Appendix B – Electric Generating Resources

Purpose and Scope

Overview

As part of its ongoing integrated resource planning activities, Seattle City Light monitors and evaluates a broad variety of electric resource technologies. Each biennial integrated resource plan report includes updated information about the electric resources that were identified and evaluated.

This appendix describes and documents information about electric generating resource options, both renewable and non-renewable resources. Other appendices to the 2008 Integrated Resource Plan (IRP) describe customer demand response, tidal energy, and distributed generation.

Consistent with standard practices for integrated resource planning, a wider range of electric generating resources has been identified and evaluated in this appendix than was included in the candidate resource portfolios that were subjected to quantitative modeling. Certain types of electric generating resource technologies were not included in the candidate resource portfolios, based on judgments that the resource was either incompatible with Seattle City Light's resource needs and objectives (e.g., nuclear power) or not yet commercially available (e.g., wave and tidal power).

Format for Generating Resource Descriptions

The description of each of the electric generating resource technologies follows a consistent format. The format used includes the following elements:

- Resource Characteristics (overview of the generating resource technology and some of its key attributes)
- Resource Potential (assessment of how much of the resource may be available, in some cases by location or area)
- Transmission Requirements (needs and costs to transmit power from the resource site(s) to Seattle City Light's service area)
- Costs (information about fixed costs and variable costs for the resource)
- Environmental Impacts (emissions, land use and other impacts)
- Feasibility for Seattle City Light (practical considerations related to acquiring and using the resource technology to help serve Seattle City Light's customers)

In some cases, additional information about a particular type of electric generating resource technology is provided.

For estimating the costs of generating resources, two primary information sources were:

1. United States Department of Energy, Energy Information Administration 2008 Annual Energy Outlook (EIA 2008 Annual Energy Outlook)
2. California Energy Commission 2007 Integrated Energy Policy Report (CEC 2007 Integrated Energy Policy Report)

Costs shown in the EIA 2008 Annual Energy Outlook are generally lower for most types of generating resources than costs shown in the CEC 2007 Integrated Energy Policy Report. For example, capital costs for several types of generating resources shown in the EIA 2007 Annual Energy Outlook are lower than those shown in the CEC 2007 Integrated Energy Policy Report. The CEC has indicated that some of the difference between the two sets of cost estimates is due to the CEC's use of construction costs for California that are higher than the national averages that the EIA used. However, a number of other assumptions used by the two sources, such as heat rates, were not the same.

Renewable Generating Resources

Overview

After cost-effective conservation, renewable resources are the most preferred form of electric power resource for Seattle City Light. This section describes and documents information about renewable electric generating resources.

Public and policy interest in renewable resources has grown in recent years. 24 states throughout the United States - including nine of eleven states in the Western region of the U.S. - have enacted renewable portfolio standard (RPS) policies that mandate the development of specified amounts of renewable resources.

Washington's RPS, the Energy Independence Act (Initiative 937, RCW 19.285), was approved by state voters in 2006. Initiative 937 requires Seattle City Light and a number of other utilities in Washington state to use renewable resources to serve at least 3 percent of their loads by January 1, 2012, at least 9 percent of their loads by January 1, 2016 and at least 15 percent of their loads by January 1, 2020.

Initiative 937 defines "renewable resources" as:

a. water

b. wind

c. solar energy

d. geothermal energy

e. landfill gas

f. wave, ocean, or tidal power

g. gas from sewage treatment facilities

h. biodiesel fuel as defined in RCW 82.29A.135 that is not derived from crops raised on land cleared from old growth or first-growth forests where the clearing occurred after December 7, 2006

i. biomass energy based on animal waste or solid organic fuels from wood, forest, or field residues, or dedicated energy crops that do not include (i) wood pieces that have been treated with chemical preservatives such as creosote, pentachlorophenol, or copper-chrome arsenic; (ii) black liquor byproduct from paper production; (iii) wood from old growth forests; or (iv) municipal solid waste.

I-937 further defines "eligible renewable resources" as:

a. Electricity from a generation facility powered by a renewable resource other than fresh water that commences operation after March 31, 1999, where: (i) The facility is located in the Pacific Northwest; (ii) the electricity from the facility is delivered into Washington state on a real-time basis without shaping, storage, or integration services; or

b. Incremental electricity produced as a result of efficiency improvements completed after March 31, 1999, to hydroelectric generation projects owned by a qualifying utility and located in the Pacific Northwest or to hydroelectric generation in irrigation pipes and canals located in the Pacific Northwest, where the additional generation in either case does not result in new water diversions or impoundments.

The following descriptions and documentation of renewable resources are designed to be consistent with the definitions of renewable resources as stated in I-937.

Efficiency Improvements to Hydroelectric Generation Projects

Resource Characteristics

Efficiency improvements to hydroelectric generation projects involve replacements, upgrades or other changes to an existing project that produce a net gain in the amount of power generated. To qualify as an "eligible renewable resource" under Washington's I-937, these projects must generate additional power without increasing the impoundment or diversion of water already created by the project. In other words, this form of renewable resource can be characterized as improvements that include the installation or modification of equipment and structures, or operating protocols at existing hydroelectric facilities that use the same amount of water to generate a larger amount of power.

As the owner of several existing hydroelectric generating projects, Seattle City Light has potential opportunities to pursue efficiency improvements. Examples of the types of incremental efficiency improvements that may be possible at Seattle City Light's hydroelectric generating projects include:

- replacement of existing turbine runners with newer turbine runners that are able to convert moving water into power more efficiently
- rewinding of existing generators
- replacing turbines with more efficient units
- generation improvements to hydraulic conveyance systems to decrease head loss
- changing control systems to optimize electricity generation

Resource Potential

City Light is evaluating potential hydro efficiency improvements. For example, past runner replacements have resulted in increased production of more than an average megawatt for each unit. However, for the purposes of the 2008 integrated resource plan, the identified hydro efficiency improvement is Gorge Tunnel 2. The expected gain in electric generation for Gorge Tunnel 2 is about 5 aMW in January and nearly 6 aMW annually.

Transmission Requirements

No new transmission requirements are anticipated for Gorge Tunnel 2. The facilities at Gorge dam were originally designed to include Gorge Tunnel 2, but the work on the tunnel was not completed at the time the plant was constructed.

Costs

Costs for hydro efficiency projects are highly dependent upon the expected operating life of the hydro plant after the efficiency improvement, the increased production, and the discount rate. For a public entity like the City of Seattle, a discount rate of 3.0% and an operating life of 50 years is used for Gorge hydroelectric dam. A cost estimate completed in April 2008 for the Gorge Tunnel 2 project was $63,135,000. Using conservative estimates of the value of the resulting energy, the project yields a positive net present value and benefit-cost ratio greater than one.

Environmental Impacts

Most potential hydro efficiency projects described under the heading “resource characteristics” would have little or no environmental impact. The main environmental consideration that is specific to the Gorge Tunnel 2 project is the disposal of the rock material that would be excavated during completion of the tunnel. City Light is planning for proper disposal in its cost estimates.

Feasibility for Seattle City Light

In general, the feasibility of hydro efficiency projects is high for City Light. There is substantial flexibility in the timing and funding of efficiency projects. They are readily accessible and do not require undertaking the types of development risks involved in new power plants. Hydro efficiency projects are well understood and hold few surprises.

Yet, there are limitations. City Light has pursued hydro efficiency projects on an ongoing basis for many years, so that many of the better opportunities have already been achieved. Also, an important concern of all hydroelectric plant operators is whether or not new hydro efficiency projects cause re-opening of Federal Energy Regulatory Commission operating licenses. Re-licensing can be a lengthy, costly, and risky process. It usually takes years. It often involves many studies and reviews by multiple regulatory agencies. Hydro plant owners are subjected to risk as interested parties may seek changes in operations, ownership, or new funding of other objectives.

Wind Power

Resource Characteristics

Wind power is the process of mechanically harnessing kinetic energy from the wind and converting it into electricity. The most common form of utility-scale wind technology uses a horizontal-axis rotor with long, slender turbine blades to turn an electric generator mounted at the top of a tall tower. For utility-scale wind power production, dozens of wind turbines may be grouped together at a wind farm project. Power generated by the wind turbines is collected at a substation where transformers increase the voltage and the power is then fed into the transmission system.

Because air has low mass, the wind itself has low energy density. The amount of wind power that can be produced at a given project site is dependent on the strength and frequency of wind. Wind velocity determines quantity of power that can be produced. For example, a doubling of wind speed allows roughly eight times as much power to be produced.

Over the last decade, the use of wind power has increased rapidly, making it the predominant form of new renewable generation resource, with many large-scale installations around the world. Major advances in wind power technology were achieved in the 1990s and 2000s, allowing much larger turbines to be developed. For example, wind turbines with a capacity of 1.5 megawatts to 2.5 megawatts are now common and wind turbines as large as 6 megawatts are being developed. This has created economies of scale, driving down the unit cost of energy from wind power resources.

According to the Global Wind Energy Council, the total amount of installed wind power capacity in the United States was 16,818 megawatts as of December 31, 2007. This amount included 5,244 megawatts of new capacity that was installed during 2007, an increase of 45 percent. At the end of 2007, Texas was the state that had the largest amount of installed wind power capacity with 4,356 megawatts, followed by California with 2,438 megawatts and Minnesota with 1,300 megawatts. Washington had the fifth-largest amount of installed wind power capacity with 1,163 megawatts, and Oregon had the seventh-largest amount with 885 megawatts. Over 5,700 megawatts of additional wind power generating capacity was under construction in the U.S. during 2008.

Some further statistics can help put wind power into perspective. During 2008, wind power is expected to produce just over 1 percent of the total electricity supply in the U.S. However, according to the U.S. Department of Energy, new investments in wind power made up 35 percent of the total amount of all forms of electric generating capacity added during 2007.

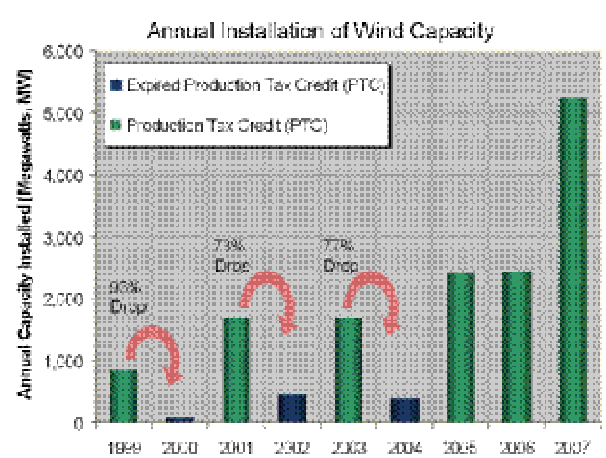
A number of observers anticipate that wind power will continue to grow and become a much larger portion of the nation's overall mix of generating resources. For example, in May 2008, the U.S. Department of Energy released a study that identified steps that would need to be taken in order to enable wind power to supply 20 percent of the total U.S. need for electricity by the year 2030.

Wind power has developed because:

- Wind power is a renewable resource.
- Wind power does not consume fossil fuels.
- Wind power does not produce carbon dioxide or other forms of emissions.
- Advances in wind turbine technology, economies of scale and growth of the wind manufacturing industry have reduced costs for wind power.
- Once permitted and equipment is available, the lead time to construct a wind power project is comparatively short (in many cases one year or less).

The growth of wind power has been constrained because:

- Wind power projects must be sited in locations where winds are stronger and more frequent. As a result, many of the more attractive sites for wind power are located in areas far from load centers and where transmission capacity is either constrained or does not exist.
- There are issues related to siting and cost allocation for the new transmission facilities that are needed to bring power from the best wind sites to load centers.
- Wind power is an intermittent resource, meaning that it is only able to generate electricity when the wind is blowing.
- To date, the economics supporting development of wind power have been dependent on the federal Production Tax Credit (PTC), which is currently $20 per megawatt-hour.
- Recent increases in the price of commodities such as steel, aluminum, copper, and cement have driven up the cost of new projects.
- Expirations of the PTC in 2002, 2002 and 2004 contributed to dramatic declines in installations of new wind power generating capacity during those years. In turn, this contributed to delays in investment in manufacturing plants for wind generating equipment.



Source: American Wind Energy Association

Resource Potential

Wind energy has a great deal of potential for supplying both national and regional demand for electricity, and is currently experiencing a period of rapid growth.

The U.S. Department of Energy estimates that good wind areas, which cover 6% of the contiguous U.S. land area, have the theoretical potential to supply more than one and a half times the current electricity consumption of the United States.

As noted above, the U.S. Department of Energy also has completed a study examining the feasibility of using wind power to meet 20 percent of the nation's need for electricity. That study concluded that technological factors would not stand in the way of reaching the 20 percent level, and it identified regulatory barriers - particularly related to construction of new transmission - that would need to be overcome.

