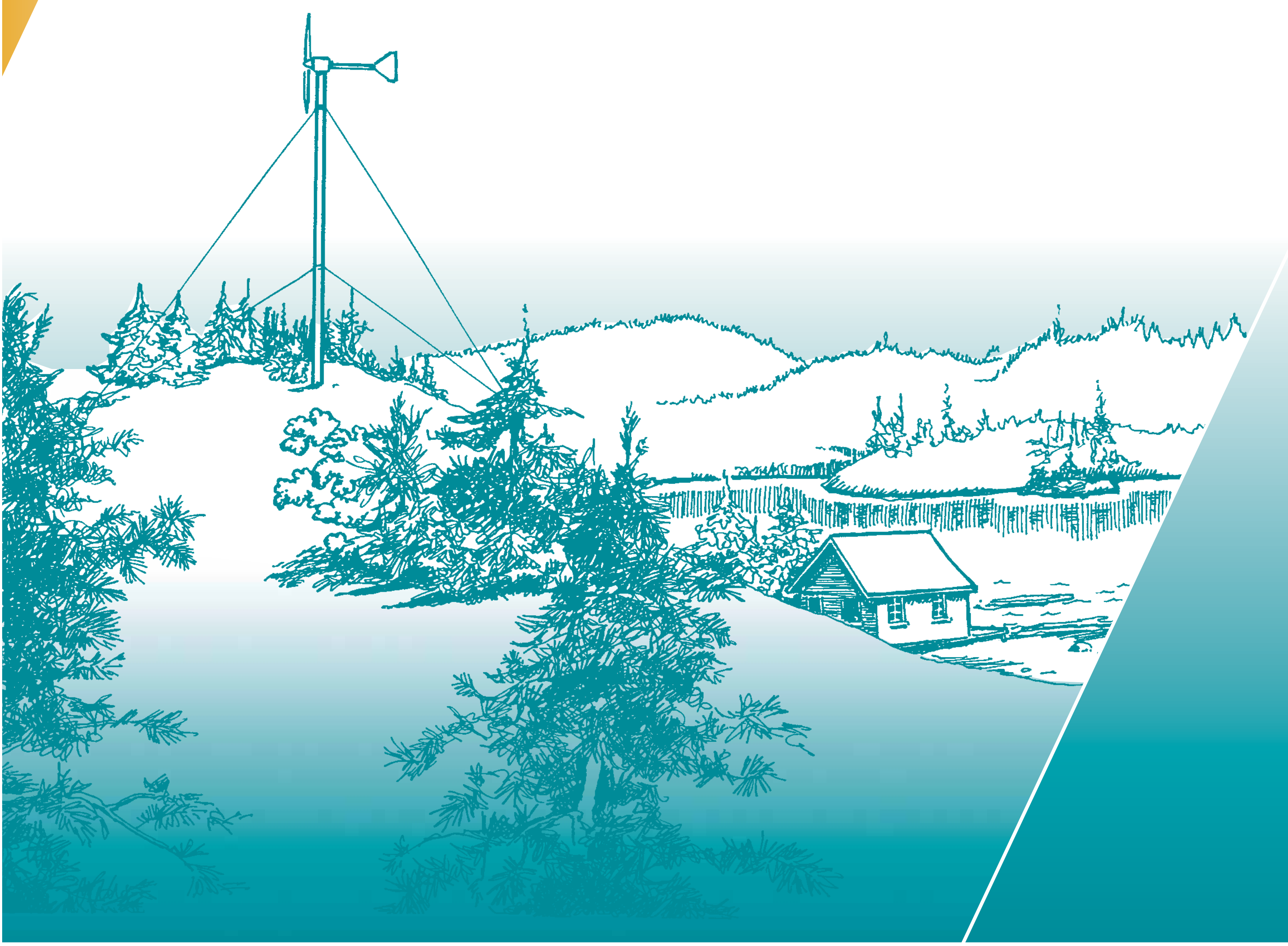
Stand-Alone Wind Energy systems

A Buyer's Guide



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Electricity Resources Branch
Renewable and Electrical Energy Division
Natural Resources Canada
580 Booth Street 11th Floor
Ottawa, ON K1A 0E4

Toll-free: 1 877 722-6600

E-mail: redi.penser@nrcan.gc.ca
Internet: www.nrcan.gc.ca/redi

Stand-Alone Wind Energy Systems: A Buyer's Guide

Text prepared by Marbek Resource Consultants and SGA Consulting for the Renewable and Electrical Energy Division, Energy Resources Branch of Natural Resources Canada (NRCan). The text builds upon an earlier version by Mr. Marc Chappell of MSC Enterprises and Mr. Raj Rangi of the CANMET Energy Technology Centre.

Important Note

The aim of this publication is to provide guidance to readers who wish to assess the benefits and risks of buying and installing a small-scale wind energy system. Because the subject is complex, and the decision to purchase or install a system depends on many variables, this guide alone does not provide sufficient information to evaluate fully all the aspects of a potential system. The guide is also not intended to serve as a "how to" manual for the installation, operation and maintenance of a system. In all cases, qualified advice and assistance to supplement the information provided here should be sought.

Prospective buyers should consult local utility and government agencies to ensure that proposed installations will meet all relevant electrical codes, building and site regulations.

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About this Guide

This buyer's guide to stand-alone wind energy systems will help you decide if wind energy is a viable option for you. The guide will:

- give you some very basic theory on how wind energy works
- give you pointers to determine how much power you need
- help you do a rough assessment of whether wind energy will fill those power needs
- introduce you to some of the components of a wind energy system
- outline how to determine if wind energy makes economic sense for your circumstances
- give you some practical examples of wind energy systems

This guide is not intended to be a "how-to" install a wind energy system. Nor does it provide you with enough information to fully evaluate whether wind energy is right for your circumstances. These systems are complicated, and require some expertise to set up and maintain properly. A qualified person will be required to determine the feasibility of the system, its design and its set up.

Before you make any buying decision, consult your local utility and government agencies to ensure that your proposed installation meets the required electrical codes, building regulations and site regulations.

1. The Power and Potential of the Wind

- **A very old power source is one of the power resources of the future**
- **How much energy is in the wind and how to get it out**

Wind is a very complex process which can be described very simply.

The sun heats the earth at different rates depending on whether an area is below clouds, in direct sunlight, or covered with water. The air above the warmer areas heats up, becomes less dense, and rises. The rising air creates a low pressure area. Cooler air from adjacent higher pressure areas moves to the low pressure areas. This air movement is wind.

People have been capturing the energy contained in the wind's movement for hundreds of years. Dutch-style windmills were first used in the 12th Century, and by the 1700s, had become a major source of power in Europe. In North America, farmers adopted windmill technology to pump water about a hundred years ago.

Today, the turning rotors of a wind energy system can still be used to run pumps, and to run a generator to generate electricity.

The wind is a renewable energy source, continuously generated or replenished by the forces of nature. Renewable energy technologies, such as wind energy systems and solar photovoltaic (PV) systems, which use sunlight, convert renewable resources into usable forms of energy that can complement or replace conventional energy sources.

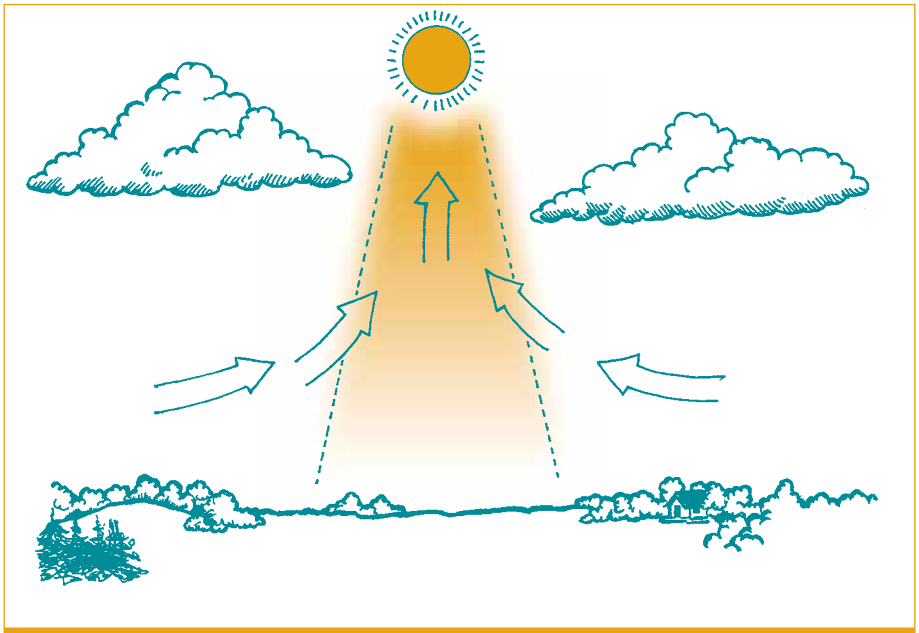

Figure 1. Wind is caused by movement of air.

Canada is a large country with a huge wind energy potential. Tapping into this potential will help decrease the amount of greenhouse gases emitted by conventional sources of energy.

Modern large wind energy installations are popping up across the Canadian landscape. These "wind farms" use an array of wind turbines, each generating around 600 kilowatts, and are hooked to the main electrical grid. While this is a promising technology, it would still take 1,500 of these large turbines to match the output of one CANDU reactor. On the other hand, if replacing an oil or coal generator, just one of these turbines could eliminate over 1,000 tonnes of carbon emissions per year.

This guide is aimed at those who are considering a wind energy system to supply energy to their homes, farms, cottages or businesses. In most cases, such small systems have capacities in the 100 watt to 25 kilowatt range.

At the low end of this scale, enough electricity is generated to run a few lights, a communications radio or entertainment equipment. At the higher end, many of the electrical needs of farm operations or institutional buildings could be met. Somewhat larger systems could also supplement municipal needs and supply power to remote communities.

While the tested technology of direct mechanical work, such as pumping water, will be touched upon in this guide, we will focus on electrical generation.

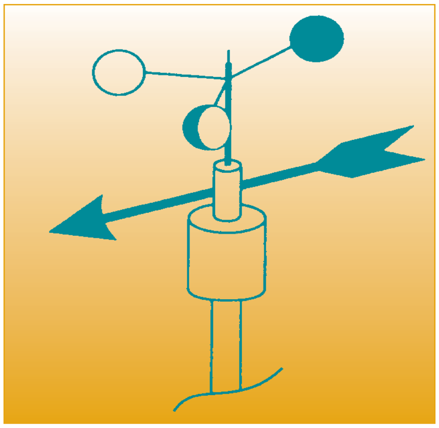

Figure 2. An anemometer.

Measuring Wind Speed

Wind speed is measured by an instrument called an *anemometer* (Figure 2) which turns faster as the wind blows harder on it. A data logger can be used to record instantaneous observations of wind speed, or to store a long term record for later analysis. A wind vane indicates the direction of the wind.

Wind speed is generally reported in kilometres per hour (km/h) or in metres per second (m/s): 1 m/s = 3.6 km/h. Direction is indicated in degrees azimuth or compass points.

How much energy is in the wind?

One of the first steps in determining if a wind energy system is feasible is finding out how much wind energy is available.

To do this, wind speeds are measured over a period of time, making note of the amount of time the wind blows at various speeds. From this, an average annual wind speed is calculated. A wind energy system usually needs an average annual wind speed of at least 15 km/h to be practical.

It is also important to know the variation in wind speed.

As it turns out, the wind is almost never calm, and rarely exceeds twice the annual average speed, and then only briefly. If you call in an expert to assess the amount of wind energy at your site, one assessment tool will be in the form of a wind speed distribution curve. This is just a chart of the number of hours the wind blows at various speeds. The Rayleigh curve represents a typical distribution (Figure 3). The wind blows most often at the speed corresponding to the highest point on the curve. In the Rayleigh distribution, the most frequent wind speed is about 75 percent of the average annual wind speed.

Features on the ground will impact the speed of the wind. Hills, ridges and valleys can block the wind or create undesirable turbulence for a wind energy system. Air movement is also slowed by friction close to the ground. As you move higher, wind speed increases. For most open spaces, wind speed increases 12 percent each time the height is doubled.

Locating a wind energy system on a hill, and on a tower will increase the amount of wind energy available.

A small increase in wind speed leads to a large increase in the amount of energy available (because volumes of air are being moved, the energy available in the wind is proportional to the cube of the wind speed).

Harnessing the Wind's Energy

A wind energy system is simply a method of extracting the energy from the wind and converting it into useful energy. This conversion can be to mechanical energy, where

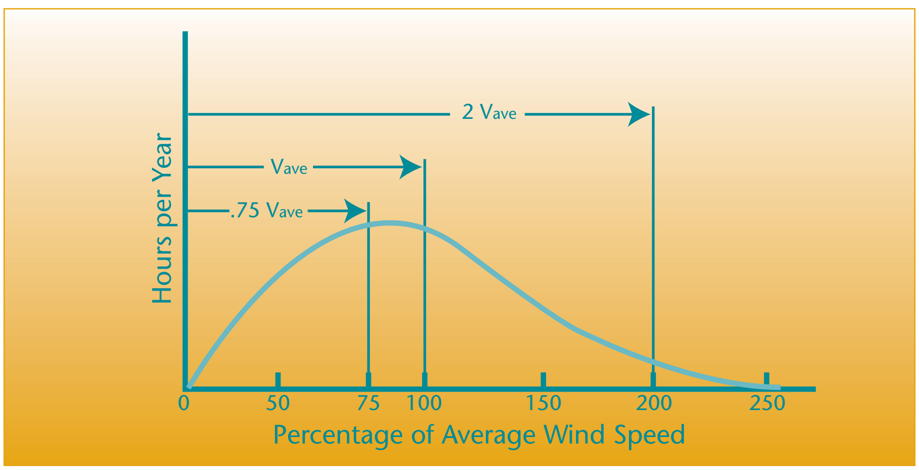

Figure 3. Annual Average Wind Speed (V_{ave})
The high point of the curve is the speed at which the wind blows most often. Such a graph is called a wind speed distribution curve – the one shown above is the Rayleigh distribution.

the wind turns a rotor which drives a mechanical device such as a gear or lever system running a water pump. The conversion can also be to electrical energy, where the rotor runs a generator.

