BONNEVILLE POWER ADMINISTRATION

Renewable Energy Technology Roadmap

(Wind, Ocean Wave, In-Stream Tidal & Solar Photovoltaic)

TECHNOLOGY INNOVATION OFFICE

September 2006

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Sections II, III and IV (Containing the Technology Reports) are sub-divided into the four sub-sections described below:

1. *Technology Overview*: Provides a general description of the technology including the fundamental physics involved, resource availability, commercial status, market penetration levels, prototypes, etc.
2. *Opportunity Overview*: An opportunity overview describes RD&D activities that have been proposed, or are underway in the Pacific Northwest and California.
3. *RD&D Challenges*: Identifies technical challenges that must be resolved before the technology can fully mature.
4. *Sector Actors*: Identifies companies, universities, public agencies, national labs, advocacy groups and private institutions that are heavily involved in renewable technologies.

1.0 Executive Summary Section I

1.1 Introduction

In 2005 the Bonneville Power Administration laid out a strategy to reinvigorate and focus the agency's research, development and demonstration activities. As part of this effort, BPA created the Office of Technology Confirmation/Innovation (TC/I) and appointed its first Chief Technology Innovation Officer.

The TC/I mission is to support BPA's objective to be a leader in the application of technologies that increase BPA's value to the Pacific Northwest.

The (TC/I) initiative will create an annual cycle of research and development funding based on strategic needs identified in the agency's technology roadmaps. Technology road-mapping is a form of technology planning used to inform and guide the agency's research and development agenda. Such roadmapping enables the agency to make better technology investment decisions by identifying critical technologies and technology gaps, and identifying ways to leverage agency research, development and demonstration (RD&D) investments.

This document is the technology roadmap for transmission grid-connected wind, ocean wave, in-stream tidal and solar photovoltaic energy resources. Similar roadmaps have been created for energy efficiency, transmission and hydro resources.[1] Roadmaps for geothermal and biomass will be developed in future cycles of the TC/I RD&D Portfolio Selection process

1.2 Scope

This roadmap focuses on the high priority intermittent renewable energy technologies that are poised to have significant impacts in the Pacific Northwest (PNW). This report is not intended to minimize other important research, development and demonstration projects(RD&D) that BPA and others are currently undertaking. This report is intended to provide information that will guide the agency's research and development agenda, and will be useful to others contributing to advances in these specific technology areas.

This document provides a snapshot in time of the current status of development in wind, ocean wave, in-stream tidal and solar photovoltaic technologies. This snapshot includes:

1. An overview of each technology describing the fundamental physics involved, resource availability, commercial status, market penetration levels, prototypes, etc.
2. An opportunity overview of each technology, describing specific RD&D activities that have been proposed or are underway in the Pacific Northwest and California.
3. A summary of the technical challenges that must be resolved before the technology can fully mature.

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[1] Fish and Wildlife R&D efforts, while a substantial and ongoing part of BPA's business agenda, are not part of the TC/I initiative.

4. Links to companies, universities, public agencies, national labs, advocacy groups and private institutions that are heavily involved in the RD&D for these technologies.

This roadmap will be updated during FY 2007 for application in FY 2008 and beyond.

1.3 Methodology

BPA's renewable energy roadmapping process began on June 23, 2006, when a group of experienced agency employees[2] attended a TC/I-sponsored brainstorming workshop. At the workshop, they were asked to identify the compelling business reasons for BPA's investment in renewable energy. These so-called "drivers" were ranked by their relative degree of importance, or value, to BPA and the region. Higher ranked drivers were then grouped into categories based on common goals or "targets" that align with Agency Strategic Objectives, specifically SBO I4: *BPA is a leader in the application of technologies that increase the value of mission deliverables.*

The higher ranked business drivers identified by workshop participants tended to fall into one of the following two target categories:[3]

1. Enhance the capability of the electric system to assimilate intermittent renewable energy technologies.
2. Encourage the development and demonstration of renewable energy technologies.

On July 18, 2006, BPA's Office of Technology Innovation invited a group of external experts from around the country to join with BPA staff in a second brainstorming workshop focused on the following objectives:

- Discuss the business challenges, opportunities and targets identified during the internal workshop described above;
- Identify the features of the most promising technologies that comport with the targets and business drivers identified during the first workshop;
- Identify the technological gaps that stand in the way of deploying these technologies;
- Identify renewable energy-related R&D investments BPA should consider.

Both workshops employed a structured nominal-group brainstorming method that encourages contributions from everyone and takes advantage of pooled judgments. Hence it was particularly important that participants have expertise from a variety of perspectives in wind, ocean wave, in-stream tidal, solar, geothermal and biomass.[4]

During the second workshop, group members identified literally dozens of technological challenges to be met if wind, ocean wave, in-stream tidal, solar photovoltaic, geothermal and

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[2] For a list of attendees to the first workshop see Appendix F

[3] This part of the road-mapping process is summarized in Appendix C.

[4] For a list of attendees and organizations participating in the second workshop see Appendix G.

biomass energy are to become commercially viable. These challenges were ranked by their relative degree of value to BPA and the region. The higher ranked challenges were: (1) assessed for their relative degree of technical risk, commercial risk and potential to add value; and, (2) grouped into categories defined by a common underlying objective or technical challenge. The following categories of technological challenges emerged from this process:

1. Utility management of grid-connected intermittent energy to include: the reduction of forecasting and scheduling errors; reduction of reserve (capacity) requirements; technology that makes renewables smaller consumers of ancillary services (regulation, load following); congestion management; renewable facility redispatch and output control; tools to manage intermittency, optimization of generation and transmission assets, etc.;

2. Wave/tidal projects that aren't very efficient yet and exist in a corrosive environment, which have the same issues as #1 above. Projects of additional interest include: efficiency improvement, anti-fouling technologies, turbine designs, permitting, mitigating environmental impacts, innovative control and protection systems, transmission integration, etc.

3. Technologies which reduce distributed generation impacts on low-voltage systems, reduce or mitigate load variability and support ancillary services in the management of intermittency.

4. On-site (short-term) energy storage;

5. Off-site (longer term) energy storage.

In addition, for each of these five categories, the group also identified: (1) key features of the category that respond to one or more of the agency's business drivers; (2) essential challenges to be met; (3) technological gaps; and (4) RD&D implications to BPA and the region.[5]

Following the workshop, BPA staff reviewed the literature to confirm the current status of each renewable technology and contacted other energy-related organizations from around the country to learn their primary areas of focus. The purpose of this survey was two-fold: (1) to make sure the roadmapping process had not missed any promising emerging renewable technologies, and (2) to understand what RD&D is currently underway or planned.

BPA staff then used the information and insights gleaned from the roadmapping process described above to identify the renewable energy RD&D technologies and research activities to be included in this year's TC/I Portfolio Selection Process. Each project or research activity had to fulfill the following criteria to be a viable candidate for selection:

1. Align with agency Strategic Business Objectives;

2. Be consistent with the outcome of the brainstorming process; and,

3. Comport with TC/I's overall business strategy.[6]

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[5] This information is summarized in Appendix E.

In identifying the renewable RD&D candidates for this year's Portfolio Selection Process, the TC/I Council narrowed the scope of the roadmap to focus on those activities that deal with ocean wave, in-stream tidal and solar photovoltaic technologies. This decision was made for the following reasons:

- The higher level business targets and technical challenges identified in the workshops focus on intermittent renewable technologies and technologies that enhance the region's ability to integrate them.

- Wind, ocean wave, in-stream tidal and solar photovoltaic technologies are currently attracting high levels of commercial interest worldwide, including the active interest of BPA customers, PNW government agencies, national labs and renewable energy advocates.

- Wind is a rapidly maturing industry with more than 2,000 megawatts (MW) online or under active development in the PNW and another 2,000 MW in planning stages. Over the long run, the Northwest Power and Conservation Council (Council) estimates that the region may see as much as 6,000 MW of wind resource integrated into the system.

- Although in a pre-commercial state, ocean wave and in-stream tidal technologies are moving forward at a rapid pace. Siting studies are underway; FERC permits are being filed; and pilot projects are being planned at several locations in Oregon, Washington and California[7].

- Solar photovoltaic has enormous potential and may be very close to commercial viability..

- The PNW is naturally endowed with high quality wind, wave and in-stream tidal resource sites.[8]

- There is a sense of urgency associated with the challenge of integrating intermittent resources. The current pace and scale of wind development has raised legitimate concerns regarding the ability of the electric system to assimilate large amounts of intermittent resources such as wind, ocean wave, in-stream tidal or solar photovoltaic. These concerns have created a need for new systems and methods of integrating these types of resources.[9]

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[6] The TC/I Business Strategy is described in the Business Integration white paper http://bpaweb/orgs/orgs%20main/techinnova/default.aspx

[7] See Ocean Wave and In-Stream technology reports included in this document.

[8] In addition, Oregon is well positioned to assume a leadership role in ocean wave technology development and manufacturing see OSU discussion in Ocean Wave Technology Report - Section 2.2.

[9] The Northwest Power and Conservation Council and the Bonneville Power Administration are cosponsoring development of a Northwest Wind Integration Action Plan. The plan will identify and commit participants to regional steps to cost effectively integrate large amounts of wind power and other intermittent renewable resources into the Northwest power system. New tools to successfully integrate large amounts of wind have been proposed; it will take regional cooperation to refine and implement them. A multidisciplinary work group representing Northwest utilities,

1.4 RD&D Recommendations for Wind, Ocean Wave, In-Stream Tidal and Solar PV

Table 1 displays a broad list of ongoing and proposed RD&D activities in wind, ocean wave, in-stream tidal and solar photovoltaic technologies that the TC/I Council may elect to address in various ways: co-sponsoring and funding, sponsoring and leading, participating in demonstration projects, or monitoring for future consideration.

Selection of these research activities was based on the information gleaned in the roadmapping workshops,[10] surveys and conversations with industry experts and a comprehensive search of the literature. The results are summarized in this report.

Some activities focus on advancing the fundamental science and engineering of a particular resource technology. Others focus on demonstration projects that enhance the commercial viability and acceptance of the technology. Still others concentrate on solving the technical challenges associated with integrating these types of intermittent resources into the power grid.

Table 1 Recommended BPA RD&D Activities for Wind, Ocean Wave, In-Stream Tidal and Solar Energy

Area of RD&D Activity **(document location)**	**Approach[11]**	**Recommended BPA RD&D Actions**	**Reference Material**
Wind integration research – Examples include BPA/NWPCC Northwest Wind Integration Action Plan, CEC sponsored PIER Intermittency Analysis Project and wind forecasting for PBL and TBL wind projects.	C,D,M,S	Support research (lead), technical approaches and demonstration projects to support this emerging critical area of integration, impact mitigation and utility optimization of intermittent resources (see pg. 6)	Pages 20-27
Offshore wind research	M	Continue Monitoring	Page 27
Wind turbine research	M	Continue Monitoring	Page 28
Ocean Wave Projects	C, D, M	Support research, technical approaches and demonstration projects	Pages 35-38
In-Stream Tidal Project	C,M	Support research and technical approaches	Pages 45-55
Demand response technologies that support active load shaping techniques and facilitate integration of intermittent	C,D,M	Identify optimal mix of EE RD&D activities, challenges, potential costs, etc., that support integration of	Energy Efficiency Roadmap

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independent power producers and other stakeholders will develop the proposed Action Plan this summer and circulate it for public discussion this fall.

[10] See Appendices D & E.

[11] BPA approach designates whether BPA intends to: (C) co-sponsor and fund research, (D) participate in demonstration projects, (M) monitor progress of research by others pending some breakthrough that would bring the technology higher on agency priorities (will not receive funding), or (S) sponsor (lead) research that is deemed critical to agency needs.

Area of RD&D Activity **(document location)**	**Approach**[11]	**Recommended BPA RD&D Actions**	**Reference Material**
resources.		intermittent resources.	
Transmission technologies that enhance communication with and to end users and provide direct control of renewable resources and deferrable loads and control of intermittent resources	C,D,M	Identify optimal mix of Transmission RD&D activities, challenges, potential costs, etc., that support integration of intermittent resources.	Transmission Roadmap
Short-term storage technologies that can load factor short-term fluctuations in power from intermittent resources. Technologies include: super-capacitors, flywheels, batteries, super conducting magnetic energy storage (SMES).	C,M	Identify optimal mix of RD&D activities, potential costs, etc., that support short-term storage capabilities and the integration of intermittent resources.	Pages 24-27, Appendix C & Transmission Roadmap
Long-term storage technologies that can provide reserves during extended periods of low resource availability. Technologies include: hydro storage, compressed air energy storage (CAES) and closed cycle pumped storage.	C,M	Identify long term storage opportunities, potential sites, costs, etc. that support long storage capabilities and the integration of intermittent resources.	Pages 24-27 Appendix C & Hydro Operations Roadmap
Solar photovoltaic	M	Continue Monitoring	Pages:57-67 & Appendix B

1.5 How will this road map be used? - Next Steps

This roadmap will be used in the following ways:

1) To guide the Office of Technology/Confirmation Innovation in developing the Renewable Energy RD&D request-for-proposals (RFP) project selection for fiscal years 2007 and 2008;

2) To guide the Office of Technology/Confirmation Innovation in developing the agency's RD&D agenda for fiscal years 2007 and 2008;

3) As an aid in the RFP solicitation process;

4) To communicate and coordinate RD&D activities within BPA and the region;

5) To initiate dialogue and develop collaborative relationships with other organizations advancing renewable technologies.

2.0 Wind Generation

2.1 Technology Overview

Like old fashioned windmills, today's wind machines use blades to collect the wind's kinetic energy. Windmills work because they slow down the speed of the wind. As the wind flows over the airfoil-shaped blades, it creates lift, like the effect on airplane wings. This lift causes a reaction torque. The torque rotates blades connected to a drive shaft that turns the rotor shaft which in turn is connected to an electric generator that produces the electricity.

The amount of power transferred to the rotor shaft is directly proportional to the density of the air, the area swept out by the turbine blades and the cube of the wind speed.

The mass of air traveling through the swept area of a wind turbine varies with wind speed and air density. As an example, at sea level, on a cool 15°C (59°F) day, the air density is about 1.22 kilograms per cubic meter (it gets less dense with higher humidity). An 8-meter/s breeze blowing through the area swept out by a 100-meter diameter turbine blade assembly would move approximately 76,000 kilograms of air per second through the swept area.

The kinetic energy of a given mass varies with the square of its velocity. Because the mass flow increases linearly with wind speed, the wind energy available to a wind turbine increases as the cube of the wind speed. The total wind power flowing past the wind turbine blades in the example described above would be approximately 2.5 megawatts.

Recent work by Gorlov[12] shows a theoretical efficiency limit of about 30 percent for the propeller-type turbine pictured at left. Actual efficiencies range from 10 to 20 percent for propeller-type turbines, and are as high as 35 percent for three-dimensional vertical-axis turbines such as the Darrieus turbine pictured at right.

Average wind speed is not the sole indicator of the amount of energy that can be produced at a given location. To assess wind potential at a particular location, a probability distribution function is often fit to the observed data. Different locations will have different wind speed and theoretical energy availability distributions. The histograms displayed below plot the distribution of wind speed (red) and available energy (blue) for all of 2002 at the Lee Ranch facility in Colorado. These distributions indicate that most of the power is generated by higher wind speeds and in short bursts. The Lee Ranch data also indicate that half of the available

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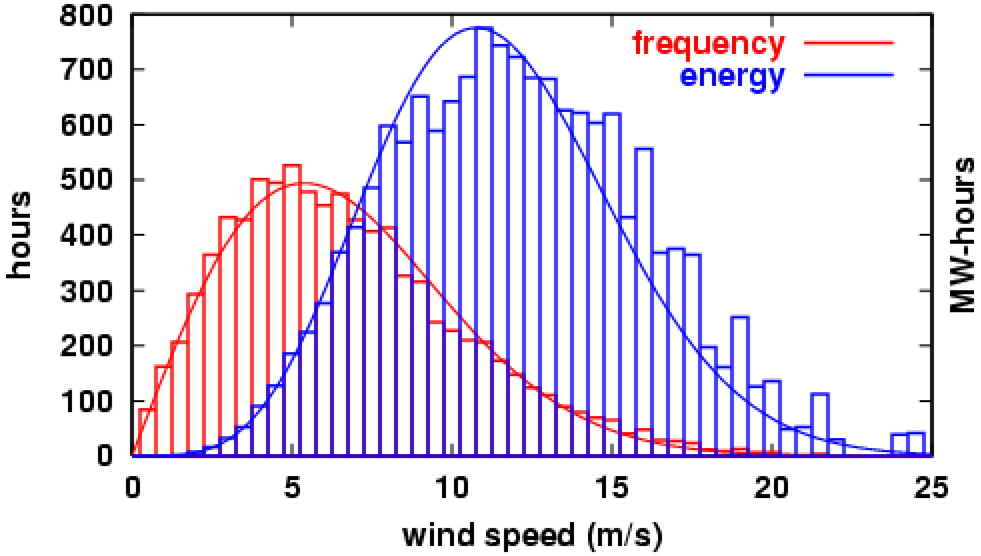
[12] Gorban, Alexander N. (December 2001). "Limits of the Turbine Efficiency for Free Fluid Flow". *Journal of Energy Resources Technology* **123**: 311-317. Retrieved on 2006-04-21.

energy was produced in just 15 percent of the operating time. Consequently, wind energy is intermittent and more difficult to predict and schedule than energy from fired power plants.



Since wind speed is not constant, a wind generator's annual energy production is never as much as its theoretical limit (i.e., nameplate rating multiplied by the total hours in a year). The ratio of actual energy produced to the theoretical limit is called the capacity factor. A well sited wind generator will have a capacity factor of approximately 35 percent. This compares to typical capacity factors of 90 percent for nuclear plants, 70 percent for coal plants, and 30 percent for oil plants. When comparing the size of wind turbine plants to fossil-fired power plants, it is important to note that a 1,000-kW wind-turbine would only be expected to produce as much energy in a year as a 500-kW coal-fired plant.

Although the short-term energy output of a wind plant can vary significantly across days or even weeks, the annual output of energy tends to vary only a few percentage points between years.

Wind turbines are designed to produce electrical energy as cheaply as possible.[13] They are therefore generally designed so that they yield maximum output at wind speeds around 15 meters per second (30 knots or 33 mph). It is not cost effective to design turbines to maximize output at stronger winds because strong winds are relatively rare.

In case of strong winds, part of the excess wind energy must be wasted to avoid damaging the wind turbine. All wind turbines are therefore designed with one of two types of turbine blade control systems; i.e., pitch control systems or stall control systems. On a pitch-controlled wind turbine, such as the one illustrated below, the turbine's electronic controller checks the power output of the turbine several times per second. When the power output becomes too high, it sends an order to the blade pitch mechanism which immediately pitches (turns) the

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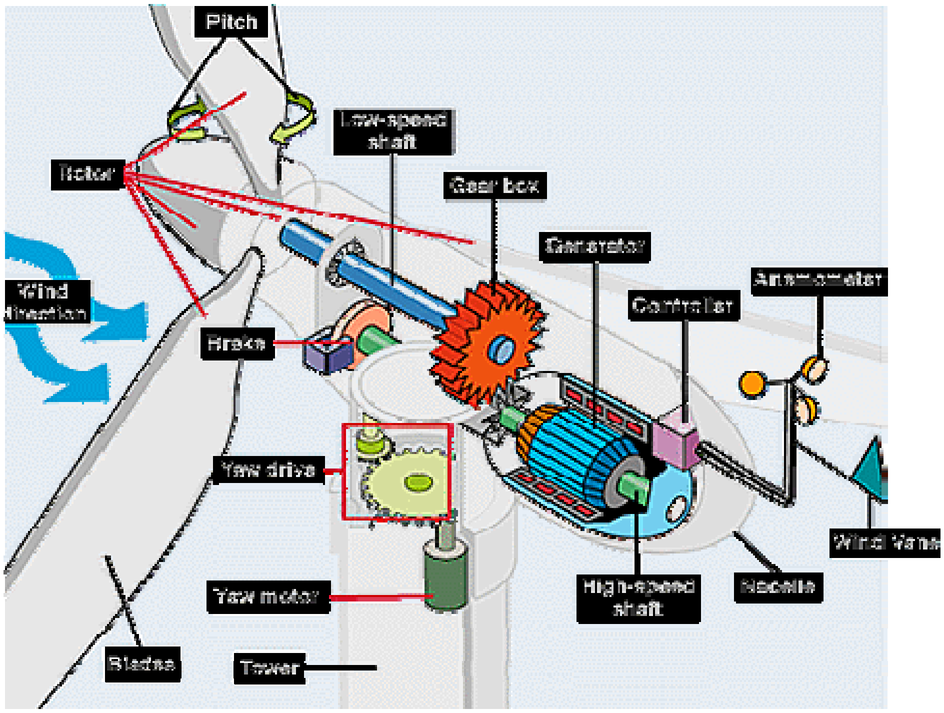
[13] The following discussion is a condensed and edited version of material contained at an excellent website describing wind turbine design and operation. See Danish Wind Industry Association, http://www.windpower.org/en/tour/rd/index.htm



rotor blades slightly out of the wind, thereby reducing lift. Conversely, the blades are turned back into the wind when the wind power returns to safe operating levels.

In passive, or stall-controlled, wind turbines, rotor blades are bolted to the hub at a fixed angle. However, the geometry of the rotor blade profile has been aerodynamically designed to ensure that when the wind speed is excessive, turbulence is created on the leeward side of the rotor blade causing it to "stall." This reduces the lifting force of the rotor blade.

The basic advantage of stall control is that it eliminates the need for a pitch-control system as well as moving parts in the rotor-hub assembly. On the other hand, stall-control systems present a complex aerodynamic design problem, and related challenges in the structural dynamics of the entire wind turbine structure;e.g., stall-induced vibrations.

Approximately two thirds of the wind turbines currently being installed worldwide are stall-controlled machines.

Almost all horizontal-axis wind turbines use forced yawing; i.e., a mechanism uses electric motors and gearboxes to keep the turbine yawed into the wind. The wind turbine is said to have yaw error if the turbine blades are not rotating in a plane that is perpendicular to the direction of the wind. A yaw error implies that a lower share of the energy in the wind will pass through the circular area swept out by the turbine blades.

Cables carry the current from the wind turbine generator down through the tower. These cables will twist if the turbine continues to yaw in the same direction. Therefore, the wind turbine is equipped with a cable twist counter that signals the controller to untwist the cables. Occasionally a wind turbine may appear to have gone berserk, yawing continuously in one direction for five or so revolutions.

The power from the rotation of the wind turbine rotor is transferred to the generator through the power train; i.e., through the main low speed shaft, the gearbox and the high speed shaft.

An obvious question is why use a gearbox? Couldn't the generator be directly connected to the main shaft and the turbine blades?

A generator can be directly connected to the turbine blade assembly. However, if a typical three-phase generator with two, four, or six poles,[14] were directly connected to the public grid – which operates at 60 Hz alternating current (AC) – the turbine blade assembly would have to rotate at 3,600, 1,800 or 1,200 revolutions per minute (rpm) respectively. At these speeds, the turbine blade assembly would fly apart.

Another approach is to build a slower rotating AC generator with many poles. However, this approach would require a three-phase generator with 240 poles to achieve a reasonable rotational speed of 30 rpm.

Another problem with eliminating the gearbox is that the mass of the turbine shaft must be roughly proportional to the amount of torque (moment, or turning force) it has to handle. So a directly driven generator will require a very heavy (and expensive) drive shaft.

The practical solution is to use a gearbox. A gearbox converts the slowly rotating, high torque power delivered by the wind turbine blades to the higher rpm, low torque power needed by the generator. One should note that the gearbox in a wind turbine employs a fixed gear ratio and does not "change gears." For example, the gear ratio of a typical four-pole, 600 or 750 kW machine would be approximately 1-to-60.

Wind turbines are designed with synchronous or asynchronous[15] generators, which have various forms of direct or indirect connection to the public power grid.[16] With direct grid connection, the generator is connected directly to the (usually three-phase) alternating current of the public grid.

Most of the world's wind turbines use a three-phase asynchronous (cage wound) generator, also called an induction generator, to generate alternating current. An induction generator is essentially a special purpose motor that is driven slightly above synchronous speed by the wind turbine. The speed of the asynchronous generator will vary with the turning force (moment or torque). In practice, the difference between the rotational speed at peak power and at no-load idle is very small, about 1 per cent. Thus a four-pole asynchronous generator directly connected to a grid with a 60 Hz current will idle at 1,800 rpm and produce maximum power at approximately 1,818 rpm.

The slip is a function of the direct current (DC) resistance (measured in ohms) in the rotor windings of the generator - the higher the resistance, the higher the slip. Thus, one way of varying the slip is to vary the resistance in the rotor. In this way one may increase generator slip to 10 percent, for example.

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[14] To learn more about generator "poles" see tutorial in Appendix A

[15] To learn more about synchronous and asynchronous generators see tutorial in Appendix A.

[16] Many of the same principles discussed in this section apply to ocean wave, in-stream tidal devices.

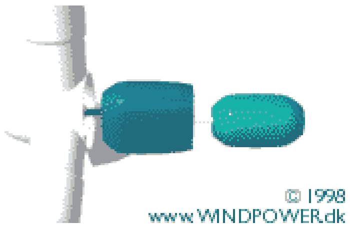
The advantage of a variable-slip asynchronous generator is that, when a wind gust occurs, the control system can increase generator slip to allow the turbine blade assembly to rotate faster. At the same time, the pitch mechanism begins to cope with the situation by pitching the blades more out of the wind. Once the pitch mechanism has done its work, the slip is decreased again. The process is applied in reverse when the wind suddenly drops. The result is that generator slip produces less wear and tear on the gearbox. A widely used Danish turbine design uses this control strategy. It runs the generator at half of its maximum slip when the turbine is operating near the rated power.

A generator’s ability to increase or decrease its speed slightly if the torque varies is a useful mechanical property. It is one of the most important reasons for using an asynchronous generator rather than a synchronous generator on a wind turbine that is directly connected to the electrical grid.

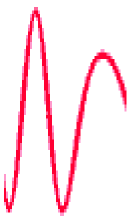
A synchronous generator has no slip because the rotational speed of the generator’s rotor is exactly equal to the rotational speed of current in the generator’s stator. Wind turbines, which use synchronous generators, normally use electromagnets in the rotor. These are fed by direct current from the exciter, which receives its power from the electrical grid. Since the grid supplies alternating current, the alternating current must be converted to direct current before it is sent through the exciter and into the coil windings around the electromagnets in the rotor.