Wind Resource Maps

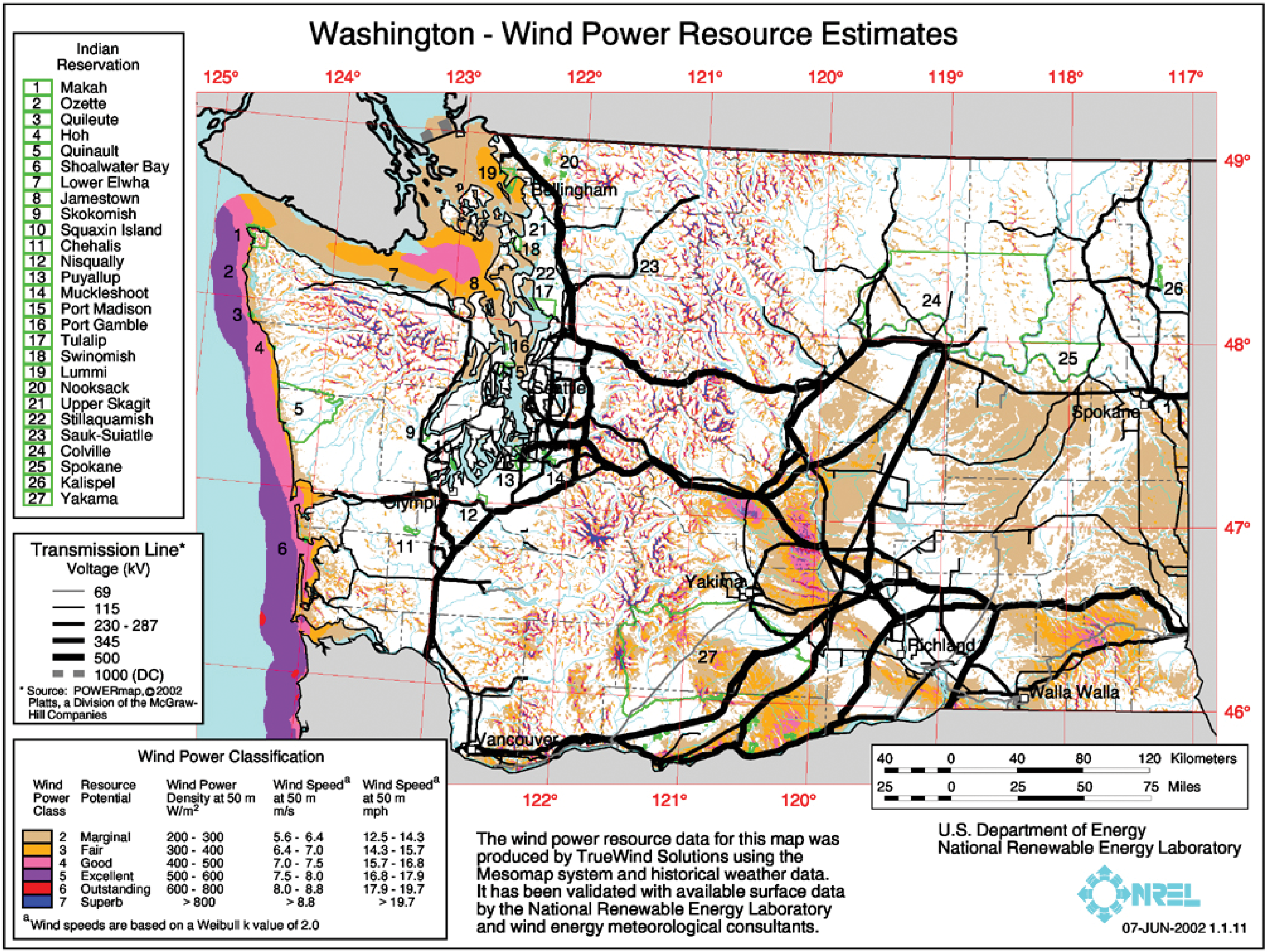
The U.S. Department of Energy's Wind Program and the National Renewable Energy Laboratory (NREL) publish wind resource maps for the northwest. These maps shows wind speed estimates at 50 meters above the ground and depict the resource that could be used for utility-scale wind development.

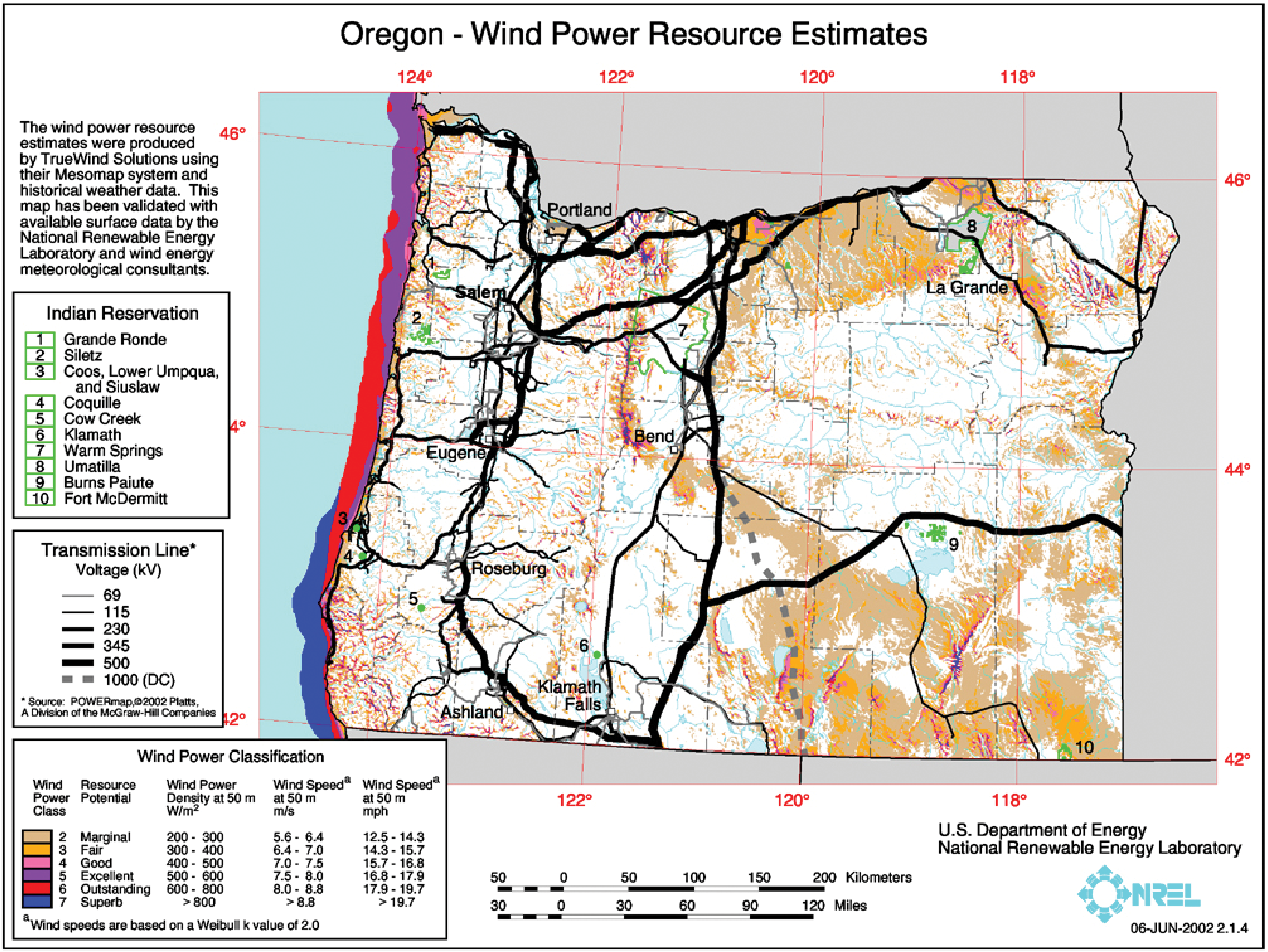
Washington's good-to-excellent wind resources are located in the central part of the state. They are concentrated in the Kittitas Valley northwest of Yakima, on the ridges west of the Columbia River northeast of Yakima, and in the Horse Heaven Hills north of the Columbia River near the Oregon border. Another area of good-to-excellent resource is north of the Blue Mountains in southeastern Washington. Ridge crest locations throughout the state can also have excellent wind resource.

Oregon's good-to-excellent resource areas are concentrated on ridge crests throughout the state. The most significant non-ridge crest areas with at least good resource are located at Vansycle ridge in northeastern Oregon, the area south of the Columbia River east of the Dalles, and southeast of La Grande.

Idaho's areas of good-to-excellent resource are concentrated on the hills and ridges south of the Snake River Plain in southern Idaho, especially the area between Twin Falls and Pocatello. Other noteworthy resource areas are located in outflow valleys in northeastern Idaho and on the ridge crests throughout the state.

Montana has very large regions of good-to-excellent resource potential. These include areas near the Rocky Mountains and foothills in the western part of the state, as well as areas in the flatter central and eastern portions of the state. The total wind resource potential in Montana is very large - by comparison, it is several times larger than that of Washington, Oregon and Idaho combined.


Washington - Wind Power Resource Estimates
Indian Reservation
1 Makah
2 Ozette
3 Quileute
4 Hoh
5 Quinault
6 Shoalwater Bay
7 Lower Elwha
8 Jamestown
9 Skokomish
10 Squaxin Island
11 Chehalis
12 Nisqually
13 Puyallup
14 Muckleshoot
15 Port Madison
16 Port Gamble
17 Tulalip
18 Swinomish
19 Lummi
20 Nooksack
21 Upper Skagit
22 Stillaquamish
23 Sauk-Suiattle
24 Colville
25 Spokane
26 Kalispel
27 Yakama
Transmission Line*
Voltage (kV)
69
115
230 - 287
345
500
1000 (DC)
* Source: POWERmap, ©2002 Platts, a Division of the McGraw-Hill Companies
Wind Power Classification
Wind Power Class | Resource Potential | Wind Power Density at 50 m W/m² | Wind Speed[a] at 50 m m/s | Wind Speed[a] at 50 m mph
2 Marginal 200 - 300 5.6 - 6.4 12.5 - 14.3
3 Fair 300 - 400 6.4 - 7.0 14.3 - 15.7
4 Good 400 - 500 7.0 - 7.5 15.7 - 16.8
5 Excellent 500 - 600 7.5 - 8.0 16.8 - 17.9
6 Outstanding 600 - 800 8.0 - 8.8 17.9 - 19.7
7 Superb > 800 > 8.8 > 19.7
[a] Wind speeds are based on a Weibull k value of 2.0
125° 124° 123° 122° 121° 120° 119° 118° 117°
49° 48° 47° 46°
Bellingham
Seattle
Olympia
Spokane
Yakima
Richland
Walla Walla
Vancouver
40 0 40 80 120 Kilometers
25 0 25 50 75 Miles
The wind power resource data for this map was produced by TrueWind Solutions using the Mesomap system and historical weather data. It has been validated with available surface data by the National Renewable Energy Laboratory and wind energy meteorological consultants.
U.S. Department of Energy
National Renewable Energy Laboratory
NREL
07-JUN-2002 1.1.11