A basic wind energy system consists of a turbine (a propeller-like rotor, a gear box and a generator), a tower, and a Balance of System (BOS) package. Components of a BOS package vary, and will be discussed further in Chapter 3.

You cannot rely on the wind, so some applications will require a battery system to store electricity, while some will be supplemented with a diesel, gas or propane powered generator which operates when the wind is not blowing.

Typically, wind speeds greater than 15 km/h are needed before a wind energy system can begin to generate electricity. This is known as the "cut-in" speed.

The "cut-out" speed, usually around 70 km/h, is where the system stalls to protect itself from damage.

The precise amount of energy that can be extracted from the wind depends on many factors, which are reflected in standard formulae. The formulae are complicated and depend on such factors as the variability and distribution of wind speed, the height of the rotor and the density of the air.

The diameter of the area swept by the rotor is also important (see box below and Figure 4).

Wind Speed Conversions

Wind speeds are often measured in metres per second but, for simplicity, we will refer to wind speeds in kilometres per hour.

m/s	km/h
4	14.4
6	21.6
8	28.8
10	36.0
12	43.2
14	50.4
16	57.6

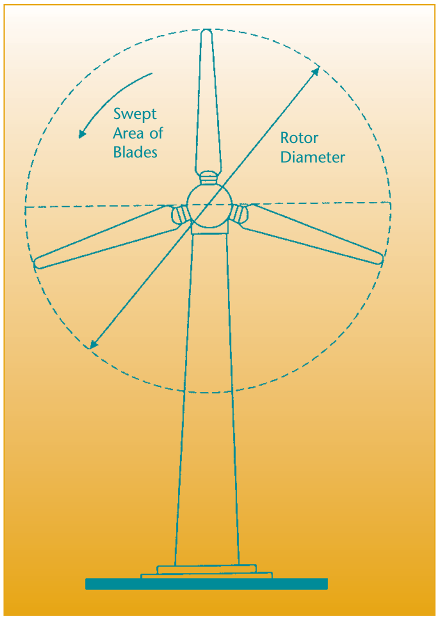

Figure 4. The "Swept Area" is the area through which the rotor blades travel.

About Wind Energy Theory

Energy production from the wind depends on several key factors:

The diameter of the area swept by the rotor blades (known as the "swept area"). The rotor blades of a wind turbine sweep through a circular area. Because we are dealing with circular area, increasing the rotor diameter, greatly increases power output. For example, doubling the rotor diameter quadruples power output.

The speed of wind. To start with, the length of time the wind is blowing above the cut-in speed is a critical factor. It is also important to remember that small increases in wind speed lead to large increases in available power. A 10 percent increase in wind speed can cause an increase in power of about 30 percent.

The variability of wind speed over time at the site. The total energy produced by a wind energy system over a period of time depends on the distribution and variability of wind speeds over time. Not surprisingly, the annual average wind speed at a site is more important than the speed at any given moment.

The density of the air. Wind power is directly related to air density, which increases as the temperature drops (warm air rises). About 16 percent more energy could be available at minus 20°C than at plus 20°C.

The Betz Limit

When energy is extracted from the wind, its speed decreases. In theory, if you took all the energy out of the wind, the wind would stop completely! In reality, however, you cannot remove all the energy from the wind. The most energy that an ideal wind energy system can extract is approximately 59 percent. This value is known as the Betz limit.

2. Different Types of Wind Energy Systems

- **You need different types of systems to fill different needs**
- **Systems range from very small to grid-connected**

This guide deals mainly with non grid-connected systems. That is, the wind energy system does not connect to the main electrical grid (such as a municipal electrical system). Changes in the way electrical utilities operate, however, are leading to some innovations which we will touch on briefly at the end of this section.

Terminology Issues

Wind energy systems that generate electricity are often referred to as *wind turbine generators* (WTGs). For the purposes of this guide, all systems that recover and convert wind energy will be referred to as *wind energy systems.*

Non Grid-Connected Systems

Small, non grid-connected systems can be stand-alone systems, which provide power solely from the wind, or hybrid systems, which use a combination of wind and another source of energy when the wind is insufficient to meet demand.

Stand-alone systems can generate electrical or mechanical energy and often have a method for storing energy when wind conditions are not good. A generator driven by a wind energy system can produce electricity which can be stored in batteries. Batteries are not necessary if the owner is willing to live with an uncertain supply.

Mechanical systems are relatively simple. They can be used to aerate ponds, pump water for livestock, irrigation or drainage, and to supply water to remote households, farms and small communities. You can think of a water tank as storage in a mechanical system. More than a million mechanical systems are said to be in use today, mostly on farms.

Hybrid systems are used in locations where the wind may fluctuate or where users might not want to be totally dependent on the wind. Hybrid systems can include solar energy or diesel generation. These systems can provide a reliable supply of energy regardless of wind conditions, but can also be costly and complex.

Hybrid Systems for Remote Communities

Many remote communities depend on diesel generators to provide electricity. If the site has good winds, a wind turbine can also be installed to help supply electricity for light industry, water treatment, municipal services, and other applications. Whenever the wind speed is within the turbine's operating range, the wind-generated electricity flows to the users and the diesel generator has to supply less, reducing the consumption of expensive fuel.

Wind-diesel hybrid systems are operating in several remote Canadian communities, including Kuujjuaq (Quebec), Fort Severn (Ontario) and Cambridge Bay and Igloolik (NWT).

Hybrid systems are especially useful where an existing energy technology, such as a generator, is already in use and fuel is expensive. A hybrid system may also be an option if the cost of storage (i.e. batteries) is high due to large loads.

Wind energy systems all have a power rating known as the rated output. This is the maximum power output of the system in a strong wind under ideal conditions.

For purposes of this guide, we will group systems into the following categories:

Micro Systems: 100 watts or less

They are useful for:

- portable systems for lighting and communications radios at hunting and fishing camps
- small appliances on yachts, recreational vehicles, in cabins and cottages
- electric fences
- remote area lighting
- emergency lighting
- trickle charging
- pond aeration
- navigational beacons and lights
- communications systems
- educational programs and displays

Mini Systems: 100 watts to 10 kilowatts

They are useful for

- small gas or diesel generator set back-up
- pumping water for cattle or for irrigation
- cottage and domestic water pumping
- navigational aids

Students of Assiniboine College in Manitoba install an 850 watt turbine. (Photo courtesy of Nor'wester Energy Systems Ltd.)

- telecommunications systems
- area and emergency lighting
- refrigeration and ice making for retaining quality of fish at remote locations
- water and waste treatment
- waste water pumping
- trash rack cleaners (in irrigation systems)
- cathodic protection
- alarm systems

Small Systems: 10 kilowatts to 50 kilowatts

These are large enough to supply the electrical needs of a farm or business, and could serve as an energy supply for remote communities or camps.

Grid-Connected Systems

Canada is entering an era of change with the way in which its utilities are regulated and how they obtain or purchase electrical power from others. New regulations will make electricity more of a tradable commodity. Power markets are now opening up to private suppliers. This means that wind energy will have the opportunity to compete with conventional carbon-emitting fossil fuel and expensive nuclear alternatives. Utilities in various provinces, for example Alberta and Ontario, are already moving in this direction.

Another force at work is concern for the environment. Climate change and Canadian international commitments to reduce greenhouse gas emissions have brought attention to the carbon emissions from fossil fuel generation. Future attempts to reduce these emissions may encourage the use of "green" or non-polluting electricity. Natural Resources Canada and Environment Canada are setting an example by purchasing green power for their facilities in Alberta.

Large wind turbines that feed electricity directly into the utility grid are commercially available in sizes ranging from 300 kilowatts (kW) to 1.5 megawatt (MW). These turbines are typically installed in arrays known as wind farms, although installations of single large turbines are not uncommon. Wind farms usually become economically viable only at the megawatt scale.

Standards

The Canadian Standards Association (CSA) Standard CSA-F418-M91 *Wind energy systems – Interconnection to the Electric Utility* deals with these issues, as well as related topics such as requirements for installation and operating specifications.

It is also technically possible to connect small-scale systems to a utility grid. This allows for "net billing". In most cases, however, it is uneconomical to do so. Certain local or provincial utilities, Hydro One for example, are now working to make grid-connection more attractive to owners of smaller systems.

A utility's key requirements for grid-connected wind energy systems are *safety* and the *quality* of the power. The utility will require that the system meets certain standards and that it poses no risk to their personnel or equipment. Quality defines the need for the electricity generated by the wind energy system to match the characteristics of the grid electricity. This will avoid damage to sensitive electronic equipment. For small grid-connected wind energy systems, power quality problems are rarely a cause for real concern. Other issues to consider are of a legal and contractual nature, and require specialized attention.

As each utility has a different policy for grid connections, those interested should contact the customer relations or business office at the local utility for further information.

Profile of a 25 kW Wenvor-Vergnet wind turbine.
(Photo courtesy of Wenvor Technologies Inc.)

- **The components you need depend on the job you are doing**
- **Help in reading technical specifications**

Wind Turbines

The wind turbine rotor is one of the most visible parts of a wind energy system, but there's more to the turbine than just the rotor.

The most familiar turbine is the horizontal axis wind turbine, known as a HAWT. The main propeller-like rotor has an axis that is parallel to the ground, and therefore horizontal to the wind. A vertical axis wind turbine, VAWT, has an axis perpendicular to the flow of the wind.

HAWTs are most common in small applications, and can be placed on a tower which does not require a large area. If servicing has to be done to a HAWT, however, the tower either has to come down, or the service technician has to go up.

The generating equipment in a VAWT is at ground level, but VAWTs require a lot more space to be cleared for guy wires.

Because any wind turbine may be exposed to high winds, rain, snow, sun, ice, and even salty air, its parts should be made of tough, durable and corrosion-resistant materials. A well-built and well-maintained turbine should have a life expectancy of 20 years or more.

Turbines consist of several sub-components (Figure 5):

Rotor

The rotor consists of blades with specially shaped, aerodynamic surfaces. When the wind blows over the blades, the rotor turns, causing the rotation of the drive train and generator. The blades should be light-weight, strong and durable to withstand the elements. They are usually constructed of composites of fibreglass, reinforced plastic or wood. The turbine should also be designed to prevent the rotor from turning too fast during strong winds.

The diameter of the rotor blades determines how much power is generated by the system. There are usually two or three blades. Three blades reduces the mechanical stresses on the system, but increases the cost of the rotor.

Generator/Alternator

Generators and alternators produce electricity from the rotation of the turbine motor. A generator produces Direct Current (DC) power or, as an alternator, it produces Alternating Current (AC) power. Most small wind turbines used for battery charging systems use alternators generating AC power which is converted to DC for the batteries.

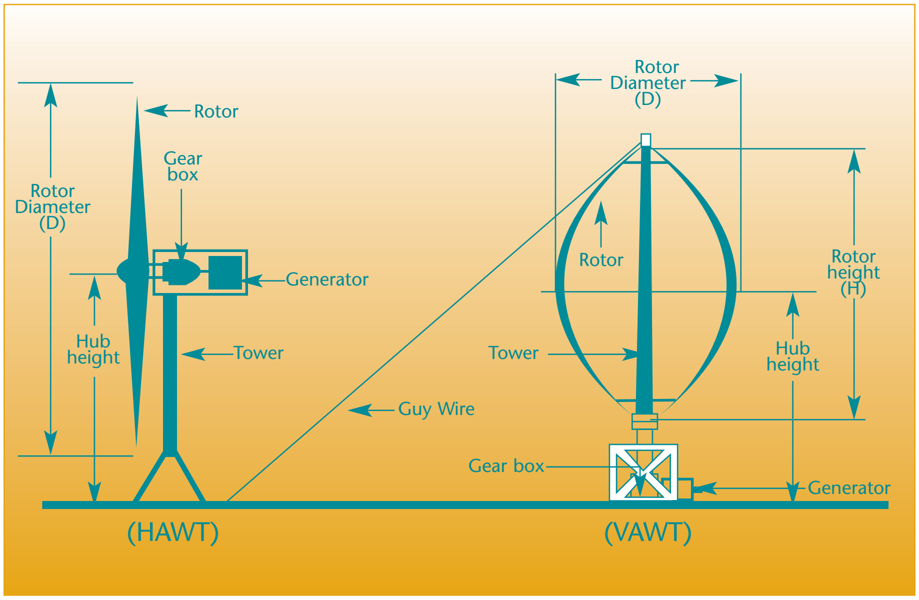

Figure 5. HAWT's and VAWT's: Horizontal and Vertical Axis Wind Turbines.

AC/DC?

Direct Current (DC) is a flow of electricity in one direction. Alternating Current (AC) flows first in one direction, then in the other. Alternating Current is used in household electricity because of AC's ability to be transmitted over long distances with minimum loss. DC, however, loses energy the greater the distance transmitted.

You do not need to know the physics, suffice it to say that the current coming from a battery is DC, while the current coming from a wall outlet is AC. Typically, DC-powered appliances run at lower voltages than AC.

