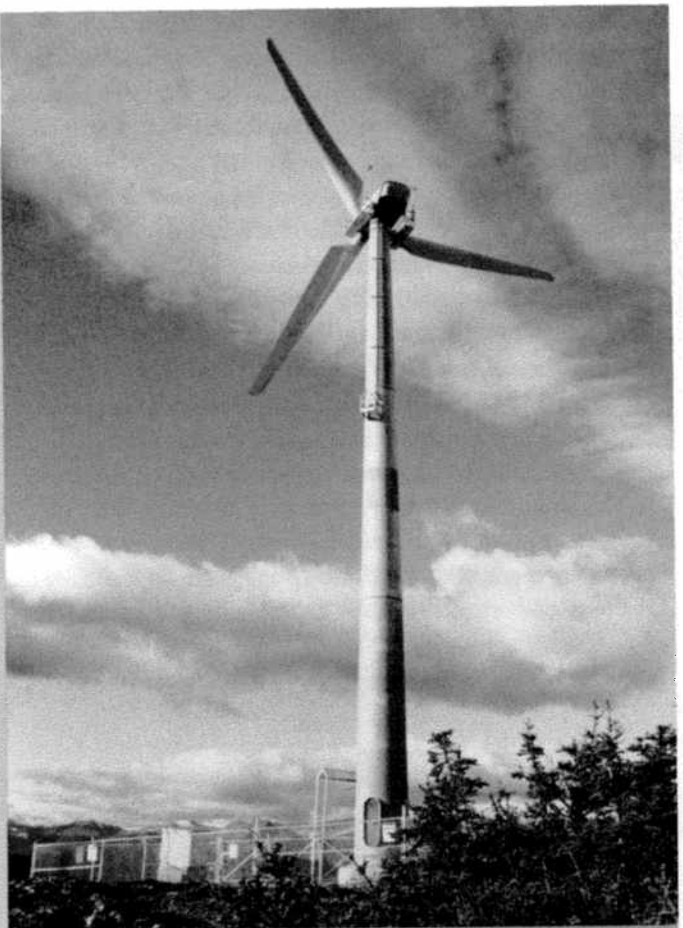

Haeckel Hill Wind Turbine (Courtesy of YEC/YECL)

This article is part of a series of publications on the Yukon's energy resources. It provides an overview of wind development in the Yukon and the factors affecting its development. It is intended to encourage investment and to stimulate informed discussion among representatives of industry, government, and members of the community. Appendices of a more technical nature are available separately for each of the articles in this series. You can obtain copies of these appendices through the

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Wind

Overview

The Yukon Government is committed to seeking ways to reduce dependence on imported fossil fuels, in order to increase economic independence and encourage the local energy industry. One option is to use wind to generate electricity. Currently, the wind potential of the Yukon is largely unknown and undeveloped. However, there is enough knowledge of the Yukon's wind regime to know that there are sites where winds are consistently strong enough to make commercial wind-farming possible. The strongest winds occur during the winter months, and the demand for electricity peaks during the winter months. Thus there is the potential for commercial scale wind-generated electricity to offset diesel-generated electricity used to meet the winter demand.

The Yukon Energy Corporation (YEC) is interested in wind power as a commercially viable energy supply option. To this end, YEC is continuing with a commercial test turbine project, that it began in 1993. YEC is also continuing studies of the wind regime at various Yukon locations.

Although there are less than a dozen small, non-commercial turbines in operation in the Yukon, there is the potential for an expansion of this market. This area offers entrepreneurs the opportunity to sell wind-generating systems to new customers, sell upgraded systems to people with existing wind-turbines, and to develop and provide maintenance expertise.

From the utilities' perspective the main challenge to using wind-generated electricity in the Yukon, is that it does not yet appear to be as steady, reliable and economical as diesel-generated electricity. So far, regulatory and environmental issues have not presented issues of concern for development.

The Resource

Yukon Wind Development

Wind power has been used, on a small scale, since the 1950's in the Yukon to provide electricity to people in isolated localities, far from the electrical system. Currently, the Yukon Government, and the Yukon's public utility, the Yukon Energy Corporation (YEC), is interested in supplementing diesel-generated electricity with less expensive electricity supply options in off-grid communities. Wind generation is one supply option YEC is considering. There is also an increasing interest by YEC and other Yukoners in using wind-generated electricity to augment the power supplied to the major electrical transmission systems. On these systems, wind power is seen as one possible means to reduce the amount of diesel-generated electricity required during winter months. In the winter, water levels available for hydro generation are low, but wind power is at its peak.

Current wind development in the Yukon can be divided into three categories:

1. the commercial test turbine owned by YEC;
2. small turbines (under 4 kW); and
3. the wind regime monitoring studies being undertaken by YEC, the Boreal Alternate Energy Centre and some mining companies.

Commercial Test Turbine

In 1993 YEC installed a wind-turbine on Haeckel Hill, near Whitehorse. Due to the severe rime icing events identified by a previous monitoring program, YEC found it necessary to adapt wind technology to local conditions, before considering a wind-farm development. Rime ice forms large granular deposits on the windward side of the wind-turbine, particularly on

Some commonly asked questions about wind energy

Why are wind-turbines sometimes motionless when the wind is blowing?

This is generally because the wind is not blowing hard enough. A wind-turbine requires a minimum wind speed of 4 to 5 metres per second. In a wind-farm, one turbine may be situated slightly more favourably than another and consequently be fully turning while another is still waiting for sufficient wind.

Is there any relationship between the revolution speed of a turbine and the 60 Hz (60 oscillations per second) of the electrical grid?

Turbines with an asynchronous generator turn at one or two fixed speeds. This generator is controlled by the grid frequency and can deviate from 60 Hz by only 2%. If there is insufficient wind and the turbines have not yet been switched onto the grid, they will turn at lower speeds. Wind-turbines with synchronous generators generally operate at variable speeds.

How are wind-turbines stopped?