Oregon - Wind Power Resource Estimates
124°
122°
120°
118°
46°
44°
42°
The wind power resource estimates were produced by TrueWind Solutions using their Mesomap system and historical weather data. This map has been validated with available surface data by the National Renewable Energy Laboratory and wind energy meteorological consultants.
Indian Reservation
1 Grande Ronde
2 Siletz
3 Coos, Lower Umpqua, and Siuslaw
4 Coquille
5 Cow Creek
6 Klamath
7 Warm Springs
8 Umatilla
9 Burns Paiute
10 Fort McDermitt
Transmission Line*
Voltage (kV)
69
115
230
345
500
1000 (DC)
* Source: POWERmap,©2002 Platts, A Division of the McGraw-Hill Companies
Wind Power Classification
Wind Power Class
Resource Potential
Wind Power Density at 50 m W/m²
Wind Speed[a] at 50 m m/s
Wind Speed[a] at 50 m mph
2 Marginal 200 - 300 5.6 - 6.4 12.5 - 14.3
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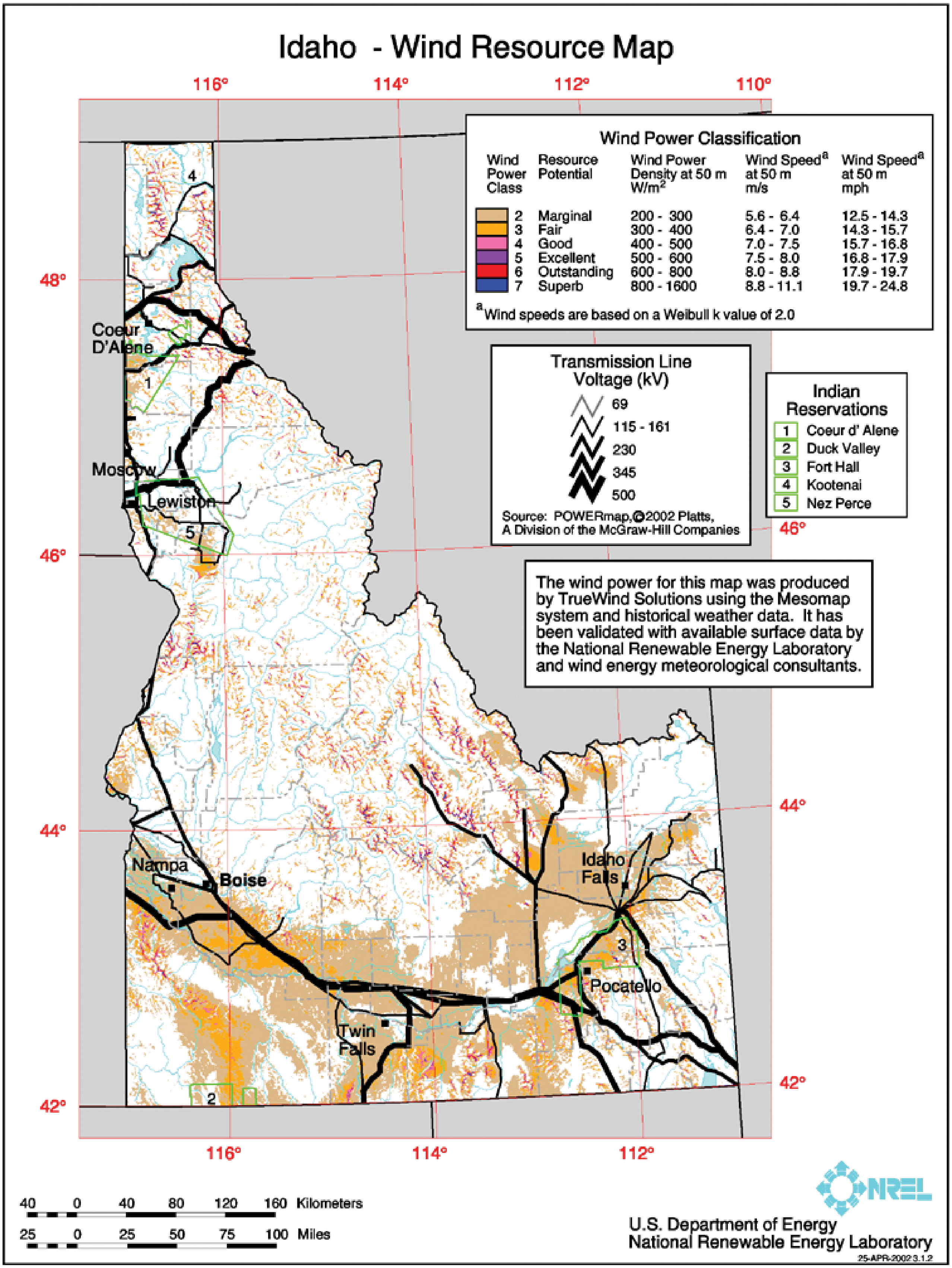
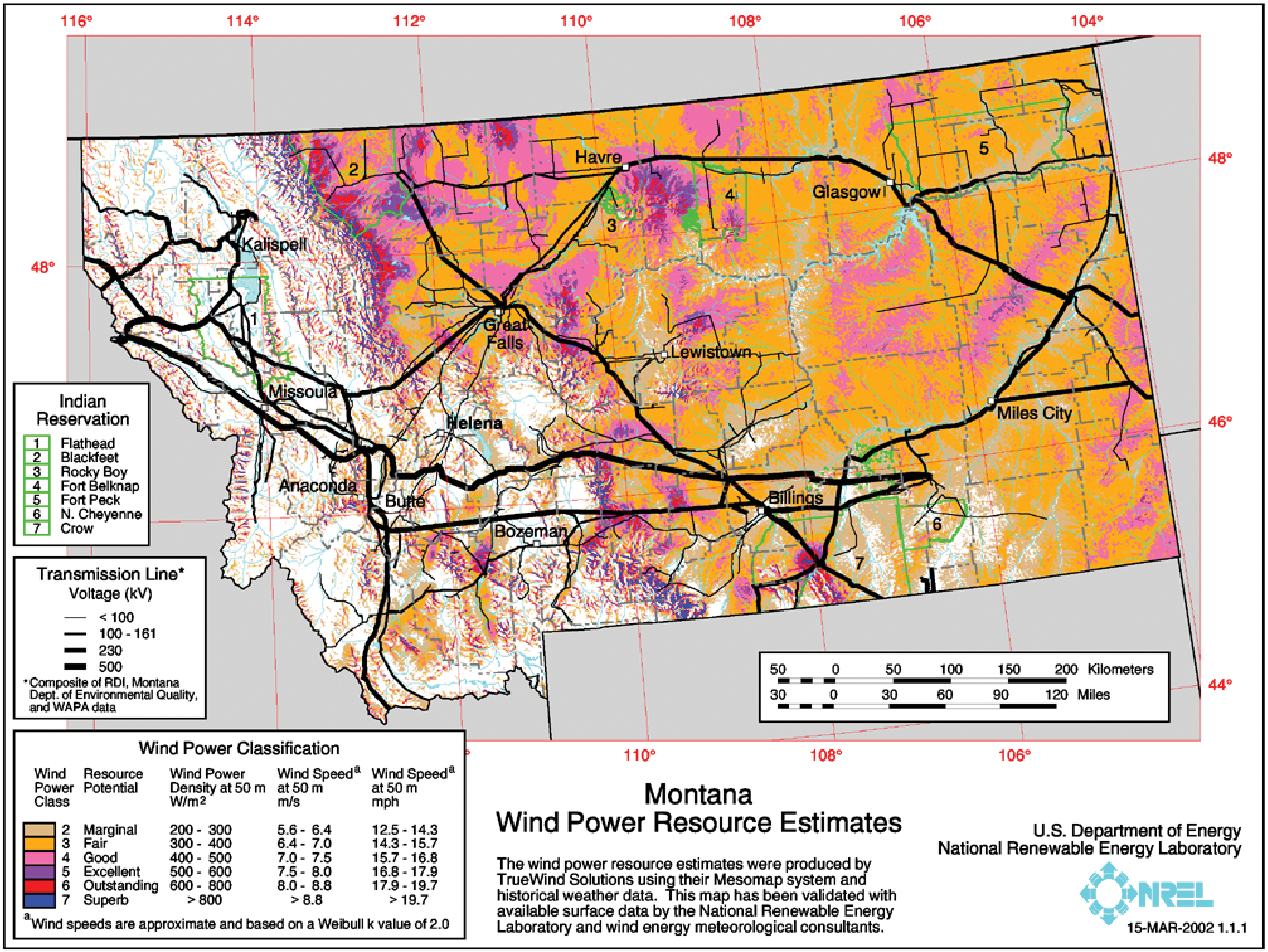
5 Excellent 500 - 600 7.5 - 8.0 16.8 - 17.9
6 Outstanding 600 - 800 8.0 - 8.8 17.9 - 19.7
7 Superb > 800 > 8.8 > 19.7
[a]Wind speeds are based on a Weibull k value of 2.0
Portland
Salem
Eugene
Bend
Roseburg
Ashland
Klamath Falls
La Grande
50 0 50 100 150 200 Kilometers
30 0 30 60 90 120 Miles
U.S. Department of Energy
National Renewable Energy Laboratory
NREL
06-JUN-2002 2.1.4


Idaho - Wind Resource Map
116°
114°
112°
110°
48°
46°
44°
42°
Wind Power Classification
Wind Power Class
Resource Potential
Wind Power Density at 50 m W/m²
Wind Speed[a] at 50 m m/s
Wind Speed[a] at 50 m mph
2 Marginal 200 - 300 5.6 - 6.4 12.5 - 14.3
3 Fair 300 - 400 6.4 - 7.0 14.3 - 15.7
4 Good 400 - 500 7.0 - 7.5 15.7 - 16.8
5 Excellent 500 - 600 7.5 - 8.0 16.8 - 17.9
6 Outstanding 600 - 800 8.0 - 8.8 17.9 - 19.7
7 Superb 800 - 1600 8.8 - 11.1 19.7 - 24.8
[a]Wind speeds are based on a Weibull k value of 2.0
Transmission Line Voltage (kV)
69
115 - 161
230
345
500
Source: POWERmap, ©2002 Platts, A Division of the McGraw-Hill Companies
Indian Reservations
1 Coeur d' Alene
2 Duck Valley
3 Fort Hall
4 Kootenai
5 Nez Perce
The wind power for this map was produced by TrueWind Solutions using the Mesomap system and historical weather data. It has been validated with available surface data by the National Renewable Energy Laboratory and wind energy meteorological consultants.
Coeur D'Alene
Moscow
Lewiston
Nampa
Boise
Idaho Falls
Pocatello
Twin Falls
40 0 40 80 120 160 Kilometers
25 0 25 50 75 100 Miles
NREL
U.S. Department of Energy
National Renewable Energy Laboratory
25-APR-2002 3.1.2


116°
114°
112°
110°
108°
106°
104°
48°
46°
44°
Havre
Glasgow
Kalispell
Great Falls
Lewistown
Missoula
Miles City
Helena
Anaconda
Butte
Billings
Bozeman
1
2
3
4
5
6
7
Indian Reservation
1 Flathead
2 Blackfeet
3 Rocky Boy
4 Fort Belknap
5 Fort Peck
6 N. Cheyenne
7 Crow
Transmission Line*
Voltage (kV)
< 100
100 - 161
230
500
*Composite of RDI, Montana Dept. of Environmental Quality, and WAPA data
50 0 50 100 150 200 Kilometers
30 0 30 60 90 120 Miles
Wind Power Classification
Wind Power Class | Resource Potential | Wind Power Density at 50 m W/m2 | Wind Speed[a] at 50 m m/s | Wind Speed[a] at 50 m mph
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[a]Wind speeds are approximate and based on a Weibull k value of 2.0
Montana
Wind Power Resource Estimates
The wind power resource estimates were produced by TrueWind Solutions using their Mesomap system and historical weather data. This map has been validated with available surface data by the National Renewable Energy Laboratory and wind energy meteorological consultants.
U.S. Department of Energy
National Renewable Energy Laboratory
15-MAR-2002 1.1.1

Onshore Wind

To date, development of wind power projects in the United States has occurred at onshore sites. Advantages of onshore wind power projects include logistics such as ease of access during construction, operation and maintenance. Access to transmission facilities can also be better at certain onshore sites. In addition, permitting can be less complicated for onshore sites.

Offshore Wind

Offshore wind farms also have great potential to supply electricity. Because water has less surface roughness than land (especially deeper water), the average wind speed is higher over open water. The cost of constructing wind farms off-shore poses a considerable barrier to its current development in the United States. Average capacity factors (utilization rates) are expected to be considerably higher for offshore sites than for similar onshore and near-shore locations. Aside from cost, concern for nautical traffic and for wildlife raises concerns about the attractiveness of offshore wind development.

There is some interest in developing offshore wind resources on the East Coast. For example, on April 3, 2008, the State of Rhode Island issued a request for proposals "from qualified firms or teams of firms to design, build, finance and operate a wind generation facility in the waters off its coast to supply not less than fifteen percent (15%) of the energy consumed by Rhode Island's electricity customers."

Wind Power Technology

Wind energy can be extracted by allowing it to blow past rotating blades that exert torque on a rotor. The amount of power transferred is directly proportional to the density of the air, the area swept out by the rotor, and the cube of the wind speed.

There are two main types of wind turbines:

- Horizontal Axis Wind Turbines (HAWT) are similar to airplane propellers, except on a much larger scale. They are currently the primary choice for wind power generation. The turbine and generator are mounted atop a tall tower, to reach the steadier wind found above the surface.
- Vertical Axis Wind Turbines (VAWT) spin vertically around a post. Though less efficient, they are spun by wind from any direction. VAWT can also be positioned closer to the ground. When mounted on office building rooftops, these wind turbines could be a potential distributed generation resource. The rooftop of a large building could provide upwards of 500 kilowatts of generating capacity.

Wind Resource Shaping and Integration

One of the challenges for integrating wind power into a utility's portfolio of resources is its intermittency. The ability to produce electricity from wind is limited by the strength and frequency of the wind. Much of the time, a wind farm will produce energy at much less than its nameplate capacity. At many sites in the Northwest, the capacity factor for wind power varies between 25 and 35%.

Intermittency of wind generation can create several types of challenges. First, wind speed varies considerably, which creates corresponding power fluctuations. These fluctuations can occur very quickly. Second, wind speeds are difficult to predict over the short or long term, and must therefore be monitored almost constantly. Third, its comparatively low capacity factors drive the average unit cost of transmission for wind power above that of other types of generating resources that operate at higher capacity factors.

For a utility to provide steady power, it must continuously balance the production of wind power by adding or removing power from other sources. Hydroelectric generation can be ideal for this, with the ability to store or release water as needed. However, as more new wind generating projects are added, the available capacity of the hydroelectric system to accommodate fluctuations in wind generation may be used up. As a result, further development of wind power may require building additional generation with shaping capacity, such as natural gas-fired combustion turbines. The operation of additional power generation, combined with the need to monitor wind production and buy non-firm transmission, has been estimated to increase the cost of wind energy by $5 to $10 per megawatt-hour.