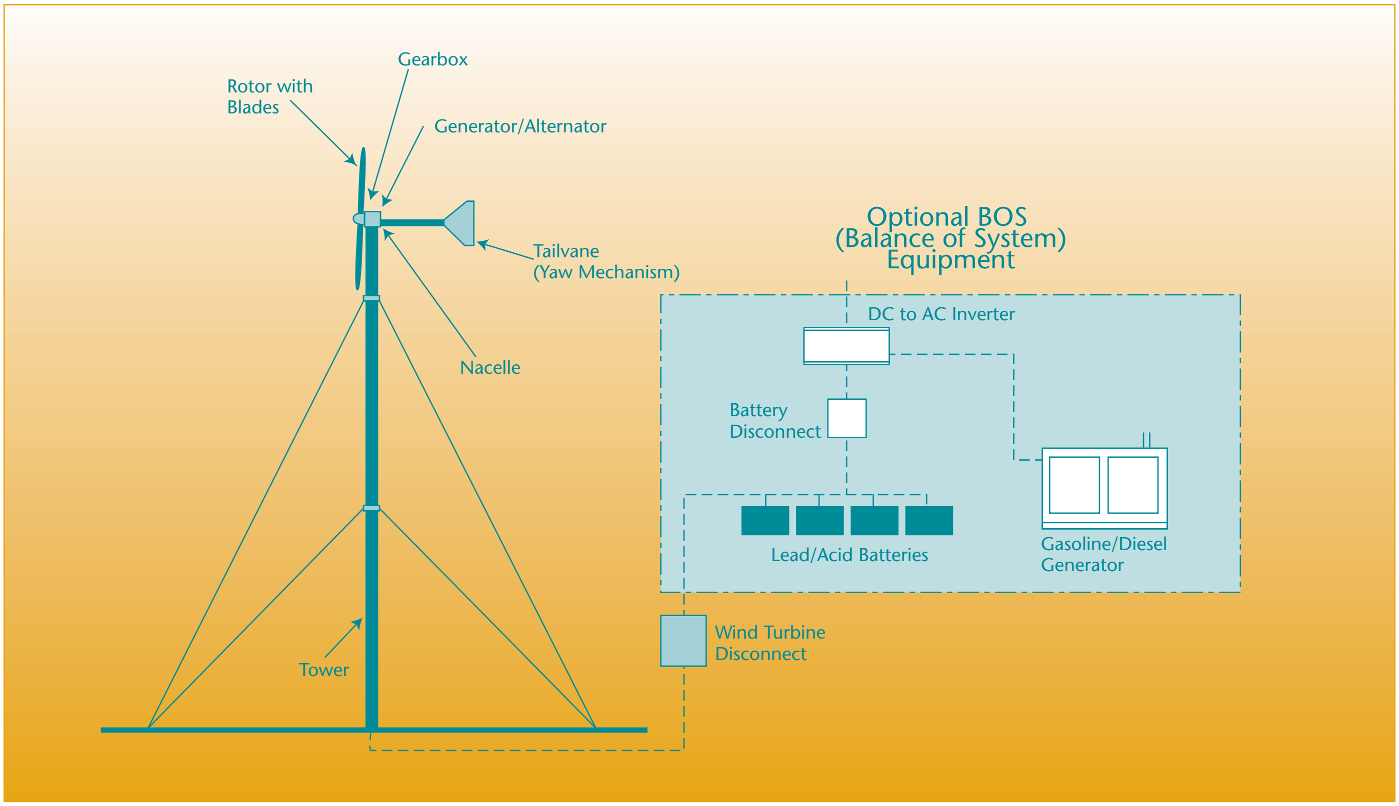

Figure 6. Wind energy system components.

Gearbox

Many turbines, particularly those above 10 kW, use a gearbox to match the rotor speed to that of the generator. Most micro and mini systems have the generator/ alternator rotating at the same speed as the rotor and do not need a gearbox.

Nacelle

This is an enclosure which protects the gearbox, generator and other components from the elements. It is removable to allow for maintenance.

Tailvane (Yaw System)

A yaw system aligns the HAWT with the wind. Most micro and mini systems use a simple tail vane that directs the rotor into the wind. In some systems, the rotor is downwind of the generator, so it naturally aligns with the wind. Some yaw systems can be offset from the vertical axis to regulate rotor power and speed. Special release mechanisms can use the yaw system to turn HAWTs out of dangerously high winds.

Control and Protection Systems

Control systems vary from simple switches, fuses and battery charge regulators to computerized systems for control of yaw systems and brakes. The sophistication of the control and protection system varies depending on the application of the wind turbine and the energy system it supports.

It is important to know some key terms used in descriptions and specifications of wind turbines. On a chart on the next page, we have outlined terms for a typical mini DC generating turbine that might be found in a manufacturer's literature.

Specification	Sample Data	Importance	Units
Rated Output	600 W	Maximum power output (usually rated at about 12 to 15 m/s or 40–50 km/h), used to size wiring and controls for maximum current.	Watts or kW
Rated Wind Speed	40 km/h	Speed at which rated output is produced.	kilometres/hour (km/h) or metres/second (m/s)
Output Voltage	12 or 24 Volts DC	Determines what type of equipment can be used or operated.	may be AC or DC
Cut-in Speed	11 km/h	Wind speed at which the turbine starts to generate power.	kilometres/hour (km/h) or metres/second (m/s)
Cut-out Speed	45 km/h	Wind speed at which the turbine turns away from the wind or stalls to protect itself from damage and stops producing power.	kilometres/hour (km/h) or metres/second (m/s)
Blade Diameter	2.5 m	Overall diameter of rotating blade, one of the main factors in determining power generated.	metres (m)
Number of Blades	3	Most common is three, but sometimes two or four are used.	
System Weight	20 kg	Weight of blades and generator/alternator, to be lifted to top of tower.	kilograms (kg)
Power Curve	n/a	A graph of power output vs. wind speed; required for an estimate of energy production.	Watts at wind speeds in metres/second (m/s)
Warranty Period	2 years	Typically one to three years.	year

Towers

The tower holds the turbine in the path of the wind and is therefore an integral part of a wind energy system. Make sure the tower is properly engineered to handle the system. Towers should be able to withstand lightning strikes, extreme winds, hail and icing.

Only towers approved by turbine manufacturers should be used. Otherwise, the warranty on the turbine may be invalid.

Several types of towers are available:

Guyed towers are economical and very strong when properly installed. The guy wires require space around the base of the tower so they can be properly anchored. The tower's concrete foundation must have its own secure anchor to withstand the maximum pull on the wires. Foundations should be placed below the frost line; sandy and poorly drained areas can be a problem. Buildings, trees, and even the lay of the land may not permit guy wires.

Tilt up towers are often used for smaller systems because they provide for safe maintenance of the turbine. Tilt up towers allow assembly of the wind turbine while the system lies on the ground. The tower is then erected by a winch or heavy vehicle. Tilt up towers can be lowered for maintenance (Figure 7).

Self supporting towers tend to be more expensive because of the heavier materials necessary in their construction. They do not have guy wires, so the foundation needs to be more substantial.

Certain micro system turbines, such as those for recreational purposes and cottages, can be mounted on a simple rigid pole.

The Importance of Tower Height

Because winds increase and become less turbulent with height above the ground, and power output increases substantially with wind speed, increasing tower height from 10 to 50 metres can double the wind energy available.

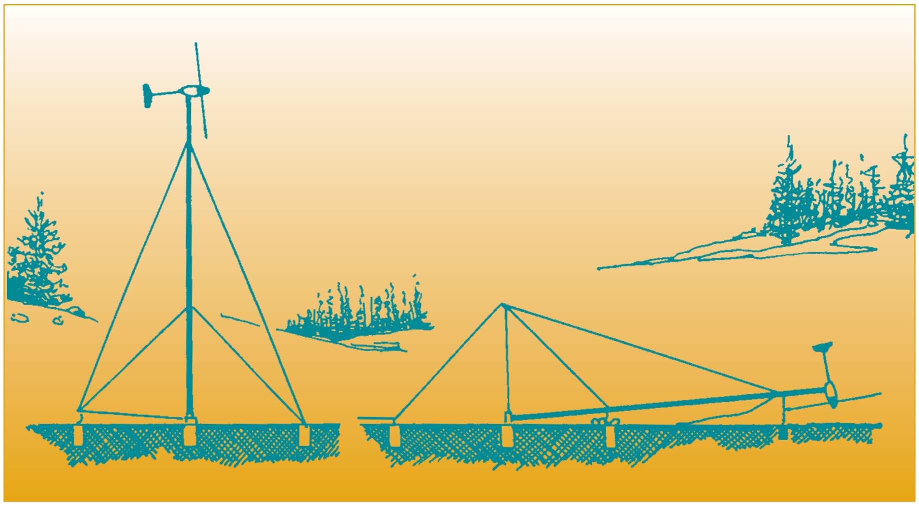

Figure 7. Tilt-up towers tilt down to ground level, where the wind generator can be easily installed and serviced.

Balance of System (BOS) Components

Depending on your application, you will need additional equipment and materials to provide electricity at the required voltage and current. This equipment is referred to as the Balance of System (BOS). The major BOS components are batteries, the inverter and, if you are using one, a fossil fuel generator (see Figure 6 on page 11).

Other BOS equipment and materials include cables, switches, circuit breakers, metres and other apparatus not necessarily supplied by the manufacturer. You should have easy access to the BOS equipment to do battery maintenance, repairs and to collect data such as the number of kilowatt hours generated. You may want to dedicate an area in a workshop, shed or home to house all the BOS equipment.

Batteries

Many wind energy systems use batteries to supply electricity when the wind is not adequate. A system without batteries will only provide power when sufficient wind is blowing to meet the demand.

Not all batteries are created equal, and terminology for batteries can be confusing. One of the most important specifications for wind energy systems is Depth of Discharge (DOD). This is the amount of power you can drain from a battery and still have it charge up again.

If you drain 100 percent of a battery's power, you will radically shorten the life of your battery, but batteries used for wind energy systems are designed to have a fairly deep discharge and still allow recharging. Usually a 50 percent discharge is used, although some batteries offer up to 80 percent DOD. This means you can safely discharge 80 percent of the battery's power without shortening battery life. Many batteries have low-voltage cut-offs to prevent a excessive DOD.

There are many kinds of suitable batteries for wind energy systems. Deep discharge lead acid batteries are usually the most economical for wind energy systems. Car batteries (lead acid SLI – starting, lighting and ignition – batteries) do not have a high DOD and will fail prematurely if used in a wind system.

For suitable batteries, check the box below.

Deep Discharge Batteries for Wind Energy Systems

Flooded cells are the most common type of battery; they have removable caps for adding distilled water, are low cost, have long life, and will withstand overcharging.

Sealed flooded cells are maintenance-free; they do not require water; they can be damaged by overcharging.

Recombinant flooded cells do not require water; they are more expensive, and can be damaged by overcharging, but will not spill acid.

Gelled electrolyte cells do not require water, are more expensive, can be damaged by overcharging, can be mounted in various positions, and will not spill acid.

The size of your battery system is also important. It may be tempting to buy a small battery capacity to save money, but this will likely lead to a deep discharge and early battery replacement. If batteries are sized correctly for the system, they should last three to five years. Some very high quality large cells can last up to 15 years.

It is recommended that batteries be connected in series. Connections in parallel may cause damage because of different states of charge among the individual battery cells.

Typical specifications on batteries are explained in the chart below.

Watt?

You do not have to know the definitions of the electrical units used in the text, nor do you need to know how they relate to each other mathematically, but it is helpful to know what each represents:

Amp: A short form for "ampere." It is a measure of electrical current. Think of it as speed, i.e. the rate of electrical flow. Wiring is rated according to how many amps it can carry.

Volt: If an ampere is speed, a volt can be thought of as pressure. Electricity can not move through a wire without something pushing it. That push is measured in volts.

Watt: When you are looking at how much capacity you need for your wind energy system, this is the number that is really important. Wattage is power.

The three measurements are related, and if you need to know the math, the number of Watts available in a circuit can be found by multiplying the Volts by the Amps. For example, a typical household circuit may be 15 Amps. Since your house is supplied at 115 Volts, the circuit has a little more than 1,700 Watts of power available. If you plug in appliances that draw more than 1,700 Watts, you'll blow a fuse or trip the circuit breaker.

Inverters

Energy stored in batteries is available as DC power. Some appliances and equipment are designed and built to run on DC power. Camping, boating and recreational vehicle equipment and lights are usually designed to be run from DC power, because they are designed to be run from a battery.

Any electrical appliance in your home, however, must use AC power.

An inverter converts the DC power in the battery to AC power. In the conversion process, about 10 percent of energy is lost.

There are different kinds of inverters. Light duty inverters (100 – 1,000 watts) are typically powered by 12 volts DC and are suitable for lights and small appliances such as televisions, radios and small hand tools. Heavy duty inverters (400 – 10,000 watts) can be powered by a range of voltages, 12, 24 or 48 volts DC, and can be used to run just about

Specification	Sample	Importance	Description
Cell Type	flooded	Specifies the operating characteristics, charging voltages, and maintenance requirements.	
Voltage	12 VDC (Volts DC)	Specifies how many batteries in series are needed to reach system voltage.	Volts DC (usually 2, 6, 12, 24 or 48)
Capacity	115 Ah (20 hr rate)	Indicates how much energy is contained in the battery, usually for a specific rated temperature and an 8 or 20 hour discharge period; determines how long the load can be maintained.	Amp-hours. The number of amps load multiplied by the number of hours the load is applied. (See explanation of Amps, Volts, Watts, top of page)
Cycle Life	750 @ 50% DOD	Specifies the number of battery cycles (i.e. discharged, then recharged) before capacity becomes inadequate.	
Size	0.3 x 0.175 x 0.200	Indicates storage space required.	Length, width and height (m^3)
Weight (including acid)	24 kg	A strong floor or sturdy racks will be necessary for multiple batteries; weight determines if one or two people can move the battery.	kg

anything found in a home or small business.