All wind-turbines have an automatic control system that continually monitors them. For example, if the temperature gets too high, the wind-turbine shuts down. A wind-turbine can be stopped in various ways. It can be turned out of the wind, in which case it no longer receives any wind and comes to a halt. The turbine's parking brake can then be set. A wind-turbine can also be stopped by a disc brake or by turning the rotor blades so that they no longer receive any wind.

What about the negative visual impact of wind-turbines on the landscape?

Studies reveal that people are most concerned about the negative visual impact of wind-turbines on the landscape in the placement of windmills, which is why project developers devote a great deal of attention to fitting wind-farms into the landscape. Wind-turbines must match the existing structure of the landscape. Reactions from the public sector indicate that people find wind-turbines situated in rows along dykes, canals and highways attractive. People consider wind-turbines in a cluster arrangement less appealing.

Notably, the attitude of residents living in the vicinity of wind parks becomes more positive with time. The wind-turbines become an element of daily life.

the leading edges of the blades, seriously impeding its performance.

The commercial turbine YEC chose for the project is a Bonus 150 kW Mark III turbine. This is a three bladed, horizontal axis, upwind and stall regulated design. 150 kW is small for a commercial turbine, but costs less than larger turbines and was seen to be sufficient for a development program. The project cost of approximately $800,000 was shared between the Federal and Territorial Governments ($300,000) and YEC ($500,000). The project is still running, with modifications being made yearly.

From August 1993 to July 1996 the Haeckel Hill wind-turbine produced approximately 675 MWh of electricity. This is equivalent to the power that could be derived from 866 barrels of diesel. Stated another way, the turbine has produced enough power per year (on average) to supply 23 non-electrically heated homes.

An engineer from YEC describes the project so far:

> *"On the whole, ... [YEC] is satisfied with the performance, especially considering the turbine's physical location, the unfamiliarity of maintenance personnel with this type of equipment, and our dependence on one or two key people."*

Small Turbines

There are at least seven privately owned small wind turbines in the Yukon, as well as one turbine owned by Parks Canada at the Sheep Mountain Interpretive Centre in Kluane National Park. The systems range in cost from $5000 to $20,000. Six of the turbines are located along the eastern border of Kluane National Park. Another turbine is situated near the North Klondike Highway between Whitehorse and Dawson City, and one more is located near the Alaska Highway between Whitehorse and Haines Junction. All of the turbines are at sites too far from the nearest electrical transmission system to be economically connected to it. The owners use the turbines to power lights, electronic equipment, household appliances and even larger appliances such as a freezer and water pump. Battery storage systems in conjunction with inverters are used. The homes are all heated with wood and have gas generators for backups, supplemented in some cases with propane backup for the lights and propane only for hot water tanks and refrigerators. The owners seem generally pleased with their systems, citing the low maintenance, quietness (compared with a gas generator) and independence from the larger system as advantages. However there is little actual data on the performance, or economics of these small turbines.

HAWT or VAWT?

The following is taken from a comparison of the Horizontal Axis Wind Turbines with the Vertical Axis Wind Turbines, provided by Dennis G. Shepherd, in his article, "Wind Power". The article appears in the *Handbook of Energy Technology and Economics* edited by Robert A. Meyers, 1983.

HAWT technology and experience are much greater than for VAWTs.

HAWTs have a higher performance capability than do VAWTs.

HAWTs require a higher tower structure than do VAWTs.

HAWTs generally require blade pitch change, total or partial, to maintain constant speed and to control overload, although there are exceptions.

HAWTs have a much smaller footprint than VAWTs.

VAWTs have inherent maximum output control, because of stall.

VAWTs have transmission, generator, and control system close to the ground.

VAWTs experience a lower average wind speed at a given site, as the absence of a tower makes the equatorial height lower than the hub height for HAWT.

VAWTs can accept wind from any direction instantaneously and no yaw mechanism is required.

VAWTs may present a somewhat more difficult problem with torque ripple than do HAWTs.

VAWTs may require auxiliary starting means.

VAWT blades can have constant cross section and no twist but may require longitudinal curvature.

Wind Monitoring Studies

During 1995 and 1996 YEC initiated monitoring the wind regime in four Yukon communities: Whitehorse, Destruction Bay, Dawson City and Old Crow. The choice of these communities was based, in part, on the results of the past studies described in the insert *History of Wind Development in Yukon.*

Whitehorse

The Whitehorse monitoring study, while still collecting data on the wind regime, is continuing as part of a development program for modifications made on the wind turbine to deal with the rime icing problem. More about this program is described in the insert *Haeckel Hill Development Wind-Turbine.*

Dawson City

The Dawson City study was planned as a winter only, heated instrument monitoring project. It was supposed to have run from the fall of 1995 through the winter of 1995-96. However, the propane-fueled instrument heating system did not work well and the study was cancelled at the beginning of January 1996. YEC had hoped that this study would build on the results of previous research undertaken by YEC that showed the Dawson City study site as having some commercial potential. An accurate picture of the wind regime at the Dawson City site was not available from that study because a considerable amount of data was lost over the winter months due to anemometer icing.

VAWTs from Alberta Renewable Energy test site. (Courtesy of J. Maissan of YEC, 1996.)

Destruction Bay

The results of both the National Research Council's and the Yukon Government's wind studies at Destruction Bay described the area as having an uneconomical wind regime. YEC is building on these past studies with its own research. YEC's study differs from past studies in four ways:

1. different measuring equipment is being used;
2. the measuring equipment is being heated electrically through power obtained from the diesel-powered Destruction Bay/Burwash Landing power system;
3. the monitoring tower is 10 metres higher than the National Research Council's tower; and
4. YEC has been able to operate a more reliable monitoring program.

The study commenced in the fall of 1995 and has been producing data steadily. YEC has not yet analyzed the results.

Old Crow

The Old Crow study commenced in the fall of 1996. This study also uses heated measuring instruments, with power obtained from the local diesel-based power system.

The Boreal Alternate Energy Centre is monitoring the wind regime at the Yukon College Campus in Whitehorse. The college is located mid-way up a hill, and so Boreal hopes it will provide them with a bridging site, between the small sites located on valley bottoms and the ridge-top monitoring sites. Boreal is also conducting the Haeckel Hill monitoring study for YEC.