Wind Power Costs

The cost of wind power declined steadily during the 1990s and early 2000s, due to technological improvements and economies of scale (e.g., larger turbine sizes, growth of the wind equipment manufacturing industry). However, during the last few years costs for new wind power projects have been rising due to a weakening dollar, high world-wide demand for wind turbines, and large increases in costs for concrete and steel.

Onshore Wind Costs

The EIA 2008 Annual Energy Outlook shows capital costs for new onshore wind power generating projects at $1,471 per kilowatt (in 2007 dollars). The CEC 2007 Integrated Energy Policy Report shows capital costs for new onshore wind power generating projects at $1,959 per kilowatt (in 2007 dollars). Fixed operating and maintenance (O&M) costs are $30.25 per kilowatt-year in the EIA 2008 Annual Energy Outlook and $31.09 per kilowatt-year in the CEC 2007 Integrated Energy Policy Report. Variable O&M costs are shown to be zero by both sources.

The CEC 2007 Integrated Energy Policy Report also shows levelized costs at $61.38 per megawatt-hour for a 50 megawatt wind power project owned by a publicly-owned utility and operating at 34 percent annual average capacity factor.

Offshore Wind Costs

Offshore wind power costs vary from site to site, depending on the seabed geology, the depth of the water and the distance from shore. The range of costs estimates from existing offshore wind projects in Europe suggests that location has a significant cost impact. For example, a relatively shallow shelf extending out a considerable distance from shore would be ideal for constructing an offshore wind farm.

Large-scale wind power installations have advantages in economies-of-scale. Installations with more than 500 megawatts of nameplate capacity located 12 miles or farther offshore average savings of 10 percent per megawatt on overall capital costs. Economies of scale in the size of the installation are also important for site determination. For a 1,000 megawatt installation, the extra cabling cost of a location 62 miles offshore relative to one 12 miles offshore would only be in the order of 5 percent of the overall capital cost. This flexibility allows for easier selection of viable sites. However, there is still relatively little experience constructing large wind installations far from shore.

Offshore wind power installations are more expensive than onshore, but the long-run costs are mitigated by the lower levels of turbulence that strike offshore wind turbine blades. Steadier wind on the hub and propeller allow a longer equipment lifespan, which improves return on the capital investment. A report from Denmark suggests the costs are about equal, while the British department of trade and industry (DTI) estimates the cost for offshore wind at 20 to 40 percent above on-shore wind.

Environmental Impacts

Wind energy is very clean, burning no fuel and creating no emissions. The main environmental concern is the visual space taken up by a large wind farm. The wind turbines are very tall, and can create flickering shadows on nearby houses. The noise of operation can also be heard nearby. These concerns need to be considered when siting is determined. Properly sited wind turbines have a very minor effect on birds.

The Danish Energy Authority, Danish Forest and Nature Agency (Dong Energy and Vattenfall), recently completed an eight year study on two large offshore wind farms detailing their impacts on the surrounding ecosystem including fish, birds, sea mammals, and seabed species. The results of the study were overwhelmingly positive and the two projects were granted permission to double their capacity.

In addition, development of wind power generating resources is likely to require construction of new transmission facilities and use of other forms of generating resources to 'back up' intermittent output from the wind power projects. Environmental impacts associated with the transmission facilities and wind-firming resources also need to be considered.

Feasibility for Seattle City Light

Seattle City Light has already gained significant experience as a purchaser of wind power from the Stateline Wind Project, beginning in 2002. This project is located on Vansycle Ridge near Touchet, Washington, across the state border from Pendleton, Oregon. It has a peak generating capacity of 300 megawatts, of which Seattle purchases 175 megawatts.

As described above, the variable quality of wind can pose challenges to the integration of large amounts of wind resources into a utility's overall resource portfolio. This must be addressed while planning new wind projects. Because wind blows intermittently and sometimes not at all, wind resources must be combined with shapeable resources, such as hydroelectric generation.

Washington state has a variety of possible wind power resources including areas of Eastern Washington, the Columbia Gorge, the mountainous regions of the Cascade Mountains, and offshore. If transmission issues can be resolved, Montana offers very large amounts of wind resource potential and may become an attractive longer-term source.

Washington and Oregon have excellent offshore resources. Developing wind energy in the ocean is less well understood, and would need to be investigated before it could be pursued. Viable examples of this type of resource do exist though, notably in Denmark, so this resource bears consideration. Looking for shallow coastal areas, and investigating their average offshore wind speeds, are actions that Seattle City Light could undertake now to prepare for possible offshore development.

Solar Power

Resource Characteristics

Solar power is the process of using energy from the sun to generate electricity. Several forms of solar power technology are available. One form is photovoltaic solar power, in which semiconductor solar cells use the photovoltaic effect to absorb sunlight and convert it into direct current power. An inverter is then used to convert the direct current power into alternating current power. Another form is concentrating solar power, which uses large reflectors and tracking systems to gather energy from sunlight and focus it into a concentrated beam. Heat from the concentrated beam is then used to create steam and turn a turbine generator to generate alternating current power.

In certain respects, the technological development and commercialization of utility-scale solar power is currently at a stage similar to that of wind power shortly before it entered its recent period of rapid growth and widespread adoption by the electric utility industry. For example, large amounts of capital are being invested in research, design and demonstration efforts to improve solar power generating technologies and achieve improved economies of scale. Examples include intensive R&D on advanced forms of solar photovoltaic technologies, as well as construction of demonstration projects based on large-scale concentrating solar generating technology.

Solar power is attractive because:

- Solar power is a renewable resource.
- Solar power does not consume fossil fuels.
- Solar power does not produce carbon dioxide or other forms of emissions.
- Because vast areas with good insolation are available in parts of the U.S., the amount of solar power that could potentially be developed is essentially unlimited.
- Once permitted and equipment is available, the lead time to construct a solar power project is comparatively short (in many cases one year or less).

Drawbacks to the development of utility-scale solar power include:

- The comparatively high cost for solar power, relative to other types of resources, remains the primary factor limiting the use of solar power.
- Solar power is an intermittent resource, meaning that it is only able to generate electricity when insolation is available.
- The amount of power that can be produced, and therefore the cost, varies based on the amount of insolation available in different geographic areas.
- In the future, issues will need to be resolved related to siting and cost allocation for the new transmission facilities needed to bring power from the best solar sites to load centers.

Resource Potential

The primary determinant of the amount of solar power that can be produced is the amount of solar energy that reaches the ground (insolation). In order to produce at highest capacity, solar plants should be exposed to the sun, without shade. A broad area with no tall structures (trees, towers, or buildings) is the most suitable for developing utility scale solar power. Large flat areas near urban areas have high-value uses, making location of solar power near existing transmission expensive. Average insolation varies slowly over miles, but this is mitigated by the ability to locate within a broad area.

The areas of greatest insolation in the United States are in the Southwest, including Arizona, New Mexico, southern California, southern Nevada and west Texas. Within the Northwest, the areas of greatest insolation are in southeast Oregon and southern Idaho. Within Washington state, the areas of greatest insolation are in the southern part of the state, east of the Cascade Mountains.

Average peak sunlight varies considerably within the Pacific Northwest. Seattle averages 3.5 hours of peak sunlight a day and Spokane gets 4.5 peak hours. These figures assume a flat plate tilted at a fixed slope; average peak hours improve considerably with single axis tracking, and a little further with dual axis tracking. Spokane goes to 6.5 peak hours and 6.7 peak hours respectively, greatly improving efficiency.

Insolation varies on a roughly hourly scale. Peak production occurs during the summer, when the sky remains clear and the days are long. Shorter winter days cut production by roughly half. This leads to moderate daily variation, and significant seasonal variation.

The second source of variation is loss of light during the daytime, due to cloud cover or direct shading. Cloud cover reduces efficiency, but does not eliminate production. Direct shade will drastically affect it, however, so care should be taken to avoid trees/buildings/towers casting shadows on collectors.

These variables lead to some need for power shaping, as well as a degree of non-firm transmission being required. Sunlight is much more predictable than wind, however, and so the cost of integration should be lower for solar power than wind power.

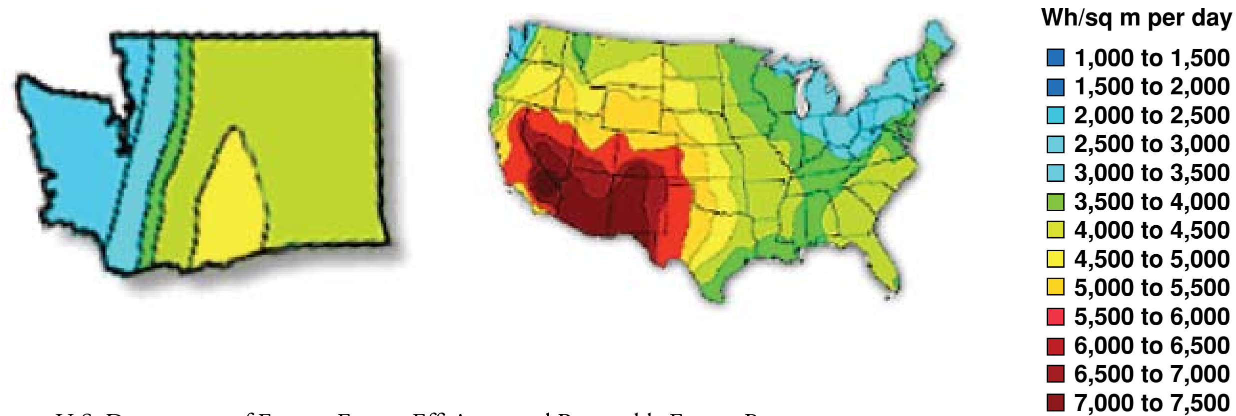
Short-term variations can be offset by the use of energy storage. Several storage methods exist, although none are very efficient. Batteries can store electrical energy directly, thermal brines are used to store heat energy, and water storage or air compression can be used to store mechanical energy.

Solar power is only limited by the availability of technology. Land exists in abundance, and a relatively small area can be used to create a lot of power.

The amount of power that can be generated using energy from the sun varies by geographic region. The following graphics show the average daily number of watt-hours of power that can be generated per square meter of collector space. The first graphic is for flat plate collectors such (i.e., photovoltaics), and the second graphic is for concentrating solar generation.

Solar resource for a flat-plate colllector

Solar resource for a concentrating colllector



Source: U.S. Department of Energy, Energy Efficiency and Renewable Energy Program

Photovoltaic Solar Power Technology

As noted above, the two primary forms of solar power generating technologies are photovoltaic and concentrating solar.

Photovoltaic systems make up the bulk of existing installed solar generating facilities, and can be produced at practically any size. There have been four generations of development for photovoltaic solar generating technology.

Solid silicon wafers are the main form of photovoltaic cells. A single layer of silicon semiconductors creates electricity from sunlight.

Thin film solar makes use of newer polymers to produce cheaper cells. Although thin film solar technology is less efficient at converting sunlight to electricity, its reduced cost of production offsets the lost efficiency. The lighter construction makes using thin film cells easier.

The third generation of research moved away from semiconductor layers. Instead, electrochemical reactions such as photosynthesis were used as the basis for generating electricity.

Finally, multi-layer wafers or films are stacked to more capture light energy from a wider range of wavelengths. The final layer of such stacks is tuned to capture light in the infra-red wavelengths, thus using heat created by the process. Trials of this technique achieve significantly higher efficiency, but are not yet used in production systems.

Concentrating Solar Power Technology

Concentrating solar is the second main type of solar power generation. It may be a lower-cost technology on a large scale, and therefore could become more attractive to utilities. Concentration allows the intensity of light to be focused at a single point, creating higher efficiency of energy conversion for a given collection area. These technologies create very high heat, which improves efficiency beyond currently available photovoltaic systems. Concentrating solar generation systems vary in how they collect and focus light.

Parabolic concentrators run a filament down the focal point of a long parabolic trough. That filament is filled with a heat transfer fluid, usually oil or molten salt, which is used to boil water for steam. Variations exist in the heat transfer fluid, and the fluid that is used to turn the turbine, with some systems using organic compounds for a lower boiling point.

Stirling dishes use a parabolic dish focused on a Stirling engine. Each unit produces a certain amount of power, with a solar installation being made up of thousands of the individual units. This allows for easy scalability of design.

Finally, solar towers use individual flat mirrors to reflect sunlight onto a central tower. The heat of the reflected light is used to create steam.

The final aspect of solar technology is the use storage systems to generate power outside of daylight hours. Several methods are being pursued, including batteries to store electrical energy from photovoltaics, and molten salts to store heat energy produced by concentrated solar power. A cost-effective energy storage technology has not yet been developed, but may become available in the future.

Transmission Requirements

Transmission costs and availability depend on the location where new solar power generating facilities would be located. As noted above, progressively higher capacity factors can be achieved in geographic areas that are increasing distances from Seattle City Light's service area. For example, while capacity factors of 12 percent may be possible for solar power in Seattle, they would be much higher in the Southwest, perhaps reaching 35 percent. In other words, the same size (and cost) of solar generating facility would be able to produce up to three times as much power in Arizona as it could in the Seattle area.