There is also the question of the quality of power coming out of the inverter. If inverter literature starts talking about "true sine wave" or "modified sine wave," it means the power is high quality, and able to safely power sensitive electronic equipment such as computers and laser printers.

Inverters are sophisticated pieces of equipment and often provide a range of other features beyond just converting DC to AC. Many, for example, feature an automatic starter for a gas or diesel back up generator.

Generator Set (Genset) – for Hybrid Systems

During extended periods of low wind, a back-up generator is required if continuous power is needed. This generator may be fuelled with gasoline, diesel oil or propane. The electricity generated is used directly where required, or indirectly after first charging the batteries.

An uninterrupted supply of power may require a "remote start" generator which will kick in automatically before battery power is exhausted. The start signal is typically provided by the system inverter. Not all generators can be remotely started, and not all inverters support remote start.

Other BOS Components

The following components may be used with a wind energy system to fulfill requirements for safety and specialized functions.

Battery Charger
Certain generators can be used to charge lead acid batteries. If the generator does not have a battery charging output, a special battery charger is required. Some inverters can act as battery chargers.

Rectifier
A rectifier converts AC power to DC power. Rectifiers are often used for battery back ups in wind energy systems which have AC generators. The AC power the generator produces has to be converted to DC power to charge the back up batteries in times of strong winds.

Disconnect Switch
Disconnect switches, circuit breakers, fuses and other protective equipment as recommended by the manufacturer and required by the electrical code are important for the safe operation of the system. They electrically isolate the wind turbine from the batteries and the batteries from the inverter and load. They can also protect the system from damage caused by any number of things. A disconnect switch allows maintenance or system modifications to be made safely.

Monitoring Equipment
Even the most basic BOS should include a method for monitoring the equipment's operation. Standard monitoring equipment usually includes a voltmeter for measuring battery voltage and depth of discharge, and an ammeter to monitor energy production or use. More sophisticated monitoring equipment includes alarms for system problems such as low or high voltage conditions.

Generators require not only up front capital expenditure, they also require fuel, periodic maintenance, rebuilding and even replacement. While they can be an important source of power, generators are also noisy, create pollution and require storage of flammable fuels.

- **An age-old technology is simple and effective**

Wind energy was used to pump water long before the discovery of electricity. Many different approaches to wind energy water pumping are still in use around the world today. Large wind powered pumps can provide significant quantities of water for irrigation and the watering of livestock. Much smaller systems are adequate to supply household water.

Two technologies used for pumping water are mechanical water pumping windmills and wind-electric water pumpers. Both are used mostly in rural or agricultural applications.

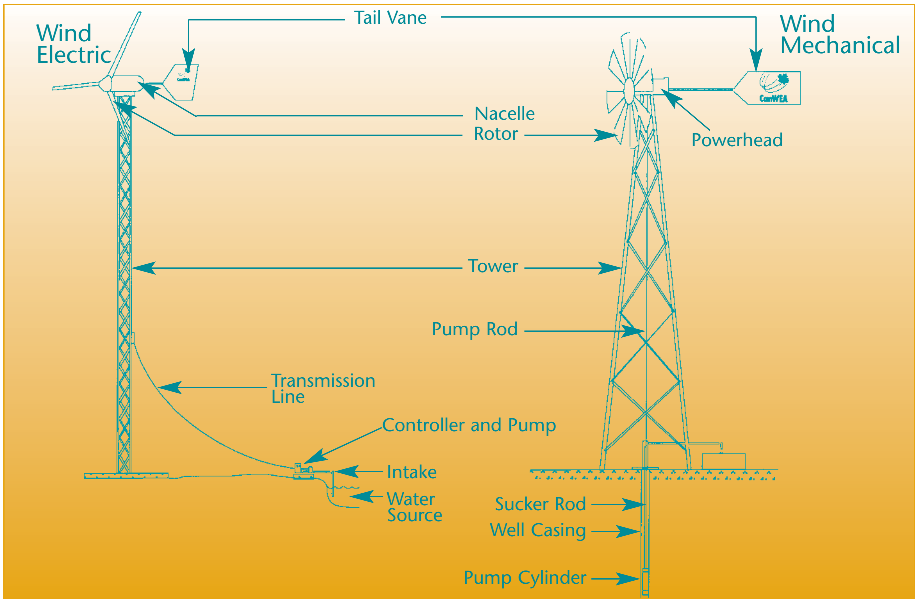

Figure 8. Mechanical and Wind-Electric Water Pumping Wind Energy Systems. Courtesy of CANWEA.

Mechanical Water Pumping Windmills

Traditional water pumping windmills use a crank mounted on the rotor shaft. They typically have many blades on a relatively slow turning rotor. The equipment changes the crank's rotary motion to an up-and-down motion which drives a piston pump mounted in a well or pond at the base of the windmill. This series of actions lifts the water.

Mechanical water pumping windmills have their advantages and disadvantages. They tend to be reliable, easy to maintain (they require no BOS components) and reasonably priced. But they may be limited in their applications because they must be located directly above the well or pond, even if the water may be required some distance away.

Wind-Electric Water Pumping Systems

Unlike a mechanical system, a wind-electric system does not have to be located near the source of the water. A wind energy system powers an electric pump, which moves water from its source (a well or pond) to where it is needed (a livestock watering trough, pond or irrigation system). The power consumed by the electric pump can be matched to the power output of the turbine so the wind energy is used efficiently.

Electric water pumping systems do not require elaborate BOS components, mainly because batteries are not required. A reservoir tank for the water serves as the energy storage device.

Mechanical water pumping system.

- **Following straightforward steps, determine if it is feasible to proceed with a wind energy system**
- **Once you have completed the steps, you can move to the next phase – a preliminary system design**

Step 1: Assess Your Site

You will need wind. A methodical and well-reasoned assessment of the amount of wind power available is extremely important. Over- or under-estimating the wind resources at a site can be costly. There are several ways to go about estimating how much energy is available.

In general, an annual average wind speed greater than15 km/h is needed to consider a wind energy system. Speeds higher than that are desirable.

The Atmospheric Environment Service (AES) of Environment Canada has measured wind speeds for hundreds of locations in Canada. From these measurements (always taken at 10 metres above the ground), they have calculated the annual average wind speed for each site and produced a "wind map" of Canada (Figure 10).

From the map, it is apparent that the windiest areas in Canada are along the east and west coasts, some parts of the far North and the southern Prairies.

AES has also published a set of wind data reports for Canada. These reports contain extensive information on speed direction and variation of winds for six different regions. A local weather station can provide information about a narrower area and may even have detailed regional wind maps.

These resources are a good place to start your assessment, but you will need more information. For example, by convention, wind speeds are taken at 10 metres above the ground. The AES data does not tell you about speeds above 10 metres. It also does not tell you about the micro-conditions that may occur at the specific location you have in mind.

In general, wind turbines should be installed in unobstructed, open areas with clear exposure to prevailing winds. If possible, find a site near the top of a hill or ridge, because wind speeds increase with height above the ground. Siting a wind energy system on the windy side of a hill will provide better access to prevailing winds than siting it on the sheltered side of the same hill (Figure 11).

Consider more than just the wind when considering a site. For example, the distance of the turbine from where the electricity will be used is important. The farther you have to transmit the electricity, the more expensive the system will become.

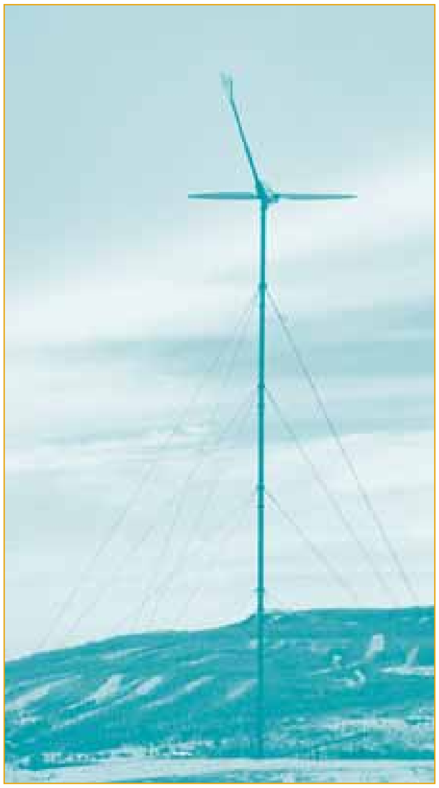

Figure 9. A small 25kW Wenvor-Vergnet wind energy system in Collingwood, Ontario, supplies electricity to a rural residence. (Photo courtesy of Wenvor Technologies Inc.)

How Much Wind is Enough?

A wind energy system needs an average annual wind speed of at least 4 metres per second (m/s) to be able to operate with any degree of efficiency.

Average Wind Speed	Wind Regime
Up to 4 m/s (about 15 km/h)	No good
5 m/s (18 km/h)	Poor
6 m/s (22 km/h)	Moderate
7 m/s (25 km/h)	Good
8 m/s (29 km/h)	Excellent

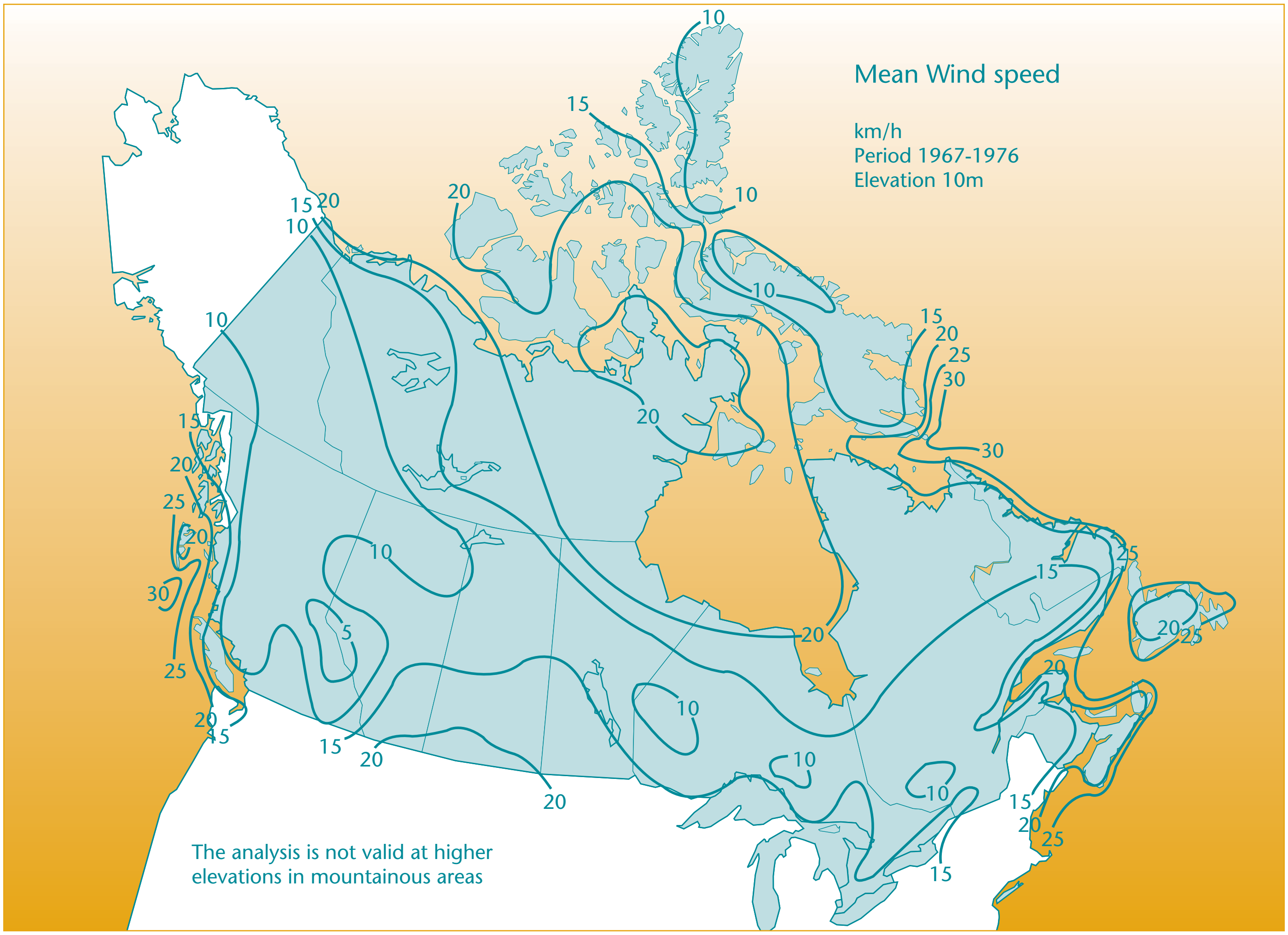

Figure 10. Annual average wind speed map of Canada. Courtesy of Environment Canada.