Occasionally, mining companies conduct studies of the wind regime near mine sites. This is to comply with environmental regulations that require the wind data for base-line environmental reviews.

History of Wind Development in the Yukon

Although it is not documented, there have probably been small wind-turbines used in isolated areas of the Yukon for some time. As early as the 1950's there was a wind-turbine in operation in Old Crow. This was used to power lights for the town's store.

In the early 1980's (1982-1984) the National Research Council (NRC) monitored the wind regime at Destruction Bay. Destruction Bay was thought to be the windiest place in the Yukon. However, the results of that study lead NRC to conclude that wind-generated power would not be economical in the Yukon.

Later that same decade (1987-1988) the Yukon Government's Public Works Branch monitored the wind regime, again at Destruction Bay. They installed the monitoring equipment at the Destruction Bay Highway Grader Station. They too, concluded that wind-generated power would not be economical.

Soon afterward, the Boreal Alternate Energy Centre conducted a study of the Whitehorse upper air wind regime, using weather balloon data. Dr. Doug Craig, the director of Boreal, had a long time interest in wind energy, heightened by the oil embargo of the 1970's and his work with the Science Council of Canada. As a mountaineering geologist Dr. Craig did a great deal of flying and spent considerable time on high, windy ridges. This sparked the idea that the wind speed around Whitehorse may increase significantly with altitude — an idea that was proven with the weather balloon data collected from the Whitehorse Environment Canada Weather Centre. The data and analysis are presented in the Boreal report, *Wind Energy Potential Whitehorse, Yukon*, August 9, 1990.

Boreal's next step was to set up their own wind monitoring station on Haeckel Hill. They did so in 1990 with financial support from the Yukon Energy Corporation (YEC) and the Federal and Territorial Government's Economic Development Agreement. The Yukon Electrical Company Limited donated the old NRC monitoring equipment as well as money for tools and other necessary equipment to undertake a monitoring study.

With YEC's support, Boreal extended the monitoring program to sites on Flat Mountain and Mt. Sumanik during 1991 and 1992. Also in 1992, YEC began two-year wind monitoring studies in Haines Junction, Dawson City and Tagish. These studies found Dawson City to be the most favourable site of the three, so in 1995 YEC undertook another study in Dawson City. The study was cancelled at the beginning of January 1996 because the monitoring instruments kept freezing.

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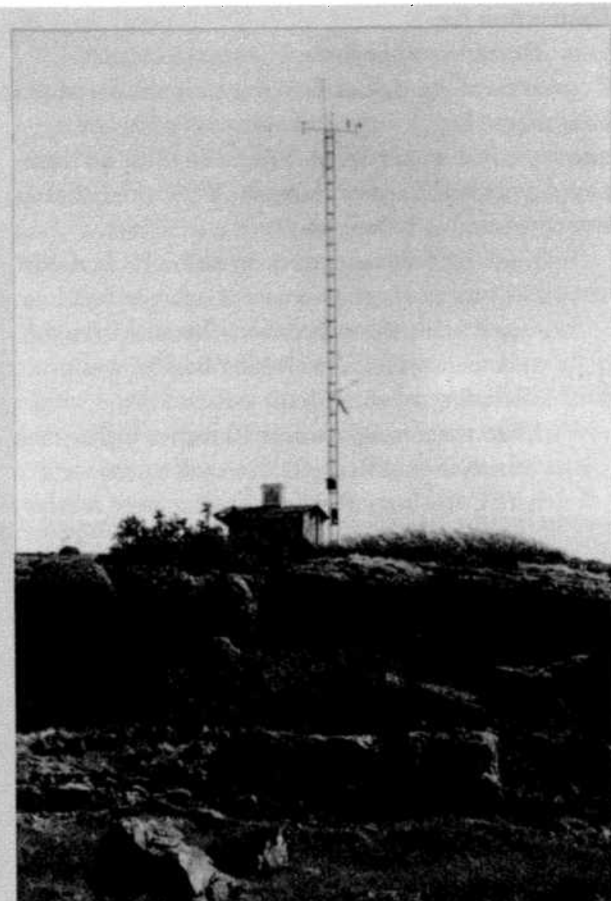
YEC found Boreal's research results from Haeckel Hill positive for commercial generation. In 1993 they installed a wind-turbine on Haeckel Hill to adapt proven wind-turbine technology and to analyze the potential for generating power, under the extreme cold temperatures and rime icing conditions encountered in the higher altitudes. The project was financed by YEC, Natural Resources Canada and the Canada - Yukon Economic Development Agreement. The Haeckel Hill wind-turbine project is still continuing in 1997.

In 1995, YEC installed a wind monitoring station at Destruction Bay and in 1996 established a monitoring station at Old Crow.

In 1991 the Northern Research Institute and Yukon College installed a wind-photovoltaic hybrid energy demonstration project at the Yukon College campus, with support from the Territorial and Federal Governments and YEC . The project had some administrative challenges that kept it from achieving optimal performance for some years. Since February 1996 the system has been part of a Boreal study of the wind regime at a mid-elevation site. Boreal improved the site by installing a new data logging system, invertor, and control master for the energy distribution. The new equipment has allowed for a consistent monitoring program since February of 1996 and will continue throughout the 1996-1997 winter.



Haeckel Hill wind monitoring site. (Courtesy of YEC/YECL Archives)

Haeckel Hill Development Wind-Turbine: Project results from 1993 to 1995-1996 winter season.

The following is from a paper entitled, *Adaptation of a Wind Turbine for Sub-Arctic Conditions with Severe Rime Icing*. The paper was presented by John Maissan, of the Yukon Energy Corporation, at the Canadian Wind Association's 1996 Annual Conference.

The following things worked well and have not needed further attention:

- The tip up tower worked well even though it is not as easy to tip up or down as expected.
- The low-temperature steels have not been a problem so far.
- Lubrication with synthetic products has worked well.
- The heating systems in the gearbox, generator, and electronic cabinets have been very reliable.

Aspects of the project that did not work previously but have since been overcome:

- The heated bearing anemometer and wind vane still iced up and were replaced with fully heated Hydro-Tech instruments which have not iced up.
- The overhead power line was causing about five outages per month due to a heavy accumulation of ice and was replaced with a buried cable which is not affected by the ice.