As a result, there is an inherent tradeoff between a) the amount of power that a solar generating facility of a given size can produce during the year, and b) the distance that the power would need to be transmitted to deliver it for use by Seattle City light's customers. This tradeoff could be quantitatively analyzed to determine whether and to what extent the advantages of being able to generate solar power more efficiently in regions with greater insolation would offset the higher costs for transmission that would be needed to move the power across longer distances to Seattle.

Solar Power Costs

To date, the costs for utility-scale solar power generation have been significantly higher than costs for a number of other types of generating resources. However, the solar industry is actively engaged in efforts to improve solar power technologies and achieve further reductions in cost.

Photovoltaic Solar Power Costs

The EIA 2008 Annual Energy Outlook shows capital costs for photovoltaic generating projects at $5,796 per kilowatt (in 2007 dollars). The CEC 2007 Integrated Energy Policy Report shows capital costs for new photovoltaic generating projects at $9,678 per kilowatt (in 2007 dollars). Fixed operating and maintenance (O&M) costs were $11.67 per kilowatt-year in the EIA 2008 Annual Energy Outlook and $24.87 per kilowatt-year in the CEC 2007 Integrated Energy Policy Report. Variable O&M costs were shown to be zero by both sources.

The CEC 2007 Integrated Energy Policy Report also shows levelized costs at $469 per megawatt-hour for a 1 megawatt photovoltaic solar power project owned by a publicly-owned utility and operating at 22 percent annual average capacity factor.

Concentrating Solar Power Costs

The EIA 2008 Annual Energy Outlook shows capital costs for "Solar Thermal" generating projects at $3,841 per kilowatt (in 2007 dollars). The CEC 2007 Integrated Energy Policy Report shows capital costs for "Solar - Parabolic Trough" generating projects at $4,021 per kilowatt (in 2007 dollars) and "Solar - Stirling Dish" generating projects at $6,187 per kilowatt (in 2007 dollars). Fixed operating and maintenance (O&M) costs are $56.68 per kilowatt-year for "Solar - Parabolic Trough" and $ per kilowatt-year for "Solar - Stirling Dish"in the EIA 2008 Annual Energy Outlook, and $62.18 per kilowatt-year in the CEC 2007 Integrated Energy Policy Report. Variable O&M costs are shown to be zero by both sources.

The CEC 2007 Integrated Energy Policy Report also shows levelized costs at $199 per megawatt-hour for a 63.5 megawatt "Solar - Parabolic Trough" power project owned by a publicly-owned utility and operating at 27 percent annual average capacity factor, and levelized costs at $393 per megawatt-hour for a 15 megawatt "Solar - Stirling Dish" power project owned by a publicly-owned utility and operating at 24 percent annual average capacity factor.

Environmental Impacts

Low environmental impact is a clear benefit of solar technology. Operation creates no emissions, and solar installations are very quiet. There are several areas of possible environmental concern. First, solar cells use minute amounts of rare earth elements, which are difficult to dispose. Second, a reasonable amount of land is needed for a utility scale installation, and it must be clear of obstruction. This results in a largely visible operation. Third, water may be necessary. Water is used for cooling in thermal systems, and for washing both mirrors and solar cells. Any run-off is uncontaminated, but must still be dealt with.

In addition, development of wind solar power generating resources is likely to require construction of new transmission facilities and use of other forms of generating resources to 'back up' intermittent output from the solar power projects. Environmental impacts associated with the transmission facilities and solar-firming resources also need to be considered.

Feasibility for Seattle City Light

Solar power is not currently an economically viable utility-scale resource option for Seattle City Light. However, if technological breakthroughs can be made to reduce its costs, solar power has the potential to become an attractive new source of electricity. It already has the advantage of being renewable, and the amount of solar power resources that could be developed is enormous. The relative ease of siting and straightforward construction would also make development of solar power flexible and low-risk.

In addition to cost-effectiveness, another feasibility issue that must be addressed for solar power is its intermittency of generation and low capacity factor. Similar to wind power, this can create several types of challenges. Insolation varies with cloud cover, which creates corresponding power fluctuations. Insolation can be difficult to predict over the short term, and must therefore be monitored. Also the variable energy production creates challenges for transmission. Because capacity factors for solar power are comparatively low, transmission costs can be higher for it than for other types of resources that produce at higher capacity factors. If cost-effective energy storage technologies can be developed, they could help mitigate many of the challenges associated with the variability of solar power generation.

Geothermal Power

Resource Characteristics

Geothermal electric power generation uses heat from beneath the Earth's surface to produce electricity. Geothermal power currently makes up a fraction of 1 percent of the total supply of electricity in the United States. Roughly 2,900 megawatts of geothermal power generating resources are operating in the U.S., primarily in California, Nevada, Alaska and Hawaii. While the majority of the existing geothermal generating capacity was developed during the 1980s, development of new projects has been undertaken during the last several years, including in Nevada and Idaho.

Characteristics that contribute to geothermal power's attractiveness include:

- Geothermal power is a renewable resource.
- Geothermal power does not consume fossil fuels.
- Geothermal power releases no or small amounts of carbon dioxide and other forms of emissions.
- Geothermal power generation is steady and reliable, making it a good baseload resource.

Characteristics that have limited the development of geothermal power include:

- Until recently, most geothermal power project opportunities have not been widely viewed as cost-effective relative to other forms of generating resources.
- Costs, technical requirements and project development risks for geothermal power plants can vary significantly depending on specific site characteristics.
- The number of available sites that could be cost-effectively developed is limited, making the amount of geothermal power resources that could be developed lower than other types of generating resources.
- Most prospective sites for geothermal power plants tend to be located in areas that would require construction of new transmission facilities.

Resource Potential

For existing technologies, geothermal resource potential depends on the availability of geologic conditions that combine a heat source relatively close to the surface, along with overlying hydrothermal circulation. The majority of such geologic structures exist in the Western U.S.

One type of area with technical potential for geothermal power generation is volcanic locations in the Cascade Mountain range such as Mount Baker, Glacier Peak, Mount Rainier, Mount Saint Helens, Mount Hood, Three Sisters, Mount Mazama, Mount Shasta, Mount Lassen, Newberry Volcano and Glass Mountain. However, the practical prospects for development at many of these locations is limited, particularly the ones located in protected wilderness areas.

Another type of area that may offer better development potential for geothermal power can be found in the Basin and Range areas of southeastern Oregon, southern Idaho, eastern California, Nevada and Utah.

The Western Governors' Association estimates that 50 megawatts of geothermal resources will be developed in Washington State, and that 1,285 megawatts are available for the remainder of the West over the next 10 years, increasing to 3,520 megawatts within 20 years.

Geothermal Power Technology

Geothermal energy is thermal energy stored in the Earth's crust. Thermal energy is distributed between the host rock and natural fluid contained in rock fractures and pores. The fluids are mostly water with varying amounts of dissolved salts. These fluids are present as a liquid phase but sometimes may consist of a saturated, liquid-vapor mixture or superheated steam vapor phase.

There are three existing types of designs for geothermal power plants where water exists-dry steam, flash, and binary. The appropriate type of plant is dependent on the temperature and pressure of available water, and the moisture content of available steam.

Dry Steam Plants use the steam to directly power a turbine. Water is then cooled and returned underground, or disposed of.

Flash steam power plants use hot water above 182°C (360°F) from geothermal reservoirs. As the water is pumped from the reservoir to the power plant, the drop in pressure causes the water to convert, or "flash", into steam to power the turbine.

Binary Cycle plants use a secondary transfer liquid to generate steam, heating it via a heat-exchanger with the geothermal liquid. Binary plants are the cleanest, as the geothermal resource need never be outside of a pipe when above ground, but are also the least efficient. Various secondary liquids are used, depending on the temperature of the resource.

In places where there is a lack of available water, another means of harvesting geothermal energy could potentially be used, known as Enhanced Geothermal Systems (EGS). By pumping water into dry hot rock beds, geothermal plants can be located where no resource existed before. EGS is a new and untried technology, but it may offer a larger potential than existing technologies.

Transmission Requirements

Prospective sites for development of geothermal power generating facilities are located at places with a near-surface geothermal heat source with an overlying hydrothermal circulation system. Because no such sites are located near Seattle City Light's service area, new transmission facilities would be needed to bring power from new geothermal generating facilities to Seattle.

However, some regions offer both geothermal resource potential and solar power potential, including southeastern Oregon and southern Idaho. This means that if cost-effective opportunities can be found for geothermal and solar resources, transmission could be developed for joint use of both types of resources.

Another transmission-related advantage for geothermal power generation is created by its very high capacity factor. This means that it would use transmission facilities on a nearly continuous basis, with little fluctuation. Because the majority of transmission costs are fixed costs, the high level of transmission utilization would help to keep the average unit cost of transmission for geothermal power generation relatively low.

Geothermal Power Costs

Costs for geothermal power generating resources are extremely site-specific and can vary significantly. Development costs of geothermal resources are dependent on 5 main components: exploration, confirmation, production drilling, plant construction, and operation and maintenance. Drilling depth and resource temperature are primary cost determinants.

The EIA 2008 Annual Energy Outlook shows capital costs for geothermal power generating projects at $1,139 per kilowatt (in 2007 dollars). The CEC 2007 Integrated Energy Policy Report shows capital costs for geothermal power generating projects at $3,093 per kilowatt (in 2007 dollars). Fixed operating and maintenance (O&M) costs were $114 per kilowatt-year in the EIA 2008 Annual Energy Outlook and $72.54 per kilowatt-year in the CEC 2007 Integrated Energy Policy Report. Variable O&M costs were shown to be zero in the EIA 2007 Annual Energy Outlook and $4.66 per megawatt-hour in the CEC 2007 Integrated Energy Policy Report.

The CEC 2007 Integrated Energy Policy Report also shows levelized costs at $65.55 per megawatt-hour for a 50 megawatt binary geothermal power project owned by a publicly-owned utility and operating at a 95 percent annual average capacity factor.

Environmental Impacts

The energy harnessed from geothermal sources is clean and safe for the surrounding environment. Closed loop binary systems have effectively zero emissions of any sort, while open loop systems release a small amount of carbon dioxide during the cooling process. Flash and Steam generation involve measurable releases, but are still orders of magnitude smaller than fossil fuel technology.

Geothermal power generating facilities require land and may require water for cooling. However, the requirements for land and water are fairly modest. A 50 megawatt geothermal power plant may require about 8 acres of land, and perhaps 5 gallons of water per megawatt-hour of generation may be needed. Water consumption could be eliminated at locations where air cooling could be used.

Feasibility for Seattle City Light

Geothermal energy has many desirable attributes including low emissions, no exposure to fuel price risks, base-load operation and comparatively low costs.

However, unlike a number of other types of resources, most geothermal power project opportunities are highly situational and involve unique characteristics. This makes the resource acquisition process more complicated for geothermal resources.

In addition, it is important to recognize that dozens of utilities in the western United States have recently become subject to new renewable portfolio standards (RPS) that mandate the acquisition of renewable resources. This means that there is likely to be significant demand by utilities seeking to acquire generation from what may be a comparatively limited pool of achievable and cost-effective geothermal power project opportunities. As a result, Seattle City Light can expect to find itself competing with other utilities to acquire new geothermal resources. If it is to be successful, Seattle City Light will need to develop the capability to identify and acquire geothermal resources with greater skill and timeliness than competing buyers.

Biogas Power

Resource Characteristics

Biogas is a term used to describe methane and carbon dioxide that are by-products of the digestion of organic material in the absence of oxygen. Biogas is produced by the anaerobic fermentation of organic matter including animal manure, sewage, municipal solid waste (landfill gas), or any other biodegradable waste.

Biogas is a renewable source of energy. It can be used to generate electricity. It can also be used as a vehicle fuel and for cooking, heating, lighting, process heat and absorption refrigeration. Biogas is also a combined heat and power resource.

During the last decade it has become increasingly economic to tap the methane produced at landfill sites for their store of biogas. This process is mature and well understood with economic and environmental benefits.

Biogas gas burns cleaner than other fossil fuels, such as coal and oil. Also, biogas is nearly a closed loop energy conversion process. The carbon in biogas has generally been recently extracted from the atmosphere by photosynthetic plants, so releasing it back into the atmosphere adds less total atmospheric carbon than the burning of fossil fuels.

In addition, combustion of methane produces far less carbon dioxide than allowing the methane to escape into the atmosphere. Methane is a potent greenhouse gas with a high global warming potential compared to carbon dioxide.

Characteristics that contribute to the attractiveness of biogas power include:

- Biogas power is a renewable resource.
- Biogas power does not consume fossil fuels.
- Biogas power produces little or no net amount of carbon dioxide, and it produces only small amounts of other forms of emissions.
- Biogas power is generated in baseload mode, but it can also provide some dispatching flexibility.
- Standard, mature generating technologies are used to produce biogas power.

- Once permitted and equipment is available, the lead time to construct a biogas power project is one year or less).

Biogas power has few undesirable characteristics. Examples include:

- The amount of supply of biogas fuel sources is limited.
- Costs for specific biogas power generation are situation-specific.