The rotor’s electromagnets are connected to the exciter using brushes and slip rings on the axle (shaft) of the generator. The DC exciter also enables the asynchronous generator to produce its own reactive power and regulate its voltage, even when it is not connected to another power source. This means that it can operate either in parallel with the utility, or it can operate in "stand-alone" mode (independent of any other power source). If the generator is disconnected from the main power grid, it has to be rotated at a constant speed to produce alternating current with a constant frequency. Consequently, with this type of generator one normally uses an indirect grid connection between the generator and the public grid. Another advantage of a synchronous generator is that, since it creates reactive power, it can improve the plant power factor. Synchronous generators require a speed reduction gear.

Indirect grid connection means that the current from the generator passes through a series of electronic devices which adjust the current frequency to match that of the grid. This occurs automatically with an asynchronous (induction) generator.

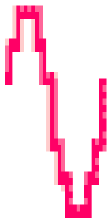


Rotor/Gearbox/Generator

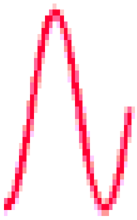


Variable Frequency AC

Direct Current DC



Irregular Switched AC



Grid Frequency AC

Most wind turbines run at almost constant speed with direct grid connection. With indirect grid connection, however, the wind turbine generator runs in its own, separate mini AC-grid, as illustrated above.

This mini-AC grid is controlled electronically, so that the frequency of the alternating current in the stator of the generator may be varied. In this way it is possible to run the turbine at variable rotational speed. Thus the turbine will generate alternating current at exactly the variable frequency applied to the stator.

However, variable frequency AC current in the mini-grid cannot be injected directly into the public electrical grid. The variable frequency AC must be converted to DC using thyristors. Thyristors are large semiconductor switches that operate without mechanical parts. The DC is then converted back to AC with exactly the same frequency as the public electrical grid. This conversion also is done using thyristors.

The quality of the alternating current from this process looks quite ugly at first sight. Instead of a smooth sinusoidal curve, there are a series of sudden jumps in voltage and current, as shown above. These rectangular waves can be smoothed out using a so-called AC filter mechanism.

The primary advantage of indirect connection is that gusts of wind can be allowed to make the rotor turn faster, thus storing part of the excess energy as rotational energy until the gust is over. A secondary advantage is that power electronics provide the ability to control reactive power (i.e., the phase shifting of current relative to voltage in the AC grid) to improve the power quality in the electrical grid. This may be useful, particularly if a turbine is running on a weak electrical grid.

The basic disadvantage of indirect grid connection is cost. The turbine will require expensive electronic controls to convert from variable frequency AC to DC and back to the public grid frequency. In addition, energy is lost in the AC-DC-AC conversion process, and the power electronics may also introduce harmonic distortion of the AC in the electrical grid, thus reducing power quality. Harmonic distortion arises because the filtering process mentioned above is not perfect, and it may leave some “overtones” (multiples of the grid frequency) in the output current.

With indirect connection, the generator may be either a synchronous generator or an asynchronous generator, and the turbine may have a gearbox or run without a gearbox.

Wind Turbines and Power Quality Issues: The term “power quality” refers to the voltage stability, frequency stability and the absence of various forms of electrical noise (e.g. flicker or harmonic distortion) on the electrical grid.

Starting (and Stopping) a Turbine: Most electronic wind turbine controllers are programmed to let the turbine idle without grid connection at low wind speeds. (If the turbine were connected to the grid at low wind speeds, it would in fact run as a motor). The turbine generator must connect to the electrical grid at the right moment once the wind becomes powerful enough to turn the rotor and generator at their rated speed; otherwise, only the mechanical resistance in the gearbox and generator will prevent the rotor from accelerating and eventually over-speeding. (There are several safety devices, including fail-safe brakes, in case the correct start procedure fails).

Soft Starting with Thyristors: If a large wind turbine were to be switched on to the grid with a normal switch, there would be a brownout (caused by the current required to magnetize the generator), followed by a power peak due to the generator current surging into the grid. Another unpleasant side effect of using a “hard” switch would be to put a lot of extra wear on the gearbox. The cut-in of the generator would work as if one suddenly slammed on the mechanical brake of the turbine. To prevent this, modern wind turbines are soft starting: i.e., they connect and disconnect gradually to the grid using thyristors.

Weak Grids, Grid Reinforcement: If a turbine is connected to a weak electrical grid, (i.e., it is in a remote corner of the electrical grid with low power-carrying ability), there may be some brownout or power surge problems. In such cases, it may be necessary to reinforce the grid in order to carry the fluctuating current from the wind turbine.

Flicker: Flicker is an engineering expression for short-lived voltage variations in the electrical grid which may cause light bulbs to flicker. This phenomenon may be relevant if a wind turbine is connected to a weak grid, since short-lived wind variations will cause variations in power output. There are various ways of dealing with this issue in the design of the turbine – mechanically, electrically and using power electronics.

Preventing "Islanding”" Islanding may occur if a section of the electrical grid disconnects from the main electrical grid because of accidental or intended tripping of a large circuit breaker in the grid (e.g., due to lightning strikes or short circuits). If wind turbines keep running in the isolated part of the grid, then it is likely that the two separate grids soon will be out of phase. Once the connection to the main grid is re-established, it may cause huge current surges in the grid and the wind turbine generator. It could also cause a large release of energy in the mechanical drive train (i.e., the shafts, the gear box and the rotor of the wind turbine) much like “hard switching” the turbine generator onto the grid would do. The electronic controller of the wind turbine must therefore constantly monitor the voltage and frequency of the alternating current in the grid. If the voltage or frequency of the local grid drifts outside certain limits, the electronic controller can then, within a fraction of a second, automatically disconnect the turbine from the grid and stop itself immediately (normally by activating the aerodynamic brakes).

2.2 Opportunity Overview

The modern age of wind power blew in in the late 1970s, and the first wind plants began to appear in California in the 1980s. Today, wind power is the fastest-growing new source of electricity worldwide. According to Charles McGowin, wind-power technical leader at the Electric Power Research Institute (EPRI), the industry is growing at 20 to 30 percent annually and has become: “the most economical renewable energy resource as a result of the large growth in the market.”

Robert Thresher, director of the U.S. Department of Energy’s (DOE) National Wind Technology Center concurs: “In the 1980s, wind cost about 40 cents per kilowatt hour. Now the cost is between 4 and 6 cents per kilowatt hour, so we've reduced the cost of wind by an order of magnitude in the past two decades."

In addition to these cost reductions, wind receives tax benefits through the federal production tax credit (PTC), making wind generation the least-cost marginal resource for all renewable generation technologies. Wind may even challenge conventional combined-cycle gas turbines (CCCT) and coal as a least-cost marginal resource, given the vulnerability of gas and coal to commodity price volatility and potential future taxes on carbon emissions.

Globally, wind generation capacity more than quadrupled between 1999 and 2005 with total capacity estimated at 58,982 MW (2005). In 2005, wind accounted for approximately 1 percent of the global electricity production (2005). By 2010, the World Wind Energy Association expects 120,000 MW to be installed worldwide.

Germany, Spain, the United States, India and Denmark have made the largest investments in wind generated electricity. Denmark, already prominent in the manufacturing and use of wind turbines, made a commitment in the 1970s to eventually produce half of the country's power by wind. Today, Denmark generates over 20 percent of its electricity with wind turbines, the highest percentage of any country. It is fifth in the world in total power generation (Denmark is 56th on the general electricity consumption list). Denmark and Germany are leading exporters of large (0.66 to 5 MW) turbines.

Germany is the leading producer of wind power with 32 percent of the total world capacity in 2005 (6 percent of German electricity). By 2010, Germany expects wind power will meet 12.5 percent of its electricity needs. Germany has 16,000 wind turbines, mostly in the north of the country – including three of the biggest in the world, constructed by the companies Enercon (4.5 MW), Multibrid (5 MW) and Repower (5 MW). Germany's Schleswig-Holstein province generates 25 percent of its power with wind turbines. In 2005, Germany produced more electricity from wind power than from hydropower plants.

Spain and the United States are next in terms of installed capacity. In 2005, the government of Spain approved a new national goal for installed wind power capacity of 20,000 MW by 2012. In 2005, Spain also produced more electricity from wind power than from hydropower plants. According to the American Wind Energy Association, in 2005 wind generated enough electricity to power 0.4 percent (1.6 million households) of the total electricity consumed in the United States, up from less than 0.1 percent in 1999.

India ranks fourth in the world with a total wind power capacity of 5,340 MW. Wind power generates 3 percent of all electricity produced in India. The World Wind Energy Conference held in New Delhi in November 2006 is expected to give additional impetus to the Indian wind industry.

On August 15, 2005, China announced it would build a 1,000 MW wind farm in Hebei for completion in 2020. China reportedly has set a generating target of 20,000 MW by 2020 from renewable energy sources. China estimates its indigenous wind power capability at 253,000 MW.

Another growing market is Brazil, with a wind potential of 143,000 MW. The Brazilian government has created an incentive program, called Proinfa, to build production capacity of 3,300 MW of renewable energy for 2008. Of this, 1,422 MW would be wind energy. The program seeks to produce 10 percent of Brazilian electricity through renewable sources

France recently announced an ambitious wind target of 12,500 MW installed by 2010.

From 2000 through 2005, Canada experienced rapid growth of wind capacity, moving from a total installed capacity of 137 MW to 943 MW, and showing a growth rate of 38 percent and rising. This growth was fed by provincial measures, including installation targets, economic incentives and political support. For example, the government of Ontario announced in March 2006 that it will introduce a feed-in tariff for wind power, also referred to as "Standard Offer Contracts," which may boost the wind industry across the entire country. In Quebec, the state-owned hydroelectric utility plans to generate 2,000 MW from wind farms by 2013.

Offshore wind turbines, now in the early stages of development, are more expensive and harder to install and maintain than turbines on land. Offshore turbines must be stabilized to survive waves and weather and must be protected against the ocean's corrosive environment. However, offshore turbines are becoming an attractive alternative to shore-based units. They can be larger to produce more power per turbine, and the ocean location provides a greater amount of wind.

Worldwide, nearly 600 MWs of offshore wind turbines are already producing power. These projects include:

Location	**Country**	**Online**	**MW**	**No Units**	**Rating**
Vindeby	Denmark	1991	4.95	11	Bonus 450kW
Lely (Ijsselmeer)	Holland	1994	2.0	4	NedWind 500kW
Tunø Knob	Denmark	1995	5.0	10	Vestas 500kW
Dronten (Ijsselmeer)	Holland	1996	11.4	19	Nordtank 600kW
Gotland (Bockstigen)	Sweden	1997	2.5	5	Wind World 500kW
Blyth Offshore	UK	2000	3.8	2	Vestas 2MW

Location	Country	Online	MW	No Units	Rating
Middelgrunden, Copenhagen	Denmark	2001	40	20	Bonus 2MW
Uttgrunden, Kalmar Sound	Sweden	2001	10.5	7	GE Wind 1.5MW
Yttre Stengrund	Sweden	2001	10	5	NEG Micon NM72
Horns Rev	Denmark	2002	160	80	Vestas 2MW
Frederikshaven	Denmark	2003	10.6	4	2 Vestas 3MW,1 Bonus 2.3MW and 1 Nordex 2.3MW
Samsø	Denmark	2003	23	10	Bonus 2.3 MW
North Hoyle	UK	2003	60	30	Vestas 2MW
Nysted	Denmark	2004	158	72	Bonus 2.3MW
Arklow Bank	Ireland	2004	25.2	7	GE 3.6 MW
Scroby Sands	UK	2004	60	30	Vestas 2 MW
Totals			**587**	**316**	

Many other countries, including the United States are also expressing serious intent in developing their offshore resource. Proposed projects include:

- Horns Rev II, Denmark, 200 MW + similar project, location to be decided.
- Mouth of the Western Scheldt River, Holland, 100 MW
- Ijmuiden, Holland, 100 MW
- Lillgrund Bank, Sweden, 48 MW
- Uttgrunden II, Sweden, 72 MW
- Barsebank, Sweden, 750 MW
- Kish Bank, Ireland 250 MW+
- Cape Wind, USA, 420 MW
- Long Island, USA, 140 MW
- Arklow II, Ireland, 500 MW
- Cape Trafalgar, Spain, 500 MW
- Thornton Bank, Belgium, 200 MW

Although wind power is becoming a mature technology, large-scale wind integration presents some unique challenges due to its intermittent nature. These and other challenges are discussed below.

2.3 RD&D Challenges

2.3.1 Coping with the Intermittency of Wind….Wave…Solar…Tidal

A moderate proportion of intermittent resources such as wind generation can be accommodated on most large power systems by coordinating and optimizing existing operating practices. However, these measures can only buy time. Eventually, the electric power system will no longer be able to assimilate additional wind (or ocean wave, in-stream tidal and solar photovoltaic) generation without significantly degrading system reliability – no matter how cleverly it is managed.

The questions, then, are where is the so-called "breaking point" and what measures are needed to accommodate more of these environmentally friendly renewable resources?

These questions are being addressed in a regional forum sponsored by BPA and the Northwest Power and Conservation Council. Members of this forum are developing the Northwest Wind Integration Action Plan. The plan will identify cost-effective steps the region can take to integrate large amounts of wind power and other intermittent renewable resources into the Northwest power system.[17]

The analysis side is being led by a technical workgroup made up of power system operators and planners, representatives of utility and customer associations, members of the wind development sector, technical specialists with an international perspective on wind integration, regional renewable advocates, members of ratepayer associations and policy specialists from state government. The technical work group is developing the findings and recommendations.

Working together and in sub-teams, the technical work group will conduct its work in three phases:

1. Phase 1: Determine the nature and magnitude of near-term wind development; assess the level of knowledge about impacts and costs based on current or previous analyses; e.g., studies done by the Northwest Transmission Assessment Committee (NTAC).

2. Phase 2: Identify individual and cooperative operational strategies related to control area reliability, system flexibility and wind fleet operation that can help manage the current phase of development in a least-cost fashion.

3. Phase 3: Identify longer-term options (and associated costs) related to transmission planning and expansion, flexibility augmentation and wind forecasting that may be required to maximize the potential of cost-effective wind resources.

Developing and implementing this action plan is a complex task that may require second generation research into control systems, storage systems, reserve sharing systems, metering systems and load management systems, as well as new modeling and analytical techniques. Some of this research may qualify for Technology Innovation funding.

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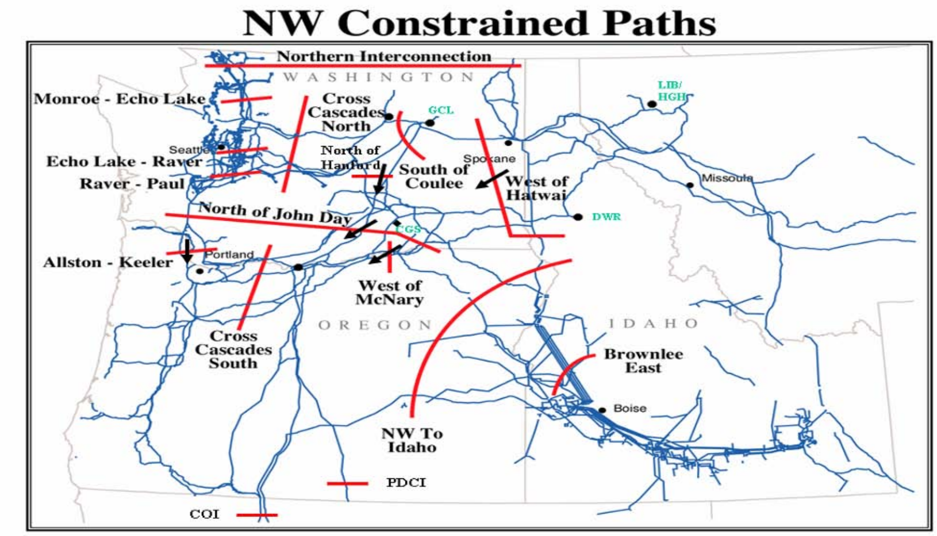
[17] See the Sector Actor Overview section below for more details. Also note that the California Energy Commission (CEC) Public Interest Energy Research (PIER) program is sponsoring a similar effort referred to as the Intermittency Analysis Project (IAP).

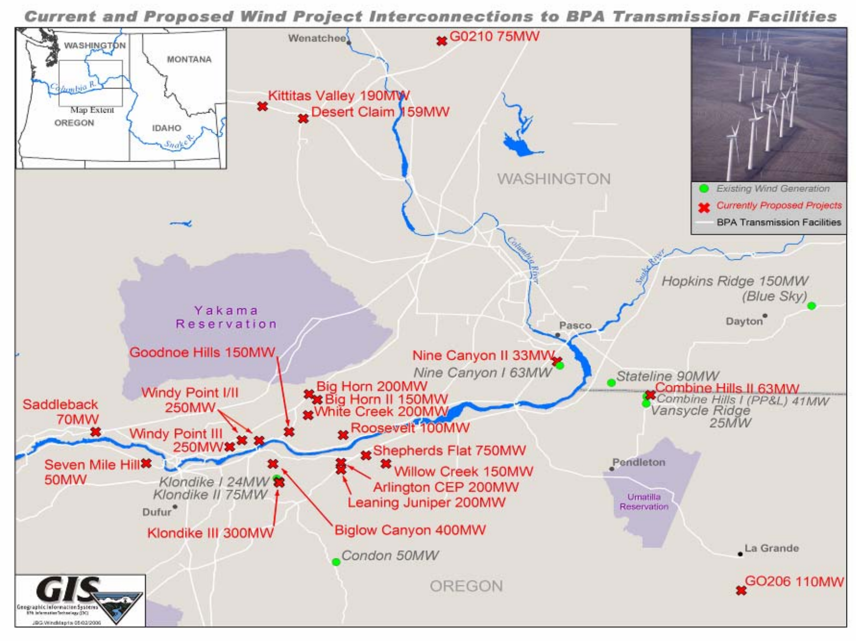
For example, Phase 3 of the work plan identifies wind forecasting as one technique for maximizing the potential of wind power. BPA is already heavily involved in advancing this technology, as the following discussion demonstrates:

Coping with Intermittent Resources: A description of BPA's Wind Forecasting Initiative

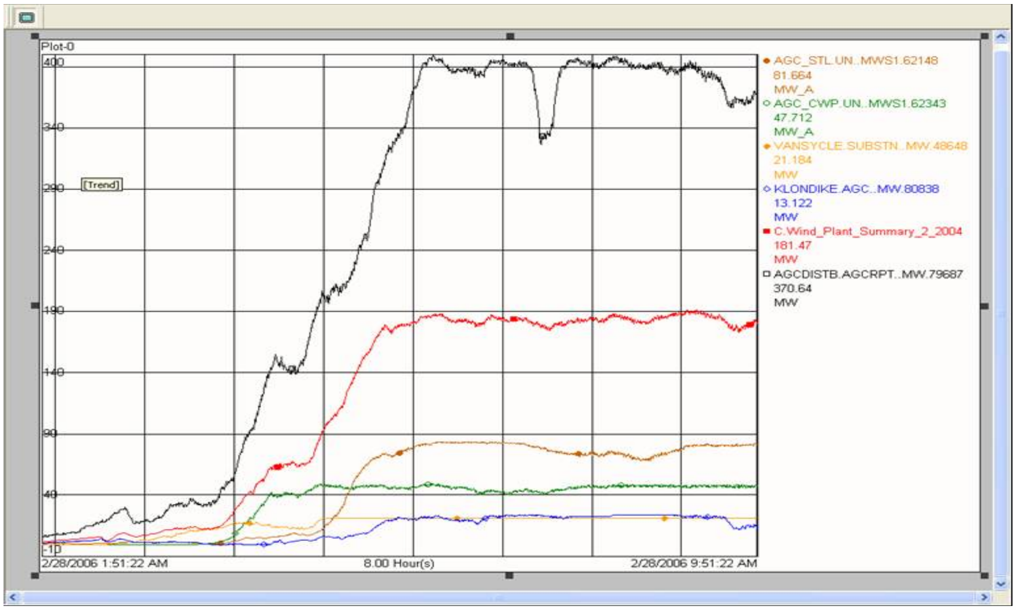


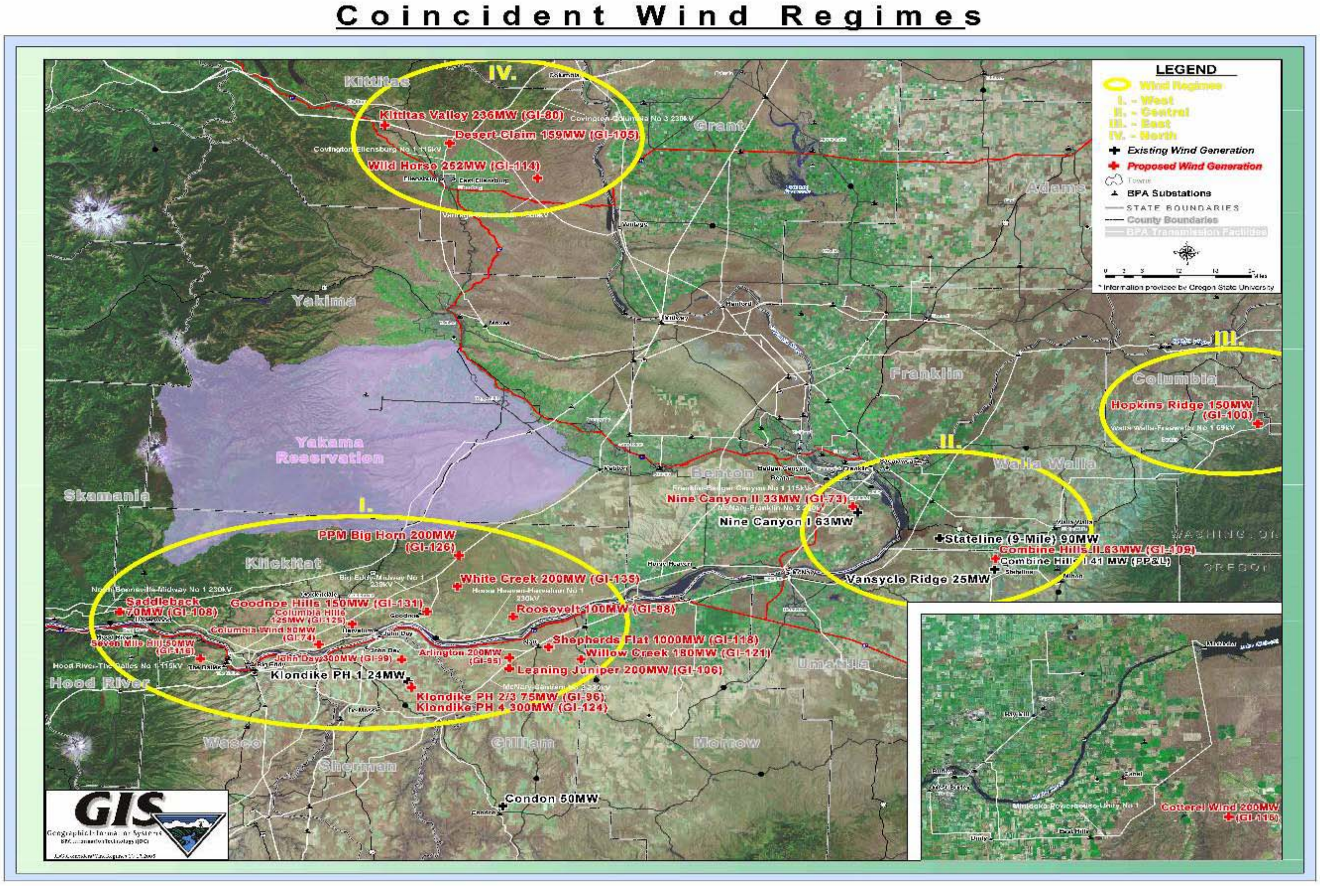
BPA's transmission system is highly constrained as shown in the illustration above.

These transmission constraints, in conjunction with other forces are providing strong incentives for developers to locate wind plants within relatively small geographic areas in BPA's control area (see diagram at right). Contributing factors are the Federal Energy Regulatory Commission's (FERC) mandate to interconnect renewable resources, the attractiveness of the Columbia River Gorge as a premier wind resource and its proximity to BPA's high voltage transmission system. What has been little understood in the past is that wind plants located in these geographic areas tend to experience similar synoptic (front driven) wind events in the late fall, winter and spring (see coincident wind regime map below).



Wind farms in these areas (i.e., yellow circles) can act in unison to produce large and difficult-to-predict ramps like the one plotted in the diagram below.

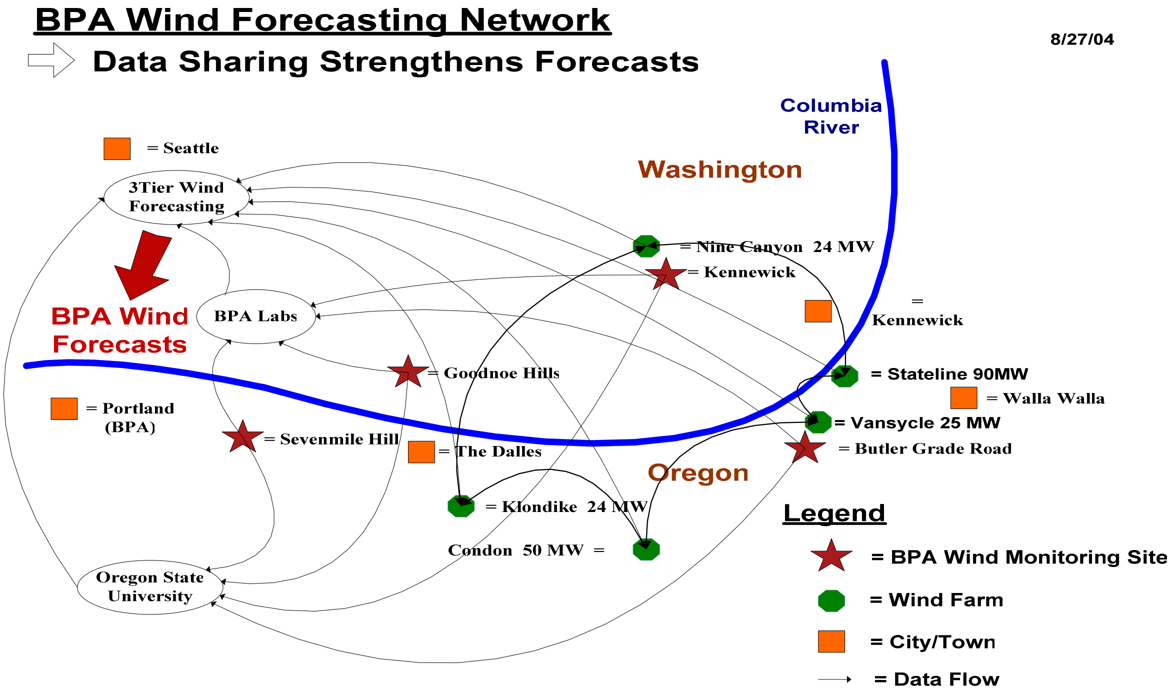




The x-axis of this diagram is divided into one-hour time periods, and the y-axis is divided into 50 MW increments of power. The red line is wind serving BPA load. The black line represents total wind generation managed in the BPA control area. The other lines represent individual projects in the control area. For this particular wind event, 400 MWs of unscheduled wind power flowed into the BPA control area at approximately 4 a.m. on February 28, 2006, when BPA hydro operations were reduced to minimum flows to preserve water (load factor). BPA reserve requirements were exceeded for this event, which could have led to sub-optimal operations (increased costs) and potential spill affecting salmon mitigation efforts.