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Aspects of the project that did not work and need further attention:

- The electrical contacts between the main blade section and the tip have not worked reliably under icing conditions. Two redesigns have failed. [YEC] has redesigned the contacts again, as adequate leading edge heating is critical to coping with rime ice.
- Changing the blade angles for the summer to increase warm weather output was not successful; the opposite happened. The leading edge heaters attached to the outside of the blade had apparently changed the shape of it enough to change the aerodynamics. They were returned to their original position and no further adjustments will be made.
- The ice detector supplied was not effective and was removed from the control circuit; the heating circuits are simply switched on for the winter. A new icing detector has been purchased and will be tested on site (but not in the control circuit) during the 1996-1997 winter.

The leading edge blade heaters (1/4 watt per square inch) have worked reasonably well, even though one burned out early last winter [1995]. They could be more effective in very severe rime icing and in very cold temperatures. Heat output was increased by 50% for the winter of 1996-1997.

The effect of rime icing on the blades of the wind turbine is such an important issue that it is worth examining in detail. Without blade heaters, rime ice builds up especially heavily on the leading edges, and the build up increases with distance from the blade root. It seems to be directly related to the velocity at any point and therefore perhaps the amount of moisture or moist ice it contacts. When shut down, the ice builds up on the edges of the blade surface facing the wind. When running through an icing event, the ice buildup on the "back" of the blade is much less than on the "front". Ice can also build up on the trailing edge.

The heaters do, under lighter icing conditions, keep portions of the blade following the heater clear. Under heavier icing conditions ice can build up on the blade right up to the heater. Buildup of ice on the leading edges does not occur except under the most severe conditions, and it clears off afterwards.

[YEC] has concluded that more heat on the front of the blade would be of benefit. It should be in the form of a wider leading edge heater, perhaps 12 inches rather than the present 6 inches, with the increase applied to the front of the blade. It is also obvious that the leading edges of the tip need to be heated to minimize the air drag and production losses associated with icing.

Future Developments

The Yukon Energy Corporation is exploring future wind developments. A draft report has been written which presents an analysis of various options for future wind-farms. No release date has been given for a final report.

Future developments in the small wind-turbine sector will come from existing owners upgrading their systems, and with an increase in the number of people owning systems. Avtech Services Ltd. is a local company which specializes in small energy systems. It is currently selling and installing them in the Yukon.

Yukon's Wind Regime

Studies of the Yukon's wind regime, dating back to the early 1980's, have begun to illustrate the Yukon's potential for wind-generated electricity. Studies have been conducted at sites near Destruction Bay, Dawson City, Haines Junction, Tagish, and Whitehorse. All but the most recent studies done at the Haeckel Hill site, near Whitehorse, have had data deficiencies: in some cases to the extent that there was insufficient data for analysis. The problem was rime ice accretion on the anemometers, disabling them for extended periods. Even so, it is possible to draw some general conclusions about the Yukon's potential for wind-generated electricity:

- wind velocities are greater at higher elevations;
- winds have the greatest velocities in the winter months, correlating with the period of peak electrical demand; and
- rime icing is a significant factor in reliability and production levels.

Wind velocities at Haeckel Hill, Mt. Sumanik and Flat Mountain (all near Whitehorse) have wind velocities greater than six metres per second (see page 8). This is considered adequate for wind farming.

Site	Average wind velocity
Haeckel Hill (4700 ft)	4000 ft 6.6m/s; 5,000 ft 6.9m/s; 6,000 ft 7.3 m/s
Mt. Sumanik (5400 ft)	~7.5 m/s
Flat Mountain	annual average unknown, but estimated to be significantly (~15%) greater than velocity at Mt. Sumanik

Studies at the three sites describe the Whitehorse ridge-top wind regime as having winds predominantly from the southeast, south and southwest. The period from September to May constitutes 85% of the energy available throughout the year. The strongest and most persistent winds occur during December, January and February. The period from June to August has a greater range of wind direction than the rest of the year. Turbulence in the area is minor and there is no significant variation in the wind characteristics on a daily basis. The atmosphere is non-corrosive, but the climatic conditions are conducive to rime icing. Glaze icing (a smooth, coating of clear ice) is uncommon. The actual output of wind-turbines, compared to their constant full output, is estimated to be from 25 to 35 percent. This percentage is known as the "capacity factor" and is commonly from 20 to 40 percent. Most commercial wind-farms try to have capacity factors above 30 percent. (For more information on capacity factors, see the article below.)

Tagish wind monitoring site. (Courtesy of YEC/YECL Archives, 1992.)

Understanding Capacity Factors

The *capacity factor* of a wind generator is a measure of its productivity which varies with location. It is the ratio of the actual average power output, to its rated capacity. For example, if the actual average output of a turbine is 75 kW, but the turbine's rated capacity is 225 kW, then the capacity factor is 75/225 = .33, or 33%. Wind turbine capacity factors are commonly from 20% to 30% and vary directly with the wind. The term 'plant factor' is less commonly used to refer to the same ratio.

Economic Issues

Meeting Load Growth

Electricity can be produced in many ways, each of which has its advantages and disadvantages. The best choice depends on many factors:

- scale of development;
- seasonal variations in the load;
- seasonal variations in energy supply;
- duration of the load, i.e. how many years, and what is the risk that the load will be terminated early;
- load location, i.e. is it on the grid and if so, where;
- environmental constraints; and
- stakeholder preferences.

Factors Required For Viable Utility-Scale Wind Generation

The factors required for viable wind generation include:

- adequate wind regime (consistent wind velocity greater than 6 m/s);
- large capital investment;
- a market for power which can accommodate the variability of wind supply, or a system with other sources that can smooth out the variable supply;
- the capability to produce electricity at a cost reasonably similar to or less than competing production methods (i.e. diesel generation); and
- skilled maintenance workers.

Cowley Ridge wind farm. (Courtesy of J. Maissan of YEC, 1996.)