Wind Energy Resource Maps for Canada

Copies of the Environment Canada report Wind Energy Resource Maps for Canada (ARD-92-003-E) are available from:

Gary Beaney
Climate Service Specialist
Canadian Climate Centre
4905 Dufferin Avenue
Downsview, Ontario
M3H 5T4

Telephone (416) 739-4328
Fax (416) 739-4446

Once you have a tentative site, monitor wind speed for several months. This is especially important if your preliminary information shows annual average wind speeds near the minimum 15 km/h. On-site monitoring will provide information about periods of calm and low wind. Monthly or even spot readings can be compared with the monthly data from AES.

Wind monitoring is worth the effort. It will help you determine the size of turbine and the amount of battery storage capacity you'll need for your energy requirements.

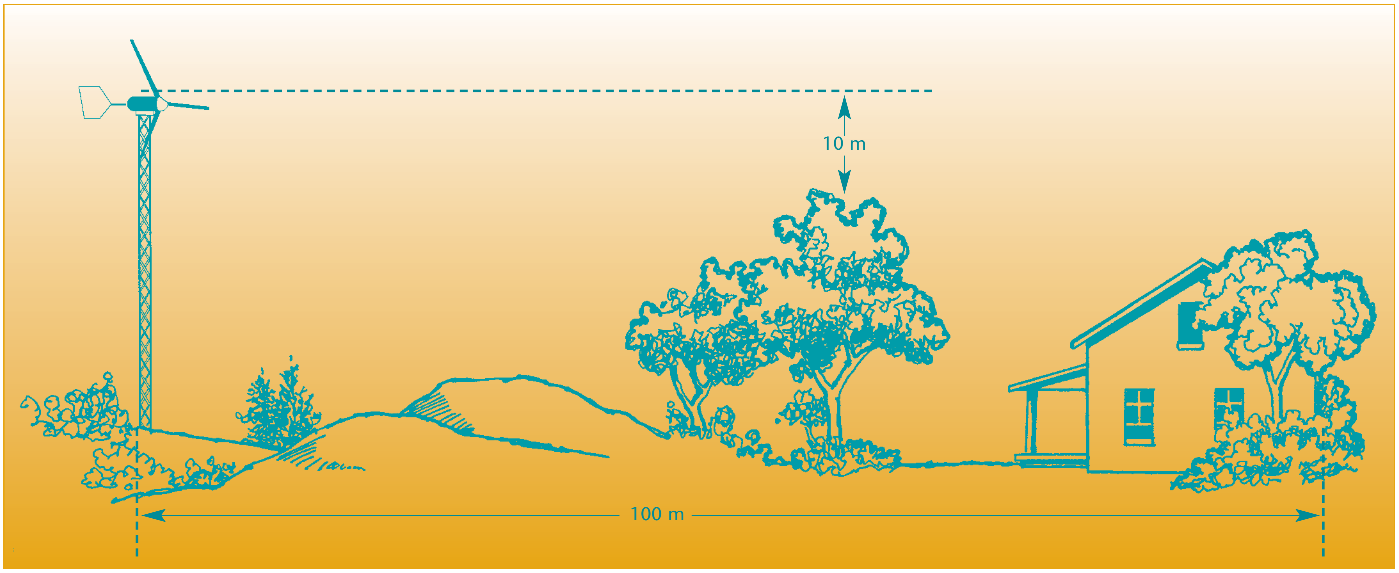

Figure 11. Siting a wind energy system.

To review, answer these questions:

1. What is the annual average wind speed for your site at a set height above the ground?
2. How does the average wind speed vary with height?
3. What is the frequency and duration of wind speeds, particularly those periods below cut-in speed and above cut-out speed?
4. Is it worth proceeding?

Note:
This step is a "go" – "no-go" decision point.

Step 2: How much Energy do You Require?

When you determine how much energy you require, you are really asking two questions. First, how much total energy do you require over a year to operate all the appliances and equipment your system will run? Second, what is the peak power requirement?

What is it you want to run?

You have to determine what it is you expect to run with the electricity generated by your small-scale wind energy system. Some household appliances such as water heaters, clothes dryers, stoves and electric heaters can draw a large amount of power, but do so only intermittently. Other appliances, such as refrigerators and freezers draw a large amount of electricity, and the supply must be reliable. Lighting, on the other hand, does not require that much power, and the draw is fairly consistent. Even so, it is best to look for the most efficient lamps and fixtures. Remember that fluorescent lamps use far less electricity than incandescents, last ten times longer, and give the same amount of light. Screw-in compact fluorescent are widely available. DC fluorescent are also available.

Remember always that saving a kW of energy is more cost-effective than producing one.

If you plan to use wind energy to run systems on a farm, remember to distinguish between equipment required to operate the farm, and the energy requirements of the home. Power needs for farming equipment vary widely, especially when it comes to livestock watering, and should be accounted for separately.

A Note About Energy Efficiency

The more power you need, the larger and more expensive the system will have to be. Try to minimize power requirements as much as possible, because saving a kW usually proves more cost-effective than producing one. Where possible, use the most energy efficient appliances available. Natural Resources Canada manages the *Energuide* appliance labelling program that collects energy consumption ratings for major home appliances available in Canada. To obtain information on *Energuide* please contact Canada Communications Group at 1-800-387-2000.

Estimating Annual Electrical Energy Requirements

You will need two pieces of information for this estimate. First, you need to know how long, in hours, each of your appliances will run. Second, you need to know how much power each appliance draws.

Power is measured in watts. We are all familiar with wattage of light bulbs, but every piece of electronic equipment will have an indication of how much power it draws. Look on the back of your television set, for example, and you will find specifications inscribed on a plate at the back. A typical power draw might be 90 watts.

If you have the television set on for two hours a day, every day of the year, that's (365 days x 2 hours) 730 hours.

Worksheet #1. Annual Energy Consumption (sample)

Appliance/ Equipment	AC	DC	Rated Wattage (W)	Hours per day	Hours per year	Annual Wh
4 – 24 watt fluorescent lamps	yes		96	5	1825	175,200
water pump	yes		400	1	365	146,000
colour television (14")	yes		90	2	730	65,700
high efficiency refrigerator		yes	250	3	1,095	273,750
Total – Annual Energy Consumption						**660,650 Wh (661 kWh)**

The TV draws 90 watts of power for 730 hours for a total annual energy consumption of (90 watts x 730 hours) 65,700 watt hours. In the standard measurement of kilowatt hours, this is 65.7 kWh.

In the back of this guide, *Appendix A, Typical Power Ratings of Appliances and Equipment,* will be helpful in estimating annual electrical energy requirements. There is also a sample worksheet at the top of this page.

Look to the future and changing energy requirements when doing your estimate as well. Will your household be expanding or shrinking in size? How will this affect energy consumption? (Keep in mind that you can take your wind energy system with you if you relocate!)

Peak Power Consumption for a Home Wind Energy System – an Example

Appliance/Equipment	Power (watts)
4 x 24 watt lamps	96 W
small colour TV	90 W
portable phone	6 W
clock	3 W
iron	1,100 W
water pump (automatic)	350 W
high efficiency refrigerator	150 W
Total	**1,795 W**

Portable Remote Power system, Canada Olympic Park, Alberta. While not all systems are this portable, you can take your system with you when you move. (Photo courtesy of Nor'wester Energy Systems Ltd.)

Estimating Peak Power Requirements

To ensure you have the right size of wind energy system, you need to know more than just annual electrical energy consumption. Many appliances, such as refrigerators, do not run constantly, but cycle on and off. Similarly, lighting is not in constant use, nor is an electric iron, electric space heater or many other pieces of equipment.

To properly size your system, you must estimate peak power consumption. Even though it is unlikely all your equipment and appliances will be turned on at once, a peak power estimate should be an extreme example.

Consider, for example, that you might be watching television with the lights on while you do a few minutes of ironing and that your water pump and high efficiency refrigerator also turn on automatically. This could be your peak load. An example of this scenario is given in the table on the previous page.

Check *Appendix A, Typical Power Ratings of Appliances and Equipment,* at the end of this guide to note the most power hungry appliances which may be operating simultaneously. Add up the wattage to obtain the peak load.

Step 3: Size a Wind Turbine and Tower

You should now have an estimate of the wind energy available at your site, and an estimate of how much energy you need. Sizing the turbine is a matter of trying to match the two.

Helpful Hints

To obtain smooth airflow, the tower should position the turbine of a mini or a small system at 100 metres horizontally from the nearest obstacle at turbine height (such as larger trees or buildings), and 10 metres above any obstructions which are closer.

Look at the manufacturer's specifications for turbines to get an idea of approximately how much energy will be available given your site's average annual wind speed. A more precise estimate will depend on the variability of the wind speed over time.

This is also the time to think about towers. A higher tower will be more expensive, but could give your turbine access to greater wind energy. A shorter tower will require a larger turbine to generate the same amount of energy as a higher tower with a smaller, less expensive turbine.

The type of tower you need will depend on your site. Is there room for the tower guy wire anchors? Is a stand-alone tower a more viable option? Does the tower height allow the turbine to operate 10 metres above nearby obstructions?

Step 4: Select Balance of System (BOS) Equipment

BOS equipment depends entirely on the answer to the earlier question, "What is it you want to run?" Will it require power every day, on demand? Will it require AC power? Is the power absolutely required 24 hours per day, every day, all year? Let us look at each of these questions in turn:

Do you need power every day on demand?

If "yes," you will require batteries. You will need to know what size of battery best fits your system. You should have an experienced wind equipment dealer help you calculate the amount of battery storage you need because the estimate is based on several factors.

For example, what is the longest period you can expect to be without adequate wind? You will need enough battery capacity to run your appliances during this period. An example of this calculation is shown in the box on the next page.

Remember also that when the wind is blowing, your wind energy system must not only run your appliance and equipment, it must generate enough excess power to recharge your batteries.

You also should determine how much time you want to spend maintaining the batteries. If maintenance will be regular, flooded cell batteries are appropriate. If not, a maintenance-free battery would be a better choice.

If the answer to the question is "no," your BOS requirements will be minor because the turbine will provide the required power.

Will AC power be required?
Any home, business or factory hooked to the electrical grid needs AC power. However, DC appliances, equipment and lighting are readily available, designed for use in cottages, recreational vehicles, and boats. Cottages, for example, could have both AC and DC power, with DC running the lights and a small water pump. In these cases, the system will have separate DC and AC wiring circuits and fuses or circuit breakers.

If, however, the wind energy system will be running equipment or appliances designed to take AC power, you will need an inverter. An inverter converts stored DC power (from a battery) into AC. Many systems actually use two identical inverters to increase reliability and improve operating efficiency.

If you will not require AC power, you will not need an inverter.

Calculating Battery Storage Capacity

Battery capacity is measured in amp hours. Here is how you calculate how many amp hours of battery capacity you will need.

From your earlier calculations on electrical requirements, you should have an estimate, likely in watt hours, of how much energy you require each day. Let us say it is 1,300 watt hours (1.3 kWh). Assume three days is the maximum amount of time without adequate wind. You will require (1,300 watt hours x 3) 3,900 watt hours.

A typical battery supply would provide 24 volts. The battery specifications tell you that this battery supply will allow for a 50 percent depth of discharge (DOD). That means only one-half the total capacity is available without draining the battery too far.

To find the number of amp hours needed, simply divide the watt hours by the voltage. In this case, 3,900 watt-hours divided by 24 volts gives us 162.5 amp hours.

But remember, your battery capacity has to be twice this because you do not want to draw more than 50% of the total capacity (i.e. the DOD is 50%).

Therefore, you need a battery supply rated at a minimum of 325 amp hours (162.5 x 2) capacity. In fact, it is best to round this number up, say to 400 amp hours.

Is power absolutely required 24 hours per day, every day, all year?
If the answer is "yes," you should be planning a hybrid system which has a back-up, fossil-fuelled generator. Find out more about hybrid systems in the next chapter.

The generator could be started manually by the operator, or, if uninterrupted power is required, a remote start generator would be necessary. This works automatically when the battery voltage reaches a pre-set lower limit. Remote start generator systems are more expensive.

If the answer is "no," the combination of wind turbine and back up batteries will be sufficient.

We have included Worksheet #2. Selecting BOS Equipment (at the back of the guide) to help you check off the BOS equipment for a proposed system. (If necessary, refer to Chapter 3 for descriptions of the components.)

Wind Energy in Use

A small stand-alone system installed in southern Alberta allows a farm to operate independently of the grid. The farm had been connected to the grid, but the owner wished to have autonomous power and to reduce the environmental impact of his farm and home energy use. The farm's wind energy system supplies power to a residence for a family of four, a machine shop, a water well and yard lights. The peak load is about 5 kW. The wind map of Canada shows that the region has a 18 km/h (5 m/s) annual average wind speed at 10 metres height.

A small stand-alone wind energy system can supply power to both the farm and residence. (Information and photo courtesy of Nor'wester Energy Systems Ltd.)

Power is generated by a 10 kW wind turbine on an extra-tall 33 metre tower. Power from the turbine is rectified (i.e. converted from AC to DC power) to 48 volts DC for storage in high quality low maintenance gelled electrolyte cell deep discharge batteries of 1000 Ah capacity. A 5 kW inverter then supplies 120 and 240 volts AC to the farm and house. To reduce peak loads and electricity consumption, major energy consuming appliances – the stove, clothes dryer, furnace and water heater – are fuelled by natural gas. Additional equipment required to control the power safely includes a transfer switch, battery charging controls, system monitor and circuit protection. If the wind turbine has charged the batteries and is still producing power, a dump load controller "dumps" (or "shunts") excess power to pre-heat water for the water heater.

This system is larger than a non-farming home would require as it provides power for both the home and farm.

The installed cost of the wind turbine, the tower, premium batteries and other BOS equipment was $60,000 (1997). The farm is now free of utility cost increases and the power being consumed has little environmental impact.