Biogas Technology

Current generation technologies which are biogas-capable include:

- Internal combustion engines (Reciprocating)
- Combustion turbines
- Microturbines
- Fuel cells

Currently, internal combustion (IC) engines and combustion turbines are the most economically feasible technologies for landfill gas-to-electricity projects. IC engines are by far the most commonly used technology due to their low costs, durability and relatively high efficiency. However, IC engines can emit a high level of NOx and may not be appropriate for non-attainment areas. Gas turbines emit lower levels of NOx, but require a higher, consistent volume of gas. Micro turbines can be used in non-attainment areas where NOx emissions must be minimized. There is also current experimentation with landfill gas powered fuel cells.

Resource Potential

Landfill Gas

Municipal solid waste landfills are the largest source of human-related methane emissions in the United States, accounting for about 25 percent of these emissions in 2004. Landfill gas (LFG) is produced from organic waste disposed of in landfills. In 2006, there were at least 424 operational LFG projects in 42 states supplying 10 million megawatt-hours of electricity and 75 billion cubic feet of LFG to direct-use applications. For every 1 million tons of MSW placed in a landfill, sufficient LFG is produced to generate approximately 0.8-1.0 megawatts of electric generating capacity.

Anaerobic Digesters

An anaerobic digester is a man-made system that employs the natural biological degradation of organic material to treat waste and produce biogas that can be converted to energy.

The anaerobic digestion process can be applied to most organic waste streams including sewage sludge, food waste, kitchen waste, farm waste, cattle or livestock manure. The process provides volume and mass reduction while converting the material to a stabilized product for recycling and producing biogas for renewable energy generation.

Transmission Requirements

Prospective sites for development of biogas power generating facilities are typically located at or near the underlying source of fuel. In some cases, biogas power project opportunities may be located nearby and in other cases candidate sites may be located up to hundreds of miles away. Depending on where the more distant sites are situated, the availability and cost of transmission can vary.

Another transmission-related advantage for biogas power generation is created by its high capacity factor. This means that it would use transmission facilities on a nearly continuous basis, with little fluctuation. Because the majority of transmission costs are fixed costs, the high level of transmission utilization would help to keep the average unit cost of transmission for geothermal power generation relatively low.

Biogas Costs

Various factors can affect the costs for a specific biogas generation project, including:

- Source digestion vs. landfill
- Size and regularity of fuel
- Moisture content

The EIA 2008 Annual Energy Outlook shows capital costs for biogas power generating projects (landfill gas) at $1,946 per kilowatt (in 2007 dollars). The CEC 2007 Integrated Energy Policy Report shows capital costs for biogas power generating projects (landfill gas) at $2,263 per kilowatt (in 2007 dollars). Fixed operating and maintenance (O&M) costs were $114 per kilowatt-year in the EIA 2008 Annual Energy Outlook and $20.73 per kilowatt-year in the CEC 2007 Integrated Energy Policy Report. Variable O&M costs were shown to be zero in the EIA 2008 Annual Energy Outlook and $15.54 per megawatt-hour in the CEC 2007 Integrated Energy Policy Report.

The CEC 2007 Integrated Energy Policy Report also shows levelized costs at $52.36 per megawatt-hour for a 2 megawatt biogas power project owned by a publicly-owned utility and operating at a 85 percent annual average capacity factor.

Environmental Impacts

Methane has 72 times the relative greenhouse gas potential in comparison to carbon dioxide. The Intergovernmental Panel on Climate Change stated that when averaged over 100 years each unit of methane warms the earth 25 times as much as the same mass of carbon dioxide.

Producing electricity from biogas is not completely emission-free, but is cleaner than most other resources. LFG projects help destroy methane, a potent heat-trapping gas, and offset the use of non-renewable resources such as coal, natural gas, and oil, generating carbon credits.

If a closed carbon loop process is used (burning renewable fuel), 95% of the carbon dioxide is recycled.

Current EPA regulations under the Clean Air Act require many larger landfills to collect and combust LFG. A landfill gas project can generate carbon credits because it is preventing greenhouse gases (in the form of methane) from dissipating into the atmosphere. Projects may also generate carbon credits by supplying electricity that would otherwise be generated by fossil fuels.

Biogas power generating projects also emit other forms of air emissions, including NOx and VOC. The amounts of such emissions can be controlled by processing the gas stream before combustion, or scrubbing the exhaust gases after combustions.

Feasibility for Seattle City Light

On the whole, biogas power projects offer a number of attractive features for acquisition by Seattle City Light. Primary issues affecting feasibility tend to be site and situation specific, including:

- Source, type, quality and quantity of fuel available
- Availability of existing facilities (e.g., gas collection system at landfill)
- Degree of competition from other utilities or other competing users
- Access to and cost of transmission from prospective generation project sites

Wave and Tidal Power

Resource Characteristics

Wave and tidal power plants are mechanical devices that generate electrical current from motion of water in the ocean. By utilizing a virtually unlimited source of energy, these types of plants have tremendous power-producing potential. The design and usefulness of wave and tidal power plants varies depending on the type of potential energy embodied in the ocean resource. There are two primary categories of electricity generation from ocean movement; they are:

- Tidal Power – Making use of the twice daily rise and fall of the level of the ocean due to the tides, or the movement of water caused by tidal currents.
- Wave Power – The up and down motion, or kinetic forward energy, provided by waves traveling on the surface, or the pressure waves at the bottom.

Characteristics that contribute to the attractiveness of wave and tidal power include:

- Wave and tidal power is a renewable resource.
- Wave and tidal power does not consume fossil fuels.
- Wave and tidal power does not produce carbon dioxide or other forms of air emissions.
- The potential amount of power that could be generated, especially from wave power is potentially very large.

Characteristics that make wave and tidal power a prospective, rather than proven resource include:

- Various forms of wave and tidal generating technologies are under development; it is not known yet which forms will prove to be most cost-effective, efficient and reliable.
- Wave and tidal power generation is intermittent; wave power varies with the intensity of wave action and tidal power follows more predictable tidal patterns.
- The capacity factor for many wave and tidal power projects would be relatively low.

- Wave and tidal power projects would need to be sited in locations that may involve difficult access or hostile operating conditions.
- At some sites, installation and operation of wave or tidal power generating facilities could create negative impacts on the local environment.
- At many prospective wave and tidal generating project sites, transmission facilities do not exist.

Wave and Tidal Power Technologies

Wave Power

Wave energy devices are classified into three types; shoreline (embedded), near shore, and offshore. Embedded devices are built into the shoreline and use the force of wave to push or rotate a mechanical coupling that in turn rotates a generator. Near and offshore devices generally use the up-and-down ripple motion of waves carrying a floating object in an elliptical trajectory to produce electricity.

Tidal Power

Tidal power generating technologies can be classified as one of two types: tidal stream system and barrages.

Tidal stream systems make use of the kinetic energy from water currents to turn turbines, similar to wind turbines, but underwater. Tidal stream power takes advantage of the high power density of water flows, which occur almost anywhere where there are entrances to bays and rivers, or between land masses where water currents are concentrated. These systems work similarly to wind turbines, but the higher density of water (832 times the density of air) improves conversion efficiency. In currents running at between 3.6 and 4.9 knots, a 15-meter diameter tidal turbine can generate as much energy as a 60-meter diameter wind turbine.

Barrage tidal power makes use of the potential energy from the difference in height between high and low tides to create a temporary tidal reservoir in high tides. These constructions spill water over turbines in low tide to generate power. A tidal barrage is basically a large dam across a tidal estuary and requires a large difference in height between high and low tides. Incoming tidal action forces water through sluices or flap gates where it is trapped when the tide recedes. The barrage system then generates power in a similar fashion to a hydro dam when the water level outside the reservoir falls and water is spilled to power turbines. There are only few suitable sites worldwide for this type of power generation. Some possible places in the U.S. where this would be feasible are: Passamaquaddy Bay, Maine, Knik Arm, Alaska, Turnagain Arm, Alaska, and Golden Gate, California.

Wave and Tidal Transmission Requirements

Transmission of electricity produced from wave energy is more costly than normal land-based generation systems, as energy must be transmitted from the water, requiring underwater cable and trenches. However, in utility scale applications this cost is shared over many MW, and could be cost effective. Wave power developments off the Pacific coast present greater transmission issues, since much of this area is not currently served by major transmission lines. The Oregon coast has slightly better transmission facilities than the Washington coast, but the amount of capacity available is limited.

Tidal Energy is extremely predictable, allowing for firm transmission, while wave energy varies hourly and daily, requiring some non-firm transmission. It is more predictable than wind, but still not a base load resource.

Wave and Tidal Resource Costs

The main costs for wave and tidal power are the conversion modules themselves, and maintenance costs. The ocean is powerful, and the salt can cause a lot of trouble, so maintenance is important. The difficulty of in-water operations also add to the cost.

The cost of electricity generated by wave energy converters (WECs) is becoming more competitive as device efficiency improves. Like wind turbines, WECs need to be placed where energy density is high in order to be efficient. Improvements in wind technology have resulted in taller towers making available higher wind velocities. The wind power increases as the cube of the wind speed, so significant gains in power are obtained for each incremental increase in wind velocity and the return on investment improves. The same is true with wave energy; the further offshore the devices are installed, the greater the available wave energy to be captured and the better the return on investment, assuming the device can withstand the wave conditions.

As WECs devices become increasingly modularized, many devices can be woven together into an integrated power system. This simplifies the device construction, reduces the cost as duplicate units are manufactured and increases the reliability as failure of one device does not bring the power system down.

Wave and Tidal Cost Estimates

EPRI estimates costs to be $110 to $130 per megawatt-hour for commercial scale projects in California and Oregon, and 2-3 times that for demonstration projects, with costs falling relatively rapidly as more commercial plants are added.

The EIA 2008 Annual Energy Outlook does not include cost estimates for wave or tidal power.

The CEC 2007 Integrated Energy Policy Report also shows levelized costs at $618 per megawatt-hour for a 0.75 megawatt pilot ocean wave power project owned by a publicly-owned utility and operating at a 15 percent annual average capacity factor. However, costs for a larger commercial project are expected to be significantly less.

Environmental Impacts

Wave and tidal power generating resources are clean in operation. No emissions are produced. However, they can still have significant impacts, particularly ecologically.

1. Visual Pollution – Utility-scale wave and tidal power projects would be large installations, and may be highly visible. Since good energy generation sites are often coincident with desirable natural locations, the visual impacts may be of concern.
2. Possible leaks or spills – Some of the technologies use pressurized oil as a hydraulic fluid. Although the amount in question is quite small, some concern for possible releases or spills in the event of a plant being damaged should be given.
3. Ecological change – Tidal barrages in particular affect areas much like dams do. Salinity, water cover, water flow, and plant life are all affected.
4. Wave dampening – large wave stations absorb a significant portion of the wave energy reaching the shore, changing the wave characteristics of an area. The dissipation of wave energy can help protect the coastline and may have a beneficial side effect in or around harbors.
5. Disruption of water use – there may be impact on boating and shipping.
6. Affect on marine biology – besides a more encompassing ecological change, there may be some direct issues created by the presence of turbines and other large objects.

Feasibility for Seattle City Light

Many ocean energy technologies are still in early stages of development. Resulting implications for the near-term feasibility of wave and tidal power for Seattle City Light include:

- Costs for currently available technologies are higher than is expected after further development and commercialization takes place.
- Project development risks are also likely to be significantly higher for the first installations of wave and tidal power projects.

Looking forward, the oscillating water column appears to be one of the more promising forms of generation. One drawback to the OWC is the need for significant shoreline construction.

After the OWC, in-stream tidal power is being tested at a number of sites around the world and has the potential to be a significant and viable resource within the next ten to twenty years. There are a number of potential sites around the Pacific Northwest where this type of power could be generated.

To date, wave power generation is not a widely employed technology. No commercial wave farm is currently operating.

At the current time, wind and tidal power represents more of a prospective, rather than commercially-proven form of electric generating resource. As such, its feasibility for inclusion in Seattle City Light's near-term resource acquisition plans appears limited. However, further progress in technology development should be monitored.

Biomass Power

Resource Characteristics

Biomass power is the use of biologically-derived fuels to generate electricity. This can be done in several ways:

1. Boilers directly burn the material to produce steam and turn a turbine. This is an older technology, but is frequently what is already in place.
2. Gasification heats the biomass until it emits volatile gases, which are then combusted. This improves both efficiency and emissions, and allows for combined cycle operation.
3. Pyrolysis is similar to gasification, but does not heat as far. As a result, a combustible liquid is output instead of a gas.
4. Direct Firing is reducing the waste to a powder, then burning it in air to drive a combustion turbine.

Several versions of these technologies exist, altering operating characteristics slightly. The fuel source used is widely variable, and can be anything from alcohol to woodchips to agricultural wastes. Different fuel sources involve different expenses, although the process remains roughly the same.

Biomass energy already makes up a large part of the renewable energy produced in the United States, roughly equal to hydropower generation.

Waste that can be used as biomass fuel is comparatively plentiful. By burning it with or in the place of coal, overall emissions can be substantially improved. Coal plants can be converted to biomass. Fuel on hand is easily measured, and waste generation is very predictable, making for good baseload power. Possible interruptions in waste transport (trucking strikes, floods) could cause short term problems.