Factors Required For Viable Small Scale Wind Generation

- adequate wind regime;
- relatively large capital investment;
- the capability to produce electricity at a cost reasonably similar to or less than competing production methods (i.e. a gas generator or a utility's rates);
- skilled maintenance worker; and
- electricity storage and/or reliable backup power.

Dutch Industries' water pumping windmill at Alberta Renewable Energy test site. (Courtesy of YEC, 1996.)

About Wind Energy

The Canadian Wind Energy Association (CANWEA) maintains an internet Web site at canwea@ad.com. The following excerpts are from CANWEA's English Brochure, as it is found on the association's Web site.

The Technology

There are two basic types of modern wind energy turbines: the horizontal axis wind turbine (HAWT), which looks like a propeller; and the vertical axis wind turbine (VAWT), which resembles an inverted egg beater. The most common wind energy turbines, by far, are the HAWTs. In both types, the rotating blades capture the energy in the wind and use that power to generate electricity or pump water.

Wind Energy Test Sites

Canada has two comprehensive testing sites where new designs are monitored by computer-controlled instrumentation systems and analyzed by experienced engineers and technicians. The Atlantic Wind Test Site, on Prince Edward Island, focuses primarily on electrical generation systems. It also operates an innovative demonstration system for wind diesel technology. The Alberta Renewable Energy Test Site, near Pincher Creek, concentrates on water pumping systems that are of particular use in Southern Alberta, on the prairies, and for export.

Wind Energy And The Environment

Wind is widely recognized as one of the most environmentally benign energy technologies. No acid or greenhouse gases are emitted. Although the production of a modern wind turbine requires the use of many non-renewable substances, some of which have environmental consequences, the reduction in carbon and acid emissions in the turbine's first year of operation more than compensates for the energy used in production. A 250 kW wind turbine at a favourable site will eliminate approximately 500 tonnes of carbon emissions per year.

Wind Energy Facts

- The world potential of wind energy is estimated to be 10,000 GW. (10 million megawatts)
- The North American potential is over 2,300 GW. Total installed wind capacity worldwide is 3 GW.
- In Canada, we could provide at least 10% of our electricity from wind. There is currently about 20 MW of installed capacity.
- Wind energy is competitive with conventional generation technologies in many regions, even when social and environmental costs are not considered.
- In California, there are over 17,000 operating wind turbines with an installed capacity of over 1,600 MW (enough to power a city the size of San Francisco).
- Canada has a better wind resource than California or Denmark.
- Wind energy results in the highest number of jobs per unit of installed capacity.
- The reliability of today's wind turbines is over 95%.

Markets

Private Sector

Home owners and business operators who install wind turbines in remote locations do so because they feel the advantages are greater than the large capital cost of a wind-energy system. Capital costs can be from $5,000 to $20,000 depending on the system, compared to $2,500 for a gas-generator. The quietness of a small wind turbine, compared to a gas-generator is seen as an advantage. This is especially important to Bed and Breakfast and Lodge owners who are trying to offer a certain ambiance to their customers. The absence of a fuel requirement and the associated storage, hauling and commodity costs are further advantages. Private wind-turbine owners also cite the mechanical reliability of their systems as an advantage. Once a system is installed, often only minor annual maintenance is required.

Utilities

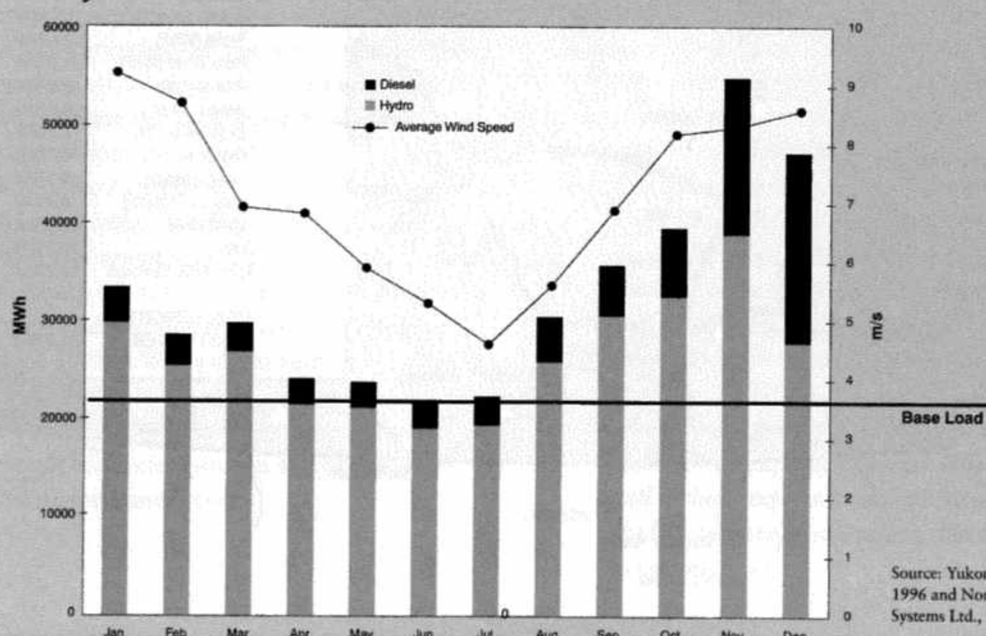
Base load is the minimum constant power required throughout the year on an entire electrical system. (see Figure 1). In 1995, the base load on the Yukon's Whitehorse - Aishihik - Faro (WAF) grid was approximately 25 MW. In the Yukon, base load is met by hydro and diesel-generated electricity. It is important for the base load to be provided by a source that is predictable, consistent and reliable. Wind generated electricity is not seen as a good choice for meeting base load because it is intermittent and not predictable. It could serve base load if it was used in conjunction with a firm peaking source, such as hydro with storage, or diesel.

Peak load is the highest level of power demanded in a given period of time (i.e. hour, day, month or year). The year's peak load in 1995, on the WAF grid, was approximately 78 MW. Approximately 32 MW of that peak was generated by diesel-generators. The largest peak loads occur in the winter months in the Yukon, which is also when the wind potential is at its greatest (see Figure 1).