Accurate day-ahead and near real-time scheduling of loads and generation is essential for efficient management of BPA's hydro and transmission assets. Unscheduled wind ramps consume high-cost ancillary services, result in sub-optimal river operation, reduce reliability and negatively impact revenues. BPA is developing a new generation wind forecasting system along with other mitigation measures to manage these risks. This effort currently consists of the following three projects:

1. Wind Forecasting (PBL): In 2004, an RD&D project to forecast wind, referred to as the BPA Wind Forecasting Network, was initiated to improve the quality of wind generation forecasts for BPA's Hydro Optimization models – Columbia Vista and NRTO (Near Real Time Optimizer). The primary value driver is to inform near-term marketing decisions by providing more accurate short-term wind forecasts (two-to-five days out). This project was the first effort (nationally) to forecast wind in this time frame. To support the project, DOE provided substantial funding as part of its interest nationally in wind/hydro optimization.



2. Assessing the Magnitude and Frequency of Wind Ramp Events for Existing and Proposed Wind Plants in the Klondike Wind Regime (PBL): This contract was to be implemented in September 2006. The contractor, 3Tier Environmental Forecast Group (3Tier) of Seattle, Washington, will quantify the magnitude and frequency of wind ramp events for existing and proposed wind projects located in the Klondike Wind Regime (see Coincident Wind Regimes map above; Klondike is the circled area at the extreme left, labeled area I West). A 10-minute average time series recording sequential power output data will be created for each wind project within the Klondike wind regime for 2004 and 2005. The contractor will perform this analysis using historical meteorological data.

3. Within-the-Hour Wind Forecasting (BPA Transmission Services): In 2005, an RD&D proposal was developed to forecast wind output within the hour. This capability will provide more timely and accurate wind forecast data. This will be used to update the Near Real Time Optimizer (NRTO)[18] for efficient use of Federal Columbia River Power System (FCRPS) resources, reduce ancillary service costs, improve congestion management, and inform system operators when large and unscheduled energy enters and leaves the BPA control area.

In addition to developing new wind forecasting technologies, the agency's renewable RD&D agenda may also involve funding for RD&D into short and long-term storage technologies that facilitate integration of intermittent resources. The following discussion describes the need for additional storage, various technologies and the challenges.[19]

Coping with Intermittency: Additional Storage Capacity[20]

A fundamental characteristic of an electric grid is that power consumed must match the power supplied at all times. Historically, the lack of economical large-scale energy storage options has forced electric utilities like BPA to construct expensive transmission infrastructure to meet incremental load growth. In addition, the lack of energy storage options has complicated interconnection of intermittent renewable generation resources due to extra reserve margins and system regulation requirements.

BPA is fortunate to have access to economical long-term energy storage in the form of the hydroelectric dams and storage reservoirs on the Columbia River system. However, it is extremely unlikely that additional large dams will be constructed in the future. Hence BPA could benefit from the development of existing pumped storage and emerging storage technologies.

A wide variety of storage technologies are presently being investigated worldwide, including super-capacitors, flywheels, batteries, compressed air, superconducting magnetic energy storage (SMES), and pumped storage hydro. Important system parameters include instantaneous power output (MW), total stored energy (MWh), number of charge/discharge cycles, capital cost, operating cost and efficiency. (A brief explanation of each technology is provided below. See Appendix B for a graphic comparison of performance characteristics for different technologies.)

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[18] Note: The Near Real Time Optimizer (NRTO). NRTO is a plant optimization program being implemented for the Federal Columbia River Power System (FCRPS) that will boost efficiency by 1 to 2 percent, which could mean an increase in revenues of as much as $80 million a year. The goal is to operate the correct number of turbine-generating units at the correct time, providing more electrical capacity using the same amount of water. An accurate and reliable near-term (two-to-three hour) and within-the-hour wind forecast will assist NRTO in its hydro optimizations goals to manage the intermittency of wind in the sub-hourly time frame.

[19] Appendix C contains the comparative performance characteristics and costs of storage technologies.

[20] The storage section is courtesy of Anders Johnson(BPA Transmission Services) & Mike Hofmann(BPA Power Services)

Short-term energy storage technologies capable of smoothing out unpredictable within-the-hour fluctuations at wind farms would be useful in integrating distributed and intermittent resources. Potential candidates include super-capacitors, flywheels, batteries, and Superconducting Magnetic Energy Storage (SMES). Medium and longer-term storage technologies such as Compressed Air Energy Storage (CAES) and pumped hydro will be required to shape wind generation from low-demand periods into peak periods or to provide backup energy when the wind isn't blowing.

However, several issues must be addressed if energy storage technologies are to become viable. These issues include:

- High Cost: One of the main barriers to greater penetration of utility-scale energy storage has been its high cost. This includes both the storage media and the power electronics interface that is required when interfacing DC devices to the AC grid. However, installation costs for new transmission lines and transformers have also increased dramatically, as have fuel costs for gas turbines and diesel generators. These shifts in the marketplace make energy storage applications more competitive than in the past. Costs could come down further due to economies of scale from more utility installations.

- Standards and Guides for Application, Specification, Operation and Maintenance: Lifecycle cost-evaluation criteria will be required to accurately compare different storage technologies against each other and against traditional solutions. Planning criteria would be useful for sizing the power and energy ratings of a system with one storage medium or a hybrid system with multiple storage media. Control optimization would be needed to operate the system efficiently, telling it when to store, when to supply, how fast and for how long. Maintenance capabilities, including personnel training and spare parts management, need to be developed once these systems are installed.

- Coordination and Cooperation Issues: Some barriers to energy storage technologies are more political than technical. Utilities and wind farm owners are likely to be uncomfortable relying on new storage technologies, especially installations inside their substation.

Examples of Storage Devices

Super-capacitors have a capacitance and energy density that is thousands of times greater than conventional electrolytic capacitors. They are excellent for short-term power quality applications because they can withstand more charge/discharge cycles (tens of thousands) than other storage media. Super-capacitors are also known as ultra-capacitors, electrochemical capacitors and electric double-layer capacitors.

Superconducting Magnetic Energy Storage (SMES) systems store energy in the magnetic field created by the flow of direct current in a coil of superconducting material that has been cryogenically cooled. SMES systems offer system stability and voltage regulation benefits by providing very high power output for a brief period with a faster response than a generator. However, SMES systems can only store a small amount of energy, and their associated cryogenics present operations and maintenance challenges. A distributed SMES system has been installed in northern Wisconsin to enhance stability of a transmission loop serving a paper mill.

Flywheels are mechanical energy storage devices that consist of a rotor and a stator. Flywheels can bridge the gap between short-term, ride-through and long-term storage with excellent cyclic and load-following characteristics.

Batteries – A wide variety of battery technologies employ chemical energy storage.

- Lead-acid batteries are a well developed technology with widespread use for power quality and backup power at the industrial level. Their short lifecycle means limited utility grid application. A handful of megawatt-class installations exist, including a 10-MW, 40-MWh system in Chino, California.
- Metal air batteries are compact, inexpensive and environmentally benign. However, because they are difficult to recharge, they are limited to applications where the battery is the primary source of power.
- Lithium-ion (Li-ion) batteries combine high energy density, high efficiency and long lifecycle. They have generally been limited to the portable consumer electronics market due to very high cost.
- Sodium sulfur (NaS) batteries applicable for both power quality and peak shaving applications operate at very high temperatures (300 degrees C). Systems deployed in Japan can supply several megawatts for several hours.
- Flow batteries are a less mature class of devices that offer the potential for greater discharge times. Several types are under development, including polysulfide bromide (PSB), vanadium redox (VRB), and zinc bromine (ZnBr).

Compressed Air Energy Storage (CAES) is a hybrid technology that combines an energy storage element with conventional natural gas-fired generation. Wind farms or other intermittent generation sources can also be included in the system. When surplus electricity is available from the grid (light load, heavy wind), compressors are operated to store air in a reservoir, such as an underground aquifer. When electricity demand increases due to heavy load or light wind, the compressed air is discharged, mixed with gas and combusted to drive a turbine. A CAES plant can produce the same amount of electricity as a conventional gas plant while using one-third to one-half as much gas.

Two CAES plants that use underground storage are in service in Germany and Alabama. A group of 74 municipal utilities has proposed the Iowa Stored Energy Plant, which would include a 200-MW CAES facility and a 100-MW wind farm. In 2006, this plant, which has an estimated construction cost of $300 million, received a $1.2 million DOE grant.

Hydro Pumped Storage – During off-peak periods, electricity from the grid is used to pump water from a lower reservoir to an upper reservoir. During peak periods, the flow is reversed, and electricity is supplied to the grid. Pumped storage provides benefits similar to conventional hydro, including frequency control, system stabilization and reserve. Like CAES, pumped storage is limited by geographical requirements, long construction times and large capital cost. Conventional pumped storage hydro using surface freshwater reservoirs has been used since the 1890s. Today, Over 90 GW (gigawatt) of capacity is installed worldwide, with many projects capable of generating hundreds or even thousands of megawatts. The first system to use the ocean as the lower reservoir was a 30-MW unit built in Japan in 1999. Other novel applications use mine shafts or other underground features for the lower reservoir.

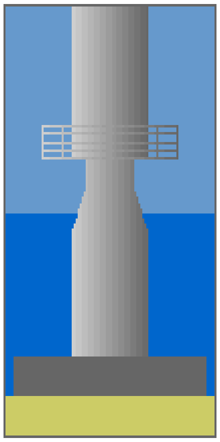
2.3.2 Offshore Wind Power Research

Multi-megawatt sized wind turbines, cheaper foundations and new knowledge about offshore wind conditions are improving the economics of offshore wind power. While wind energy is already economical in good onshore locations, offshore wind energy is rapidly becoming competitive with other power generating technologies. Until recently, undersea cabling and foundations made offshore wind energy an expensive option. New studies of foundation technology, plus megawatt-sized wind turbines, are now at the point of making offshore wind energy competitive with onshore sites, at least for shallow water depths up to 15 meters (50 feet). The fact that offshore wind turbines generally yield 50 percent higher output than turbines on nearby onshore sites (on flat land) makes offshore siting attractive.

Methods of Anchoring to the Seabed:

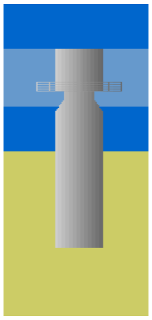
The first offshore pilot projects in the world were in Denmark. They used concrete gravity caisson foundations as pictured below. As the name indicates, the gravity foundation relies on gravity to keep the turbine in an upright position. Vindeby and Tunoe Knob offshore wind farms are examples of this traditional foundation technique. The caisson foundations were built in dry dock using reinforced concrete and floated to their final destination before being filled with sand and gravel to achieve the necessary weight. The principle is thus much like that of traditional bridge building.

The foundations used at these two sites are conical to act as breakers for pack ice. This is necessary because solid ice is common in the Baltic Sea and the Kattegat during cold winters. The use of traditional concrete foundation techniques made the cost of the completed foundation approximately proportional with the water depth squared – the quadratic rule. The water depths at Vindeby and Tunoe Knob vary from 2.5 to 7.5 meters. This implies that each concrete foundation has an average weight of some 1,050 metric tons. According to the quadratic rule, the concrete platforms tend to become prohibitively heavy and expensive to install at water depths above 10 meters. Therefore, alternative techniques had to be developed to break through the depth barrier.



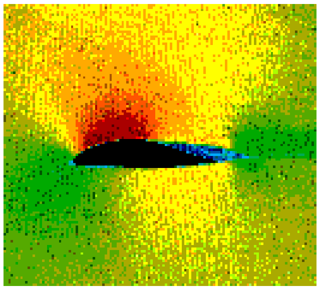
Today most of the existing offshore wind parks use gravitation foundations. A new technology, illustrated at left, offers a method similar to that of the concrete gravity caisson. Instead of reinforced concrete, it uses a cylindrical steel tube placed on a flat steel box on the sea bed. A steel gravity foundation is considerably lighter than concrete foundations. Although the finished foundation must have a weight of around 1,000 metric tons, the steel structure will only weigh 80 to 100 tons for water depths between 4 and 10 meters. (Another 10 tons must be added for structures in the Baltic Sea, which require pack ice protection.) The relatively low weight allows barges to transport and install many foundations rapidly, using the same cranes used to erect the turbines. The gravity foundations are filled with olivine, a dense mineral, which gives the foundations sufficient weight to withstand waves and ice pressure.

The tripod foundation, illustrated at right, is a lighter weight cost-efficient three-legged steel structure whose design draws on the experiences of the offshore platforms in the oil industry. A steel frame emanating from a steel pile below the turbine tower transfers the forces from the tower into three steel piles. The three piles are driven 10 to 20 meters into the seabed depending on soil conditions and ice loads. The advantage of the three-legged model is that it is suitable for deeper water depths. In addition, only minimum preparation is required at the site before installation. The foundation is anchored into the seabed using a relatively small steel pile (0.9 meters in diameter) in each corner. Because of the piling requirement, the tripod foundation is not suited for locations with many large boulders.



The mono pile foundation illustrated at left is simple to construct. The foundation consists of a steel pile with a diameter of between 3.5 and 4.5 meters. The pile is driven 10 to 20 meters into the seabed depending on the type of seabed. The mono pile foundation effectively extends the turbine tower under water and into the seabed. An important advantage of this foundation is that no preparations of the seabed are necessary. On the other hand, it requires heavy duty piling equipment, and the foundation type is not suitable for locations with many large boulders in the seabed. If a large boulder is encountered during piling, it is possible to drill down to the boulder and blast it with explosives.

2.3.3 Wind Turbine Research



Wind turbine engineers use techniques such as stall, which aircraft designers try to avoid at all costs. Stall is a complex phenomenon because it involves airflow in three dimensions on wind turbine rotor blades. (For example, the motion of the turbine blades will induce an airflow that makes the air molecules move in a radial direction along the rotor blade from its root toward the tip of the blade). Three dimensional computer simulations of airflows are rarely used in the aircraft industry, so wind turbine researchers have to develop new methods and computer simulation models to deal with these issues. Computational Fluid Dynamics (CFD) is a method for simulating airflow around rotor turbine blades. The computer simulation, pictured above, is of the airflows and pressure distributions around a wind turbine rotor blade moving toward the left.

A number of aircraft industry technologies are being applied to improve the performance of wind turbine rotors. One example is vortex generators, which are small fins, often only about 0.01 meter (0.4 inch) tall, which are fitted to the surface of aircraft wings. The fins are alternately skewed a few degrees to the right and the left to create a thin current of turbulent air on the surface of the wings. The spacing of the fins is very accurate to ensure that the turbulent layer automatically dissolves at the back edge of the wing. Curiously, this creation of minute turbulence prevents the aircraft wing from stalling at low wind speeds. Wind turbine blades are prone to stalling even at low wind speeds close to the root of the blade where the profiles are thick. Consequently, some of the newest rotor blades may have a stretch of one meter or so along the back side of the blade (near the rotor) equipped with a number of vortex generators.

2.4 Sector Actors

Many engineering and advocacy organizations promote the integration and use of utility scale wind energy. These organizations include the following.

A. The Northwest Power and Conservation Council and the Bonneville Power Administration are cosponsoring development of a Northwest Wind Integration Action Plan. The plan will identify and commit participants to regional steps to cost effectively integrate large amounts of wind power and other intermittent renewable resources into the Northwest power system. The Council's fifth Northwest Power Plan calls for 6,000 megawatts of new wind generation over the next 20 years. More than 2,000 megawatts already have been built or are under active development, while another 2,000 megawatts are in planning stages. New tools have been proposed to successfully integrate large amounts of wind, and it will take regional cooperation to refine and implement them. A multidisciplinary work group representing Northwest utilities, independent power producers and other stakeholders is developing the proposed Action Plan and will circulate it for public discussion. http://www.nwcouncil.org/energy/Wind/

B. The California Energy Commission's Public Interest Energy Research (PIER) program, which is an excellent resource for all renewables, is conducting an extensive review of intermittency issues in a project referred to as the Intermittency Analysis Project (IAP). http://www.energy.ca.gov/pier/renewable/projects/

C. The U.S. Department of Energy's Wind Energy Program is directed by the Office of Wind and Hydropower Technologies under the Assistant Secretary for Energy Efficiency and Renewable Energy.

The mission of the Wind Energy Program is to support the President's National Energy Policy and departmental priorities for increasing the viability and deployment of renewable energy; to lead the nation's efforts to improve wind energy technology through public/private partnerships that enhance domestic economic benefit from wind power development; and to coordinate with stakeholders on activities that address barriers to wind energy.

To accomplish these goals and support the program mission, two of DOE's principal research laboratories, the National Renewable Energy Laboratory (NREL) and Sandia National Laboratories (Sandia), work side by side with private industry partners and researchers from universities nationwide to develop advanced wind energy technologies.

Each laboratory is extensively equipped with a unique set of skills and capabilities to meet industry needs. NREL's National Wind Technology Center (NWTC) near Boulder, Colorado, is designated as the lead research facility for the wind program. NWTC conducts research and provides its industry partners with support in design and review analysis; component development; systems and controls analysis; structural, dynamometer, and field testing; certification; utility integration; resource assessment; subcontract management; and technical assistance. Sandia, based in Albuquerque, New Mexico, conducts research in advanced manufacturing, component reliability, aerodynamics, structural analysis, material fatigue and control systems.

The wind energy research conducted at both laboratories is divided into three categories:

1. Applied Research: The main areas of applied research are in the areas of aerodynamics, inflow and turbulence, and modeling structures and dynamics.

2. Turbine Research: The main areas of turbine research are in the areas of developing new concepts and using cutting-edge technology to develop low-wind-speed utility-class wind turbines; developing new components for utility-scale wind turbines to improve performance, reduce loads, increase reliability and decrease the cost of wind-generated electricity to 3 cents/kWh. Lowering the cost of small-wind-generated power for remote locations is key for the adoption of clean energy in low-demand situations and for providing the wind industry with technical support critical to the development of advanced wind turbine technologies.

3. Cooperative Research and Testing: Helping the wind and utility industries understand the effects of wind power on power grids by researching and documenting how, where, and when the wind blows around the world and working with industry members to develop efficient, reliable, cost-effective technologies.
   http://www.eere.energy.gov/ http://www.sandia.gov/wind/
   http://www.nrel.gov/wind/

D. American Wind Energy Association (AWEA) is a national trade association that represents wind power plant developers, wind turbine manufacturers, utilities, consultants, insurers, financiers, researchers and others involved in the wind industry. In addition, AWEA represents hundreds of wind energy advocates from around the world. www.**awea**.org/

E. Utility Wind Interest Group (UWIG) provides a forum for the critical analysis of wind technology for utility applications and serves as a source of credible information on the status of wind technology and deployment. The group operates in collaboration with the U.S. Department of Energy and its National Renewable Energy Laboratory, which provide co-funding for the group. http://www.uwig.org/

F. The Danish Wind Industry Association (DWIA) is a nonprofit association whose purpose is to promote wind energy at home and abroad. The association was founded in 1981. DWIA today represents 99.9 per cent of Danish wind turbine manufacturing measured in MW and more than 122 companies with activities in the Danish wind industry.
http://www.windpower.org

G. The European Wind Energy Association http://www.ewea.org/

EWEA's mission is to strengthen the development of wind energy markets and technology in Europe and worldwide to allow wind energy to achieve its full potential and contribute to a sustainable energy future; to develop effective strategic policies and initiatives; to tackle barriers to allow the full deployment of wind energy; and to communicate the benefits and potential of wind energy to politicians, opinion formers, decision makers, the media, the public and other key stakeholders.

H. United States Department of Energy, Office of Electricity Delivery & Energy Reliability
http://www.oe.energy.gov/randd/energy_storage.htm
Dr. Imre Gyuk, Program Director (Imre.Gyuk@hq.doe.gov, 202-586-1482)

I. Electricity Storage Association, http://www.electricitystorage.org/
This website lists BPA as a member, and Mike Hoffman from Power Services is listed as the contact (503-230-3957)

J. Danish Wind Industry Association http://www.windpower.org/en/core.htm

3.0 Ocean Wave

3.1 Technology Overview

Ocean waves represent a form of renewable energy created by wind currents passing over open water. Since wind currents are generated by uneven solar heating, wave energy can be considered a concentrated form of solar energy. Incoming solar radiation levels on the order of 100 W/m2 are transferred into waves with power levels that can exceed 1,000 kW/m of wave crest length. The transfer of solar energy to waves is greatest in areas with the strongest wind currents (primarily between 30° and 60° latitude), near the equator with persistent trade winds and in high altitudes because of polar storms.

Waves are also efficient transporters of solar energy. Storm winds generally create irregular and complex waves. In deep water, after the storm winds die down, the storm waves can travel thousands of kilometers in the form of regular smooth waves, or swells, that retain much of the energy of the original storm waves. The energy in swells or waves dissipates after it reaches waters that are less than 200 meters deep. At 20-meter water depths, a wave's energy typically drops to about one-third of the level it had in deep water.

The total annual average wave energy[21] off the U.S. coastlines (including Alaska and Hawaii), calculated at a water depth of 60 meters, has been estimated (Bedard et al. 2005) at 2,100 terawatt-hours (TWh). The fraction of the total wave power that is economically recoverable in U.S. offshore regions has not been estimated, but it is significant even if only a small fraction of the 2,100 TWh/yr available is captured. (Currently, approximately 11,200 TWh/yr of primary energy is required to meet total U.S. electrical demand.)

Wave energy potential varies considerably in different parts of the world, and wave energy can't be harnessed effectively everywhere. Areas of the world rich in wave power include the western coasts of Scotland, northern Canada, southern Africa, Australia, *and the Northwest coast of the United States*. The estimated wave energy capacity available off the Oregon coast is approximately 14,000 MW (Bedar et al).

Wave energy offers several advantages over wind energy, including smoother power output, higher energy density, better demand matching, greater predictability, local manufacturing opportunities and reduced visual impact. Despite these advantages, wave energy technology is still pre-commercial, and it is too early to predict which technology or mix of technologies will prevail. EPRI has conducted cost-of-electricity assessments at specific locations and for certain devices such as Ocean Power Delivery's Pelamis device, which is pictured below. EPRI estimated the cost of electricity from a Pelamis device at 9 to16 cents/kWh. More accurate cost estimates are premature until further research and development addresses the

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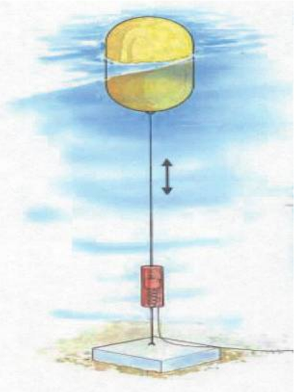
[21] The common measure of wave power is $P = (\rho g^2 T H^2)/ 32\Pi$ watt per meter (W/m) of crest length (distance along an individual crest) where:

P = the density of seawater = 1,025 kg/m3,
G = acceleration due to gravity= 9.8 m/s/s,
T = period of wave (s), and
H = wave height (m).

technical and commercial barriers that must be resolved before wave energy is commercially competitive.

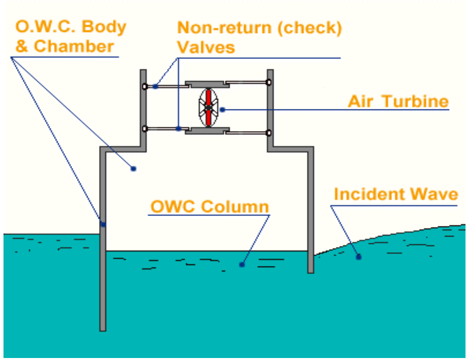
A variety of offshore wave-energy devices are undergoing field testing. These devices are generally classified as point absorbers, terminators, attenuators and overtopping devices. Some systems extract energy from surface waves. Others extract energy from pressure fluctuations below the water surface. Some systems are fixed in position and let waves pass by them, while others follow the waves and move with them. And some systems concentrate and focus waves to maximize electrical generation. Below are descriptions and commercial status of each type of wave energy conversion technology.



Point absorbers, (illustrated at left), are floating structures with components that move relative to each other due to wave action (e.g., a floating buoy inside a fixed cylinder). The relative motion drives electromechanical or hydraulic energy converters.

Commercial status*:* The Ocean Power Technologies (OPT) PowerBuoy demonstration unit, pictured at right, is rated at 40 kW and was installed in 2005 for testing offshore from Atlantic City, New Jersey. Tests are being conducted in the Pacific Ocean with a unit installed in 2004 and 2005 off the coast of the Marine Corps Base in Oahu, Hawaii. A commercial-scale PowerBuoy system is planned for the northern coast of Spain, with an initial wave park (multiple units) at a 1.25-MW rating. Initial operation is expected in 2007.

Point Absorber
(OPT Power Buoy)

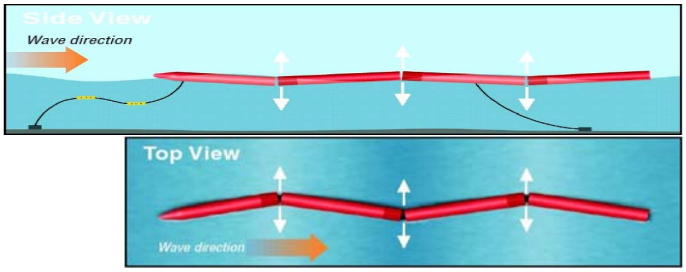


Terminator devices extend perpendicularly to the direction of wave travel and capture or reflect the power of the wave. These devices are typically onshore or near-shore; however, floating versions have been designed for offshore applications. In the oscillating water column (OWC), illustrated above, water enters through a subsurface opening into a chamber with air trapped above it. Wave action causes the captured water column to move up and down like a piston to force the air though an opening connected to a turbine.

