created by a pumped storage project is consumed in losses created by pumping water up into, and then releasing it from, the storage reservoir.

Natural Gas

There are a number of natural gas-fired generation technologies. Many have the potential to efficiently provide energy, and capacity and flexibility products. The major categories of gas-fired plants are described below.

Boiler-Steam-Turbines Although gas-fired boiler technology is no longer deployed for new electricity generation in the United States, and the northwest does not have any on its grid, a number of gas fired boilers still operate in the Western Interconnect. These facilities have a limited ability to provide capacity and flexibility products when they are online. Start-up times generally are too great to provide intra-hour flexibility where the gas-fired boiler is not already online. Boiler plants have operating limitations that lower their ramping flexibility relative to many other generation options.

Frame Unit Simple Cycle Combustion Turbines Due to their design, frame unit simple-cycle gas turbines have little operating flexibility and generally must ramp up to rated capacity once they are started. Varying output in any significant way creates operational and environmental challenges. Traditionally these power plants provide energy and reactive power. Some frame units can be operated to full load within ten minutes, allowing them to provide non-spinning reserves.

Aero-Derivative Simple Cycle Combustion Turbines Aero-derivative simple-cycle turbines are operationally similar to their frame unit cousins; however, most aero-derivative plants have quick-start capabilities, allowing them to provide load and generation following in the upward direction, as well as non-spinning reserves.

Hybrid Simple Cycle Combustion Turbines Hybrid simple-cycle plants combine the features of frame and aero-derivative units. Their emission control systems allow them to operate at partial load levels, providing intra-hour ramping while retaining efficient combustion. Hybrid units can provide most of the energy, and capacity and flexibility products discussed in this paper, at least for a portion of their nameplate rating.

Combined-Cycle Gas Turbines Combined-cycle combustion turbines (CCCTs) are based on frame or aero-derivative main units, coupled to a heat recovery steam generator that generates steam for use in a steam turbine. Oftentimes the heat recovery steam generator is equipped with "duct firing" capability, enabling it to generate more steam and thus higher output than would otherwise have been generated using the gas turbine exhaust alone.

A CCCT plant can provide many of the energy, and capacity and flexibility products discussed in this paper; however, emission and physical configuration limit its operational ranges to only a portion of nameplate capacity ratings. Also, given complex steam cycle configurations, generally CCCTs cannot ramp up quickly after being offline for extended periods of time. Non-spinning reserves are unavailable. The plants are able to generate once they are online and synched to the electricity grid, but only up to their maximum ramp ratings.

Reciprocating Engines Reciprocating engines generally are fired with natural gas or diesel. The units are small individually, but when grouped together they provide a significantly flexible generating resource. Much like an automobile motor, reciprocating engines are operationally flexible and in some cases may be able to operate across nearly their entire operating range. This flexibility means that these plants can produce all of the capacity products described in this paper in quantities nearly equal to their nameplate ratings.

Coal

Coal-fired generation traditionally has provided base-load power for the grid; the plants were not built for rapid operational changes. Coal plants ramp much more slowly than other generation options, but, given their large unit sizes, have the potential to provide energy, and capacity and flexibility products, including spinning reserves and regulation. Investments in new control technologies and software might be required on northwest plants to enable the significantly greater flexibility required for spinning reserves and regulation.

Biomass

Biomass covers a broad range of technologies, including wood, manure, solid waste combustion and landfill gas, among others. Depending on the fuel source, biomass plants can resemble coal-fired plants, gas-fired plants, reciprocating engines, or other configurations. The flexibility of a biomass plant is dictated by the type of facility and its integrated control systems.

Geothermal

Geothermal plants convert thermal energy from the earth into electrical energy by extracting steam and running it directly through steam turbines or indirectly by transferring heat from steam or hot water source to another working fluid for use in a turbine. Traditionally these plants have operated in a base-load operations mode because the fuel is free. Modifying a geothermal design to provide capacity and flexibility products, though possible, likely is beyond it economic and physical characteristics.

Solar–Photovoltaic

Photovoltaic (PV) Solar operates only during the day, and its output is the greatest only under direct sunlight. Generation levels are fairly predictable over the day on average, with output increasing during the day and then falling off as darkness approaches. PV solar can consume large quantities of system flexibility and capacity products. Clouds passing over a PV array can create very large swings in electrical output. Other system resources must stand ready to follow the variation. PV solar might have the potential, in limited situations, to provide some down-ramping capability where generation is curtailed through tracking. Other capacity products might be developed, but likely would be too expensive and rely on additional technologies (e.g., on-site storage such as batteries).

Solar–Thermal

Solar thermal plants have the potential to greatly reduce solar variation relative to PV solar. Solar thermal projects are designed in a manner providing limited storage capability that might be used to create power when called on. Because thermal solar energy does not have to be used instantaneously, in these systems the output profile might be modified by system controllers to create many of the energy, and capacity and flexibility products described in this paper, including shifting output into hours later in the day after the sun has fallen on the horizon but loads continue to increase.