A utility-scale wind-farm would be most useful displacing diesel-generated power. This could reduce the cost of generating electricity, if it cost less than diesel fuel plus the variable operation and maintenance costs.

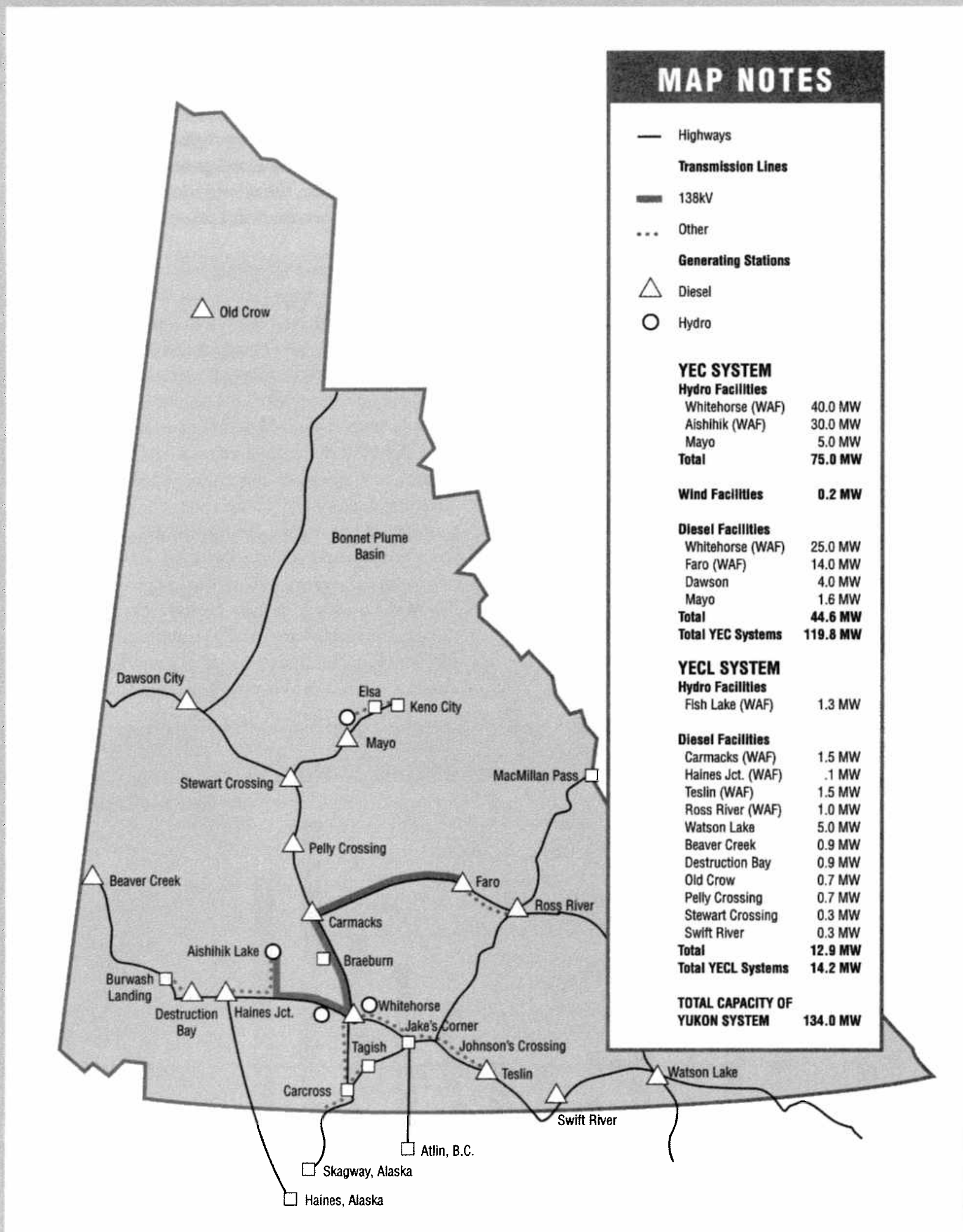
In the off-grid communities both peak load and base load are met with diesel generators. The diesel facilities in the off-grid communities range in capacity from 0.2 MW in Swift River to 5.0 MW in Watson Lake. The majority of community diesel generators have less than 1 MW of capacity (see Figure 2 for a complete list of Yukon diesel facilities). While small wind-farms could provide the same capacity, they could not replace the diesel-generators in these communities due to the certainty of calm periods. However, because these communities are totally reliant on imported diesel fuel for their electricity generation, wind-generated electricity could be welcome as a supplement.

Figure 1. Electricity Generated in the Yukon.



Source: Yukon Bureau of Statistics, 1996 and Nor'wester Energy Systems Ltd., 1991.

Figure 2. Electrical Power Facilities in the Yukon. (YDC 1995 Annual Report)



Load Growth

The current total capacity of the Yukon's electrical system is 134 MW (see Figure 2). According to the YEC 1992 Capital Plan, by the year 2011, YEC is expecting to require as much as 50 MW of new capacity due to increasing electrical load growth and the need to replace decommissioned diesel-generators.

The Yukon's electrical load is driven by mining projects, tourism, government employment and the resulting service sector spin-offs. The load can decrease or increase substantially with the closing or opening of a single mine. This was the situation with the Faro mine in the early 1990's. The mine's last full year of operation, before it reopened, was 1992. In that year the annual load was 456 GWh. In 1994 when the mine did not operate at all, the annual load was 263 GWh - a decrease of 42% from 1992.

Risk and Reliability

Given that wind-generated power would most likely be used to offset diesel-generated power, it is useful to compare the two to gain some perspective. Utility scale wind farms have a large initial capital investment when compared with diesel generators. Diesel generators used for peaking purposes have an installed capital cost of about $500/kW, and diesel generators used for base load have a capital cost of about $1000/kW of nameplate capacity. Wind generators can have an installed capital cost of from $1,800/kW to $2,500/kW of name plate capacity. A wind-generator typically has a capacity factor of from 20 to 30 percent depending on the wind, while a base load diesel-generator can operate at approximately 90 percent capacity. Thus the same sized diesel-generator can put out three times the annual energy.