Terminator
(Energetech Oscillating Water Column)

Commercial status: The full-scale, 500-kW prototype OWC, pictured above, was designed and built by Energetech and underwent testing in 2006 offshore at Port Kembla in Australia.

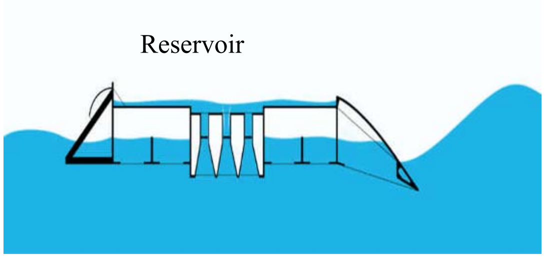
Attenuators, such as the one illustrated below, are long multi-segment floating structures oriented parallel to the direction of the waves. The differing heights of waves along the length of the device causes flexing where the segments connect, and this flexing is connected to hydraulic pumps or other converters.



Commercial status: A full-scale, four-segment production prototype, the Ocean Power Delivery (OPD) Pelamis, pictured below, is rated at 750 kW and was sea tested for 1,000 hours in 2004., This successful demonstration was followed in 2005 by the first order of a commercial wave energy conversion system from a consortium led by the Portuguese power company Enersis SA. The first stage, scheduled to be completed in 2006, consists of three Pelamis machines with a combined rating of 2.25 MW to be sited about 5 kilometers off the coast of northern Portugal. An expansion to more than 20-MW capacity is being considered. A Pelamis-powered 22.5-MW wave energy facility is also planned for Scotland, with the first phase targeted for 2006.

Attenuator
(OPD Pelamis)

Overtopping devices, such as the one illustrated at right, have reservoirs that are filled by incoming waves to levels above the average surrounding ocean. The water is then released, and gravity causes it to fall back toward the ocean surface. The energy of the falling water is used to turn hydro turbines. Specially built seagoing vessels can also capture the energy of offshore waves. These floating platforms create electricity by funneling waves through internal turbines and then back into the sea.



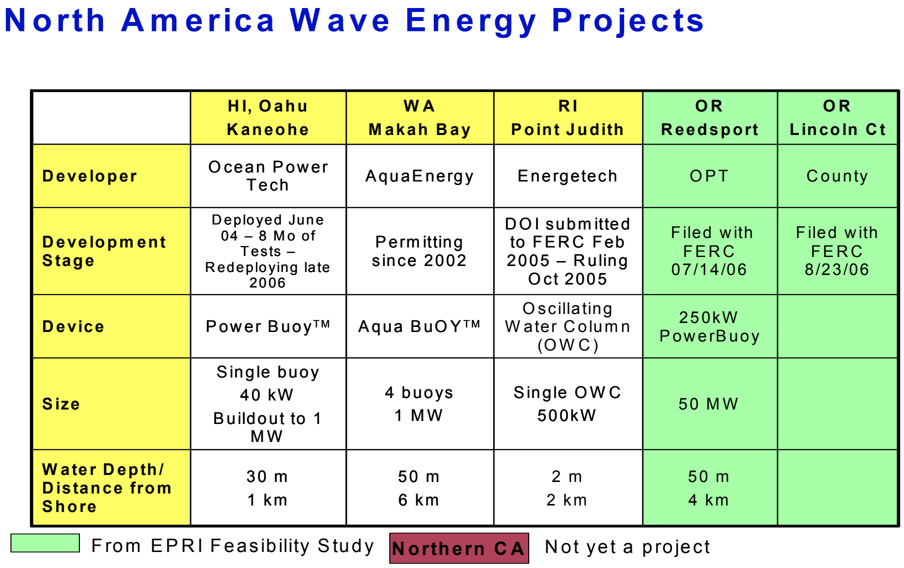
Overtopping
(Wave Dragon)

Commercial status: In March 2003, the 237-ton Wave Dragon prototype, pictured at left, was towed to the Danish Wave Energy Test Station in Nissum Bredning. Sea tests were conducted in this location through January 2005 to determine hydraulic behavior, turbine strategy and power production to the grid in Denmark.

In April 2006, a modified prototype was deployed at a more energetic wave climate site, and testing will continue until the summer of 2007. There has been over a year of operating and maintenance on all sub-systems, components and materials used on the prototype. Future Wave Dragon development includes a 7-MW demonstration project off the coast of Wales

3.2 Opportunity Overview

The Northwest is actively engaged in exploring the potential of its wave energy resource.



North America Wave Energy Projects

	HI, Oahu Kaneohe	**WA Makah Bay**	**RI Point Judith**	**OR Reedsport**	**OR Lincoln Ct**
Developer	Ocean Power Tech	AquaEnergy	Energetech	OPT	County
Development Stage	Deployed June 04 – 8 Mo of Tests – Redeploying late 2006	Permitting since 2002	DOI submitted to FERC Feb 2005 – Ruling Oct 2005	Filed with FERC 07/14/06	Filed with FERC 8/23/06
Device	Power Buoy™	Aqua BuOY™	Oscillating Water Column (OWC)	250kW PowerBuoy	
Size	Single buoy 40 kW Buildout to 1 MW	4 buoys 1 MW	Single OWC 500kW	50 MW	
Water Depth/ Distance from Shore	30 m 1 km	50 m 6 km	2 m 2 km	50 m 4 km	

🟩 From EPRI Feasibility Study **Northern CA** Not yet a project

The table above indicates that the Northwest is pursuing three of the five North American wave energy conversion projects. Northwest stakeholders have conducted site feasibility studies and filed FERC site permits for sites near Makah Bay, Washington, and Reedsport, Oregon, and are currently evaluating alternative technologies for future deployment and testing.

Each of these projects is described below along with a brief overview of Oregon State University's commitment to becoming America's leading institution in wave energy research and development.

Makah Bay Project:

The AquaEnergy Group, Ltd., plans to develop and operate a wave energy project in the Pacific Ocean in Makah Bay, Clallam County, near the city of Neah Bay, Washington. The land portion of the project is on Makah Indian Nation property. Part, or all of the aquatic portion of the project is within Washington state waters, the Olympic Coast National Marine Sanctuary (OCNMS) and the Flattery Rocks National Wildlife Refuge.

The Makah Bay Project is supported by a consortium of public and private agencies, the Makah Indian Nation, Washington State University, Clallam County PUD, Clallam County

Economic Development Council, BPA, Battelle, Energy Northwest and Washington State Public Utility Districts Association. AcquaEnergy and the Makah Tribe are working together with Washington state's federal legislative delegation to strengthen governmental awareness of the Makah Plant.

The project involves the design and construncion of a pilot 1-MW offshore wave energy power plant. It is made up of four wave energy conversion buoys, called AquaBuoys (pictured at right), which are based on a heaving buoy principle. The portion of each buoy that is above water is similar in size to large navigational buoys used to mark shipping lanes and identify obstructions. Four AcquaBuoys will be placed 3.7 statute miles (3.2 nautical miles) west of Hobuck Beach in Makah Bay in water depths of approximately 150 feet. Energy will be transported to a small shore station via an anchored transmission cable which will run along the sea floor, except near shore, where it will be buried using a horizontal directional drilling (HDD) technique.

AquaEnergy is developing the entire project to conduct research, to produce electricity for Clallam County Public Utility District and to demonstrate the economic, environmental and tribal benefits of wave energy conversion power plants.

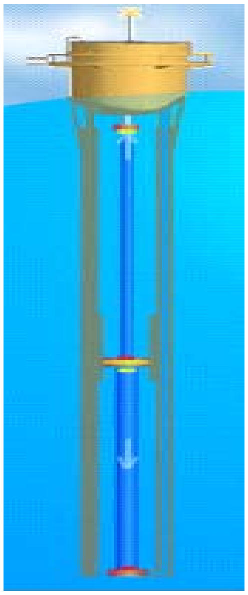
Additional elements of the Makah Bay wave energy plant include:

- Excellent wave energy potential (approximately 8.5 kw/ft or 28 kw/m wave front). The site has good wave energy content and consistent annual wave height;
- The Makah Bay site represents one of the better wave energy resources of sites evaluated in the 48 lower states;
- Sufficient water depths (at least 120 feet) reasonably close to shore;
- Nearby major utility electrical distribution lines;
- Participating land manager and electricty consumer in the Makah Indian Nation;
- Need for energy source on the west side of Clallam County PUD distribution service territory, and;
- Close to boating facilities of Neah Bay.

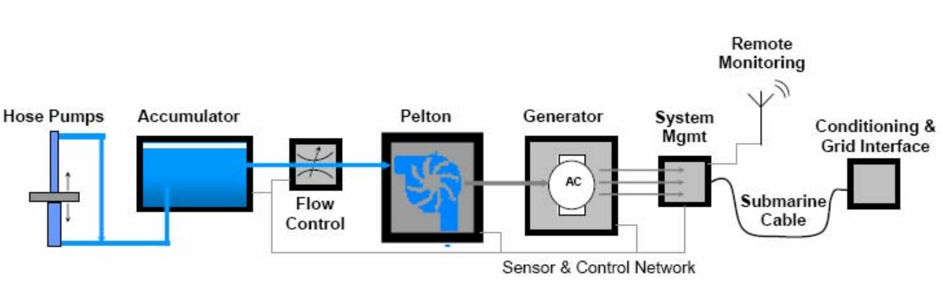
AquaEnergy is in the final stages of a three-year FERC Alternative Licensing Process involving the following public agency participants: FERC, National Oceanic and Atmospheric Administration (NOAA), Washington State Department of Natural Resources, Washington State Department of Ecology, Washington State Department of Fish and Wildlife, U.S. Coast Guard, U.S. Fish and Wildlife Service, U.S. Army Corps of Engineers, Washington State Historical Preservations Office, Tribal Historical Preservation Office and Bureau of Indian Affairs.

An Environmental Assessment (EA) has already been completed by AquaEnergy consultant Davine Tarbell and Associates with a finding of no significant impact. AquaBuoy has also completed oceanography surveys, and samplings and surface measurement devices were deployed to determine wind and wave intensities over a period of several months. AquaBuoy intends to submit a FERC license application before the end of 2006, with the goal of making this project the nation's first fully operable offshore wave energy plant connected to a grid. This prototype plant will feature:

- A unique hose-pump power take-off system that uses only water as its hydraulic liquid;
- A point absorbing omni-directional wave energy converter;
- A non-toxic, environmentally friendly material composition that meets the Kyoto Protocol Standards;
- A low riding silhouette that conforms to aesthetic sensitivities;
- An offshore power plant configuration that avoids interference with marine traffic and fishing;
- An economic alternative to fossil fuel power plants; and,
- A green energy power plant with construction and components supplied locally.



Energy transfer takes place by converting the vertical component of wave motion into pressurized water flow by means of two-stroke hose pumps. Pumped water is directed into a conversion system consisting of a Pelton turbine driven generator. The buoy closest to shore will function as the collection buoy or hub, where the power cables from each AquaBuoy are connected to the sub-sea cable. The expected output from each buoy is 480-V AC current, with power levels between 0 and 250kW and with an estimated average output of 46kW. The Makah Bay pilot power plant is projected to deliver 1,500 MWh annually.



The AquaBuoy, illustrated above, consists of four elements:

- Buoy
- Acceleration tube
- Piston
- Hose-pump

The acceleration tube is a vertical, hollow cylinder rigidly mounted under the body of the buoy. The tube is open at both ends to allow unimpeded entry and exit of seawater in either direction. The piston, a broad, neutrally buoyant disk, is at the midpoint of the acceleration tube, When the buoy is at rest, the piston is held at the midpoint by the balanced tension of two hose pumps attached to opposite sides of the piston. They extend to the top and bottom of the acceleration tube, respectively.

The hose-pump is a steel reinforced rubber hose. When the hose is stretched, its internal volume is reduced, thereby acting as a pump. Pressurized sea water is subsequently expelled into a high-pressure accumulator, and, in turn, fed to a turbine which drives a generator.

Other AquaEnergy wave energy projects include:

- Figuera da Foz (Portugal), planned to be installed in 2008
- Ucluelet (British Columbia), planned to be installed in 2010

These three projects will have a combined power generation potential of 200 MW when at full capacity.

Reedsport Oregon Project

Oregon's first wave energy project will be located along the southern Oregon coast near the city of Reedsport. Ocean Power Technologies has filed a preliminary permit with FERC to develop a wave energy park.

The Reedsport site is a prime location for wave energy development because it has an excellent wave resource, an existing power substation with capacity for 50 MW, and a three-kilometer underwater effluent pipeline from a closed paper mill just north of Reedsport and at the mouth of the Umpqua River. This pipeline can be used to run underwater power cables from the wave park buoys to the Gardiner substation where the energy would enter into the grid.

New Jersey-based Ocean Power Technologies Inc. (OPT) has already applied for a permit from FERC to build and test the wave power installation. OPT intends to install its ocean-tested PowerBuoys pictured at left. The Reedsport OPT project would start with a 2-MW pilot-scale installation made up of 13 to14, 150-kW PowerBuoys. The second phase of the project would be commercial scale and produce up to 50 megawatts using the larger 500-kW version of the PowerBuoy which OPT is planning to develop. (Each time the power diameter is doubled, the power conversion device quadruples the amount of wave energy captured. Thus, wave energy has a very strong economy of scale similar to that for wind power).

Approval for the full-scale 50-MW wave power plant following completion of the initial program is expected to result in significant investment and creation of jobs in Oregon. Central Lincoln County Public Utility District supports the project and has said it would purchase power from the Reedsport wave park.

The first phase of this project, which BPA is proposing to fund at $100,000, includes deploying a wave energy conversion device, working with the marine industry to identify the components of a study plan and developing a permitting roadmap. The work plan for the first phase of the project consists of four tasks:

1. Perform an Environmental Assessment (EA) that must be completed before any prototype wave energy buoy is deployed in the ocean. An EA is a concise document that a federal agency prepares under the National Environmental Policy Act (NEPA) to provide sufficient evidence and analysis to determine whether a proposed agency action would require preparation of an environmental impact statement (EIS) or a finding of no significant impact.

2. Initiate a Marine Industry Outreach program to reach out and develop communication and consensus with other existing marine users on such topics as ideal wave park locations, operation and maintenance of wave devices, impacts on fishing and other marine issues.

3. Conduct a permitting study to identify all of the permitting agencies, data requirements and sequence of steps in filing with FERC. FERC will lead this effort since the permitting process for such projects has yet to be defined.

4. Data Acquisition: The ability to track and understand the dynamics of the energy delivered to the utility grid is an important component of the demonstration project. Central Lincoln PUD and OPT will develop a way to track the energy injected at the point of interconnection.

OPT is also planning a 1.5-MW project off the coast of Spain, a 2 to 5-MW project in France and a potential project in southwest England

<u>Lincoln County Wave Park Project</u>

Oregon is on the verge of developing the nation’s first commercial scale wave energy park. In an independent study conducted by EPRI, Oregon was identified as an ideal location for wave energy conversion based on its tremendous wave resource, coastal port infrastructure and transmission capacity. These factors, combined with Oregon State University’s world leading research on wave energy, the state’s highly capable manufacturing clusters and Oregonians’ long-term commitment to renewable energy make Oregon the complete candidate to lead the United States in development of the wave energy industry.

The Oregon State College of Engineering, the Oregon Department of Energy and EPRI are hoping to establish a national wave energy conversion research, development and demonstration center at one of several locations off the Lincoln County coast. (See Oregon State University’s National Wave Energy Research Center discussion below)

In August 2006, Lincoln County applied for a FERC preliminary permit for multiple wave plants situated in the open ocean in water depths between 1 and 70 meters, somewhere within the rectangular area bounded by Lincoln County’s northern and southern borders, the shoreline and the state’s jurisdictional three-mile territorial limit.

Lincoln County, together with Central Lincoln People's Utility District (CLPUD), has identified at least nine potential interconnections between the existing CLPUD near-shore substations on the power distribution grid and possible "wave energy park" locations just off the coast. A BPA substation in Toledo, Oregon, can distribute power beyond the county on the electrical grid. The project will comply with all interconnection requirements as specified by CLPUD and BPA. There also are possible interconnections with Pacific Power in the northern portion of Lincoln County.

Lincoln County will work closely with Oregon State University and other stakeholders to identify and deploy the most suitable wave energy conversion technologies from all of the available alternatives capable of generating commercially viable energy. Wave parks of various sizes will be explored.

Oregon State University's National Wave Energy Research Center

Oregon State University has been pushing for federal funding for a proposed National Wave Energy Research Center in Newport, Oregon. The OSU facility would likely be modeled after the European Marine Energy Center (EMEC) in the Orkney Islands off northern Scotland.

The EMEC facility includes four "plug-and-play" test berths at the 50-meter depth for wave energy device testing. Armored cables link each berth to a substation and an 11-kV transmission cable connecting to the national grid and to a data/communications center located in nearby Stromness.

The berths are pre-permitted, allowing wave energy device manufacturers to do full-scale grid-connected temporary installations of their devices without going through a full (and lengthy) permitting and siting process. (Ocean Power Delivery with its Pelamis wave energy device has benefited a great deal from use of the EMEC facility, as have several other wave energy companies). The EMEC facility also includes state-of-the-art onshore research laboratory facilities to enable research and development of wave energy conversion devices, longer-lasting marine materials and other related projects.

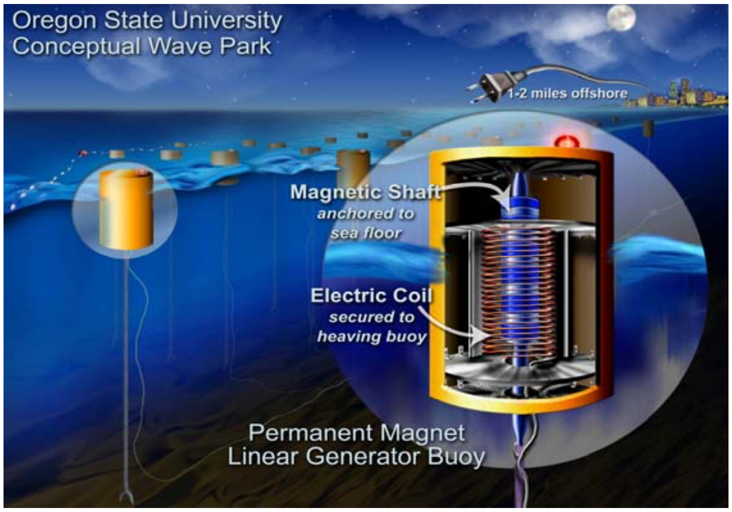
The Newport facility would create new local jobs, both in the construction phase and in daily operations, promote development and add to the state's goal of energy self sufficiency. It would receive direction and support from OSU and its Hatfield Marine Science Center in Newport, which is pictured below. In addition, OSU's College of Engineering, which has been doing cutting-edge research on wave energy conversion devices and is involved in the Reedsport project discussed above, is home to the Motor Systems Resource Facility, the highest-power energy systems laboratory at any university in the nation, and the O. H. Hinsdale Wave Research Laboratory. Both resources would be available for researchers working at the site.

Motor Systems Resource Facility

O. H. Hinsdale Wave Research Lab

Hatfield Marine Science Center

One of the OSU buoy devices on the drawing board is what engineers describe as a "permanent magnet linear generator." The 12-by15-foot long structure of the buoy is made of an impervious composite of plastic and fiberglass. A coil of copper wire within the buoy surrounds a neodymium magnet shaft, which is stationary and tethered to the ocean floor by a steel cable. As the buoy rises and falls on the waves, the coil moves up and down relative to the shaft, inducing voltage as it passes through the magnetic field. A power take-off cable carries the resulting electric current about 100 feet down to the seafloor where another cable transfers the power generated by many buoys to an onshore substation.



Each buoy is projected to generate 100 kilowatts of power, on average. A network of about 500 such buoys could power downtown Portland. Moreover, wave parks could address the state's energy imbalance. West of the Cascades, Oregon consumes about 1,000 megawatts more than it generates. By tapping about 5 percent of the coastline, wave energy could make up the difference without a need for new transmission lines.

The engineers' goal is to produce a device that is lean and streamlined and can withstand gale-force winds, monster storms and the vagaries of sea life. These vagaries can include anything from rafts of floating bull kelp to colonies of seals looking for a place to haul out. Engineers are now working on their fourth and fifth prototypes. They call their simplified approach to energy conversion “direct drive.”

3.3 RD&D Challenges

Although many wave energy devices have been invented, only a small proportion have been tested and evaluated at sea in ocean waves rather than in artificial wave tanks. Many research and development goals remain, including cost reduction, efficiency and reliability improvements, identification of suitable sites, interconnection with the utility grid, and better understanding of the impacts of the technology on marine life and the shoreline. It is also essential to demonstrate the ability of the equipment to survive the salinity and pressure environments of the ocean as well as weather effects over the life of the facility.

Some environmental issues associated with permitting an ocean wave energy conversion facility include:

- Disturbance or destruction of marine life (including changes in the distribution and types of marine life near the shore);
- Possible threat to navigation from collisions due to the low profile of the wave energy devices above the water, making them undetectable either by direct sighting or by radar. Interference of mooring and anchorage lines with commercial and sport fishing is also possible;
- Degradation of scenic ocean front views from wave energy devices located near or on the shore and from onshore overhead electric transmission lines;
- Toxic releases from leaks or accidental spills of liquids used in those systems with working hydraulic fluids;
- Noise generation above and below the water surface.

Some of the mechanical and electrical issues associated with ocean wave devices include:

Survivability

Onshore devices do not experience conditions as severe as offshore devices, since waves break, and their power dissipates while traveling into shallow water. To date, most of the shoreline devices have been based on the concept of the Oscillating Water Column (OWC). However, even with shoreline devices, the turbine must be protected from over-speeding, which is caused by high wave power input or grid disconnection. This protection could be provided by an electronic feedback control system, which uses generator torque, valve position and air pressure in the turbine chamber as signal parameters.

The geometry and the dimension of onshore devices are important as well. Almost all wave devices are fairly large in order to capture as much energy as possible from the sea. However, after the OWC in Toftestallen, Norway, was destroyed by a large storm in 1988, later OWCs have become smaller with an inclined surface facing the wave direction. In addition, the materials for onshore devices should be carefully selected; e.g., reinforced sulfate-resistant concrete for structure work and corrosion-resistant steel for turbine blades.

The size of offshore devices is also critical in determining their performance. However, because of their size, the geometric design must allow them to survive through destructive waves and storms. For instance, Pelamis has flexible joints between its rigid units and can punch through strong waves.

Offshore devices may also require special seals to prevent sea water leaking into the device through joints or other openings. The material used should be flexible and inert; e.g., reinforced rubber membrane for heaving buoys. Inert polymers with high strength or anti-corrosion steels can be used in flexible structures, such as Pelamis.

Mooring

Since the offshore devices are floating, the mooring system requires careful design. It should be able to withstand fatigue and stress from the motion of the sea, while letting the devices move in an allowed range. So far, three mooring methods have been developed. The first type uses heavy blocks of concrete lying on the seabed. The second type requires holes to be drilled into the seabed and filled with concrete to moor the device. This method can resist quite strong waves. The last method, which is now under research, is the seabed surface suction.

Maintenance and Accessibility

As with any power station, breakdowns or malfunctions are always possible. Exposure of wave energy conversion devices to the marine environment and large storms increases the chances of failure. In addition, the probability of breakdown is greater during winter when access to the system may be restricted by bad weather. Any delays in access can lead to a loss of energy.

Maintenance of certain wave devices could be carried out by the use of small submarines (already in use in Japan). The advantage of submarine maintenance is that it can work independently of the wave climate on the sea surface. This makes it possible to plan a periodic maintenance procedure. Onshore devices are obviously easier to construct and maintain. In addition, the possibility of breakdowns due to large storms is less for onshore systems.

The transmission of electricity from an offshore wave power plant requires the use of flexible submarine power cables. The bending fatigue characteristics of these cables and their steel armoring must be well understood and adequately designed for the conditions at hand. There is also the potential for insulation leakage and breakdown. Relay protection systems can help with this problem, but obviously the design and choice of materials for submarine cables requires further research.

3.4 Sector Actors

EPRI reports - EPRI Ocean Energy Program is for the public benefit. All technical work is totally transparent and available at www.epri.com/oceanenergy

EPRI WP-001-US, WEC Device Performance Estimation Methodology
EPRI WP-002-US, WEC Economic Assessment Methodology
EPRI WP-003-HI, Hawaii Site Survey
EPRI WP-003-ME, Maine Site Survey
EPRI WP-003-OR, Oregon Site Survey
EPRI WP-003-WA, Washington Site Survey
EPRI WP-004-NA, TISEC Device Survey and Characterization
EPRI WP-005-US, System Design Methodology
EPRI WP-006-HI, Hawaii System Level Design Study
EPRI WP-006-ME, Maine System Level Design Study
EPRI WP-006-MA, Massachusetts System Level Design Study

EPRI WP-006-SFA, SF California System Level Design Study - Pelamis
EPRI WP-006-SFB, SF California System Level Design Study – Energetech
EPRI WP-007-US, Environmental Issues Study
EPRI WP-008-USA, Regulatory Issues Study
EPRI WP-009-US, Final Summary Report

A. European Marine Energy Center Test Facility - www.bwea.com/marine/facilities.html

The European Marine Energy Centre (EMEC), based in the Orkney Islands north of Scotland, is among the first of its type in the world and will provide a unique one-stop facility for the industry to test potential wave and tidal energy generators.

B. Oregon State University Ocean Wave Energy Research. http://eecs.oregonstate.edu/msrf/

Development & Demonstration Center (under development – OSU is establishing a U.S. marine energy research center on par with EMEC

C. Wavegen - http://www.wavegen.com/

Located in Inverness, Scotland, Wavegen owns and operates one of the most advanced marine renewable development test facilities in the world. Its technology is based on the Oscillating Water Column (OWC) technology. Wavegen developed and operates Limpet, the world's first commercial-scale wave energy device that generates wave energy for the grid.

D. Energy Systems Research Unit (ESRU) - http://www.esru.strath.ac.uk/

ESRU is a research group within the Department of Mechanical Engineering at the University of Strathclyde in Glasgow which was established in 1987 as a cross-discipline team concerned with new approaches to environment energy demand reduction and sustainable energy supply.

E. Companies involved in ocean wave RD&D include:

- AquaEnergy - http://www.aquaenergygroup.com
- Archimedes WaveSwing - http://www.waveswing.com
- Ocean Power Delivery Ltd. – http://www.oceanpd.com
- Ocean Power Technologies - http://www.oceanpowertechnologies.com
- Ocean Wave Energy Company - http://www.owec.com
- Sea Power International AB - http://www.seapower.se
- WaveDragon ApS - http://wavedragon.net
- Wavegen - http://www.wavegen.com/.
- WavePlane - http://www.waveplane.com

4.0 Tidal In-Stream Energy Conversion (TISEC)

4.1 Technology Overview

Tidal flows result when the gravitational forces of the sun and the moon move a mass of water with speed and direction. Because it is closer to the earth, the moon exerts roughly twice the tide raising force of the sun. The gravitational forces of the sun and moon create two "bulges" in the earth's oceans: one closest to the moon, and the other on the opposite side of the globe. These bulges result in two tides (high to low water sequences) each day.