6. **Hybrid** Wind Energy Systems

- **Hybrid systems provide a reliable source of electricity**
- **Some pointers to help you assess whether a hybrid system might be your answer**

If the preliminary assessment in the last chapter shows that you need reliable power 24 hours a day every day, a hybrid system should be considered. Hybrid systems draw on more than a single source of energy, resulting in a reliable supply of electricity. A number of power sources can be used in combination with wind energy: solar, gas or diesel generators, and even hydro power.

This remote radio repeater in Kananaskis, Alberta uses solar energy to produce electricity in addition to wind. (Photo courtesy of Nor'wester Energy Systems Ltd.)

Hybrid systems are far more complex than stand-alone systems and entail more elaborate design features. But, depending on your situation, a hybrid system can be an attractive option. They are dependable, more environmentally friendly than fossil-fuelled generators and, often, are more economical.

Hybrid systems are as varied as the needs of wind users, from micro and mini applications, where dependability is a requirement (such as at a remote homestead or for telecommunications sites), to small applications (such as for remote community grids).

It is likely not possible to buy an off-the-shelf hybrid system that is right for your application, and, just as with stand-alone systems, a careful assessment of requirements should be made before you start shopping.

The rules for assessment of a hybrid system are similar to those for stand-alone systems, but consider the cost and availability of the other source of energy that makes up the hybrid:

- you still have to know the availability of wind energy at your site, just as with a stand-alone system. For a hybrid, you should also look at the availability of other renewable resources, such as solar.
- consider the cost of fossil fuel to power the generator; how dependable is the supply of fossil fuel, and how difficult is it to get the fuel to the site?
- you still have to know what your power requirements are. Use the same guidelines as were set out in the stand-alone assessment in the last chapter – look at occurrence of peak loads, daily demand, the requirement for dependable power. Keep in mind as well the quality of power required. Sophisticated equipment, such as computers or telecommunications equipment, requires high quality electricity which does not fluctuate.

Here is where the assessment becomes more difficult than for stand-alone systems. Hybrid systems should be designed for technical reliability and cost effectiveness.

If the generator is to start itself when wind energy production drops below a certain point, for example, sophisticated control systems will have to be installed. Even with these controls, the generator may not start the instant it is needed. If the generator is running below its design capacity, it may not be very efficient, driving up operating costs.

Batteries may still be desired to accommodate excess power during periods of high wind, but if the system is providing a large amount of power, the cost of battery storage will be high.

To recap, some of the difficulties in planning a hybrid system are:

- The variable nature of the wind and the load make it difficult to predict how to match these reliably.
- Large generator sets used for back-up do not always start the instant they are needed.
- Running a generator set below its design capacity is very inefficient.
- Battery storage can be used to provide continuous power in the face of wind variations and the stop-start operation of generator sets, but batteries are expensive, especially for large loads.

To ensure that your hybrid system provides dependable power and is cost effective, you should seek professional help to assist with the required analysis and to consider the design options.

7. Economics

- **Compare costs over the long term to determine the real value of a wind energy system**

A wind energy system is a serious investment, and should be assessed like an investment. It is likely wind energy will be cost competitive, and may even be less expensive over the long term. But there is also a chance that a wind system is just not economically right for your application. This section will provide you with an overview of some of the key issues in determining whether a wind energy system is a viable economic option.

How much does the system cost?

There are two costs to consider: initial costs and annual costs. Initial costs are those that occur at the beginning of the project before any electricity is generated. Annual costs, or operating and maintenance (O & M) costs, recur on a regular basis to keep the wind energy system in running order. Generally, wind energy systems have high initial costs, but relatively low annual costs compared to, say, a generator set which requires re-fuelling.

Initial Costs

If you have done the assessment in Chapter 5, you should have an idea of the basic configuration for your system. It is possible now to obtain a complete system price for the installation. Alternatively, you could list the components and obtain a quote by calling equipment suppliers and checking catalogues and price lists.

> **Helpful Hints**
>
> Suppliers should indicate what spare parts are important for a system so they can be purchased right away. The after-purchase price will often be significantly higher.

Remember to include the costs for BOS components such as batteries and inverters, and other associated costs such as tower foundations, buildings for controls or battery storage, electrical distribution and connection equipment and the costs of installing all of that.

Once you have added up all this, you still do not have the initial cost of the system. There are also “soft” costs to consider and, depending on the size and complexity of the project, they can add considerably to initial costs. Here are some examples:

Prefeasibility Study: Just going through the quick assessment guideline in Chapter 5 will not be sufficient for larger systems or hybrid systems. You may want to call in an expert to take a quick look at potential, before moving to higher cost engineering designs and feasibility studies. A prefeasibility study may be completed without a site visit, using resource and demand estimates from other sources. (Calculate up to 2 percent of the total initial costs). NRCan has developed a pre-feasibility software tool called RETScreen™ to assist you. RETScreen™ is a standardized renewable energy project analysis software that could help you determine whether a wind energy system is a good investment for you. Please refer to Chapter11, Need More Information? to find out how to get your copy of RETScreen™.

Feasibility Study: This is the design phase, and the analysis of the design. It is useful for small and some micro and mini systems. Costs will vary depending on access to the site and the availability of wind data. For a small hybrid wind energy system, a wind resource assessment will be required if no there is no data. This will involve at least one year of readings from a tower-mounted anemometer. A site investigation will be required for all feasibility studies. This will try to match the site with an appropriate design. An environmental assessment of the project may be required, especially if access roads to the site are needed or there is a possibility of visual impact from a tall tower. (Calculate up to 7 percent of the total initial costs).

Project Development: For small wind energy systems and systems which may be community-based, project development often requires time and expense. These costs may include permits and approvals for construction, land rights and surveys, project financing, legal and accounting costs, and project management. (Costs vary depending on the project).

Engineering: All but the smallest micro systems will require mechanical, electrical or civil engineering services. These requirements increase as the systems increase in size and complexity. (Calculate up to 7 percent of total initial costs).

Transportation: This is often overlooked, but the cost of transporting equipment to the site can be significant, particularly for remote locations. (Costs vary depending on the location and application).

Access Road Construction: For small systems, this is not an issue, but for larger community- based systems, year-round access by road may be important, and roads may have to be built for drainage and snow clearance. (Costs vary depending on the location and application).

Erection and Installation: The equipment supplier may install the system and erect the tower, otherwise, outside services may be required. For larger systems especially, special equipment such as cranes or heavy vehicles, winches or gin poles may be required. These can be rented, but might be costly. Skilled labour may also be required for mechanical and electrical work. (Costs vary depending on the application).

Annual Costs

The most important annual costs are parts and labour for system maintenance, but, depending on your specific application, they may also include land leasing, property taxes and insurance premiums.

Wind turbines require maintenance once or twice a year. Mechanically-inclined owners may choose to do their own maintenance, and that will be cheaper than paying a technician to travel to the site and check the turbine.

Maintenance costs for most wind turbines are well-established and should be available from the manufacturer. Typically, annual maintenance costs run in the range of 3 percent of the initial capital cost per year. As with all mechanical and electrical equipment, maintenance costs are low when the unit is new, and increase over time. A good quality, properly maintained wind turbine can be expected to last up to 20 years.

O&M Costs

The annual Operating and Maintenance cost for a wind turbine may be estimated as a percent of the initial capital cost of the installed equipment. Values typically range around 3 percent for a well-designed and well-built wind turbine.

If you are making a total cost calculation of a wind system, use 15 or 20 years for the life of the project.

Other equipment may have to be replaced during the lifetime of the wind turbine. Include in your estimate the cost of replacing batteries every five to ten years. For a hybrid system, a small generator would need to be replaced or overhauled after two or three years of continuous use.

We have summarized some of these expenses in the chart below and there is a worksheet in the *Appendix D*.

Compare the alternatives

All this information on the cost of your wind energy system over time tells you nothing unless you look at the cost of other methods of generating electricity. A thorough analysis is likely not necessary for some mini and most micro systems, but as the systems get larger, a full economic analysis is valuable.

Depending on the size and cost of the system, you may want to call in an experienced professional to do this analysis. It may involve such specialized issues as tax savings, the time value of money and life cycle costing.

Life cycle costing is all the costs incurred over the lifetime of the project. From the previous section, we have determined the

Annual Maintenance Cost Components of a Wind Energy System

Component	Operation Costs	Replacement Schedule (Approx.)
Wind turbine	Monitoring, routine lubrication and adjustments; snow, ice and dirt removal	20 years
Batteries	Monitoring for failure and low state of charge after recharge, hydrogen build-up, water levels; terminal cleaning	5 to 10 years
Gasoline/diesel generator	Lubrication and servicing; fuel	2 to 15 years
Distribution lines	Tree clearing and damaged parts replacement.	As required

approximate cost of a wind energy system over 15 or 20 years. Now, we must compare that to the cost of alternate methods of generating electricity. For example, if the alternative is a diesel generator, you will have to determine the costs of running a diesel generator with the same power capacity over 15 or 20 years. This will include the cost of the generator, the cost of replacing or overhauling the generator (since it is not likely to last as long as the wind turbine), and, of course, the cost of fuel needed to run the generator.

The table below gives an example of life cycle costing comparisons.

Table 1. Cost Streams

	500 W Wind Energy System with Batteries			1 kW Diesel Genset with Batteries				
	Initial Cost	Ongoing and Annual Costs		Initial Cost	Ongoing and Annual Costs			
Year	Equipment Material & Services	5 Year Battery Replacement	Annual O&M (3% of system cost	Equipment Material & Services	3 year Generator Replacement	5 Year Battery Replacement	Annual O&M (3% of system cost)	Annual Fuel and Oil
0	$7480			$2280				
1		0	$194		0	0	$68	$380
2		0	$200		0	0	$70	$391
3		0	$206		$874	0	$73	$403
4		0	$212		0	0	$75	$415
5		$580	$219		0	$580	$77	$428
6		0	$225		$955	0	$79	$441
7		0	$232		0	0	$82	$454
8		0	$239		0	0	$84	$467
9		0	$246		$1044	0	$87	$481
10		$672	$254		0	$672	$89	$496
11		0	$261		0	0	$92	$511
12		0	$269		$1141	0	$95	$526
13		0	$277		0	0	$98	$542
14		0	$285		0	0	$100	$558
15		$779	$294		$1246	$779	$103	$575
16		0	$303		0	0	$107	$592
17		0	$312		0	0	$110	$610
18		0	$321		$1362	0	$113	$628
19		0	$331		0	0	$116	$647
20		0	$341		0	0	$120	$666

Using Simple Payback to Evaluate a Project

In smaller systems, where the recurring annual costs are relatively low, you can determine if a project is viable by using a simple payback approach. Simple payback is a straightforward measure of the number of years it would take to have your annual energy savings pay for the initial and annual costs of operating the wind energy system. This method does not account for inflation or how the value of money may change over time.

While this approach can be useful under certain circumstances, it is not suitable if the annual costs or the annual savings are large or if they occur in irregular amounts.

The formula for calculating simple payback is:
simple payback (in years) = net installed cost/net annual savings

An example is shown in the box below.

Simple Payback

Energy requirements in a remote cabin are about 2kWh per day. A 500 W wind turbine with a 20 metre tower and 220 Ah of batteries will cost about $7,500. Operation and Maintenance (annual costs) and battery replacement every five years will amount to about 5 percent of the capital costs or ($7,500 x 5%) $375.

The alternative is a small diesel generator which will cost about $2,500 and $1.56/kWh to run, including fuel and maintenance.

The net installed cost is the initial cost of the wind energy system, less the original cost of the generator: $7,500 – $2,500 = $5,000

The net annual savings are the annual cost of the generator:
$1.56 per kWh x 2 kWh/day x 365 days = $1,139
minus the annual cost of operating the wind energy system (which we said was $375):
$1,139 – $375 = $764

Simple Payback = $5,000 ÷ 764 = 6.54, or about 6-1/2 years.

More in-depth economic analysis

There are other ways to compare more accurately the cost of various energy alternatives over time. Some of these are fairly complex. If you are interested in this analysis see *Appendix F, Using Net Present Value (NPV) to Evaluate a Project and Comparing Unit Costs of Energy*.

8. Other **Issues** to consider

- **You may have your own reasons for choosing renewable wind energy, and these are just as important to consider as cost**

Chances are you had several good reasons to consider wind energy that had nothing to do with economics. There are also other considerations to think about that have nothing to do with technical issues. Most of these are difficult to quantify, but this does not mean that they do not have technical or economic implications, or that they are less important than those which can be costed out.

There are also other issues which cannot be quantified, but which might impact your wind energy system.

The chart below lists a number of issues to consider when deciding if wind energy is right for your situation.

Environment. Wind energy is non polluting, reduces the demand on the grid, and reduces the use of fossil fuels, the construction of hydroelectric dams or nuclear generators. Buyers of wind energy equipment need to decide whether and how to put a price on the environmental advantages of wind power use, and what role the environment should play in the decision-making process.

Safety. In cold regions, ice can accumulate on wind turbine blades. This can cause severe vibrations; the ice may be thrown great distances. Hydrogen venting from batteries is another potential safety issue. Climbing of towers by the owner or maintenance persons is a potential liability. Special safety precautions are required if children have access to the system.

Extreme weather. In some parts of the country, the environment is very hard on equipment and can cause operational and durability problems for the wind energy system and batteries.

Neighbours. The proximity of a wind turbine to a neighbour's property should be discussed with the neighbour before proceeding with a wind energy system purchase. Neighbours could be concerned about the size of the system and the noise a system's generator might make.

Aesthetics. The wind energy system can affect a view, or that of your neighbours', and it might block or change an historic landscape.