Characteristics that contribute to the attractiveness of biomass power include:

- Biomass power is a renewable resource.
- Biomass power does not consume fossil fuels.
- Biomass power produces little or no net amount of carbon dioxide, and it produces relatively small amounts of other forms of emissions.
- Biomass power is generally generated in baseload mode, but it can also provide some dispatching flexibility.
- Standard, mature generating technologies are used to produce biomass power.
- Once permitted and equipment is available, the lead time to construct a biomass power project is comparatively short.

Biomass power has relatively few less-desirable characteristics. Examples include:

- The amount of supply of biomass fuel sources is not unlimited.
- Certain types of biomass fuels may have low heat content or high moisture content that reduce efficiency.
- High costs to transport various forms of biomass fuels tend to require projects to be sited near the fuel source; availability and cost of transmission from these locations varies.
- Costs for specific biomass power generation project opportunities are relatively situation-specific, and generally tend to be higher than several other forms of generating resources, including wind power and biogas power.

Resource Potential

To qualify as biomass power under Initiative 937, the fuel source must be:

> *based on animal waste or solid organic fuels from wood, forest, or field residues, or dedicated energy crops that do not include (i) wood pieces that have been treated with chemical preservatives such as creosote, pentachlorophenol, or copper-chrome arsenic; (ii) black liquor byproduct from paper production; (iii) wood from old growth forests; or (iv) municipal solid waste*

The Northwest Power and Conservation Council's 5th Power Plan identified various potential fuel sources for biomass power production.

	Fuel Supply (TBtu/yr)	Undeveloped Potential (aMW)	Fuel Price ($/MMBtu)
Logging residue	27	–	$0.70 - $4.90
Forest thinning residue	39 - 125	310 - 980	$0.75
Mill residue	18	140	$0.0 - $2.05
Recovery boiler cogeneration	80	280	$0.0
Municipal solid waste/clean wood and paper fraction	64/45	365/350	($2.40 - $4.80)
Agricultural field residues	134	Not estimated	$2.40
Animal manure	–	525	$0.00
Hybrid cottonwood residue	3	25	$1.00
Dedicated hybrid cottonwood	No estimated	–	$3.90

Data from the 5th Northwest Electric Power and Conservation Plan (May 2005)

Transmission Requirements

Transmission requirements for biomass power generation projects tend to be relatively situation-specific.

Because the costs of transporting most forms of biomass fuels over long distances are relatively high, biomass generating projects are typically located near the originating fuel source. As a result, the availability and cost of transmission from such locations to Seattle City Light's service area can vary significantly.

Biomass Resource Costs

The EIA 2008 Annual Energy Outlook shows capital costs for biomass power generating projects at $2,882 per kilowatt (in 2007 dollars). The CEC 2007 Integrated Energy Policy Report shows capital costs for biogas power generating projects (stoker boiler) at $2,917 per kilowatt (in 2007 dollars). Fixed operating and maintenance (O&M) costs were $64.33 per kilowatt-year in the EIA 2008 Annual Energy Outlook and $134.72 per kilowatt-year in the CEC 2007 Integrated Energy Policy Report. Variable O&M costs were shown to be $6.70 per megawatt-hour in the EIA 2008 Annual Energy Outlook and $3.11 per megawatt-hour in the CEC 2007 Integrated Energy Policy Report.

The CEC 2007 Integrated Energy Policy Report also shows levelized costs at $110 per megawatt-hour for a 25 megawatt biomass power project (stoker boiler) owned by a publicly-owned utility and operating at a 85 percent annual average capacity factor.

Environmental Impacts

Biomass power projects that qualify as renewable resources under Initiative 937 are likely to have relatively attractive environmental characteristics.

For example, qualifying forms of biomass power represent closed-loop systems that produce little or no net emissions of carbon dioxide. Emissions of other pollutants would also be limited, especially when control technologies are used.

Recently, concerns have been raised about certain types of biomass fuel sources, particularly ethanol derived from food crops such as corn. These concerns include questions about the actual net impact of corn-based ethanol production on fossil fuel use and carbon dioxide emissions. There are also growing concerns that diverting agricultural land to biofuels production may be contributing to reduced supplies of grains and increasing food prices.

Feasibility for Seattle City Light

Feasibility considerations related to biomass power resources for Seattle City Light primarily involve the following:

- Source, type, quality and quantity of fuel available
- Degree of competition from other utilities or other competing users
- Access to and cost of transmission from prospective generation project sites

Other Electric Generating Resource Alternatives

Overview

In addition to the renewable generating resources described in the previous section, various other types of electric generating resource alternatives are available. This section describes two basic categories of other electric generating resource alternatives.

The first group of other electric generating resources described in this section is thermal generating resource technologies that consume natural gas, coal or nuclear fuels. Each of these types of resources has characteristics that, unless resolved, appear incompatible with Seattle City Light's environmental objectives. At the same time, each has other characteristics that make them potentially attractive in terms of economics or operations, including in certain cases the potential to help accommodate intermittent generation from renewable resources.

This section also provides brief descriptions of combined heat and power and distributed generation resources. These resource alternatives are not specific types of generating resource technologies, per se. Rather, they can be characterized as types of resources that use an electric generating technology (several of which are described in this Technical Appendix) to serve multiple purposes. For example, combined heat and power resources generate electricity while also producing heat that can be used for residential or commercial heating, industrial processes, or other applications. Distributed generation resources generate electricity while also providing other benefits such as improving power flows on the utility transmission or distribution system.

Natural Gas-Fired Generation

Resource Characteristics

The most prevalent source of natural gas-fired generation uses combustion turbine technology, which has been used to generate electricity for several decades. A combustion turbine is a rotary engine composed of three basic parts. First, air is taken in through a compressor. Next, fuel is mixed with the air and burned in a combustion chamber. The resulting mechanical energy is then used to turn a turbine at a speed of 3,600 revolutions per minute.

There are two types of natural gas-fired combustion turbine generating projects. The combined-cycle combustion turbine (CCCT) uses the combustion turbine to generate power and then recovers exhaust heat from the combustion turbine to make steam for a turbine generator that in turn produces additional power. The simpler and less fuel-efficient simple cycle combustion turbine (SCCT) generates power directly, without recovering energy from the exhaust heat.

CCCT generating projects are more complex than SCCT projects, and have higher capital costs. However, because CCCT projects are more fuel-efficient than SCCT projects, operating costs and air emissions are lower for CCCT projects than for SCCT projects.

Both CCCT and SCCT generating projects are primarily fueled with natural gas. Three interstate pipelines transport natural gas to the Northwest. The Northwest Pipeline from British Columbia runs from north to south through western Washington. The two other pipelines transport gas from Alberta in Canada and from the Rocky Mountains, converging in Northeastern Oregon, proceeding through Portland and then south.

During the past 15 years, most new generating projects have used CCCT technology. The Pacific Northwest has more than 4,000 megawatts of CCCT generating capacity, most of it brought on line between 1995 and 2004. During that period, many CCCT projects were developed by non-utility generating companies for sale of power into competitive wholesale power markets. Several of these projects have recently been acquired by regional utilities.

The Northwest also has slightly more than 1,500 megawatts of SCCT generating capacity, including projects developed during the 1980s and more recently.

Characteristics that contribute to the attractiveness of natural gas-fired combustion turbine generation include:

- Capital costs are relatively low.
- Combustion turbine technology is proven, mature and reliable.

- Combustion turbine generation projects provide relatively good dispatchability, which helps utilities balance their loads and resources.
- Development of natural gas-fired combustion turbine projects is quicker and involves lower construction risk than other, more capital-intensive forms of thermal generation.
- Natural gas-fired combustion turbine generation produces relatively low emissions of carbon dioxide compared to most other forms of fossil-fueled generation.

Less desirable characteristics for natural gas-fired combustion turbine generation include:

- Fuel costs make up a comparatively large portion of total costs for this form of resource; as a result its costs are less certain and more volatile.
- Market prices for natural gas have risen dramatically during the last several years, cutting into the previous cost advantage.
- While lower than coal, natural gas-fired generation still produces significant amounts of carbon dioxide.

Resource Potential

The amount of resource potential that is available for natural gas-fired generation using combustion turbines is effectively unlimited in terms of equipment. A number of suitable sites are also available.

As a result, the amount of resource potential is effectively limited by the overall availability and market price of natural gas. During the past decade, a large number of new natural gas-fired generating projects have been developed, both in the Pacific Northwest and throughout the United States. This has added a large amount of new demand for natural gas. More recently, natural gas prices have increased significantly, which has contributed to a moderation in the development of new natural gas-fired generating projects.

Transmission Requirements

New natural gas-fired generating projects must be developed at sites that have access to both a natural gas pipeline and electric transmission facilities. While such sites have become somewhat scarcer, some suitable sites may be available that would not require construction of new high-voltage transmission lines

Resource Costs

The EIA 2008 Annual Energy Outlook shows capital costs for natural gas-fired CCCT projects at $736 per kilowatt (in 2007 dollars). The CEC 2007 Integrated Energy Policy Report shows capital costs for natural gas-fired CCCT generating projects at $779 per kilowatt (in 2007 dollars). Fixed operating and maintenance (O&M) costs were $12.46 per kilowatt-year in the EIA 2008 Annual Energy Outlook and $9.86 per kilowatt-year in the CEC 2007 Integrated Energy Policy Report. Variable O&M costs were shown to be $2.06 per megawatt-hour in the EIA 2008 Annual Energy Outlook and $4.42 per megawatt-hour in the CEC 2007 Integrated Energy Policy Report.

The CEC 2007 Integrated Energy Policy Report also shows levelized costs at $87 per megawatt-hour for a 500 megawatt natural gas-fired CCCT project owned by a publicly-owned utility and operating at a 60 percent annual average capacity factor.

The EIA 2008 Annual Energy Outlook shows capital costs for natural gas-fired SCCT projects at $431 per kilowatt (in 2007 dollars). The CEC 2007 Integrated Energy Policy Report shows capital costs for natural gas-fired CCCT generating projects at $793 per kilowatt (in 2007 dollars). Fixed operating and maintenance (O&M) costs were $11.70 per kilowatt-year in the EIA 2008 Annual Energy Outlook and $11.00 per kilowatt-year in the CEC 2007 Integrated Energy Policy Report. Variable O&M costs were shown to be $3.45 per megawatt-hour in the EIA 2008 Annual Energy Outlook and $25.72 per megawatt-hour in the CEC 2007 Integrated Energy Policy Report.

The CEC 2007 Integrated Energy Policy Report also shows levelized costs at $318 per megawatt-hour for a 100 megawatt natural gas-fired SCCT project owned by a publicly-owned utility and operating at a 5 percent annual average capacity factor.

Environmental Impacts

Combustion turbine generation consumes natural gas and emits pollutants such as carbon dioxide, sulfur dioxide (SO2) and nitrogen oxide (NOx). Control technologies are used to eliminate most, but not all emissions of SO2 and NOx. However, carbon dioxide production remains a major consideration in developing generating projects based on natural gas-fired combustion turbine technology. Projects that consume large amounts of water can also be a concern.

Feasibility for Seattle City Light

From a technical perspective, the feasibility of acquiring natural gas-fired generating resources appears relatively good. Further, natural gas-fired generation provides operating flexibility that could help Seattle City Light maintain a reliable balance of its loads and resources while integrating the intermittent production of power from renewable resources like wind and solar.

However, recent dramatic increases in market prices for natural gas make the economic feasibility for natural gas-fired generation much less attractive, both in terms of expected costs and in terms of exposure to price risks. In addition, the emissions of carbon dioxide produced by natural gas-fired generating resources would create undesired environmental impacts, as well as added cost risks for Seattle City Light.

Coal-Fired Generation

Resource Characteristics

Today, half of the electricity produced and consumed in the United States is generated using coal. The U.S. has plentiful supplies of coal and conventional coal-fired generating technologies are mature, proven and reliable.

Conventional coal-fired generation technology burns coal in a boiler to heat water, produce steam and turn a turbine. Coal power plants can be built in various sizes, but economies of scale are reached at unit capacities of several hundred megawatts. Some central-station coal plants have several units and can reach capacities of over 1,500 megawatts.

Conventional coal-fired generating plants are typically operated in baseload mode, producing a constant, steady stream of power. While some coal-fired power plants are located close to load centers, many are located near coal mines. The latter approach has been more common in the Western U.S., where long-distance transmission lines have been built to move power from distant coal plants to power-consuming areas.

In recent years, increasing attention has been focused on various pollutants by conventional coal-fired generation. Many existing plants have been retrofitted with scrubbers and other forms of controls to reduce emissions such as sulfur dioxide, NOx and mercury. However, coal-fired generation also produces carbon dioxide in larger amounts per unit of generation than any other major source of electricity.

In response to growing concerns about the environmental impacts of carbon dioxide produced by conventional coal-fired generating plants, efforts have been undertaken to develop new forms of coal-fired generating technologies. One form of so-called 'clean' coal technology is designed to gasify coal rather than crushing and combusting it in a conventional boiler. During the gasification process, sulfur and other impurities are removed. Then the purified gas is used to fuel the same type of combustion turbine that is also used to produce natural gas-fired generation.