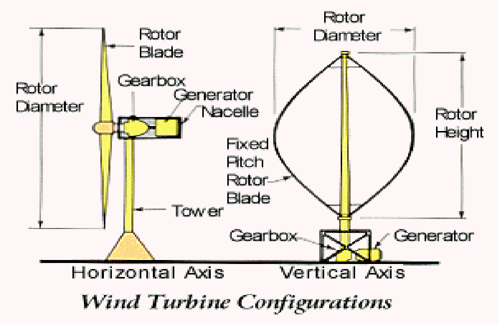
Electricity generation using tidal power is achieved by capturing the energy contained in a moving water mass due to tides. Two types of tidal energy can be extracted: the potential energy from the difference in height (or head) between high and low tides, and the kinetic energy of currents between ebbing and surging tides. The former method, which is pictured below and to the left, uses tidal barrages or dams across bays or estuaries. The latter method, illustrated below and to the right, employs submerged turbines to generate energy from in-stream tidal currents.

In-stream tidal technology is considered much more feasible than barrages or dams because of significantly lower construction costs, impacts on marine life, ecological disruptions and navigational problems.

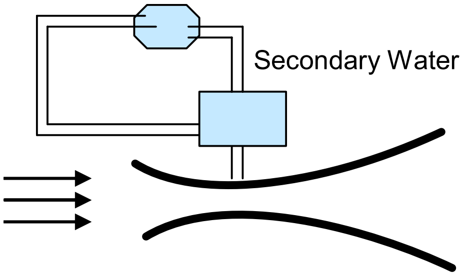
In-stream tidal technology generally employs submerged turbines that are similar in function to wind turbines, capturing energy through the processes of hydrodynamic, rather than aerodynamic, lift or drag.

There are four basic types of in-stream tidal flow energy conversion devices: horizontal axis turbines, vertical axis turbines, venture devices and oscillatory devices. These devices are illustrated below.

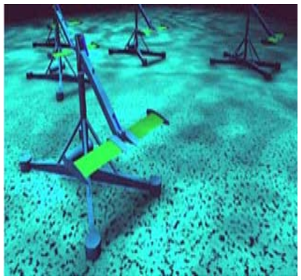
Horizontal Axis Turbine **Vertical Axis Turbine**



Venturi

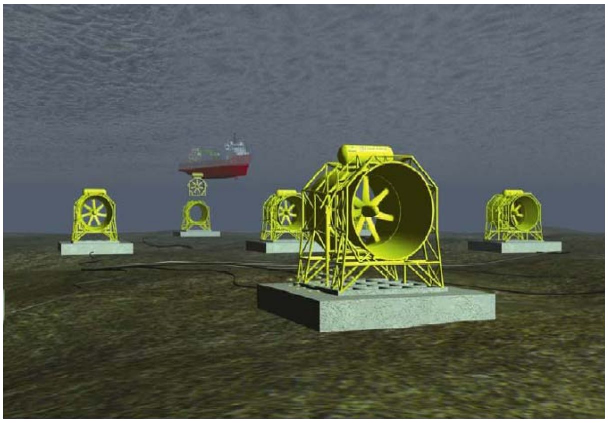


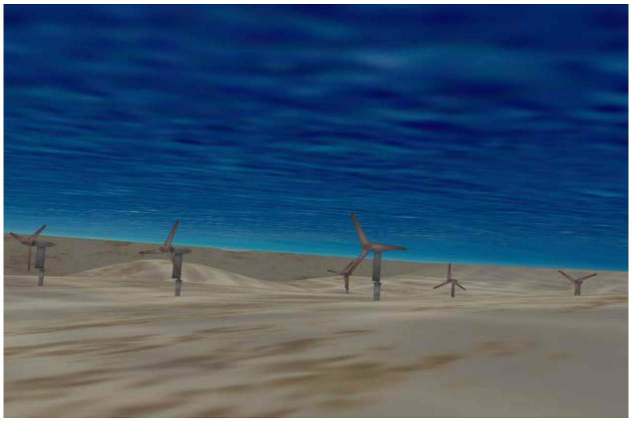
Oscillatory



In-stream tidal flow devices have generators for converting kinetic energy into electricity, along with a means to transport electrical current to shore where it can be incorporated into the electrical grid.

Mechanisms such as posts, cables or anchors keep the turbines stationary relative to the currents with which they interact. In large areas with powerful currents, tidal flow devices may be installed in groups or clusters to create a “marine current facility” as shown below. Turbine spacing would be determined based on wake interactions and maintenance needs.





Tidal in-stream energy devices also have some inherent advantages over other renewable technologies such as wind and ocean wave. For example, wind and to a lesser extent wave technologies, depend on weather, whereas tides are based on the gravitational pull of the moon and the sun on the oceans. These forces follow a set pattern that can be predicted far into the future, allowing power production from tidal in-stream devices to be predicted with confidence. This predictability of tidal power will allow for easier integration within network planning.

The energy per second intercepted by an energy conversion device is a function of the frontal area of the device, the density of the water and the cube of the speed of the water. Since water is about 835 times denser than wind, the energy contained in a 12-mph water flow is approximately equal to that contained in an air mass moving at about 110 mph. This means that tidal turbines can produce the same amount of energy as wind turbines using much smaller and slower moving turbine blades.

In-stream tidal energy devices, which are generally submerged, also minimize the aesthetic issues that plague many energy infrastructure projects, from nuclear and coal to wind generation.

In spite of these advantages, in-stream tidal energy development worldwide is still in a pre-commercial state when compared to wind development. In fact, there are no commercially operating in-stream tidal turbines currently connected to any electric power transmission or distribution grid.[22]

However, a number of global market drivers are making tidal in-stream generation a more viable alternative to traditional energy sources:

- The worldwide demand for electricity is expected to double within the next 20 years, with the strongest growth in developing areas of Asia.
- The decommissioning of nuclear power stations and an increased reliance on natural gas resulting in concerns over security of supply and an increased push for renewables.
- Global warming and the introduction of emissions-trading schemes will enhance the economic viability of renewables.

In addition to these market drivers, the potential worldwide supply of untapped ocean current energy is enormous:

- The total worldwide power in ocean currents has been estimated to be about 5,000 GW, with power densities of up to 15 kW per square meter.
- India's minister of state for non-conventional energy sources estimated that over 15,000 MW of tidal power potential exists in the gulfs of Kachh and Cambay and in Gujarat and Durgaduani Creek in Sunderbans in West Bengal.
- It has been estimated that capturing just 1/1,000 of the available energy from the Gulf Stream would supply Florida with 35 percent of its electrical needs. The Gulf Stream

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[22] The only commercially operating tidal power plants are barrage designs: a 240-MW plant in France, a 20 MW plant in Nova Scotia and a .5-MW plant in Russia.

has 21,000 times more energy than Niagara Falls in a flow of water that is 50 times the total flow of all the world's freshwater rivers.

- The West Coast of North America has significant in-stream tidal resources, which could be tapped. For example, depending on the exact location, the annual average power density in Alaska's Bay of Fundy is between 5-10 kW per square meter, while Puget Sound and San Francisco Bay densities vary between 1-2 kW per square meter.[23]

In 2003, Brian Wilson,[24] the former United Kingdom DTI Energy Minister made the following statement: "Wave and tidal power have huge potential to supply a significant proportion of the country's [Britain] energy needs." Wilson also recognized the business opportunities presented by tidal and wave technologies:

> It is essential that we move from the research and development phase, which has been going on for many years, into commercial application. The potential for such devices in the UK is significant but it also important to remember that there is going to be a global demand for proven technologies and we are well placed to capture this market once they are operating successfully in the UK. Success in projects of this sort will further the commercial development of wave and tidal energy and could lead to the creation of a major industrial sector with export potential.

In 2005, EPRI addressed this question of the most promising in-stream tidal power technologies by evaluating the techno-economic feasibility of all known tidal in-stream energy conversion (TISEC) devices.[25] Seven states and provinces in North America participated in this collaborative study, including Alaska, Washington, California, Massachusetts, Maine, New Brunswick and Nova Scotia. In-kind funding was provided by state agencies, utilities within these states, and DOE through the National Renewable Energy Laboratory (NREL).

EPRI characterized the following eight in-stream turbines as acceptable for selection by the state/province advisors for application in pilot plant testing at several North American sites. Permitting, device selection, design and testing are already underway at several locations. (Highlights of the Puget Sound and San Francisco Bay tidal projects are summarized in section 4.2.)

1. The Gorlov Helical Turbine ("GHT"), pictured at left, is a cross-flow turbine with airfoil shaped blades that provide a reaction thrust that can rotate the device at twice the speed of the water flow. It is self-starting and can produce 1.5 kW of power from a water flow as low as three knots (1.5 m/sec). GHT output power is 110 volts, 60 Hz AC. The standard model GHT (1 meter in diameter and 2.5 meters in length) can be installed vertically or horizontally in multiple GHT arrays and in waters as shallow as four feet. Due to its axial symmetry, the GHT always rotates in

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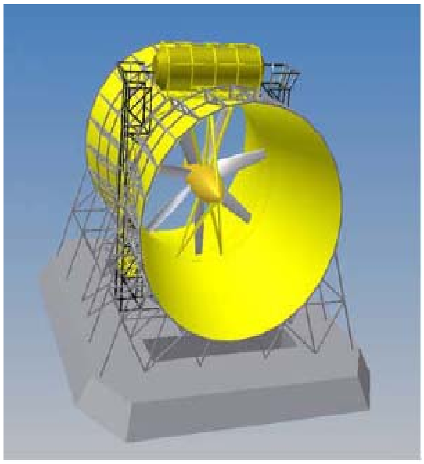
[23] EPRI presentation to International Energy Agency, Nov. 16, 2005

[24] Minister of State for Industry and Energy, DTI (Department of Trade & Industry UK)

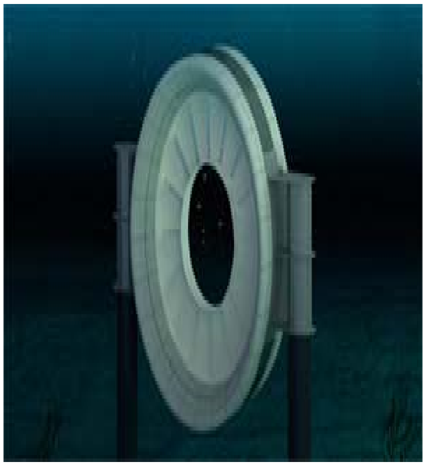
[25] Survey & Characterization, Tidal In-Stream Energy Conversion (TISEC) Devices, EPRI-TP-004 NA

the same direction, even when tidal currents reverse direction.



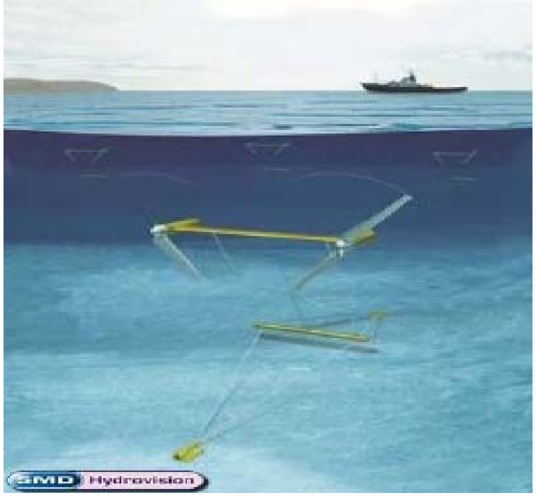
2. The Lunar Energy technology, known as the Rotech Tidal Turbine (RTT), illustrated at left, is a horizontal axis turbine located in a symmetrical duct. A fixed bi-directional duct, a patent pending blade and a hydraulic pump and motor all eliminate the need for yaw control, variable pitch blades and a mechanical gearbox, respectively. The RTT 2000 will be approximately 105 feet high and 100 feet long, weigh approximately 2,500 tons (mostly concrete and ballast) and produce 2 MW from a 6 knot (3.1 m/sec) tidal current. RTT output power is 11 kV, AC 50-60 Hz, three phase. Lunar anticipates that the turbine must be at a depth of at least 30 feet of water to allow unhindered navigation for all but the largest vessels. All electrical components are located in a hermetically sealed, nitrogen-filled airtight chamber without any dynamic rotary seals. The center cassette is intended to be removed for servicing every four years so that divers and remotely controlled vehicles will not be required during installation or servicing.

3. The Marine Current Turbine (MCT) SeaGen device, illustrated at left, has twin 18-meter diameter, open axial flow rotors mounted on wings on either side of the monopole support structure, which is set in a socket drilled in the seabed. Rotors have 180-degree pitch bi-directional flow control and drive induction generators at variable speed through three stage gearboxes. The entire wing and rotor assembly can be raised up the pile for maintenance. The MCT device will produce 2.5 MW in a 3-meter/sec flow with variable frequency AC at a nominal 600 volt and power conditioning and transformer output of 11 kV at 50-60 Hz.



4. The Open-Center Turbine, pictured at left, was developed by OpenHydro Inc. and features a fixed permanent magnet rim and an inner single-piece rotating disc. The technology is distinguished by its simplicity. No gearbox is needed thanks to the use of an encapsulated rim generator so that there is only one moving part – the turbine itself. There are no seals. The device features twin 15-meter diameter, counter-rotating turbines to offset torque and produces 1.52 MW in 5-knot (2.57 m/sec) flows. The output power is 11kV, 50-60 Hz, 3-phase. The device is mounted on the seabed and has been successfully tested in sea trials by the U.S. Navy under a cooperative research and development agreement.

5. The EXIM Tidal Turbine Power Plant (TTPP), pictured at left, is manufactured by Seapower and based on the Savonius turbine design, which is S-shaped if viewed from above. The dual vertical axis rotor, 1 meter in diameter by 3 meters high, will generate 44 kW in 2.4 m/sec water flow. Output power is 400 VAC, 50-60 Hz, three-phase induction generation.



6. SMD Hydrovision's (SMDH) TidEl system, pictured at left, consists of two horizontal-axis counter rotating rotors linked by a crossbeam and tethered to the seabed with mooring lines that orient the rotors downstream on flood and ebb tides. Each turbine is driven by an 18.5-meter diameter rotor with fixed pitch blades and housed in a buoyant pod. The pods contain high integrity seals, a planetary gearbox and an 11-kV, AC generator. The output power of the device is 11-kV, three-phase AC producing 1 MW at 2.3 m/sec water speed. Every two years, the unit, which floats when released from its mooring system, can be tugged to shore and swapped with a spare.

7. The Underwater Electric Kite (UEK), illustrated at left, is a twin fixed-pitch blade axial turbine that features a very high solidity turbine design and a 5.18-meter diameter augmentation ring that increases the internal velocity of the water flow to create a system with high efficiency. The device, which is rated at 400 kW in 3m/sec water flow is slack moored to the seabed so that it is oriented in the direction of flow. The mooring system allows the device to be floated to the surface for maintenance.

8. The Verdant Kinetic Hydro Power System (KHPS), illustrated below, is a three-bladed axial flow turbine incorporating a patented blade design, which is highly efficient over a large range of speeds. The turbine rotor drives a synchronous planetary speed increaser, which drives a grid-connected, three-phase induction generator. The gearbox and generator are mounted on a pylon assembly that has internal yaw

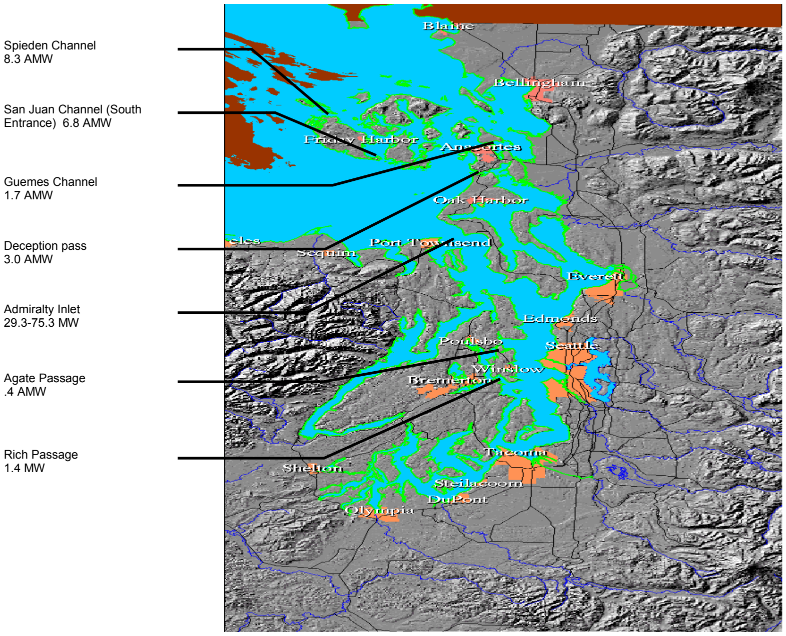
bearings, allowing the device to pivot in the direction of the tidal current. The turbine has a maintenance cycle of two years. A prototype being tested in New York City's East River has a 5-meter rotor diameter and is rated at 35.9 kW at 2.2 m/sec water speed.

Preliminary cost data on these technologies is proprietary and difficult to come by. However, Verdant Power estimated its pre-commercial production costs at $100,000 for the 40-kW machine illustrated above. These costs do not include mooring, cabling, integration and maintenance. As with the ocean wave technologies, much research and development remains to be done before reliable cost estimates become available.

4.2 Opportunity Overview

Although tidal in-stream energy technology is pre-commercial at this point, several pilot projects will be tested nationwide in the next few years. In 2005, EPRI conducted site feasibility and pilot studies at several North American locations in Maine, Massachusetts, New Brunswick, Nova Scotia, Alaska, Washington state and California. The three West Coast pilot projects identified in the study are summarized below.

- <u>Snohomish PUD Tidal Project</u> - EPRI identified the tidally active Puget Sound area as an exciting and sustainable energy source for meeting some of the Northwest's future generating needs. Puget Sound's proximity to large load centers means the electricity generated can be



connected directly to the local grid, eliminating the need to construct and maintain expensive transmission lines. In June 2006, Snohomish PUD filed preliminary study permit applications with FERC for seven tidal projects located in Admiralty Inlet, Agate Passage, Rich Passage, San Juan Channel, Spieden Channel, Guemes Channel and Deception Pass (see illustration above). Combined, these sites could provide as much as 100 average-megawatts of energy – or enough power for about 60,000 homes. FERC is expected to make a decision before the end of 2006. If granted, the FERC permits would not authorize construction, and Snohomish has not made any commitment to construct tidal facilities. Rather, the permits would allow the utility to apply for construction permits in the future if studies prove the sites are socially, environmentally and economically feasible. The PUD will only consider moving forward on tidal projects once it confirms the environmental and economic viability of the sites.

Pending FERC's approval of the preliminary study permits, Snohomish PUD anticipates commissioning EPRI to conduct the initial scoping and environmental studies. The overall objective of this work has been separated into four phases (see table below), with go-no-go decision milestones between each phase.

The objective of Phase I is to: (1) identify and select potential sites; (2) assess existing and near-term tidal flow power devices; (3) evaluate these devices for each site; (4) assess the environmental impacts of each site-device combination; (5) select a preferred site-device combination and make a recommendation, if appropriate, for a Phase II through Phase IV feasibility demonstration project; and (6) develop a detailed implementation plan for Phase II and a preliminary implementation plan for Phase III and IV.

The objective of Phase III is the installation of a prototype tidal flow power device at one of the sites with evaluation over one-to-two years. Snohomish PUD favors the modular design of newer tidal energy devices, in large part, because they allow for small test installations and can be easily removed should complications arise. An example of this technology is the turbine being tested by Verdant Power in New York's East River. Several manufacturers are developing similar technologies, and Snohomish PUD intends to evaluate each and tailor device selection to the requirements and specifications of each particular location.

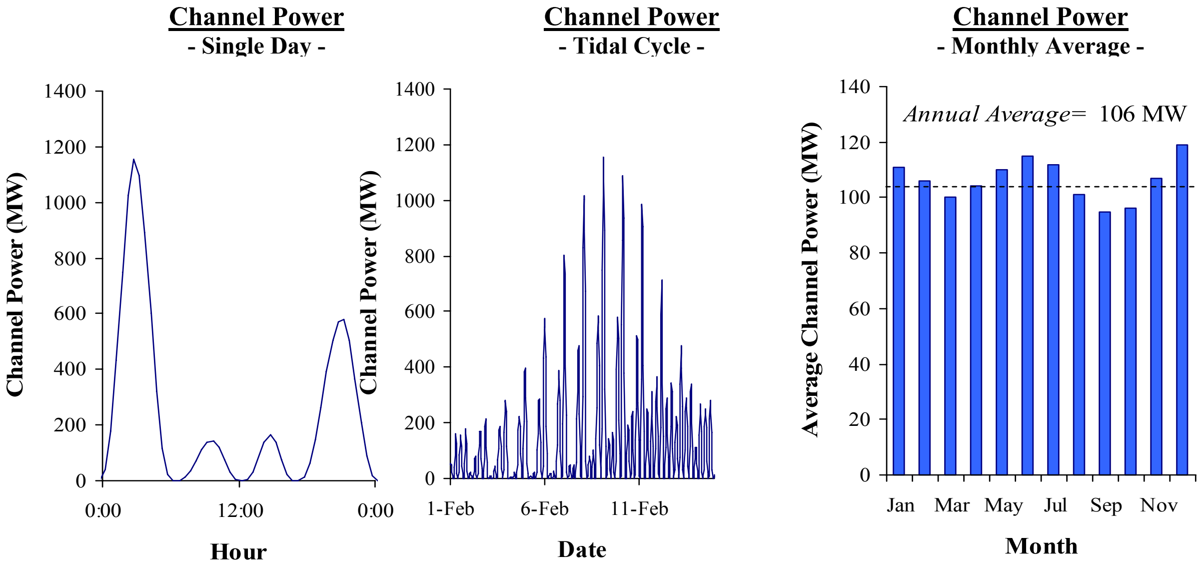
Snohomish anticipates that many obstacles will need to be overcome before construction can begin on a prototype tidal flow generation project. First, there are environmental concerns including impacts on marine mammals, fish and marine flora, as well as impacts to the shoreline and seabed from transmission cables. Second, social concerns from fishermen, commercial shipping traffic and recreational users of the waterways will need to be examined. Third, the permitting process, which is currently marked by a lack of coordination among various agencies and jurisdictions, must be understood and navigated.

BPA anticipates funding a portion of the Phase I costs. The exact amount has not yet been determined. This funding will enable Snohomish PUD to conduct a robust investigation of the various tidal energy sites.

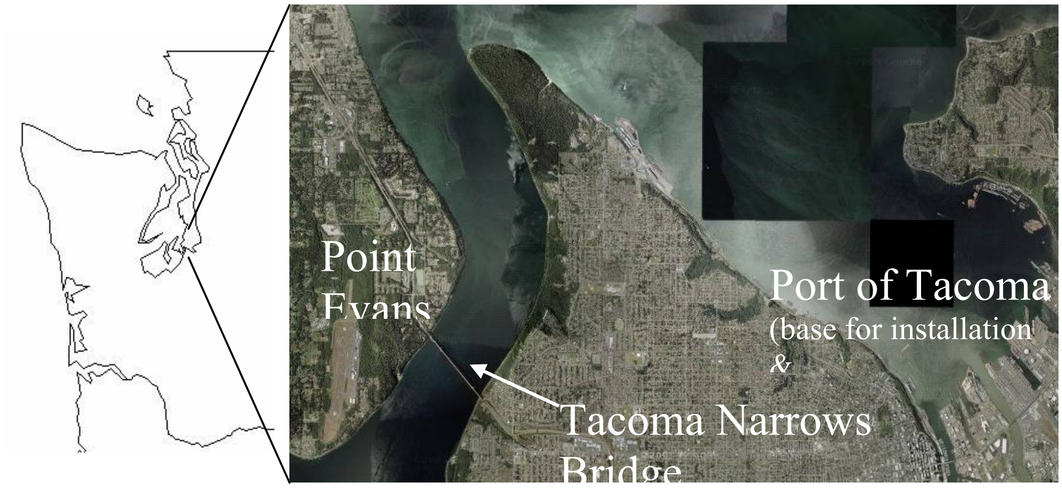
- <u>Tacoma Narrows Tidal Project</u>: Tacoma Power is assessing the potential of installing a series of turbines near the Tacoma Narrows Bridge and has received a preliminary permit from FERC for a pilot project. In addition, scientists and regulatory experts at Devine Tarbell

& Associates have been working with Tacoma Power, EPRI, Verdant Power and other Northwest entities to evaluate the environmental and regulatory aspects of tidal energy at various sites in the Puget Sound area. Tacoma Narrows tidal resource performance data is provided below.

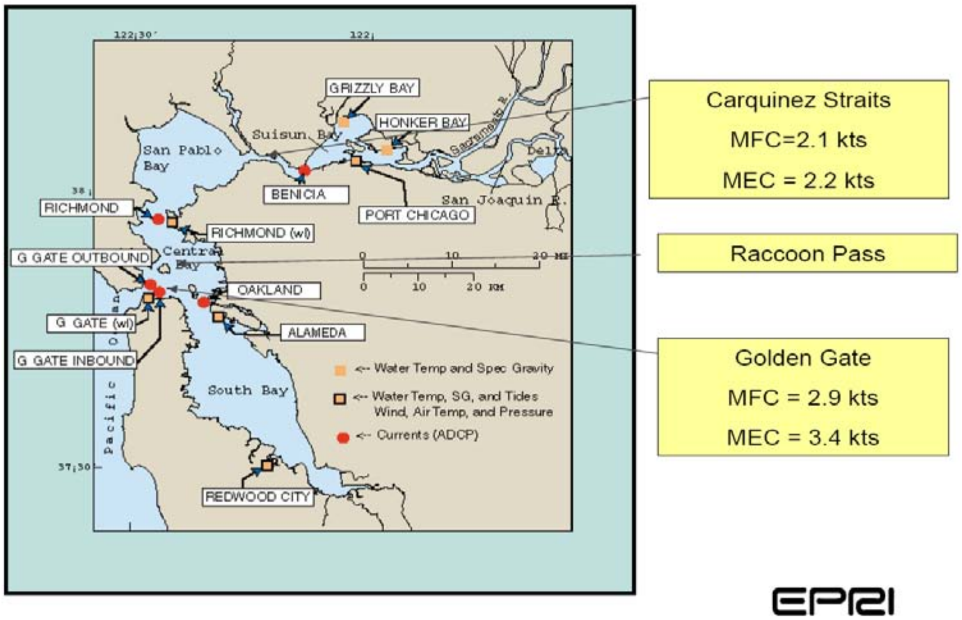
Tacoma Narrows Performance data



➡ Extraction Limit (15% Annual Average) = **16 MW**



- San Francisco Bay Tidal Project: The Golden Gate spans one mile. With two meters of tidal height at a velocity of 2 meters per second, up to 2.5 billion cubic meters of water races through the Golden Gate every six hours. It is estimated that in-stream tidal turbines at this strategic location could provide up to 1,500 megawatts of power.