Wind

A wind plant provides generation based primarily on the wind speeds blowing through its footprint. As with PV solar, output varies greatly, with large up-ramp and down-ramp events occurring on a frequent basis. Individual plants can have generation profiles that are ten times as volatile as utility load profiles, and the resource ultimately is a net consumer of system flexibility.

Because wind projects cannot store their fuel they have a very limited ability to reliably provide the products identified in this paper, though certain state-of-the-art wind turbines ("Type IV") can provide reactive power and voltage support in addition to real power. When the wind is blowing the projects do have the potential to follow system requirements down, but this comes at the expense of "feathering," or wasting, valuable energy that is otherwise free. Because of this, in most instances wind's major contribution to the electrical system is energy.

Tidal

Tidal technologies have a generation profile and capability that might be used by a system operator to generate capacity and flexibility products. Unlike wind, coastal tides are very predictable. Unlike solar, these projects are not subject to variations from cloud cover. However, like other renewable generation assets, backing down tidal facilities to generate anything besides energy comes at a high opportunity cost because the fuel is essentially free; it cannot be stored.

Distributed Generation

Distributed generation projects are located on customer sites and are not under the control of the utility. There is no utility control because the resources are small and cannot afford expensive control systems. In cases where distributed generation facilities are renewable energy projects, they have operating characteristics very similar to the descriptions provided above. These renewable energy projects rarely provide non-energy capabilities. However, some stand-by units (e.g., diesel generators) can provide capacity and flexibility products where they have installed necessary infrastructure and utility communications equipment.

Storage Products

A number of storage products have the ability to provide capacity and flexibility products. By storing power during periods of low demand they can release it later to meet system needs at higher demand periods. Commercially-available storage products include battery technologies, capacitors, water storage and space (i.e., heating and cooling) conditioning. Each has varying capabilities to provide capacity and flexibility products and should be evaluated individually.

Demand Side Management

Though not the focus of this paper, retail customers can contribute to system reliability by participating in demand side management programs. Demand side management programs include energy efficiency and demand response. Energy efficiency projects provide only energy, though oftentimes the largest savings are coincident to system peak periods. Demand response programs can provide some of the capacity and flexibility products referenced in this paper, but their abilities are very specific to the type of load being affected. Automated demand response programs provide higher reliability because the utility operators can directly affect loads. Voluntary or customer-controlled programs can also provide some of these products, but with less certainty and reliability.

Resource Capabilities Illustration

The following table provides an illustration of the energy, capacity and flexibility products of various generation and demand-side technologies. The information is not intended to be comprehensive or accurate, as the ultimate capability of any resource is dependent on its design. For each listed resource, an assumed nameplate installation of 100 megawatts is used to make comparisons across resource types simpler for the reader.

Resource Category	Sub-Category	Nameplate Rating (MW)	Peaking Capacity (MW)	Annual Energy (aMW)	Regu-lation (MW)	Spinning (MW)	Non-Spinning (MW)	Following Up (MW)	Following Down (MW)	Reactive Power (MVaR)	Storage (MWh)
Hydroelectric	Reservoir Storage	100	100	40	50	50	100	100	100	100	100
	Run-Of-River	100	100	40	50	50	100	100	100	100	100
	Pumped Storage	100	100	-15	50	50	100	100	100	100	100
Gas	Frame SCCT	100	100	90	15	15	100	15	15	50	0
	Aero SCCT	100	100	90	15	15	100	15	15	50	0
	Hybrid SCCT	100	100	90	20	15	100	20	20	50	0
	CCCT	100	100	95	15	20	0	15	15	50	0
	Boiler + STG	100	100	90	20	15	0	20	20	50	0
	Reciprocating Engine	100	100	90	25	25	100	25	25	50	0
Coal		100	100	85	5	5	0	10	10	100	0
Nuclear		100	100	85	5	5	0	10	10	100	0
Biomass	Boiler	100	100	85	5	5	0	25	25	100	0
	Reciprocating Engine	100	100	85	50	50	100	100	100	100	0
	Turbine	100	100	85	35	35	100	70	70	100	0
Geothermal		100	100	90	35	35	0	10	10	100	0
Solar	Photovoltaics	100	0	15	0	0	0	0	0	0	0
	Central Tower	100	0	15	0	0	0	0	0	0	50
Wind		100	0	30	0	0	0	0	0	0	0
Tidal		100	0	30	0	0	0	0	0	0	0
Distributed Generation	Wind	100	0	20	0	0	0	0	0	0	0
	Solar	100	0	15	0	0	0	0	0	0	0
Storage	Batteries	100	100	-10	50	50	100	100	100	0	100
	Hot Water	100	100	-10	50	50	100	100	100	0	50
	Refrigeration	100	100	-10	50	50	100	100	100	0	50
	Capactors	100	100	0	0	0	0	0	0	100	100
Demand Reduction	Conservation	100	100	10	0	0	0	0	0	0	0
	Non-Utility	100	100	10	0	0	100	0	0	0	0
	Utility-Controlled	100	100	10	50	50	100	100	100	0	0