Operating costs are lower for a wind-farm than for a diesel-plant because wind-generators require no fuel. Operating and maintenance costs could be as low as $0.02/kWh for a wind-farm. For a base-load diesel plant, operation and maintenance costs are about $0.015/kWh to $0.02/kWh with an additional cost for fuel of about $0.08/kWh, giving a total operating cost of $0.095/kWh to $0.10/kWh. More than 75% of a diesel-generator's life cycle costs are due to fuel and operation and maintenance costs.

The price of diesel fuel can vary significantly over time, creating an uncertain economic environment. This increases the risk associated with diesel-generated electricity. However, there is a constant zero fuel cost for wind-power, enhancing the long-term economic stability of the electrical system thus lowering the risk associated with wind-generation.

An advantage that diesel-generators have over wind-generators is that diesel-generators have a dependable, or firm capacity. For example, if 10.8 MW of diesel capacity is installed, then the utility can rely on the ability to generate 10.8 MW of electricity at virtually any given time. However, wind-power cannot offer firm capacity because there will be periods of calm.

Wind is a renewable resource with an endless fuel supply. Wind turbines have no emissions, so using them, rather than diesel-generators has the potential to reduce the amount of CO_2 and other contaminants emitted to the atmosphere. This may be of particular significance if governments expand their efforts to reduce greenhouse gas emissions.

Like diesel-generators, wind-turbines can be added to wind farms incrementally, increasing capacity as needed. If capacity drops and the generators become redundant, it is easier to sell and move diesel-generators than wind-turbines.

New tax measures for renewables and energy conservation may make investing in wind power more attractive in the near future. In the summer of 1996 the Federal Government introduced new measures to make it easier to finance renewable energy ventures. A Canadian Wind Association *News Message* states:

> *"the new measures make the tax treatments. of renewable and non-renewable energy sectors more similar by introducing Canadian Renewable and Conservation Expenses (CRCE) which are similar to the intangible costs claimed by the non-renewable sector as Canadian Exploration Expenses (CEE). These expenses will be fully deductible and allow improved access to financing in the early stages of operations when there may be little or no income to utilize these expenses against. The CRCE will include expenses such as feasibility studies and pre-construction development expenses."*

Rime Icing

One of the biggest obstacles to developing reliable and economic wind farms in the Yukon is the territory's set of climatic conditions that lead to rime icing at the higher altitudes, where attractive wind regimes are found. These conditions are prolonged periods of freezing temperatures, coupled with very high relative humidity. Rime icing has garnered a great deal of attention from the Yukon Energy Corporation (YEC) and the Boreal Alternate Energy Centre in their studies of wind-power on ridge tops. (Ridge tops are believed to be the best places for commercial wind-farms in the territory, due to the increase in wind velocity with elevation.) According to an engineer with YEC, there needs to be a substantial improvement in dealing with this problem to make wind-generated power costs comparable to diesel-generated power costs.

Rime ice builds up on the windward side of objects. It looks similar to hoarfrost. A colourful description of rime ice is supplied by YEC's senior utility engineer, John Maissan:

> *"... any solid object accumulates ice which "grows" into the wind. Trees become ice domes, towers become ice posts, powerlines enormous popsicles, and fences solid walls."*

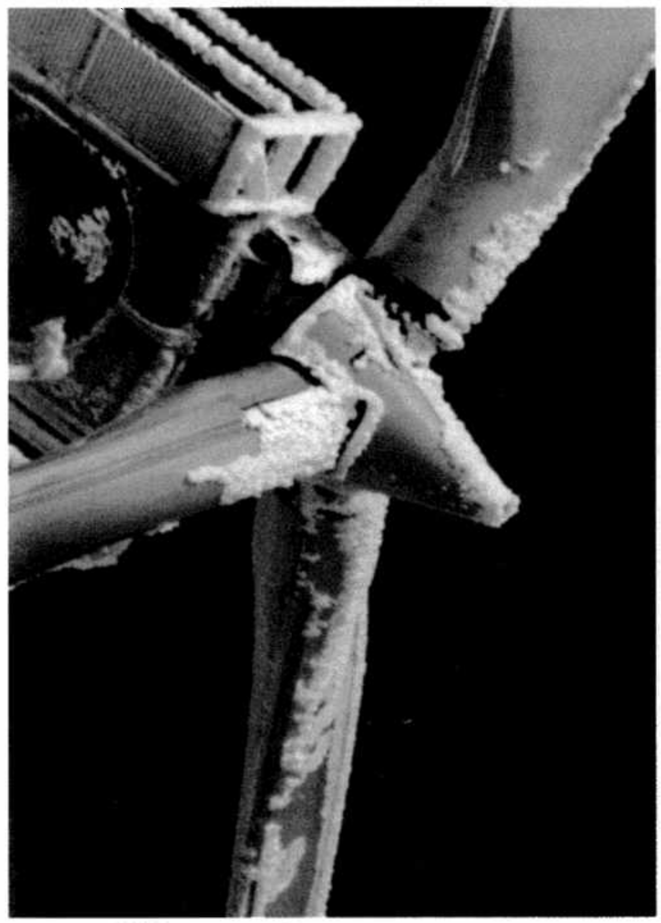
Six years of monitoring the wind regime in the Whitehorse area shows that the most severe period for rime icing to occur is from mid-October to late December. In the 1995 test season at YEC's Haeckel Hill test turbine, production dropped by 55% due to rime icing.

To mitigate the effects of rime icing, YEC has made several modifications to its Bonus 150 kW wind turbine:

- installing a heated anemometer and wind vane (1994);
- equipping the blades with six inch wide heating strips that run the length of the leading edges (at purchase in 1993);
- painting the blades with a black fluoreurothane, low adhesion coating (1996); and
- increasing the blade heater output by 50% (1996).

YEC painted the fluoreurothane coating on the blades in the summer of 1996 and will be monitoring the coating's effectiveness over the 1996-1997 winter.