San Francisco Bay Tidal Sites

EPRI

4.3 RD&D Challenges

New technologies for generating in-stream tidal power offer many advantages. However the environment in which tidal turbines operate presents some daunting technical, environmental and regulatory challenges for both developers and the agencies responsible for regulating these devices.

A number of potential problems need to be addressed if in-stream tidal energy is to become viable. For example, tidal devices must be able to operate in the corrosive seawater environment. Mooring devices and turbines must be designed to withstand the forces imposed from high velocity and high density water flow; electrical equipment must be insulated from moisture of any kind; clearances must be maintained with surface shipping and commercial fishing; marine environments must be protected from seabed scouring and turbidity and leaking oils and fluids.

In addition, toxic agents in anti-fouling measures must be avoided or minimized; turbine operations must not impose unacceptable mortality rates on aquatic life; electric power quality and reliability must be maintained; and maintenance intervals must be kept to a minimum as the logistics of maintenance are likely to be complex and costly.

These challenges are exacerbated by the fact that tidal streams are a diffuse form of energy, requiring large numbers of energy devices spread over relatively large areas of seabed to produce significant mounts of energy.

4.4 Sector Actors

A. EPRI Reports - EPRI Ocean Energy Program is for the public benefit. All technical work is totally transparent and available at www.epri.com/oceanenergy.

EPRI TP-001-NA,	TISEC Resource/Device Performance Estimation Methodology
EPRI TP-002-NA,	TISEC Economic Assessment Methodology
EPRI TP-003-MA,	Massachusetts Site Survey
EPRI TP-003-ME,	Maine Site Survey
EPRI TP-003-NB,	New Brunswick Site Survey
EPRI TP-003-MA,	Nova Scotia Site Survey
EPRI TP-004-NA,	TISEC Device Survey and Characterization
EPRI TP-005-NA,	System Design Methodology
EPRI TP-006-AK,	Alaska System Level Design Study
EPRI TP-006-WA,	Washington System Level Design Study
EPRI TP-006-CA,	California System Level Design Study
EPRI TP-006-MA,	Massachusetts System Level Design Study
EPRI TP-006-ME,	Maine System Level Design Study
EPRI TP-006-NB,	New Brunswick System Level Design Study
EPRI TP-006-NS,	Nova Scotia System Level Design Study
EPRI TP-007-NA,	North America Environmental and Regulatory Issues
EPRI TP-008-NA,	Final Summary Report

B. European Marine Energy Center Test Facility - www.bwea.com/marine/facilities.html

The European Marine Energy Centre (EMEC), based in the Orkney Islands north of Scotland is among the first of its type in the world. It will provide a unique one-stop facility for the industry to test potential wave and tidal energy generators.

C. Oregon State University Ocean Wave Energy Research, Development & Demonstration Center (under development – OSU is establishing a U.S. marine energy research center on par with EMEC).

D. Companies Involved in In-Stream Tidal Energy Development

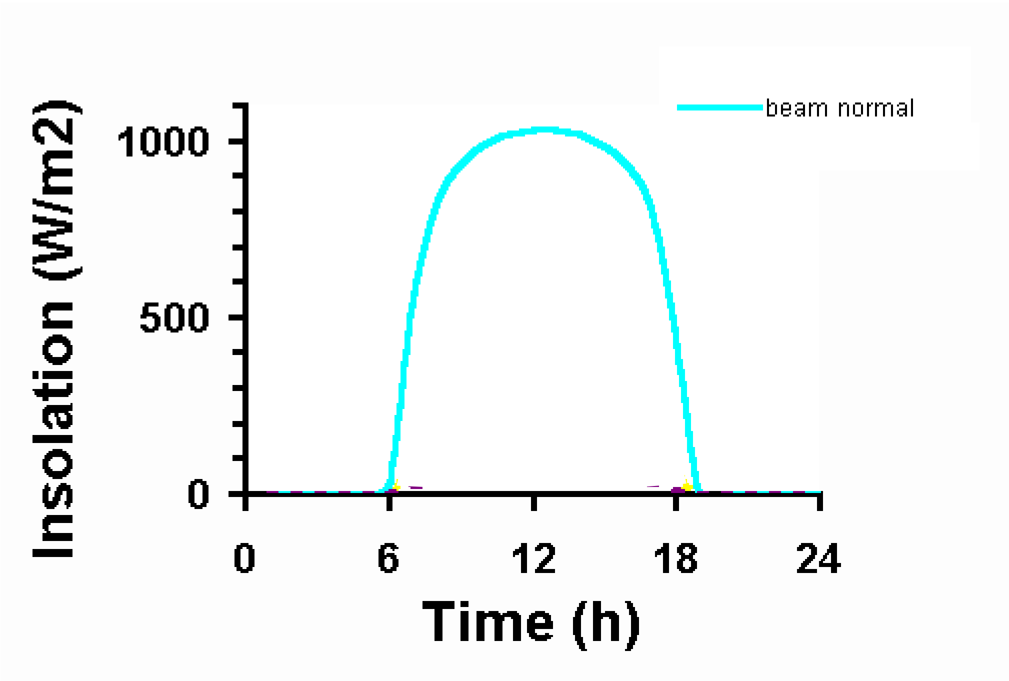
- Marine Current Turbines (MCT), www.marineturbines.com
- Blue Energy Canada, www.**blue**nergy.com
- The Engineering Business, www.engb.com
- SMD Hydrovision, www.smdhydrovision.com/products
- Verdant Power, www.verdantpower.com
- Rotech, www.rotech.co.uk
- Lunar Energy, www.lunarenergy.co.uk
- OpenHydro, www.openhydro.com
- Seapower, www.seapower.com.au
- Underwater Electric Kite, www.uekus.com

5.0 Solar Photovoltaic (PV)

5.1 Technology Overview

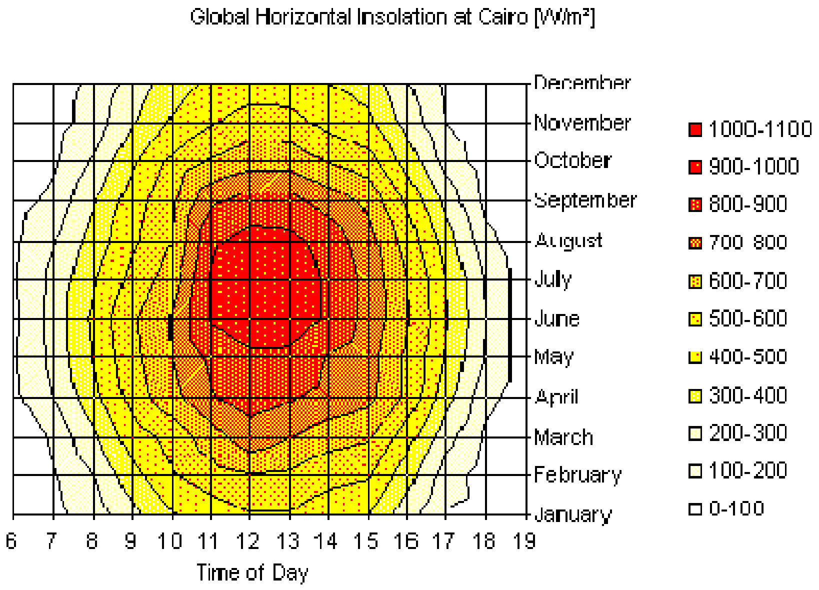
On a bright sunny day, the sun shines approximately 1,000 watts of energy per square meter of the planet's surface. Solar photovoltaic devices generate electricity directly from this sunlight via an electronic process that occurs naturally in certain types of materials. The photovoltaic effect produces direct current (DC) electricity, while using no moving parts.

The following graph shows the variation of insolation over a full, clear day in March at Daggett, California, a meteorological measurement site. The blue curve represents the rate of incident energy coming directly from the sun (beam normal insolation) and falling on a square meter of surface area. The peak rate of incident solar energy occurs around noon and is 1,030 watts per square meter. Over the full day, 10.6 kilowatt-hours of energy have fallen on every square meter of surface area as represented by the area under this curve.



Insolation data from Daggett, California on a clear March day.

An example of a complete set of beam normal insolation data for a given location is shown in the following graph. Here hourly insolation data are summarized over a day for each month of a year. This type of data for a specific site makes it possible to predict accurately the output of a solar energy conversion system.



Photovoltaic (PV) cells are made of special materials called semiconductors such as silicon, which is currently the most commonly used material. Basically, when light strikes the cell, a portion of it is absorbed within the semiconductor material. The energy of the absorbed light is transferred to the semiconductor, illustrated at left. The energy knocks electrons loose, allowing them to flow freely. PV cells also all have one or more electric field that act to force electrons freed by light absorption to flow in a certain direction. This flow of electrons is a current. When metal contacts are placed on the top and bottom of the PV cell, the current can be drawn off to use externally. This current, together with the cell's voltage (which is a result of its built-in electric field or fields), defines the power (or wattage) that the solar cell can produce.[26]

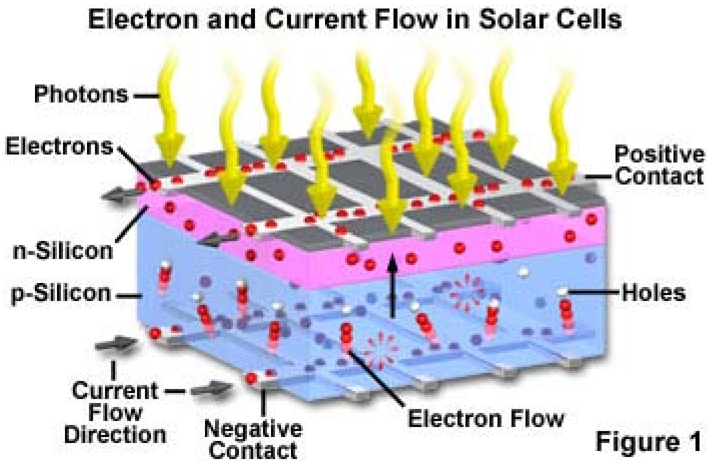


Figure 1

There are four factors that make PV a good alternative to existing grid-connected energy sources: (1) it is powered by the sun so it is renewable; (2) it is a domestic source of energy; (3) it is a high-technology industry offering good jobs in research, development and installation; and (4) solar power is available during the daytime when electricity loads are high.

PV is a versatile technology that can be used in many applications from solar calculators and residential energy applications to 100-MW solar farms.

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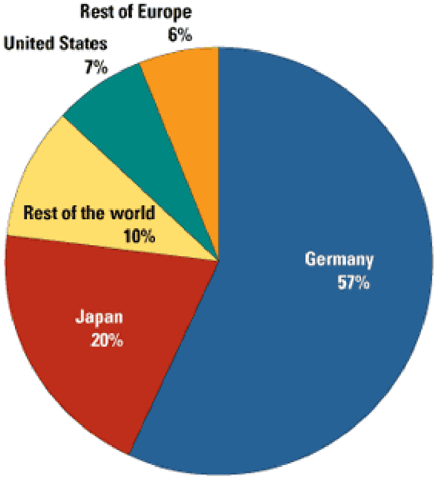
[26] For a more detailed discussion of the physics and material science of PV cells see Appendix B



Since the late 1990s, the PV market has grown at an annual average rate of 20 percent, and for the last five years, the industry had a 24 percent average growth rate.[27]

The solar industry estimates that growth will continue at this rate or higher, making PV a $27 billion annual market by 2020. NREL more optimistically estimated that by 2020, PV will have a direct market of $15 billion and an indirect market of $30 billion.

PV market installations reached a record high of 1,460 megawatts in 2005 representing an annual growth rate of 34 percent. Germany, Japan and the United States accounted for 57 percent, 20 percent and 7 percent of the global PV market respectively.

Capital cost subsidies, along with tax and financial incentives, driven by the Japanese and German solar building programs are propelling global PV power market growth.

In the long term, larger manufacturing facilities being constructed in the United States and abroad are expected to achieve economies of scale that reduce the cost of manufacturing PV cells, making PV power cost effective in more markets with fewer subsidies.

The U.S. market is characterized by several niches defined by the following applications:

- Building Integrated Photovoltaics (BIPV). These are PV arrays mounted on building roofs and facades. This market segment includes hybrid power systems, combining diesel generators, batteries and PV generation capacity for off-grid remote cabins.

- Non-BIPV Electricity Generation (grid interactive and remote). This market includes distributed generation (e.g., stand-alone PV systems or hybrid systems including diesel generators, battery storage and other renewable technologies), water pumping and power for irrigation, and power for cathodic protection.

- Communications. PV systems provide power for remote telecommunications repeaters, fiber optic amplifiers, rural telephones and highway call boxes. PV modules provide power for remote data acquisition for both land-based and offshore operations in the oil and gas industry.

- Transportation. Examples include power for boats, cars, recreational vehicles and for transportation support systems such as message boards or warning signals on streets and highways.

- Consumer Electronics. A few examples are calculators, watches, landscaping lights, battery chargers, etc.

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[27] The market data and discussion in this section was provided by Tugrul Daim, Ph.D., associate professor of Engineering and Technology Management, Maseeh College of Engineering and Computer Science, Portland State University

5.2 Opportunity Overview:

Large-scale PV systems are becoming a reality. Some examples of these systems are presented below.

Germany has embraced renewable energy in general and solar power in particular. The key driver of green generation in Germany has been the Renewable Energy Law (REL) adopted in 2000. The REL, along with mandates for national carbon dioxide reductions under the Kyoto Protocol, has been responsible for development of 2,000 biomass plants, 6,000 small hydro plants, 16,500 wind turbines – and 110,000 photovoltaic systems. The latest available data indicate that $3.6 billion was spent on German PV projects alone in 2005, up from $2.7 billion in 2004. Germany made the costs of installing PV bearable by guaranteeing 20-year interconnection contracts and spreading subsidy costs across all ratepayers. The downside of spreading PV development costs across all consumers is upward pressure on rates. Average residential rates are now hovering at 18.6 cents/kWh with taxes accounting for 7.3 cents of the total.[28]

Two years ago Germany generated one billion kilowatt-hours (kWh)of PV power, and the solar industry there expects that number to rise to nearly three billion kWh's by 2011. In 2005 alone, Germany's installed PV capacity grew 53 percent to 837 MW, or 57 percent of the world market.

The 10-MW Bavaria Solarpark, christened by PowerLight Corp (Berkeley California), Deutsche Structured Finance and other project partners on June 20, 2005, is the world's largest grid-connected PV system, at least for now. The system consists of three individual parks in the cities of Muhlhausennkey (6.3 MW pictured below), Gunching (1.9 MW) and Minihof (1.9 MW) Germany.

PowerLight Corp., which designed, developed and built the $62.5 million system on a turnkey basis, is also responsible for servicing it.[29] The system uses PowerLight's patented PowerTracker technology to follow the sun, maximizing solar insolation and output.

The PV modules come from Sharp Electronics, while Siemens AG provided all electrical construction and equipment including inverters. Interconnection to the grids was provided by the regional German utility E.ON.

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[28] This discussion is from the Power Trade Journal, Vol 150, No 6, July/August 2006, p36, Bavaria Solarpark

[29] $6,250/KW

Given how far north the system is, it is not surprising that 76 percent of its annual production takes place between April and September. Plant data from January to September 2006 confirm that the tracking system exposes the panels to 33 percent more solar insolation than horizontal systems and 15 percent more solar insolation than fixed, 30-degree tilt systems, such as the one pictured at right. The plant became fully operational in December 2004, and it has been 100 percent reliable during all daylight hours since.

On June 6, 2006, GE Energy Financial Services, PowerLight Corp., and Lisbon-based Catavento Lda. broke ground on what will be the world's largest PV power project when it is completed in January 2007. The $75 million, 11-MW plant, comprising 52,000 PV modules, is under construction in Serpa, Portugal, in one of Europe's sunniest areas.

Israel is building a 100-MW PV plant in the Ashalim area of Negev to supply energy to homes in the southern part of the country. Conceivably, this project could be expanded to 500 MW, at a cost of $1 billion. A recent study found that Israel could produce 2,500 MW from solar energy by 2025, one fourth its current demand.

The Las Vegas Valley Water District initiated the development of a 3.1-MW photovoltaic PV project in October 2004. This project, pictured at right, will be one of the largest ever built by a public agency in the United States. Solar electricity generated at the facilities will support on-site operations. The Ronzone Reservoir system is made up of 4,005 Sharp solar panels arranged into multiple rows, which rotate on a single axis to track the sun. This tracking system allows the solar array to produce up to 25 percent more energy than a stationary solar array of the same size.

LAS VEGAS VALLEY WATER DISTRICT
RONZONE RESERVOIR, NEVADA

PowerTracker Ground System at the Ronzone Reservoir

On September 5, 2006, Applied Materials, the world's biggest tool provider for the semi-conductor industry, announced it is expanding into equipment for the booming solar industry. In July 2006, the company acquired Applied Films, a supplier of thin-film deposition equipment.

While most cells depend on silicon, thin-film coating material being developed for panels can reduce the amount of silicon needed, making PV cells cheaper.

Chief Executive Officer Mike Splinter promised to reduce the costs of generating solar power from current levels of approximately $3 to $5 per watt, to $1 per watt. According to Splinter:

> *The solar industry has reached the inflection point that Applied Materials has been waiting for.*[30]

5.3 RD&D Challenges:

The world currently uses about 10 terawatts (TW) of energy (the United States about 3 TW) and by 2050 is projected to need about 30 TW. Therefore, to stabilize CO^2 emissions at current levels, the world will need about 20 TW of non-carbon-based energy. Hoffert (NYU), Rick Smalley (Rice Nobel Laureate) and Nate Lewis (CalTech) call this the "*Terawatt Challenge.*"[31]

CalTech's Nate Lewis argues that:

> Among the renewables, only solar has a resource base sufficient to meet a major fraction of the world's energy needs. "Solar is the only big number out there."

PV has a long way to go to before anyone entertains terawatt-sized markets. A number of questions need to be addressed, such as:

- Which PV technologies have the most potential and why?
- What key drivers will determine which technologies scale successfully and which never make it out of the lab?
- How can companies pursuing new PV technologies and approaches help drive the per-unit costs lower?
- What are the limitations for increasing the efficiency of these technologies?
- How much is there to gain in the production costs compared to panel efficiencies?
- What are the obstacles to commercializing new PV technologies?
- How much do thin-film PV technologies depend on the silicon shortage? The cost of raw silicon is a major factor in the cost of a finished PV cell, whereas it is insignificant in the cost of a packaged IC chip. This means that PV will be extremely sensitive to fluctuations in the pricing and availability of raw silicon.

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[30] Financial Times, Wednesday, Sept. 6, 2006, "Applied Materials in Solar Strategy"

[31] The Terawatt Challenge for Thin-Film PV, NREL/TP-520-38350, Ken Zweibel
Future Global Energy Prosperity: The Terawatt Challenge, Richard E. Smalley,
www.mrs.org/publications/bullinten

- Since an entire supply chain is needed to connect finished PV cells to the grid, how strong/complete is that chain?

- Where are the opportunities for entrepreneurs?

One of the most challenging PV hurdles for entrepreneurs appears to be thin-film technology. Thin films are a direct response to the high cost of wafer PV modules. The idea of thin films is simple: use low-cost materials (e.g., glass, metal, plastic) and very little high-cost semi-conductor material. This idea has been around as long as PV, but the difficulty has been in developing thin-film semi-conductors that have sufficiently high conversion efficiencies and finding ways to make them cheaply at high yield.

Thin-film modules have a lot in common with crystalline silicon modules. For example: they require top and bottom protection from the outdoor environment, need top and bottom contacts, bus bars and a connection to an external circuit to carry away current. They need ways to connect the cells together to provide the correct balance of voltage and current. They need some sort of mounting scheme, edge seals and edge protection.[32]

Another challenge is that thin-film semi-conductors, which are only a few microns thick, have their own peculiar stability issues, both intrinsically and at the module level.

The first thin films were made of copper sulfide and had an electrochemical instability that led to degraded performance. Copper sulfide never became a commercially significant thin film. The second commercial thin film, amorphous silicon, suffers from a serious degradation associated with (ironically) exposure to light. Called the Staebler-Wronski Effect, it results in about a 20 to 40 percent degradation unless checked by design modifications such as thinner intrinsic layers and multi-junctions. This degradation keeps a-Si efficiencies below those of other thin films. Combined with some start-up problems with encapsulation and quality control, the poor outdoor performance of a-Si products has until recently defined the reputation of thin films.

Fortunately, many of these problems have been dealt with. Numerous minor problems (designing encapsulation, controlling the quality of the modules themselves) have been overcome as a-Si has matured. A major breakthrough came when it was observed that a-Si devices degrade to a reduced level and then do not degrade further.

The future of thin films looks strong. Despite serious obstacles, amorphous silicon has established itself as a viable competitor for wafer-based crystalline silicon devices. Once established in the marketplace, amorphous silicon is likely to make good progress and could even come to dominate the world PV market. Meanwhile, the next generation of thin films – CIS and CdTe – shows stronger technical performance (laboratory efficiency and stability) and similar or lower potential cost. Although the goals for truly inexpensive PV are ambitious (15-percent modules, 30-year life, price under $75/Wp,[33] or about $0.5/Wp), thin films seem capable of reaching and even exceeding these goals. The future is likely to be as checkered as the past as technologies experience the harsh realities of early production and

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[32] This discussion is from “Thin Films: Past, Present and Future” Ken Zweibel, Thin-Film PV Partnership Program National Renewable Energy Laboratory.

[33] Wp – peak wattage capability of photovoltaic.

companies are forced to endure losses that extend well past expectation. There will be other technical plateaus, but most issues can be overcome. The technical basis for thin films is solid, and the accomplishments up to now have been in line with the technical basis and are likely to continue. As thin-film goals are met, low-price photovoltaics will become real. The key will be the resources and endurance needed to overcome technological challenges

5.4 Sector Actors

A. National Renewable Energy Laboratory, http://www.nrel.gov/

See: Thin-Film PV Partnership Program.

NREL's Solar Energy Technologies Program performs research in two major solar energy technologies.

Photovoltaic Research

NREL performs fundamental research in PV-related materials; develops PV cells in several material systems; characterizes and improves performance and reliability of PV cells, modules and systems; assists industry with standardized tests and performance models for PV devices; and helps the PV industry accelerate manufacturing capacity and commercialization of various PV technologies.

The nation's premier research facility for PV is the National Center for Photovoltaics (NCPV), headquartered at NREL.

Solar Thermal Research

Concentrating Solar Power — NREL plays a leadership role in analyzing cost and performance of solar systems, developing parabolic trough technology for solar electricity generation and developing advanced technologies such as concentrating photovoltaics. Researchers support development of new designs and manufacturing processes for solar components and systems with an emphasis on improved performance, reliability and service life.

Solar thermal research is performed in NREL's Center for Buildings and Thermal Systems.

Solar Radiation Research

Optimal siting of renewable energy systems requires knowledge of the resource characteristics at any given location. Solar radiation research and data collection is performed at NREL's Solar Radiation Research Laboratory. This unique research facility continually measures solar radiation and other meteorological data and disseminates the information to government, industry, academia, and international laboratories and agencies. These data are used for climate change studies, atmospheric research, renewable energy conversion system testing and more.

SERI - The Solar Energy Research Institute (SERI) was established on July 1, 2005. SERI's solar energy research focuses on (1) solar thermal systems, (2) zero energy architecture and sustainable material in buildings, (3) solar radiation studies, (4) photovoltaic systems and components, (5) social economic impact of solar energy systems and sustainable materials in building, (6) solar hydrogen production systems, (7) solar cells fabrication and characterization, and (8) off grid and grid-connected photovoltaic hybrid systems. http://pkukmweb.ukm.my/~SERI/

WWW.SolarBuzz.com - This site, connected to solar energy companies worldwide, follows solar energy developments and provides research and consultancy services.

Companies cited in report:

Applied Materials - http://www.appliedmaterials.com/
PowerLight - http://www.powerlight.com/

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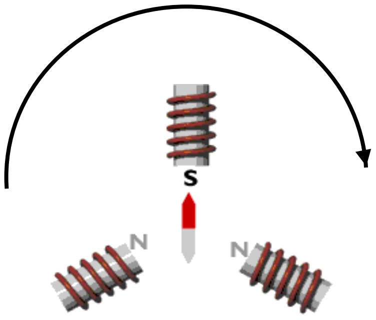
Appendices A-G

Appendix A Principles of Synchronous and Asynchronous Machines

(Courtesy of http://www.windpower.org/en/tour/)

The three-Phase Synchronous Generator



3-Phase Rotating Magnetic Field
Supplied by Grid

All three-phase generators (or motors) use a rotating magnetic field. In the picture at right, a natural magnet rotates within three electromagnets positioned 120 degrees apart. Each magnet is connected to its own phase in the three-phase electrical grid.

The setup with the three electromagnets is called the stator because this part of the generator remains static (in the same place). The compass needle in the center is called the rotor. The compass needle (with the north pole painted red) will follow the magnetic field exactly and make one revolution per cycle. With a 60-Hz grid, the needle will make 60 revolutions per second; i.e., 60 times 60 = 3600 rpm (revolutions per minute).

This is a two-pole permanent magnet synchronous generator. It is called a synchronous generator because the center magnet will rotate at a constant speed, which is synchronous with the rotation of the stator's magnetic field (see discussion on variable pole generators below).

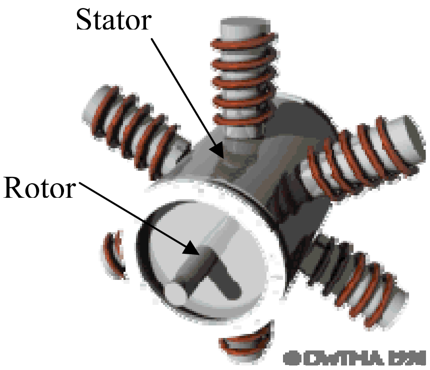
It is called a two-pole generator because the rotor and the stator each have one north and one south pole. It may look like the stator has three poles, but in fact the compass needle feels the pull from the sum of the magnetic fields around its own magnetic field. So, if the magnetic field at the top of the stator is a strong south pole, then the two magnets at the bottom will add up to a strong north pole.