Noise. With a hybrid system, generator noise may be a problem. It would be a good idea to listen to the generator to see how much noise it makes when operating. The turbines themselves are relatively quiet.

Corrosion. Corrosion of system parts at locations close to the ocean can be a problem.

Zoning restrictions and other potential legal obstacles. Local municipal offices should have information about restrictions on elements such as noise and permissible tower height.

Local bird life. Birds can be injured or killed if they collide with the blades or the tower; and their breeding, nesting and feeding habits could be disturbed. To minimize these potential problems, avoid siting a wind energy system on a migration route or where many birds nest and feed. The system should be designed to reduce perching and nesting opportunities. This is typically not a problem with smaller systems.

Electromagnetic interference. Systems sometimes produce electromagnetic interference that can affect television or radio reception. The interference can usually be traced to the generator, alternator, or metal blades. This problem can be avoided if the parts are shielded, filtered or made of wood, plastic or fibreglass.

Technical know-how. Some small wind energy system can be maintained by the owner. This may require basic technical skills. It will save money, but will require time and the inclination to do what is necessary.

Access. The existence of an access road for remote systems will simplify construction, maintenance and fuel delivery, and will likely bring with it associated cost benefits.

Insurance, construction standards, private property deed restrictions should also be considered.

9. Buying a Wind Energy System

- **This chapter provide you with a guide to shopping for wind energy system**

Experts Can Help

Finding an expert

To find an expert, contact one of the organizations or associations identified in *Chapter 11 Need More Information?*

Even if you have diligently followed every step in this guide, it is very important to consult an independent expert or a supplier or manufacturer to ensure that any system you buy and install is as efficient, cost effective and safe as possible. Before approaching an expert, you should have the details of your preliminary assessment, and some ideas about your basic design. Even if you are a do-it-yourselfer, you should discuss your project with an expert before committing to a particular system.

Some areas where experts can be of assistance:

Preliminary assessment: They can review your preliminary assessment and confirm the accuracy of the energy and wind resource estimates, and give you some advice on your preliminary design.

Detailed assessment: They can visit the site, identify appropriate applications and do a more detailed resource assessment, and an in-depth economic assessment.

System design: They will help you determine the optimal capacity of the wind energy system, and the size and configuration of the system components, based on the results of the assessments. Expert assistance becomes more important as a system becomes more complex.

Equipment selection and costing: Based on their experience, they can find the best equipment for your system design.

Cost estimates and financing arrangements: The economic assessment and the cost of the final design will lead to accurate cost estimates – then you will know if you need financing and if so, how much.

Installation, servicing, routine maintenance: For larger and more complex systems, outside expertise in these areas becomes more important.

Selecting a supplier

Manufacturers or dealers in wind energy systems can be a valuable resource for information.

Different suppliers specialize in different types of systems. A supplier should have proven experience in design and installation of the type of system you require. Suppliers differ in terms of the level of service they provide. Some offer turnkey (i.e. ready-to-operate) installation. Others offer the option of direct purchase from the factory for self-installation.

Request and review equipment catalogues and price lists. Many catalogues offer useful information about system design.

Dealers vs. Manufacturers

Local dealers may be more familiar with local conditions, and are in a better position to provide service than a more "remote" manufacturer. Also, dealers may have access to a choice of systems from a variety of manufacturers.

Do not hesitate about asking suppliers to see equipment manuals for BOS or wind turbines you are especially interested in. Manufacturer's typically charge for the manual, but the price can usually be applied toward the purchase price of the unit should a purchase be made.

The manual should describe, in clearly understood terms, the assembly and installation procedure for the unit and the subsequent operation and maintenance requirements.

Do not buy from a manufacturer who does not provide the required product literature.

Read all the manuals carefully and look for details that will answer these questions:

- What type of equipment is the inverter capable of operating?
- What quality of AC power does the inverter produce?
- Does the generator have remote start capability?
- What is included in the BOS package?
- Are the wiring and smaller parts supplied?

Reading Equipment Manuals

Standard items to review in the literature provided by the manufacturer:

- Installation and operating instructions
- Maintenance requirements
- Warranty details
- CSA verification
- Other certifications, e.g. ISO 9000

Important Questions when Choosing a Dealer:

- Years in business?
- Background or qualifications?
- Familiarity with local electrical requirements, codes, zoning regulations?
- Technical and pricing details available?
- List of customers available for reference?
- Copy of installation and maintenance manual available?
- Independent test reports of equipment available?
- Operational experience satisfactory? Able to service systems in remote locations? Under various, possibly harsh, conditions?
- Services offered? Installation? Warranty support? Maintenance?
- Price and payment options? Purchase the system outright or lease on a term arrangement? Performance contracting?
- Member of the Canadian Wind Energy Association?

10. Installing, Operating and Maintaining Your System

- **Considerations when installing your wind energy system**
- **Commissioning procedures**
- **Regular maintenance**

Some micro systems are relatively simple and easy to install and maintain, but, as systems increase in size, more expertise is required. Installation and maintenance of a hybrid system of virtually any size requires a fair degree of knowledge.

Even if you are a do-it-yourselfer, chances are you should be looking for some expert help in both the planning and installation of the system.

If you are involved in the installation, however, chances are you will have a much better understanding of how the system works, and may be able to do maintenance when it is not possible to reach a service representative.

Safety... Safety...Safety

This cannot be emphasized enough when working in the field, and wind turbine installations are no exception. Many potential hazards can injure you when you are installing a wind turbine: you can fall off a tower, you can get struck by falling tools or parts, you can get struck by a blade, you can get electrocuted... the list goes on and on. The only sure way to avoid getting hurt, or worse, is to recognize the potential hazards, and avoid them.

Doing it yourself can also save you money. However, it becomes your responsibility to ensure that you have all the required building and electrical permits and approvals, and that you follow all the necessary electrical codes. Read and follow all instructions carefully to ensure safety.

When in doubt, ask for advice!

Installation

Installation requires excellent mechanical and electrical skills as well as experience working with heavy objects and high voltages. This information is not intended to serve as a "how to," it is merely to set out some very basic rules about installation.

Specifics of installing a wind turbine vary according to the size, design and application. If you are looking for more detailed information, check the turbine's manual, consult the Canadian Standards Association Standard CAN/CSA-F429-M90, *Recommended Practice for the Installation of Wind Energy Conversion Systems*, and ask about publications available from the Canadian Wind Energy Association. We have also listed other resources in Chapter 11 of this guide.

The basic installation rules

- If you do not have the experience or confidence to do it yourself, use an experienced subcontractor.
- Make sure proper climbing and tool securing equipment is used when working with the tower.

Helpful Hints

Discussing the requirements of the application with the electrical inspector and the electrical contractor before you commence the installation will prove to be a valuable investment in time and dollars.

- Ensure nobody stands below the tower since falling objects can cause severe injury.
- If the system is using more than 24 volts, use a qualified electrician, and seek the local utility's approval for hook-up.
- Planning is key to successful and inexpensive installation. Realizing that you forgot to pick up the cable clips when you were in town yesterday is an expensive exercise if you have a crane holding the tower in place!
- Tower foundation requirements are going to depend on turbine design, tower design and size and soil conditions at the site. Before you start, consult a local engineer or contractor to determine whether the soil at the site requires special consideration for the foundation type proposed by the manufacturer.
- An installation must conform to local electrical codes and regulations. For mini and small systems in the multi kilowatt power range, voltages and current are high enough to cause problems if they are not handled correctly. Hire an electrician.

- Make sure you have enough space to assemble the turbine. Make sure you understand each step in the installation and have the right tools at the right time.
- For micro units, turbine erection can be done by hand. Small units may need a tower mounted gin pole and, if the turbine is larger than about 10 kilowatts, you may need a crane or base mounted gin pole. A small mistake during the erection phase can destroy your turbine or case injury. Fully understand all the loads and distances involved in this step.

Commissioning

Once the wind turbine is erected, it must be commissioned. This means that tests are performed on the unit to ensure each of its systems and subsystems performs as they are supposed to. The commissioning process will check, for example, that not only does the brake work, but it will reliably engage during an emergency condition, such as high winds.

Once again, the commissioning procedure becomes more complex as the wind energy system becomes more complex.

The commissioning procedure should be fully outlined in the owner's manual. If the turbine is not commissioned properly, the manufacturer may not honour warranty claims if problems arise later. It may also be necessary to have a manufacturer's representative present during each step of the commissioning procedure, depending on the size of the project.

You have to be careful during commissioning, and each step in the procedure should be well documented (with notes describing tests conducted and results obtained including, where practical, photos).

Operation and Maintenance (O&M)

Most wind energy systems that are commercially available require little owner intervention during operation. For simpler turbines, such as those used as battery chargers or water pumpers, the control systems to ensure safe and reliable operations are quite simple.

More complex designs may change maintenance demands. Many manufacturers offer maintenance service for the wind turbines they install. The manufacturer should at least have detailed information on maintenance procedures and when they should be carried out.

Most turbines can operate for long periods of time without troubleshooting or repair. Minor maintenance is usually done on a quarterly basis or twice a year. More comprehensive maintenance is required annually. Maintenance can range from simple checking of oil levels, which just about anyone can do, to intricate checking of gear backlash or blade pitch settings, which may require a high degree of expertise.

Helpful Hints

Batteries should be kept at the proper operating temperature; freezing will damage the cells.

Charge and discharge rates should not be exceeded.

Special switches, fuses and circuit breakers will help ensure the safe operation of battery systems.

Lead-acid batteries that are not sealed require regular maintenance, topping up of water and verifying state of charge.

Unsealed batteries may give off hydrogen and should be housed in ventilated enclosures.

11. Need More Information?

Natural Resources Canada
Renewable and Electrical Energy Division
Energy Resources Branch
580 Booth Street, 17th Floor
Ottawa, Ontario
K1A 0E4

Fax.: (613) 995-0087
Web Site:
http://www.nrcan.gc.ca/redi

CANMET Energy Technology Centre
Natural Resources Canada
580 Booth Street, 13th Floor
Ottawa, Ontario
K1A 0E4

Fax.: (613) 996-9418
Web Site:
http://www.nrcan.gc.ca/es/etb

The Canadian Wind Atlas
Web Site:
http://www.windatlas.ca

Canadian Wind Energy Association (CANWEA)
100, 3553 - 31 St., NW
Calgary, Alberta
T2L 2K7

Toll Free: 1-800-9-CANWEA
Outside of Canada: 403-289-7713
Fax.: (403) 282-1238
Web Site: http://www.canwea.ca

To read more on wind energy technologies or other types of renewable energy technologies, visit the Web site of NRCan's Canadian Renewable Energy Network (CanREN) at http://www.canren.gc.ca.

Free software available to assist you in your decision.

Renewable energy technologies, such as a wind energy system, can be a smart investment. RETScreen™ just made it easier. RETScreen™ is a standardized renewable energy project analysis software that will help you determine whether a wind energy system is a good investment for you. The software uses Microsoft® Excel spreadsheets, and a comprehensive user manual and supporting databases to help your evaluation.

The RETScreen™ software and user manual can be downloaded **Free** from the following web site at: http://retscreen.gc.ca or by contacting NRCan by phone at 1-450-652-4621 or by fax at 1-450-652-5177.

Appendix A

Typical Power Ratings of Appliances and Equipment

Typical annual energy consumption levels in the following charts are approximate values, based on an estimated number of hours use per small household. Individual habits and the number of family members will have a large impact on overall energy usage. You can estimate your household hours of television viewing, vacuuming, tool usage, and other activities to determine your annual electricity consumption. Check the reverse side and nameplates of your appliances for watts energy consumption, and use those values if they are different from the information in the table.

Large appliance energy consumption is based on Energuide data for the standard major appliances listed. Manufacturer data was used for the high efficiency appliances.

Electric hot water heaters and furnaces are not listed because it is generally not economical to use wind energy for these energy hungry loads.