The smaller turbines have not experienced the same rime icing problems as YEC's 150 kW turbine. This is probably due to a mix of factors, including the lower wind speeds at their sites, plus the higher rotor speeds of the smaller turbines. The biggest factor may be the location of the smaller turbines in valley bottoms as opposed to the YEC turbine's ridge-top location. However, further study is required before the exact effect of this factor is determined.



Haeckel Hill wind-turbine showing rime ice on blade roots and nacelle. (Courtesy of YEC/YECL Archives, 1993.)

Rime Ice Reduction Methods

Electrical Methods

- Leading edge blade heaters (in use at the development turbines on Haeckel Hill and in central Finland)
- Other possible heating, including internal blade heating.
- Pulsed electrical de-icing (NASA apparently has developed such) and is used on transmission lines.

Coating Methods

- Black colour - to increase absorption of sunlight to melt the ice free enough for it to come off.
- Icophobic coating - surface coat (paint) of material to which rime ice will not adhere as easily. Black fluoroeurothane - low adhesion coating applied by Yukon Energy Corporation in the summer of 1996.

Chemical Methods

- Spraying of de-icing fluid on blades, as is done with aircraft. Costs and environmental concerns may preclude this, but it deserves consideration.
- Other aircraft de-icing techniques including expandable rubber boots or bladders in the leading edges of the blades. Such can draw on the extensive aircraft maintenance industry already present in the Yukon. However, such would involve some fairly large scale experiments and the facilities (and resources) to at least modify commercially manufactured blades.

Mechanical Techniques

- Impact or vibrations - mechanical or acoustical.
- Compressed air jets - much like a sand blaster. Referred to in Finland as an "Air Brush".

Source: Boreal Alternate Energy Centre

Regulatory Issues

Wind developments on public land must go through an environmental screening process in order to secure land use permits. The Canadian Environmental Assessment Act specifies the requirements for environmental review. The Development Assessment Process (DAP) will be the Yukon's new assessment process once legislation is in place. It was negotiated and agreed to as part of the Yukon First Nations Umbrella Final Agreement. It is intended to provide a comprehensive and integrated way to assess resource development in the Yukon. DAP will consider economic, environmental and social impacts, including the impacts on the heritage and culture of Yukon First Nations people. Unlike CEAA, it will apply to developments on Territorial (Commissioner's) land and settlement lands, as well as Federal (Crown) land.

To date, all the privately owned wind-turbines in the Yukon have been used only to supply power to their owners. If one of these owners, or some future private entrepreneur, wished to sell power they could do so to a single customer or a franchised utility, under the *Public Utilities Act - 1986* (revised 1995). The Act states that a transmission line is allowable only if it "does not duplicate any existing or planned facilities of any public utility."

Environmental Issues

In the Yukon, wind may have fewer environmental concerns associated with it than other energy sources such as some hydro developments and diesel. However, wind development in the territory is currently very small. As development increases, the environmental issues that surround wind farms in other jurisdictions may gain greater attention in the Yukon. These issues are discussed below.

Bird Strikes

Wind-turbines in other jurisdictions, such as California, have had a history of strikes by large birds of prey. The Haeckel Hill wind-turbine is located in an area that has one of the highest recorded densities of Golden Eagles in North America. Also, Haeckel Hill is in a migratory corridor used by a significant number of waterfowl, including swans and geese. A monitoring program was put in place to study the potential problem in 1993. To date, there have been no bird strikes. It is now known that the water-fowl migration routes are in the valleys, below the elevation of the wind-turbine. The monitoring program is due to continue until the fall of 1997.

Visibility and Noise

People who live next to wind-farms, or sites for potential wind-farms, are sometimes concerned about the noise and sight of the turbines. However, private owners of small turbines in the Yukon cite the quietness of their turbines as one of the advantages they have over gas-generators. As well, no one seems concerned with their visual aesthetics. These individuals live far enough away from neighbours that the possibility of conflict is small. Commercial wind-farms in the Yukon would most likely be located on ridge-tops, out of hearing range, but perhaps visible. Thus noise conflicts with residential areas should also be small for commercial wind power producers, although the potential for aesthetic objections is increased.

Cowley Ridge wind farm and surrounding area. (Courtesy of J. Maissan, YEC, 1996.)

Road Access to Fragile High Country

Whenever a road or other traversable corridor, such as a power line, is pushed into a previously inaccessible area, there is the potential for increased human impact on the area. This is a concern that will vary with installation sites. The test site on Haeckel Hill already had a road going to it, but the road was upgraded. This has allowed more traffic into the area and there has been some vandalism at the test site. Grizzly bears, sheep, moose and small furbearers are known to range in the area, but no conflicts with wildlife have been reported.

Impacts of Electricity Transmission Corridor and Lines

Along with affording greater access to wind-farms, electricity transmission lines also have an aesthetic impact on the landscape. Care can be taken to minimize this impact. In some cases, especially above the tree line, the lines can be buried. This was done with the final spans of the lines to the Haeckel Hill site.

Electromagnetic Interference

In areas where wind-turbines have aluminum blades, they have sometimes interfered with telecommunications signals. This problem can be mitigated by locating the turbines away from telecommunications towers and by using blades made of a non-metallic material, such as wood, fiberglass or polyester. Commercial scale wind-turbines are no longer made with metal blades. The blades on the Haeckel Hill turbine are made of fiberglass-reinforced polyester.

Credits

Prepared for the Cabinet Commission on Energy

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Glossary of Energy Terms

GWh	Gigawatt hour (one million kWh)
joule (J)	a unit of energy (metric). One kilowatt hour equals 3.6 million joules. Raising a sandwich from your plate to your mouth requires approximately one joule of energy.
kWh	kilowatt hour, a unit of energy, the product of power and time. A person can work steadily at an output of approximately 100 watts, and therefore 10 hours of hard labour would result in one kilowatt hour of work.
MW	megawatt, one million watts or one thousand kilowatts
Watt (W)	a unit expressing the rate of energy use. One watt is equivalent to one joule used in one second.

Reader Survey

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Appendices available with this issue are:

___ Appendix A Yukon Wind Developments

___ Appendix B Haeckel Hill Wind Turbine Specs.

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