When the magnet is forced around (instead of letting the current from the grid move it), it works like a generator, sending alternating current back into the grid. The more force (torque) applied, the more electricity is generated. However, the generator will still run at the same speed dictated by the frequency of the electrical grid. Wind turbines which use synchronous generators normally use electromagnets in the rotor, which are fed by direct current from the electrical grid. Since the grid supplies alternating current, AC must be converted to DC before it is sent into the coil windings around the electromagnets in the rotor. Rotor electromagnets are connected to the current by using brushes and slip rings on the axle (shaft) of the generator.

The Asynchronous (Induction) Generator

The pictures below illustrate the basic principles of the asynchronous generator (or motor).

Most wind turbines in the world use a so-called three-phase asynchronous (cage wound) generator, also called an induction generator, to generate alternating current. Although this



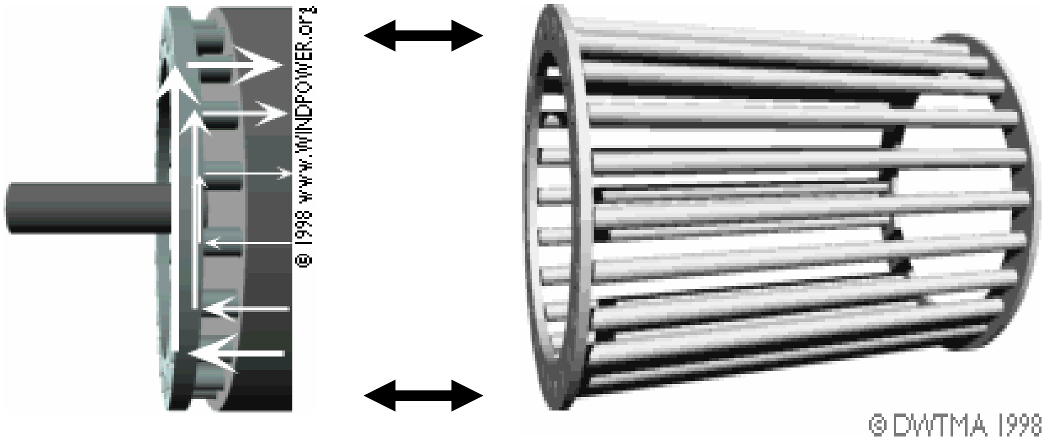
type of generator is not widely used outside the wind turbine industry (other than in small hydropower, wave and tidal units), the world does have a lot of experience with it .

The curious thing about this type of generator is that it was originally designed as an electric motor. In fact, one-third of the world's electricity consumption is used to run induction motors driving machinery in factories, pumps, fans, compressors, elevators and other applications where electrical energy must be converted to mechanical energy.

One reason for choosing this type of generator is that it is very reliable and tends to be comparatively inexpensive. The generator also has some mechanical properties that are useful for wind turbines: generator slip and a certain overload capability.

<u>The Cage Rotor of an Asynchronous Machine</u>

The key component of the asynchronous generator is the cage rotor.



The rotor distinguishes the asynchronous generator from the synchronous generator. This type of rotor consists of a stack of thin, insulated iron laminations with holes punched to allow for the outer ring of conducting aluminum or copper rods. The rods and end rings form a “cage” electrically connected by the end rings.

The rotor is placed in the middle of the stator, which in this case, is a four-pole stator that can be directly connected to the three phases of the electrical grid.

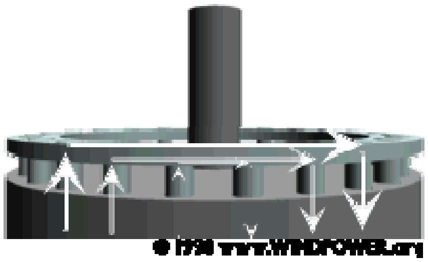
<u>Asynchronous Motor Operation</u>

When all three phases of the stator are connected to the grid, this machine will start turning and accelerate until its rotational speed approaches the synchronous speed of the rotating magnetic field in the stator.

The difference between the rotational speed of the stator's magnetic field and rotational speed of the rotor is referred to as "slip." The slip induces voltage, currents and an opposing magnetic field in the rotor, which reacts with the stator's magnetic field causing it to accelerate until the motor reaches its "no-load" speed.

Viewing the rotor from above (as in the picture to the right), one can see the magnetic field that moves relative to the rotor. This induces a strong current in the rotor bars. They offer very little resistance to the current, since they are short circuited by the end rings.

The rotor then develops its own magnetic poles, which in turn are dragged along by the electromagnetic force from the rotating magnetic field in the stator.



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Asynchronous Generator Operation

Now what happens if this rotor is manually cranked around at exactly the synchronous speed of the generator, which for a four-pole machine is 1,800 rpm? The answer is "nothing." Since the stator's magnetic field rotates at exactly the same speed as the rotor's magnetic field, there is no induction phenomena in the rotor, and it will not interact with the stator.

But what if the rotor's speed is cranked above 1,800 rpm? This forces the rotor to rotate faster than the magnetic field in the stator, causing the machine to "slip" and the stator to induce strong voltages, currents and magnetic fields in the rotor. The harder the rotor is cranked, the more power will be transferred as an electromagnetic force to the stator, and in turn converted to electricity to be fed into the electrical grid.

Generator Slip

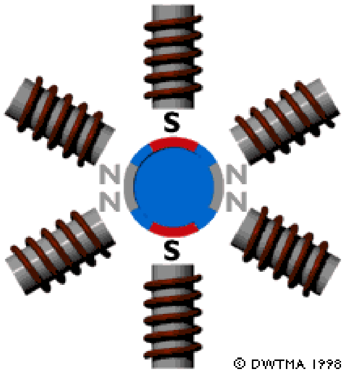
The speed of the asynchronous generator will vary with the turning force (moment or torque). In practice, the difference between the rotational speed at peak power and at idle is very small, about 1 percent. This difference in percent of the synchronous speed is called the generator's slip. Thus a four-pole generator will run idle at 1,800 rpm if it is attached to a grid with a 60-Hz current. If the generator is producing at its maximum power, it might be running at 1,818 rpm.

It is a very useful mechanical property that the generator will increase or decrease its speed slightly as the torque varies. This means that there will be less wear and tear on the gearbox. Slip acts as a cushion in the drive train of the turbine, which is one of the most important reasons for using an asynchronous generator rather than a synchronous generator on a wind turbine directly connected to the electrical grid. (Note: a synchronous generator must stay synchronized with the rotating magnetic field of the stator).

Automatic Pole Adjustment of the Rotor

The number of poles of the cage rotor described above is not specified. That's because the cage rotor automatically adapts itself to the number of poles in the stator. The same rotor can therefore be used with a wide variety of pole numbers.

Some manufacturers fit their turbines with two generators, a small one for periods of low winds and a large one for periods of high winds. A more common design on newer machines is pole changing generators; i.e., generators that (depending on how their stator magnets are connected) may run with a different number of poles and thus a different rotational speed. Washing machines which can also spin dry clothes usually have pole changing motors that are able to run at low speed for washing and at high speed for spinning. Similarly, kitchen exhaust fans may be built for two or three different speeds.



Poles

The speed of a synchronous and asynchronous generator (or motor) that is directly connected to a three-phase grid is dictated by the frequency of the grid. However, if the number of magnets in the stator are doubled, it will ensure that the magnetic field rotates at half that speed. In the picture at left, the magnetic field moves clockwise for half a revolution before it reaches the same magnetic pole as before. The six magnets are simply connected to the three phases in a clockwise order. This generator (or motor) has four poles, two south and two north poles. Since a four-pole generator will only take half a revolution per cycle, it will make 30 revolutions per second on a 60-Hz grid, or 1,800 revolutions per minute. (Note: when the number of poles in the stator of a synchronous generator are doubled, the number of magnets in the rotor will also need to be doubled, as illustrated in the picture. Otherwise the poles will not match.)

Appendix B PV Cell – The Physics and Material Science

(Courtesy of: http://www.howstuffworks.com/solar-cell.htm)

The Physics of PV

Silicon has special chemical properties, especially in its crystalline form. An atom of silicon has 14 electrons, arranged in three different shells. The first two shells, those closest to the center, are completely full. The outer shell is only half full, with only four electrons. A silicon atom will always look for ways to fill up its last shell (which would like to have eight electrons). To do this, it will share electrons with four of its neighbor silicon atoms. It's as if every atom holds hands with its neighbors; except that in this case, each atom has four hands joined to four neighbors. That's what forms the crystalline structure, a structure that turns out to be important to this type of PV cell.

Pure, crystalline silicon, as described above, is a poor conductor of electricity because none of its electrons are free to move about, as electrons do in good conductors such as copper. Instead, the electrons are all locked in the crystalline structure. The silicon in a solar cell is modified slightly so that it will work as a solar cell.

A solar cell has silicon with impurities – other atoms mixed in with the silicon atoms, changing the way things work a bit. Impurities usually connote something undesirable, but in this case, the cell would not work without them. These impurities are actually put there on purpose. Consider silicon with an atom of phosphorous here and there, maybe one for every million silicon atoms. Phosphorous has five electrons in its outer shell, not four. It still bonds with its silicon neighbor atoms, but in a sense the phosphorous has one electron that doesn't have anyone to hold hands with. Although it doesn't form part of a bond, there is a positive proton in the phosphorous nucleus holding it in place.

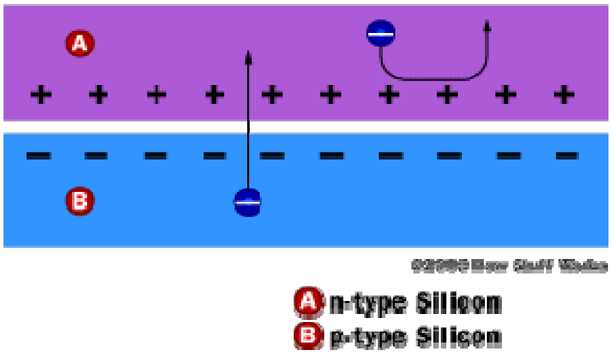
When energy is added to pure silicon, for example in the form of heat, it can cause a few electrons to break free of their bonds and leave their atoms. In each case, there’s a hole left behind. These electrons then wander randomly around the crystalline lattice looking for another hole to fall into. Such electrons are called free carriers, and they can carry electrical current. There are so few of them in pure silicon, however, that they aren't very useful. The impure silicon with phosphorous atoms mixed in is a different story. It turns out that it takes a lot less energy to knock loose one of those "extra" phosphorous electrons because they aren't tied up in a bond – their neighbors aren't holding them back. As a result, most of these electrons break free, and there are a lot more free carriers than with pure silicon. The process of adding impurities on purpose is called doping. When doped with phosphorous, the resulting silicon is called N-type ("n" for negative) because of the prevalence of free electrons. N-type doped silicon is a much better conductor than pure silicon.

Actually, only part of our solar cell is N-type. The other part is doped with boron, which has only three electrons in its outer shell instead of four, to become P-type silicon. Instead of having free electrons, P-type silicon ("p" for positive) has free holes. So-called holes are just the absence of electrons, so they carry the opposite (positive) charge. They move around just like electrons do.

The interesting part starts when N-type silicon is put together with P-type silicon. It’s important to remember that every PV cell has at least one electric field. Without an electric field, the cell wouldn't work, and this field forms when the N-type and P-type silicon are in contact. Suddenly, the free electrons in the N side, which have been looking all over for holes, see all the free holes on the P side, and there's a mad rush to fill them in.

<ins>The Anatomy of a Cell</ins>

Before now, the silicon was all electrically neutral. Extra electrons were balanced out by the extra protons in the phosphorous. The missing electrons (holes) were balanced out by the missing protons in the boron. The neutrality is disrupted when the holes and electrons mix at the junction between N-type and P-type silicon. Do all the free electrons fill all the free holes? No. If they did, then the whole arrangement wouldn't be useful. Right at the junction, however, they do mix and form a barrier, making it harder and harder for electrons on the N side to cross to the P side. Eventually, equilibrium is reached, and there is an electric field separating the two sides.

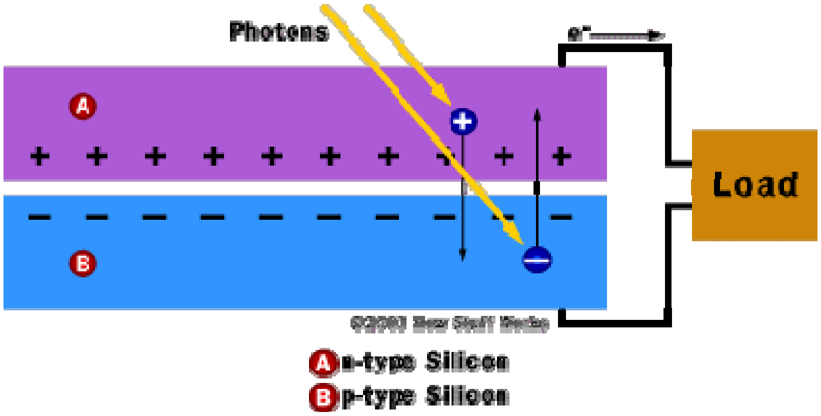


The effect of the electric field in a PV cell

This electric field acts as a diode, allowing (and even pushing) electrons to flow from the P side to the N side, but not the other way around. It's like a hill – electrons can easily go down the hill (to the N side), but can't climb it (to the P side).

Now there is an electric field acting as a diode in which electrons can only move in one direction. What happens when light hits the cell? When light, in the form of photons, hits the solar cell, its energy frees electron-hole pairs.

Each photon with enough energy will normally free exactly one electron, and result in a free hole as well. If this is close enough to the electric field, or if a free electron and free hole happen to wander into its range of influence, the field will send the electron to the N side and the hole to the P side. This further disrupts electrical neutrality. If an external current path is provided, electrons will flow through the path to their original side (the P side) to unite with holes that the electric field sent there, doing work along the way. The electron flow provides the current, and the cell's electric field causes a voltage. The product of both current and voltage is power.



Operation of a PV cell

How much sunlight energy does the PV cell absorb? Unfortunately, the most that the simple cell could absorb is around 25 percent, and more likely is 15 percent or less. An obvious question is why so little?

Visible light is only part of the electromagnetic spectrum. Electromagnetic radiation is not monochromatic – it is made up of a range of different wavelengths and, therefore, energy levels. (See How Special Relativity Works for a good discussion of the electromagnetic spectrum.)

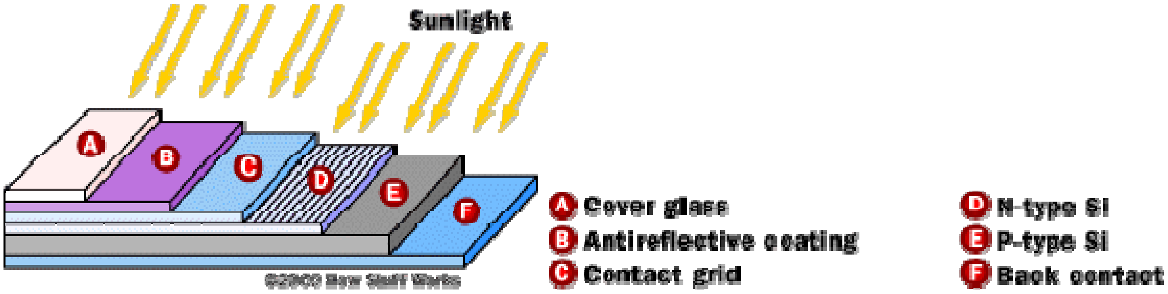
Light can be separated into different wavelengths, appearing in the form of a rainbow. Since the light that hits the cell has photons of a wide range of energies, some photons won't have enough energy to form an electron-hole pair. They'll simply pass through the cell as if it were transparent. Still other photons have too much energy. Only a certain amount of energy, measured in electron volts (eV) and defined by the cell material (about 1.1 eV for crystalline silicon), is required to knock an electron loose. This is called the band gap energy of a material. If a photon has more energy than required, the extra energy is lost. (An exception is if a photon has twice the required energy and can create more than one electron-hole pair, but this effect is not significant). These two effects alone account for the loss of around 70 percent of the radiation energy incident on the cell.

Would a material with a really low band gap work, so more of the photons can be used? Unfortunately, the band gap also determines the strength (voltage) of the electric field, and if it's too low, then what is made up in extra current (by absorbing more photons) is lost by having a small voltage. Remember that power is voltage times current. The optimal band gap balancing these two effects is around 1.4 eV for a cell made from a single material.

There are other losses as well. Electrons must flow from one side of the cell to the other through an external circuit. The bottom can be covered with a metal, allowing for good conduction. However, if the top is covered, the photons can't get through the opaque conductor and all current is lost (in some cells, transparent conductors are used on the top surface, but not in all). If the contacts are only at the sides of the cell, the electrons have to travel an extremely long distance (for an electron) to reach the contacts. Because silicon is a semiconductor, it's not nearly as good as metal for transporting current. Its internal resistance (called series resistance) is fairly high, and high resistance means high losses. To minimize these losses, the cell is covered by a metallic contact grid that shortens the distance for electrons to travel while covering only a small part of the cell surface. Even so, some photons are blocked by the grid, which can't be too small, or else its own resistance will be too high.

There are a few more steps left before the cell is usable. Like any shiny material, silicon is very reflective. Photons that are reflected can't be used by the cell. For that reason, an antireflective coating is applied to the top of the cell to reduce reflection losses to less than 5 percent.

The final step is the glass cover plate that protects the cell from the elements. PV modules are made by connecting several cells (usually 36) in series and parallel to achieve useful levels of voltage and current, and putting them in a sturdy frame complete with a glass cover and positive and negative terminals on the back.

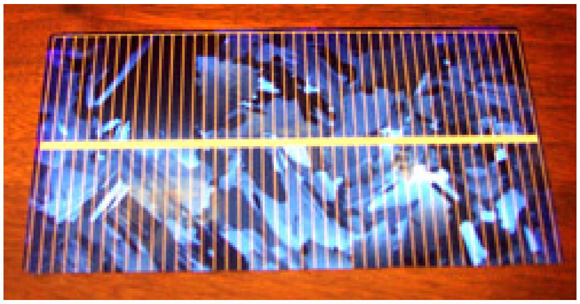


Single crystal silicon isn't the only material used in PV cells. Polycrystalline silicon is also used to cut manufacturing costs, although resulting cells aren't as efficient as single crystal silicon. Amorphous silicon, which has no crystalline structure, is also used, again in an attempt to reduce production costs. Other materials used include gallium arsenide, copper indium diselenide and cadmium telluride. Since different materials have different band gaps, they seem to be "tuned" to different wavelengths, or photons of different energies. One way to improve efficiency is to use two or more layers of different materials with different band gaps. The higher band gap material is on the surface, absorbing high-energy photons while allowing lower-energy photons to be absorbed by the lower band gap material. This technique can result in much higher efficiencies. Such cells, called multi-junction cells, can have more than one electric field.

Silicon PV

Crystalline silicon (c-Si) solar cells, such as the one pictured above, have captured 93 percent of market share. Historically, crystalline silicon has been used as the light-absorbing semiconductor in most solar cells, even though it is a relatively poor light absorber and requires a considerable thickness (several hundred microns) of material. Nevertheless, it has proved convenient because it yields stable solar cells with good efficiencies (11-16 percent, half to two-thirds of the theoretical maximum) and uses process technology developed from the huge knowledge base of the microelectronics industry.

Two types of crystalline silicon are used in the industry. The first is mono-crystalline, produced by slicing wafers (up to 150 mm diameter and 350 microns thick) from a high-purity single crystal boule.[34] The second is multi-crystalline silicon, made by sawing a cast block of silicon first into bars and then wafers. The main trend in crystalline silicon cell manufacture is toward multi-crystalline technology.



For both mono- and multi-crystalline Si, a semiconductor homo-junction is formed by diffusing phosphorus (an n-type dopant) into the top surface of the boron doped (p-type) Si wafer. Screen-printed contacts are applied to the front and rear of the cell, with the front contact pattern specially designed to allow maximum light exposure of the Si material with minimum electrical (resistive) losses in the cell.

The most efficient production cells use mono-crystalline c-Si with laser-grooved, buried-grid contacts for maximum light absorption and current collection.

Some companies are using technologies that bypass some of the inefficiencies of the crystal growth/casting and wafer-sawing route. One route is to grow a ribbon of silicon, either as a plain two-dimensional strip or as an octagonal column, by pulling it from a silicon melt.

Another is to melt silicon powder on a cheap conducting substrate. These processes may bring with them other issues of lower growth/pulling rates and poorer uniformity and surface roughness.

Each c-Si cell generates about 0.5 V, so 36 cells are usually soldered together in series to produce a module with an output to charge a 12-V battery. The cells are hermetically sealed under toughened, high transmission glass to produce highly reliable, weather resistant modules that may be warranted for up to 25 years.

Thin Film PV

The high cost of crystalline silicon wafers (they make up 40 to 50 percent of the cost of a finished module) has led the industry to look at cheaper materials to make solar cells.

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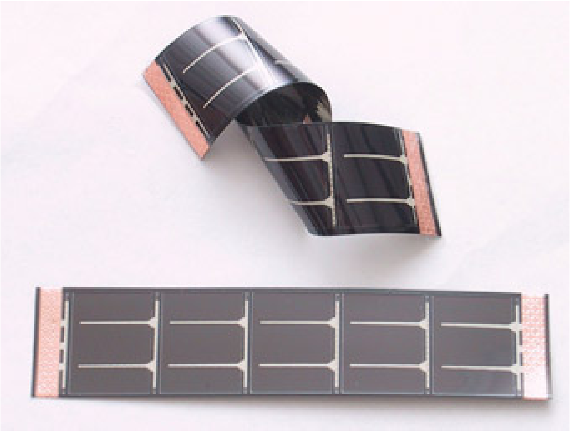
[34] Boule – in order to grow wafers, a large ingot is drawn from a molten silicon melt. The ingot is also referred to as a boule.

The selected materials are all strong light absorbers and need only be a few microns thick, significantly reducing material costs. The most common materials are amorphous silicon (a-Si, still silicon, but in a different form), or the polycrystalline materials: cadmium telluride (CdTe) and copper indium (gallium) dis-elenide (CIS or CIGS).



Each of these three is amenable to large-area deposition (onto substrates of about 1 meter dimensions) and hence high volume manufacturing. The thin-film semiconductor layers are deposited onto coated glass, stainless steel sheet or plastic (as pictured at right).

The semiconductor junctions are formed in different ways, either as a p-i-n device in amorphous silicon or as a hetero-junction (e.g. with a thin cadmium sulphide layer) for CdTe and CIS. A transparent conducting oxide layer (such as tin oxide) forms the front electrical contact of the cell, and a metal layer forms the rear contact.

Thin-film technologies are all complex. They have taken at least 20 years, supported in some cases by major corporations, to get from the stage of promising research (about 8 percent efficiency at 1cm2 scale) to the manufacture of early product.

Amorphous silicon is the most developed of the thin-film technologies. In its simplest form, the cell structure has a single sequence of p-i-n layers. Such cells suffer from significant degradation in their power output (in the range 15-to-35 percent) when exposed to the sun.

The mechanism of degradation is called the Staebler-Wronski Effect, after its discoverers. Better stability requires the use of extremely thin layers in order to increase the electric field strength across the material. However, this reduces light absorption and hence cell efficiency.

This has led the industry to develop tandem and even triple layer devices that contain p-i-n cells stacked one on top of the other. In the cell at the base of the structure, the a-Si is sometimes alloyed with germanium to reduce its band gap and further improve light absorption. All this added complexity has the downside of making the processes more complex and process yields likely to be lower.

To build up a practical and useful voltage from thin- film cells, manufacturers usually include a laser scribing sequence that enables the front and back of adjacent cells to be directly interconnected in series, with no need for further solder connection between cells.

As described before, thin film-cells are laminated to produce a weather resistant and environmentally robust module. Although they are less efficient (production modules range from 5 to 8 percent), thin films are potentially cheaper than c-Si because of their lower materials costs and larger substrate size.

However, some thin film materials have shown performance degradation over time, and stabilized efficiencies can be 15 to 35 percent lower than initial values. Many thin film technologies have demonstrated better cell efficiencies at research scale above 13 percent, and better prototype module efficiencies above 10 percent. In the long run, the most successful technology in achieving low manufacturing costs is likely to be the one that can deliver the highest stable efficiencies (probably at least 10 percent) with the highest process yields.

Amorphous silicon is the most well-developed thin film technology to date and has an interesting avenue of further development through the use of "microcrystalline" silicon, which seeks to combine the stable high efficiencies of crystalline Si technology with the simpler and cheaper large-area deposition technology of amorphous silicon.

However, conventional c-Si manufacturing technology has continued its steady improvement year by year, and its production costs are still falling.

The emerging thin-film technologies have yet to make significant in-roads into the dominant position held by the relatively mature c-Si technology. However, they do hold a niche position in low-power (<50 W) and consumer electronics applications and may offer particular design options for building integrated applications.

Developing Technologies:

Concentrators: Solar cells usually operate more efficiently under concentrated light. This has led to a range of approaches using mirrors or lenses to focus light onto specially designed cells and the use of heat sinks, or active cooling of the cells, to dissipate the large amount of heat that is generated. Unlike conventional flat-plate PV arrays, concentrator systems require direct sunlight (clear skies) and will not operate under cloudy conditions. They generally follow the sun's path through the sky during the day using single-axis tracking. Two-axis tracking is sometimes used to adjust to the sun's varying height in the sky through the seasons.