Typical Daily Energy Consumption of Appliances
(annual kWh includes automatic on/off cycling)

115 VAC Loads		
Appliance/Equipment	**Power Rating (watts)**	**Annual kWh**
Refrigerator:		
450 litres (16 ft^3) standard		440
450 litres (16 ft^3) hi efficiency		200
113 litres (4 ft^3) standard		350
113 litres (4 ft^3) high efficiency		60
Freezer:		
540 litres (19 ft^3) standard		500
540 litres (19 ft^3) high efficiency		440
113 litres (4 ft^3) standard		250
113 litres (4 ft^3) high efficiency		120
Dishwasher, excluding hot water	1300	292
Clothes Dryer	4000	500
Stove		800
Block Heater	500	180
Clock	2	18
Clothes Washer: excl. hot water		
Wringer	300	75
Automatic	500	100
Coffee Maker	900	100
Computer:		
Portable desk top	200	200
Laptop	15	16
Printer	10-300	2-100

Typical Daily Energy Consumption of Appliances
(annual kWh includes automatic on/off cycling)

115 VAC Loads		
Appliance/Equipment	**Power Rating (watts)**	**Annual kWh**
Drill	300	3
Fan, portable	120	70
Furnace fan	350	1100
Hair dryer	1000	20
Iron	1000	140
Lighting:		
60 watt incandescent bulb	60	110
24 watt compact fluorescent (75 watt incandescent equiv.)	24	44
fluorescent 15 cm single ended	9	17
Oven, microwave	1000	100
Radio, transistor	5	10
Saw, circular	400 – 1000	5
Radiotelephone: idle	12	50
Radiotelephone: transmitting	100	2
Single side band radio (idle)	4	12
Stereo, portable	30	22
Telephone, portable	3	26
Telephone, answering machine	6	52
Television:		
14" b&w	40	29
14" colour	90	65
Toaster	1100	40
Vacuum cleaner, portable	800	40
VCR	30	10
Water Pump	400	150
DC Livestock pumps:		
250 litre/hour @ 6 m head	15	
400 litre/hour @ 25 m head	60	
180 litre/hour @ 70 m head	72	

Typical Daily Energy Consumption of Appliances

12 VDC Loads		
Appliance/Equipment	**Power Rating (watts)**	**Annual kWh**
Air Compressor	60	5
Auto Stereo	6	7
Clock, digital	5	44
Drill	144	5
25 watt incandescent bulb	25	46
25 watt equivalent fluorescent	25	46
Circular saw	200 – 1000	5
Television:		
b&w (2 hr/day)	20	15
colour (2 hr/day)	60	45
Toaster	1100	40
Ventilation Fan (15 cm blade)	24	5
Water Pump:		
13 l/min automatic demand	90	70
11.6 l/min	36	26
7.5 l/min	18	13

Worksheet #1. Annual Energy Consumption

Appliance/Equipment	AC	DC	Rated Wattage (W)	Hours per day	Hours per year	Annual Wh
Total Annual Energy Consumption						Wh (kWh)

Worksheet #2. Selecting BOS Equipment

BOS Component	Description	Specification	Required (yes/no)
Batteries			
DC to AC Inverter with:			
Remote Start Signal			
"true sine wave"			
Back-up Generator Set:			
Manual Start			
Remote Start			
Other BOS Equipment:			
Battery Charger			
Disconnect Switch			Yes
Monitoring Equipment			
Wiring, Miscellaneous			Yes
Other Equipment (e.g. rectifier)			

Worksheet #3. Costing Estimates

Initial Costs	**No. of Units**	**Cost/Unit**	**Total Cost**
Equipment and Materials			
Wind Turbine			
Tower			
Tower Foundation			
Batteries			
Inverter			
Disconnect Switch			
Transfer Switch			
Distribution Box			
Control Building			
System Monitor			
Circuit Protection			
Wiring, Conduit, Misc			
Scheduled Spare Parts			
Generator Set			
Total Equipment/Material Cost			
Planning Service Costs (for larger mini and small systems)			
Prefeasibility Study			
Feasibility Study			
Project Development			
Engineering			
Transportation			
Access Road Construction			
Erection and Installation			
Contingency			
Total Planning/Installation Service Cost			
Total Initial Costs			
Annual Costs	**Frequency (yrs)**	**Total Replace Cost**	**Total Annual Cost**
O&M – WTG	annual		
O&M – Batteries	annual		
O&M – Generator set (including rebuild)	annual		
Generator Fuel and Lubricant	annual		
Battery Replacement			
Gen-Set Replacement			
Other Part Replacement			
Miscellaneous			
Total Annual Costs			

Worksheet #4. Dealer Information

	Dealer 1	Dealer 2	Dealer 3
Dealer Name:			
Address:			
Phone:			
Fax:			
Contact:			
Years in Business			
Qualifications/Background			
Familiar with local electrical requirements, etc.			
Technical/pricing details available?			
References			
System manual available?			
Test reports of equipment available?			
Experience satisfactory?			
Services offered:			
Installation?			
Warranty support?			
Maintenance?			
Price			
Payment options			
Member of CanWEA			
General comments/			
Observations			

Appendix F

Using Net Present Value (NPV) to Evaluate a Project and Comparing Unit Costs of Energy

This section on Net Present Value and the one following on Unit Costs of Energy are not intended to serve as a "how-to," they are intended only to give you an indication of what a professional will consider when doing a full economic analysis.

Using Net Present Value (NPV) to Evaluate a Project

Larger, more costly projects require a very accurate analysis to see it they make economic sense. This is done using a calculation known as Net Present Value.

Net Present Value determines how much money you would have to put aside today to pay for the start up and operating costs of the project over its lifetime – keeping in mind that if you put money aside today, it would earn interest over the course of the project. For example, a Net Present Value calculation can tell you how much money you would have to put in the bank today in order to have $1,000 in the bank five years from now at an interest rate of 5 percent.

For purposes of the Net Present Value calculation, the rate of interest is referred to as the "discount rate." Today's dollars will also be worth more in the future because of inflation.

Most computer spreadsheet programs have a function to find Net Present Value, if you want to try the calculation yourself.

By comparing the costs of different energy options in today's dollars, the true economic value of any one option can easily be seen.

Table 2 shows how Net Present Value has been applied to four possible energy alternatives: a wind energy system with batteries; a photo-voltaic system with batteries; an extension to the grid; and, a diesel generator set with batteries. The calculation shows that despite the fact the wind energy system does not have the lowest initial cost, over time, its cost is the lowest of the four options.

It makes a number of assumptions which are detailed in the table caption.

Comparing Unit Costs of Energy

When alternate approaches produce different amounts of energy, often the best way to make a comparison is by calculating the unit cost of the energy, usually expressed in dollars per kilowatt hour ($/kWh). In these situations, it is important to compare projects based on the present value of their unit costs of energy, to make sure they are being evaluated based on a common variable.

Let us consider the example of a wind energy system as an alternative to extending a line to the grid. In our example, we will consider establishing a 2 kilometre line from the grid, as compared to a 500 W wind energy system.

In the wind energy system, design considerations do not permit an increase in the amount of energy the system can provide. The grid, on the other hand, can accommodate an almost unlimited growth in demand. To compare them fairly, we have to look at the unit cost of energy generated by the wind energy system over its lifetime with the unit cost of the energy generated by the grid. It is also best to compare the net present value of the cost of a kilowatt hour of energy.

We set out the sample calculations on page 44.

In this case, the wind energy option is not the preferred choice. Extending a line to the grid will cost $1.71 per kilowatt hour while wind generation will cost $1.82 per kilowatt hour, in today's dollars.

Table 2. An Economic Comparison of Costs

Year	500 W Wind Energy System with Batteries		750 W PV System with Batteries		2 km Extension to the Grid		1 kW Diesel Genset with Batteries	
	Initial Cost and 5 yr. battery repl.	Annual O&M Cost (3% of system cost)	Initial Cost and 5 yr. battery replacement	Annual O&M Cost (1% of system cost)	Initial Cost (2 km grid extension)	Annual O&M Cost ($16/month + $0.08/kWh)	Initial Cost and 5 yr. battery repl. 3 yr. gen-set repl.	Annual Fuel, Oil and O&M Cost (3% of system cost)
0	$7480		$10095		$10000		$2280	
1	0	$194	0	$100		$225	0	$448
2	0	$200	0	$103		$233	0	$462
3	0	$206	0	$106		$241	$874	$476
4	0	$212	0	$109		$249	0	$490
5	$580	$219	$580	$113		$258	$580	$505
6	0	$225	0	$116		$267	$955	$520
7	0	$232	0	$119		$276	0	$535
8	0	$239	0	$123		$286	0	$551
9	0	$246	0	$127		$296	$1044	$568
10	$672	$254	$672	$130		$306	$672	$585
11	0	$261	0	$134		$317	0	$603
12	0	$269	0	$138		$328	$1141	$621
13	0	$277	0	$143		$340	0	$639
14	0	$285	0	$147		$352	0	$658
15	$779	$294	$779	$151		$365	$2025	$678
16	0	$303	0	$156		$378	0	$699
17	0	$312	0	$160		$392	0	$720
18	0	$321	0	$165		$406	$1362	$741
19	0	$331	0	$170		$421	0	$763
20	0	$341	0	$175		$436	0	$786
NPV	$8613	$2831	$11228	$1456	$10000	$3416	$7003	$6529
Total (Initial, Equipment Replacement and Annual Costs)		**$11444**		**$12684**		**$13416**		**$13532**

Comparing the Costs of a Unit of Energy

	500 W Wind Energy System with Batteries	2 km Extension to the Grid
Energy Supply	Energy supply remains constant at 1.5 kWh/day, 548 kWh/year over the 20-year life of the system	Energy supply increases by 3 percent each year for 20 years, starting at 548 kWh in the first year, based on 1.5 kWh/day for that year
Total energy supplied after 20 years	6,280 kWh (with no load growth and after NPV calculation)	7,980 kWh (with 3 percent load growth and after NPV calculation)
Total NPV of the system costs after 20 years	$11,445	$13,629 (includes 3 percent increase in total annual cost of electricity due to increased load)
Present Value of unit cost of electricity	$1.82/kWh	$1.71/kWh

Assumptions for Table 2

- For systems with batteries: The equipment and material costs include the initial hardware costs plus the cost of replacing batteries every five years.
- For the diesel genset system: The equipment and material costs include the cost of replacing the genset every three years.
- For the grid extension project: The cost for the extension to the grid is $5,000 per kilometre; O&M costs are $0; the annual costs assume a 6% annual increase in the grid kWh charge; a $16/month service charge to connect to the grid; and a cost of $0.08/kWh charged by the utility for electricity.
- For all systems: The annual inflation rate for maintenance, battery costs, and hydro connect fee is 3%; the discount rate for the calculation of NPV is 6%.

Glossary

Terminology

Amp (A) is a measure of electric current; one A of current represents one coulomb of electrical charge moving past a specific point in one second (1 C/s = 1 A).

Amp-hours (Ah) is used to express the storage capacity of a battery (that is, 100 Ah battery can provide 1 A over a period of 100 hours or 100 A over a period of 1 hour).

Anemometer is a device used to measure wind speed.

Annual average wind speed (AWS) is the average of all instantaneous wind speeds for a location over the course of a year.

Annual energy output (AEO) is the total energy produced by a wind turbine over the course of a year.

BOS is the Balance of System or the equipment beyond the standard wind turbine and tower required to install a complete wind system.

Commissioning is the procedure of inspection, installing and monitoring of a new wind energy system to confirm proper operation at startup.

Control system is a sub-system that receives information about the condition of the wind turbine and/or its environment, and adjusts the turbine to maintain operation within prescribed limits.

Current is the rate at which electricity flows through a conductor; measured in amps (A).

Cut-in wind speed is the lowest wind speed (at hub height) at which the turbine starts to produce power.

Cut-out wind speed is the maximum wind speed (at hub height) at which the wind turbine is designed to stop producing power.

Discount Rate is the assumed interest rate that is applied to calculate the time value of a future cash flow. It should account for the principal and interest that could have been earned had the money used for the system been invested in some other way.

Downwind wind energy system is a turbine whose rotor operates downwind of the tower, that is, in the main wind direction.

Energy is that which can accomplish work; usually measured in Watt-hours (Wh) or kilowatt- hours (kWh).

Free standing tower is a tower that does not use external supports, such as guy wires.

Generator set (genset) a machine using an internal combustion engine (gasoline or diesel) and generator to produce AC or DC electricity.

Guy anchor is a foundation designed for guy wire connection.

Guy cable is a cable or wire used as a tension support between a guy anchor and a tower.

Guyed tower is a tower that uses external guy supports.

Horizontal axis wind turbine (HAWT) is a wind turbine whose rotor axis is horizontal or parallel to the ground.

Hub is the fixture for attaching the blades or blade assembly of a HAWT to the rotor shaft.

Hub height is the height of the centre of the wind turbine rotor above the ground. For a vertical axis wind turbine the hub height is the mid-height of the rotor.

Maximum power (wind turbines) is the highest sustained level of net electrical power delivered by a wind turbine in normal operation (approximately the same as Rated Power).

Mean wind speed is the statistical mean of the instantaneous value of the wind speed averaged over a given time period which can vary from a few seconds to many years.

Nacelle is the housing which contains the drive-train and other elements on top of a horizontal axis wind turbine tower.

Net present value (NPV) is the value of a system's lifecycle costs in today's dollars.

Photovoltaics (PV) is the direct conversion of sunlight into electricity.

Power is the expression of the rate of doing work. It is usually measured in watts (W) or kilowatts (kW).

Power curve is a graph that depicts the power output of a wind turbine as a function of wind speed.

Power output is the amount of power produced by a wind turbine at a given speed.

Rated power is the power produced by a wind turbine at the rated wind speed (approximately the same as Maximum Power).

Rated wind speed is the specified wind speed at which a wind turbine's rated power is achieved.

Rayleigh wind speed distribution is a statistical curve whose shape approximates the actual shape of a wind speed distribution curve. It is used as a standardized distribution curve to estimate the energy production performance of a wind turbine.

Rotor is the set of blades of the wind turbine including the hub.

Rotor speed is the rate of rotation of a wind turbine rotor about its axis.

Simple payback is the length of time required to recover the cost of an investment from the cash flow produced by the investment. It does not account for the discount rate.

Swept area is the area through which the rotor blades rotate. It is the area of the disk formed by the blade rotation.

Tower is the structure of a wind energy system that supports the rotor and power train, etc., above the ground.

Upwind wind energy system has a rotor which operates upwind of the tower. These systems use yaw mechanisms to keep them pointed into the wind.

Vertical Axis Wind Turbine (VAWT) is a wind turbine whose rotor axis is vertical to the ground. These turbines do not have to be yawed into the wind. They will accept wind from any direction.

Voltage is a measure of the electric potential difference between two points; usually expressed as volts (V).

Watts is the unit to measure the rate at which work is done (power) or energy is consumed; usually expressed as Watts (W) or kilowatts (kW). Note that W = V x A.

Yaw is the rotation of a HAWT about its vertical axis to align it with the wind.

Symbols

AC	=	alternate current
D	=	rotor diameter (for HAWTS) m
DC	=	direct current
DOD	=	Depth of discharge
kW	=	kilowatt
kWh	=	kilowatt hours
PV	=	Photovoltaic
W	=	Watt

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