It is also hoped that the coal gasification process can be integrated with new technologies that are intended to extract carbon dioxide from the combustion turbine exhaust and then 'sequester' the carbon dioxide by injecting it into geologic formations underground.

Development of coal gasification technologies has shown some promise. However, carbon capture and sequestration technologies have yet to be developed and shown to be technically and economically viable.

Characteristics that have historically contributed to the attractiveness of coal-fired generation include:

- Conventional coal-fired generation technology is proven, mature and reliable.
- Conventional coal-fired generating projects provide valuable baseload power.

- The cost of coal as a fuel has generally been lower than other forms of fossil fuels.
- Because it is a capital-intensive form of resource, coal-fired generation has been attractive to publicly-owned utilities that can use tax-exempt bonds to finance their participation in coal-fired generating projects.

Meanwhile, the undesirable characteristics of coal-fired generation include:

- Higher emissions of carbon dioxide from conventional coal-fired generation than from any other major form of electric generating resource.
- Increased public and legislative concerns about the environmental impacts of coal-fired generation.
- Recent setbacks that have delayed RD&D on ‘clean' coal technologies, and have increased uncertainty about the eventual viability of carbon sequestration.
- Comparatively high capital costs.
- Long construction lead times and significant project development risks.

Resource Potential

Similar to natural gas-fired generation, the resource potential for conventional coal-fired generation is not limited in a purely technical sense. Instead, the resource potential for development of new conventional coal-fired generation in the U.S. has become much more limited in recent years due to environmental concerns. In turn these concerns have created significant economic and risk constraints. Together, these factors have called into question the suitability of further development of conventional coal-fired generation.

Meanwhile, progress on development of advanced technologies for ‘clean' coal generation has been slower than had previously been hoped. In other words, the resource potential for ‘clean' coal generation currently appears cloudy due to technological limitations.

Transmission Requirements

As noted above, it has generally been more common to develop conventional coal-fired generating projects closer to coal-producing areas such as Wyoming and Montana. In part, this has been because the cost of electric transmission tended to be lower than the cost of transporting coal across long distances.

In the future, it appears likely that development of large new coal generating facilities would also require the construction of new long-distance electric transmission facilities.

Resource Costs

The EIA 2008 Annual Energy Outlook shows capital costs for conventional (scrubbed) coal-fired generating projects at $1,574 per kilowatt (in 2007 dollars). Fixed operating and maintenance (O&M) costs were $27.49 per kilowatt-year in the EIA 2008 Annual Energy Outlook. Variable O&M costs were shown to be $4.58 per megawatt-hour in th e EIA 2008 Annual Energy Outlook.

The CEC 2007 Integrated Energy Policy Report does not include conventional coal-fired generation.

The EIA 2008 Annual Energy Outlook shows capital costs for integrated coal gasification combined cycle projects with carbon sequestration at $2,603 per kilowatt (in 2007 dollars). Fixed operating and maintenance (O&M) costs were $38.60 per kilowatt-year in the EIA 2008 Annual Energy Outlook. Variable O&M costs were shown to be $2.91 per megawatt-hour in the EIA 2008 Annual Energy Outlook.

The CEC 2007 Integrated Energy Policy Report does not include integrated coal gasification combined cycle projects with carbon sequestration. However, the CEC 2007 Integrated Energy Policy Report shows levelized costs for an integrated coal gasification combined cycle project without carbon sequestration at $81 per megawatt-hour for a 575 megawatt project owned by a publicly-owned utility and operating at a 60 percent annual average capacity factor.

Environmental Impacts

As described earlier, various emissions including high levels of carbon dioxide are significant undesired features of conventional coal-fired generation. Advanced technologies such as integrated gasification combined cycle combustion turbine generation with carbon capture and sequestration are being pursued, but progress in achieving technical success and proving economic viability have not met expectations.

Coal extraction activities also create other undesirable environmental impacts, including negative impacts on land and water resources, as well as human safety.

Feasibility for Seattle City Light

At the current time, no form of coal generation appears feasible for Seattle City Light.

Conventional coal-fired generation involves a number of major environmental drawbacks that also translate to negative economic and risk attributes.

Advanced technologies for 'clean' coal generation have not been proven technically feasible or commercially viable.

Nuclear Power

Resource Characteristics

Nuclear power is generated by a process of controlled fission of isotopes of uranium where the released heat is then used to create steam and turn a turbine-generator.

As of 2004, nuclear power plants generated about 19 percent of the electricity consumed in the United States. There are 104 licensed nuclear generating units in the U.S., including 69 pressurized water reactors with combined capacity of 65,100 megawatts and 35 boiling water reactors with combined capacity of 32,300 megawatts. The last new nuclear generating unit in the U.S. came on line in 1996. All existing nuclear generating units in the U.S. use

During the 1980s, the nuclear power industry was plagued by a series of highly-publicized accidents at operating plants, as well as long construction delays and massive cost overruns for new projects. Popular support for nuclear power dropped to very low levels. Since that time, existing nuclear power plants in the U.S. have been operated at high capacity factors and without further major accidents.

Nevertheless, the risks associated with nuclear power remain at the forefront of public consciousness today. In particular, the challenges associated with transportation and storage of nuclear wastes continue to be major unresolved concerns.

Meanwhile, research and development of advanced nuclear generation technology has been proceeding. To a large extent, this has been due to continued development and use of nuclear power in countries such as Japan, China and India. More recently, proponents of nuclear power have emphasized that nuclear power does not produce emissions of carbon dioxide.

Several companies (e.g., Duke Power) have recently undertaken efforts to gain permits to begin construction of new nuclear power plants in other regions of the U.S. The eventual outcome of such efforts is difficult to predict.

Favorable characteristics of nuclear power include:

- Nuclear power generating projects provide valuable baseload power.
- Nuclear power generation does not consume fossil fuels or produce carbon dioxide.
- Fuel costs for nuclear power are generally lower and subject to less market price volatility than fossil fuels.

Meanwhile, the undesirable characteristics of power include:

- Public concerns about nuclear power plant operating safety, based on previous accidents.
- Difficulties associated with transportation and storage of nuclear wastes, including safety and cost issues.
- Comparatively high capital costs.
- Long construction lead times and significant project development risks.

Resource Potential

Various factors limit the effective amount of resource potential for nuclear power.

Limited availability of facilities for long-term storage of nuclear waste, along with related problems, may limit the number of new nuclear power plants that can be built in the U.S.

Transmission Requirements

Nuclear power plants are typically located at least some distance from large population centers. As a result, new electric transmission facilities are often required when nuclear power plants are developed.

Resource Costs

The EIA 2008 Annual Energy Outlook shows capital costs for advanced-design nuclear power projects at $2,539 per kilowatt (in 2007 dollars). The CEC 2007 Integrated Energy Policy Report shows capital costs for advanced-design nuclear power projects at $2,950 per kilowatt (in 2007 dollars). Fixed operating and maintenance (O&M) costs were $68 per kilowatt-year in the EIA 2008 Annual Energy Outlook and $140 per kilowatt-year in the CEC 2007 Integrated Energy Policy Report. Variable O&M costs were shown to be $0.49 per megawatt-hour in the EIA 2008 Annual Energy Outlook and $5.00 per megawatt-hour in the CEC 2007 Integrated Energy Policy Report.

The CEC 2007 Integrated Energy Policy Report also shows levelized costs at $91 per megawatt-hour for a 1,000 megawatt advanced-design nuclear power project owned by a publicly-owned utility and operating at an 85 percent annual average capacity factor.

Environmental Impacts

Environmental impacts of nuclear power include risks of potentially major damages associated with accidents at operating plants, as well as transportation and storage of nuclear wastes.

Feasibility for Seattle City Light

For a number of reasons, including economic, technical and policy considerations, the feasibility of new nuclear power for Seattle City Light appears unlikely for the foreseeable future.

Combined Heat and Power

Combined heat and power is the process of generating electricity along with thermal energy for use in nearby residential, commercial or industrial applications. Examples of such uses of thermal energy include space conditioning (heating and cooling), water heating, commercial cooking and drying, and industrial processes.

Various forms of electric generating resource technologies can be used for combined heat and power production, including:

- Combustion turbines
- Microturbines
- Fuel cells
- Boiler steam turbines
- Internal combustion (reciprocating) engines

While various fuels could be used, natural gas is the most common fuel source for combined heat and power.

In a typical combined heat and power facility, an electric generating resource technology is used to produce electricity. Exhaust heat from the generator is then captured and used to produce heated air, hot water or steam for delivery to the thermal host.

One of the primary reasons for interest in combined heat and power is because it provides the opportunity to make more productive use of the fuel source than just using to generate electricity alone. In many cases, the use of waste heat helps to partially or fully offset fuel use that would otherwise be needed to meet the needs of the thermal host. As a result, overall emissions of carbon dioxide and other pollutants from the combustion of fuels can be reduced.

Combined heat and power also has the potential to provide net economic benefits when compared to the separate generation of electricity and production of thermal energy.

While combined heat and power has significant conceptual appeal, the number of projects that have actually been developed is less than might have been imagined. Consequently, combined heat and power has not captured a large share of the total amount of electric generation.

Factors that have contributed to the relative dearth of development of combined heat and power resources include the following:

- Specific opportunities for combined heat and power are highly diverse and situation-specific. For example, thermal requirements vary significantly depending on the size, type and other characteristics of the host facility. As a result, many combined heat and power projects require customized designs, leading to higher project costs and development risks.
- With the exception of some large industrial applications, most host facilities have thermal requirements that can be satisfied with comparatively small sizes of electric

generating capacity. This can result in lower fuel efficiencies than is often possible with larger-scale electric generating resources.

- Interconnection requirements and development of mutually-acceptable agreements can present barriers.
- Operating requirements for combined heat and power facilities can at times be subject to divergent objectives. For example, the operational needs of the thermal host may be driven by weather patterns or industrial production schedules which may or may not be compatible with the electric utility's needs for electricity generation.
- By definition, combined heat and power projects involve multiple parties, including the thermal host and the electric utility. In addition to the operational issues described above, the larger number and differing needs of the project participants creates added complexity for project financing and development.

Where feasible and cost-effective, combined heat and power projects can provide a number of benefits and could be useful electric generating resources for Seattle City Light. However, the process of identifying the most promising opportunities can be difficult and confusing for prospective thermal hosts and third-party developers.

For example, prospective thermal hosts and third-party developers may not always understand how utilities value the power that would be generated by a specific combined heat and power project opportunity, compared to other available forms of electric resources.

One approach that may help to address this barrier would be for Seattle City Light to identify approximate ranges of values that would apply to its evaluation of various types of power generation (e.g., firm vs. non-firm, constant vs. seasonally varying generation, etc.). Then prospective thermal hosts or third party developers could use the price information to identify which specific combined heat and power projects have stronger economic potential.

Distributed Generation

Distributed generation basically involves the strategic installation of electric generating facilities at locations that are beneficial to the operation of the transmission grid and/or local distribution facilities.

Potential benefits of distributed generation include:

- Improved reliability of the overall utility system (e.g., voltage support)
- Higher quality of service for specific customers or portions of the system (e.g., standby power for hospitals, uninterruptible industrial processes)
- Deferral or avoidance of the need to construct new transmission and/or distribution facilities
- Lower costs from an overall system perspective (i.e., total costs for generation plus transmission plus distribution)
- More cost-effective approach for serving remote electrical loads

Various forms of electric generating resource technologies can be used for distributed generation, including:

- Combustion turbines
- Microturbines
- Fuel cells
- Solar photovoltaics
- Boiler steam turbines
- Internal combustion (reciprocating) engines

Various types of fuels could be used for the thermal generating technologies listed above. Natural gas is a common fuel source, but biofuels could also be used.

While distributed has significant conceptual appeal, the number of projects that have actually been developed is less than might have been imagined. Consequently, distributed has not captured a large share of the total amount of electric generation.

Factors that have contributed to the limited development of distributed generation resources include the following:

- Specific opportunities for distributed generation are highly diverse and situation-specific. For example, the type and frequency of events when operation of distributed generation resources is needed to support grid requirements can vary significantly.
- In some situations, grid requirements can be satisfied with comparatively small sizes of electric generating capacity. This can result in lower fuel efficiencies than is often possible with larger-scale electric generating resources.
- Interconnection requirements and development of mutually-acceptable agreements can present barriers.
- Evaluation of distributed generation requires a system-wide perspective, including costs and benefits to customers as well as the utility's power supply, transmission and distribution systems, and environmental impacts. Methods and processes for addressing these types of cross-functional topics are not widely understood or used.

Obviously, a number of the same sort of circumstances that may support development of distributed generation could also favor combined heat and power facilities. These types of opportunities may be more economically attractive than otherwise similar situations where only combined heat and power or distributed generation is possible.

Where feasible and cost-effective, distributed generation projects can provide a number of benefits and could be useful electric generating resources for Seattle City Light. Specific opportunities for distributed generation are situation-specific. Assessing the net costs and benefits is a complex process that requires integration of several functional perspectives. Screening criteria could be useful for potential distributed generation opportunities, and perform more detailed evaluation of those opportunities that appear most promising.