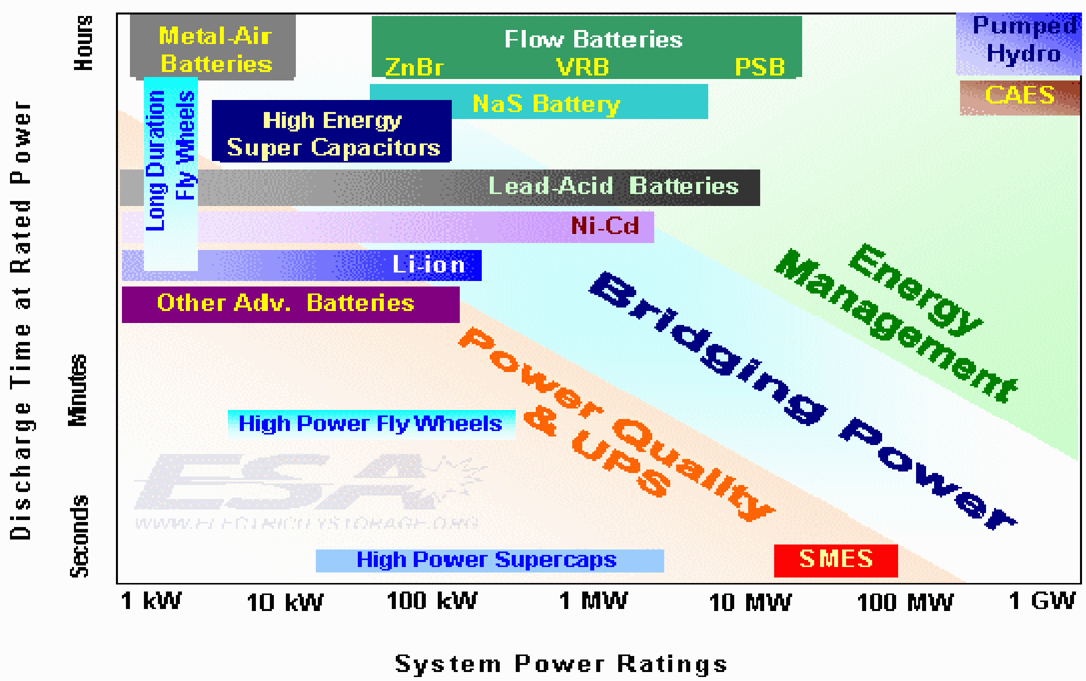
Concentrators have not yet achieved widespread application in photovoltaics, but solar concentration has been used widely in solar thermal electricity generation technology where the generated heat is used to power a turbine.

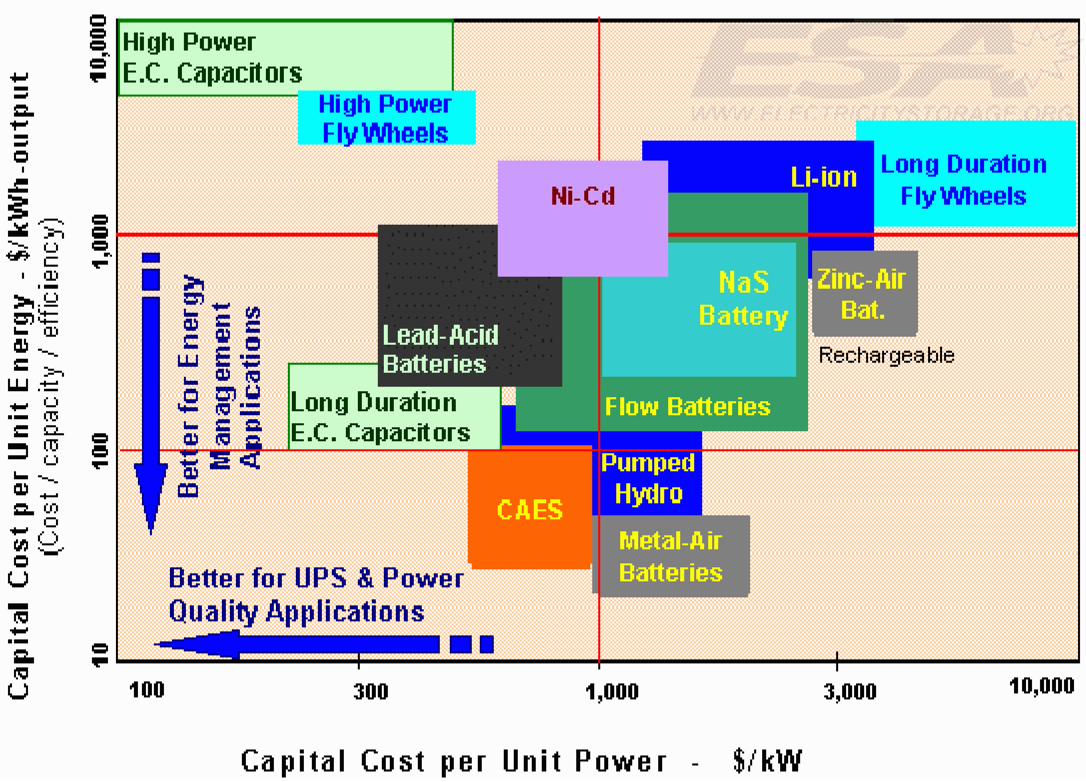
Electrochemical PV Cells: Unlike the crystalline and thin-film solar cells that have solid-state light absorbing layers, electrochemical solar cells have their active component in a liquid phase. They use a dye sensitizer to absorb the light and create electron-hole pairs in a nanocrystalline titanium dioxide semiconductor layer. This is sandwiched between a tin oxide-coated glass sheet (the front contact of the cell) and a rear carbon-contact layer, with a glass or foil backing sheet.

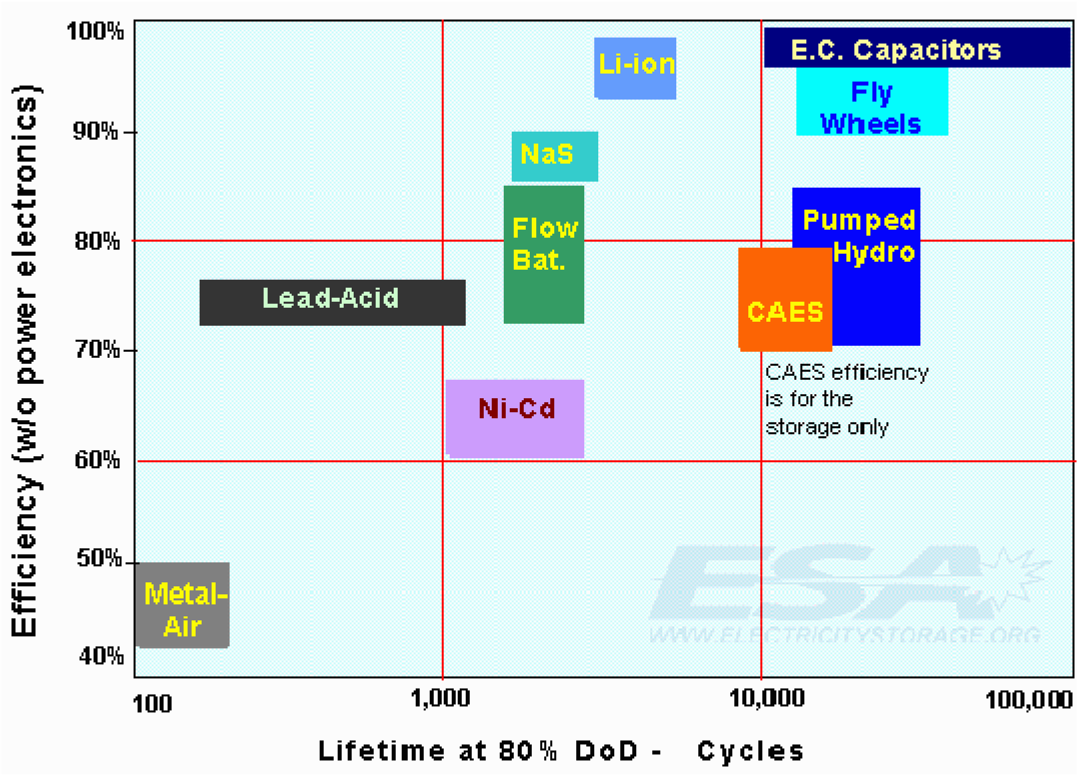
There is speculation that these cells will offer lower manufacturing costs in the future because of their simplicity and use of cheap materials. The challenges of scaling up manufacturing and demonstrating reliable field operation of products lie ahead. However, prototypes of small devices powered by dye-sensitized nanocrystalline electrochemical PV cells are now appearing (120cm2 cells with an efficiency of 7 percent).

Appendix C Performance Characteristics of Storage Devices

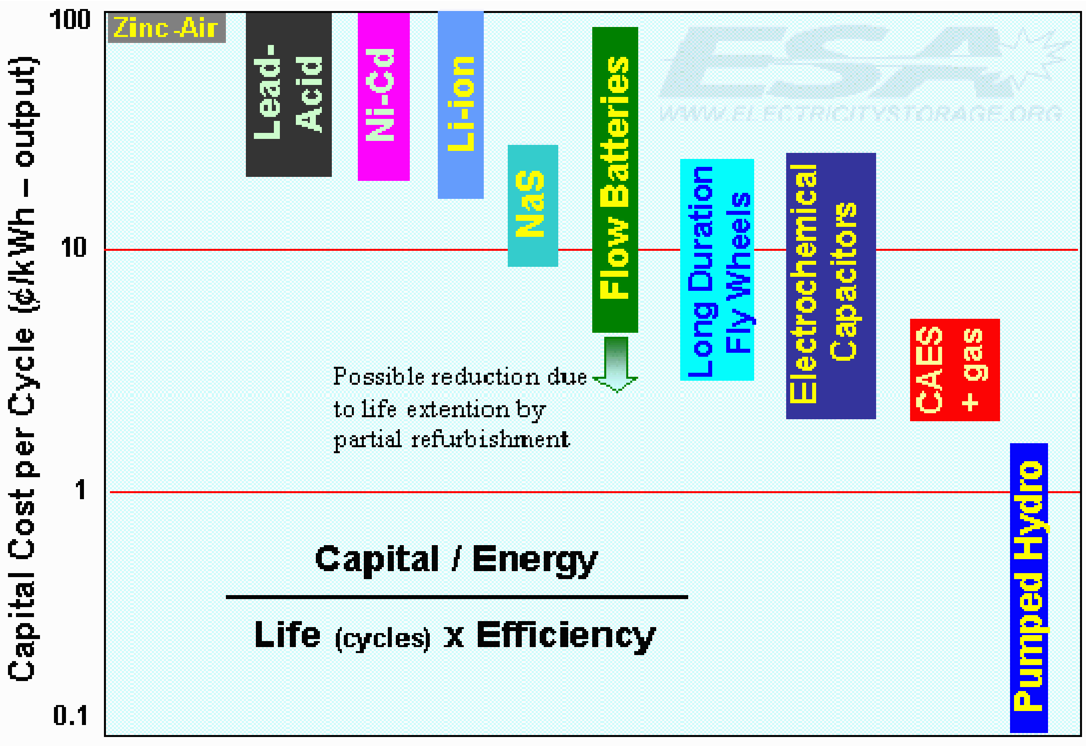
A Performance Comparison of Different Storage Technologies (from Electricity Storage Association)







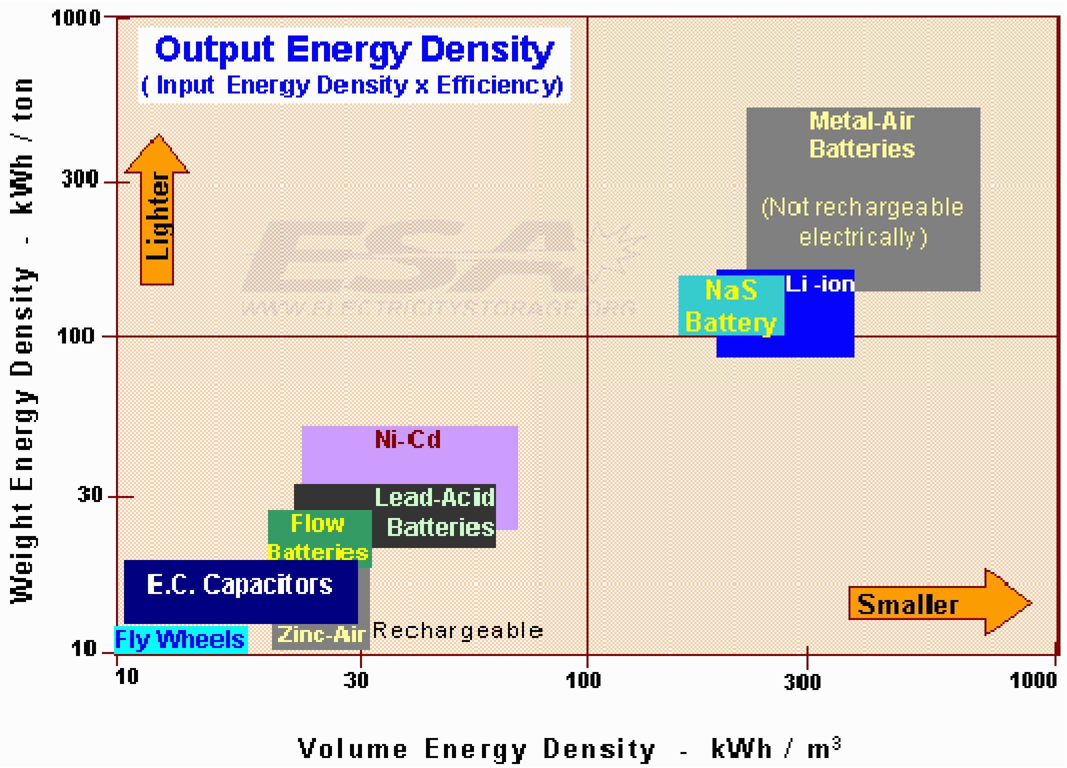
CAES efficiency is for the storage only



Possible reduction due to life extention by partial refurbishment

$$\frac{\textbf{Capital / Energy}}{\textbf{Life}\ (\text{cycles})\ \textbf{x Efficiency}}$$

Carrying charges, O&M and replacement costs are not included


Output Energy Density
(Input Energy Density x Efficiency)
Lighter
Smaller
Metal-Air Batteries
(Not rechargeable electrically)
NaS Battery
Li -ion
Ni-Cd
Lead-Acid Batteries
Flow Batteries
E.C. Capacitors
Fly Wheels
Zinc-Air Rechargeable
WWW.ELECTRICITYSTORAGE.ORG
1000
300
100
30
10
10
30
100
300
1000
Weight Energy Density - kWh / ton
Volume Energy Density - kWh / m3

Appendix D Business Drivers Targets & Agency Strategic Objectives

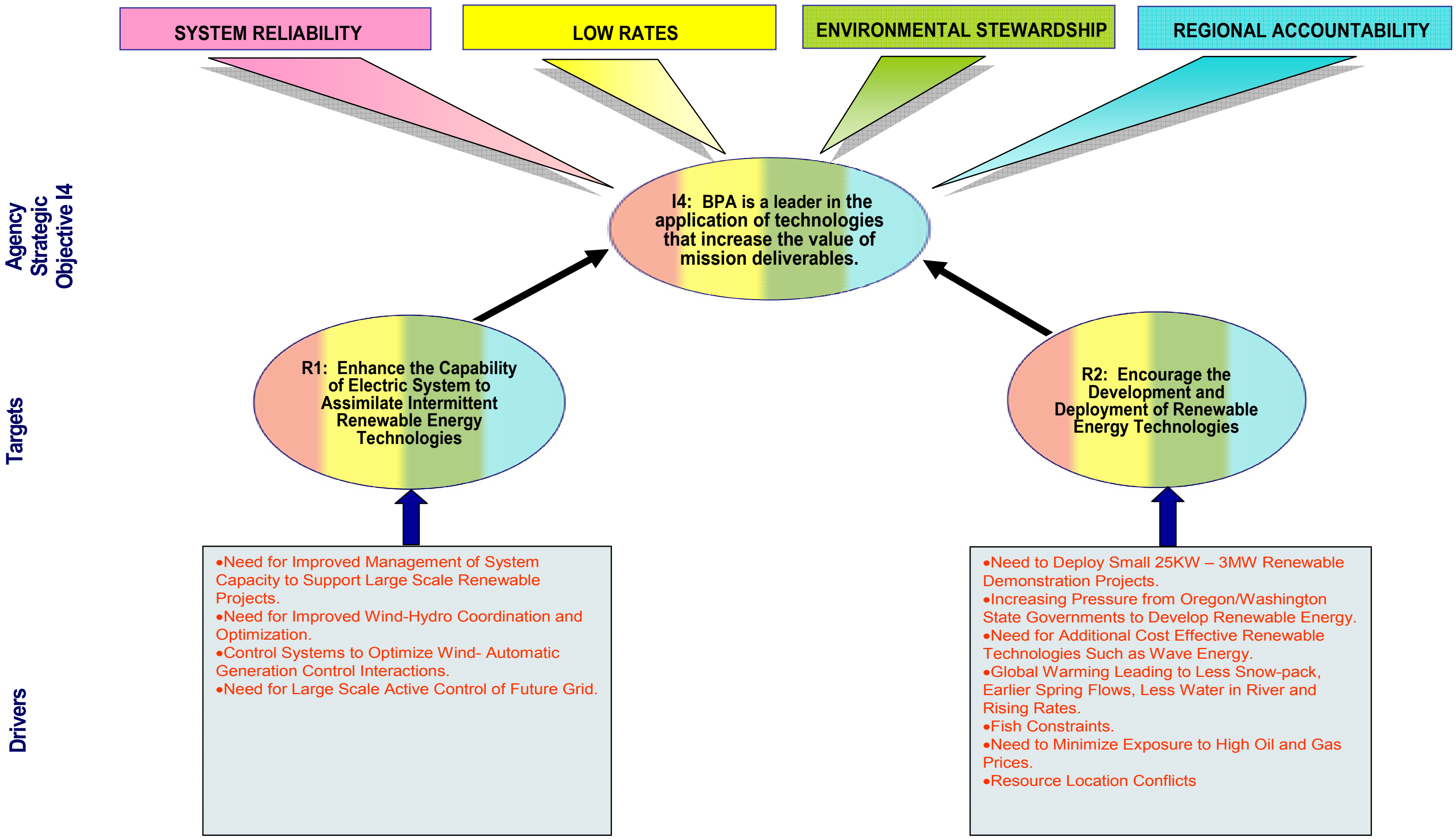
DRAFT

Technology Confirmation and Innovation

RENEWABLE ROADMAP

DRIVERS → TARGETS → OBJECTIVE

DRAFT



SYSTEM RELIABILITY

LOW RATES

ENVIRONMENTAL STEWARDSHIP

REGIONAL ACCOUNTABILITY

Agency Strategic Objective I4

I4: BPA is a leader in the application of technologies that increase the value of mission deliverables.

Targets

R1: Enhance the Capability of Electric System to Assimilate Intermittent Renewable Energy Technologies

R2: Encourage the Development and Deployment of Renewable Energy Technologies

Drivers

- Need for Improved Management of System Capacity to Support Large Scale Renewable Projects.
- Need for Improved Wind-Hydro Coordination and Optimization.
- Control Systems to Optimize Wind- Automatic Generation Control Interactions.
- Need for Large Scale Active Control of Future Grid.

- Need to Deploy Small 25KW – 3MW Renewable Demonstration Projects.
- Increasing Pressure from Oregon/Washington State Governments to Develop Renewable Energy.
- Need for Additional Cost Effective Renewable Technologies Such as Wave Energy.
- Global Warming Leading to Less Snow-pack, Earlier Spring Flows, Less Water in River and Rising Rates.
- Fish Constraints.
- Need to Minimize Exposure to High Oil and Gas Prices.
- Resource Location Conflicts

Appendix E Technological Challenges Identified in 2nd Workshop

	1) Control & Communications to End Users[35]	***2) Distribution Voltage (~12.5 kv) Load shape mngmt with Renewables***	***3) On-Site Renewable Energy Storage***	***4) Large Storage***	***5) Resource Adequacy Forecasting in an Increasingly Intermittent Resource Mix***
Identify key product features that respond to one or more BPA Business drivers:	(7) Benefit to billing, metering and rate design. (7) Assists development and identification of distributed resources and opportunities. (7) Community supports large scale renewable integration.	(16) Potential to accommodate large amounts of intermittent resources with limited grid impact. (5) Improve asset management of FCRPS	(11) TOU Rates (big day/night spread) support ES for peaking. (6) Deployable to meet utility needs.	(7) Leverage existing assets (5) Improve system performance with less snow-pack and more rain (4) Improve water available for fish	(8) Enables BPA to appropriately integrate renewables into the energy mix (7) Need to minimize exposure to high oil and gas prices (5) Integrating intermittent resources bring new costs and risks to BPA revenue requirements
Essential Challenges:	(5) Security - Cyber; Control Feedback (5) Technological standards may be an issue, if so it requires correction before if becomes a barrier. (3) Software Development; integration into AGC; Control systems, (software development; What to read? What to send? (3) Standard communication protocols	(8) Regional locations specific load profiles and distribution/generation profiles (6) Cost (4) Estimation of long term impacts	(8) On site need to prove economic case (5) Integration with other DSM (4) Control/ communication system to know how much there is and where	(7) Cost. (3) Match system need with existing storage technology. (3) Existing technology is site specific (CAES & pump storage) (3) Determine best storage medium (e.g. salt, oil, etc.) (3) Integration of many medium-sized units	(7) Need to model resource stack of intermittent renewables to get gaps that must be filled (6) Find out how much regulation is needed per 'X' MW of new resource (5) Identifying the mix of renewables that can best cover the northwest demand for power (4) Resource sharing regionally

Table continued on next page…..

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[35] Number denotes relative rank or importance of this item - members voted their preferences by placing “hot-dots” next to list of all ideas proposed – those ideas with 3 or more votes are listed above.

Appendix E Technological Challenges Identified in 2nd Workshop

	1) Control & Communications to End Users [35]	***2) Distribution Voltage (~12.5 kv) Load shape mngmt with Renewables***	***3) On-Site Renewable Energy Storage***	***4) Large Storage***	***5) Resource Adequacy Forecasting in an Increasingly Intermittent Resource Mix***
Gaps in Technology:	(7) Cheap accurate sensors (6) Wireless cloud(wifi or wimax) to cut cost; expand utility & end use of low cost sensors (5) Routers w/multi in/out communication to support smart appliances. DR & DC (4) Standards for equipment performance (4) Identification of parameters; hardware/software	(10) End user data collection and resource assessments (7) Storage and Dispatch (5) ID system needs	(9) Modeling of system: use value (rates) minimum size and maximum use (7) Onsite cycle life limited for batteries	(5) High power PCS >>100 MWh (3) Field demonstration	(7)* Good resource assessment data (wind, wave, solar, geothermal) (6) Create resource standards that address intermittency
RD&D Implications:	(8) Small scale demonstrations of promising technologies (hardware/software (7) Tie end user load to intermittent resources	(7) Standard for use of sensors and database/comm. to delay meter change need (smart meter-labor $/or DR/gauge) (7) Regional modeling of load and distr./gen profiles (5) Test local use rates to flatten loads. - How? (5) More Ashland/ Milton-Freewater demos (5) Use load shape mgmt to reduce 'tails' on intermittent resources	(7) Can distributed ES units (GML controlled) be aggregated to large scale? (6) Need demo to prove reliability and benefits	(9) Need demo to prove reliability and benefits (4) RD&D interaction with system sizing	(7) How to decide what resource to use (cost, stability, location, scalability) (6) Build in data collection and forecasting for all new projects (4) How do we mitigate risk from intermittent resources? (4) What renewables (such as biomass) can offset intermittent generation (such as wind)?

Appendix F Internal Renewable Energy Brainstorming 1st Workshop Attendee List
Jume 23. 2006

Name	Phone #	BPA Organization
Tom Osborn	509-527-6211	PNJD-WALLA WALLA
Lori Blasdel	503-230-7448	PTS-5
Shannon Stewart	503-230-5928	KEC-4
Steve Enyeart	360-619-6059	TOC-TPP-4
Kelly Mason	503-230-4735	KEC-4
Jamie Murphy	360-418-2413	TOT-DITT2
Mark Johnson	503-230-7669	PNJC-1
Sheila Riewer	503-230-5473	PTS-5
John Pease	503-230-3299	PTS-5
Al Ingram	503-230-4062	PFR-6
Mike Hoffman	503-230-3957	PNI-1
Deb Malin	503-230-5701	PT-5
Elliot Mainzer	360-418-8995	TO-DITT2
Cain Bloomer	503-230-4755	DE-7
Terry Oliver	503-230-5853	DE-7
Dennis Phillips	503-230-5062	DE-7

Appendix G Renewable Brainstorming 2nd Workshop Attendee List
Friday, June 23, 2006

Name	Organization	Phone	Email	Title/Area
Elaine SisonLebilla	CEC	(916) 653-0363	esisonle@energy.state.ca.us	Manager Energy Generation Research Office
Kay Moxness	CLPUD	(541)-574-2004		NA
Tony Schacher	CLPUD	"	NA	NA
Dave Hawkins	*CaISO* *Could not attend*	*(916) 351-4465*	*dhawkins@caiso.com*	*Manager Special Projects Engineering*
Mike Nelson	Washington State University	(360) 956-2148	mike.nelson@northwestsolarcenter.org	Northwest Solar Center
Brian Ward	*City of Palo Alto Utilities* *Could not attend*	*(650) 329-2161*	*PaloAltoGreen@cityofpaloalto.org*	*Renewable Energy Program*
Peter Moulton	Climate Solutions	(360) 352-1763	peter@climatesolutions.org	Harvesting Clean Energy/Biomass
Justin Klure	Oregon Department of energy	(503) 373-1581	Justin.klure@state.or.us	Senior Policy Analyst
Kevin Bannister	PNGC Power	(503)-288-1234	Kevin.bannister@PNGC.com	Renewables
Gordon Bloomquist	Washington State University	(360) 956-2016	bloomquistr@energy.wsu.edu	Geothermal Science
Frank Vignola	University of Oregon	(541) 346-4745	fev@uoregon.edu	Solar Radiation
SMUD (left message)	*Could not attend*			

Appendix G (continued) Renewable Brainstorming 2nd Workshop Attendee List

Name	Organization	Phone	Email	Title/Area
John Boyes (left message)	Sandia Could not attend		jdboyes@sandia.gov	Energy storage Applications for renewables
Stanley Bull (left message)	*NREL* *Could not attend*	*(303) 275-3016*	*http://www.nrel.gov/research_organization/biography.html*	*Director of Research*
Bart McManus	BPA-TBL	(360)-418-2309	bamcmanus	Transmission/Wind Integration
John Pease	BPA-PBL	(503-230-3299	jhpease@bpa.gov	Renewables
Lori Blasdel	BPA-PBL	(503) 230-7448	ljblasdel@bpa.gov	Renewables
Kelly Mason	BPA-PBL	(503) 230-4735	kjmason@bpa.gov	Environment
Sheila Riewer	BPA-PBL	(503)-230-5473	smriewer	Renewables
Al Ingram	BPA-PBL	(503)-230-4062	alingram@bpa.gov	Renewables/Rates
Mike Hoffman	BPA-EE	(503)-230-3957	mghoffman@bpa.gov	Renewables & Energy Efficiency
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