# PRELIMINARY SITE FEASIBILITY REPORT
# Draft Copy

# Ipswich

June 1,2003 – May 31,2004

Prepared for

Town of Ipswich
Massachusetts

by

James F. Manwell
Anthony F. Ellis
Mohit Dua

October 11, 2004

Report template version 1.0

## Table of Contents



## List of Figures



## List of Tables

# EXECUTIVE SUMMARY

Wind monitoring at Ipswich commenced in May 2003. Wind speed and direction were monitored at multiple heights for over one year before the meteorological tower was taken down in June 2004. A detailed analysis of the data collected is reported in the Annual Wind Data Report for the site. This preliminary site analysis report uses the monitored wind data to analyze power production and preliminary economics for two samples wind turbines, the V47-660 and the GE1.5sl, with rated capacities of 660 kW and 1,500 kW respectively. For this analysis the average annual wind speed was estimated at 50 m and 80 m heights using two different methods. Wind energy production by the V47-660 at a hub height of 50 m and the GE1.5sl at a hub height of 80 m was also estimated. The report lists the regulatory, environmental and public acceptance issues the town needs to consider for installing wind turbines.

# SECTION 1 - Site Description

Ipswich is one of the oldest towns in the United States, located on the North Shore of Massachusetts, approximately 28 miles north of Boston. The town is 33 square miles and has a landscape that includes marshes, dunes and beaches, upland, forests, fields, and farmland [1]. The monitoring tower used for measure wind speeds and direction at multiple heights was installed by the Renewable Energy Research Laboratory at the town transfer station (old landfill) on a small hill with salt marshes to the west and some trees to the north. The site is located at 42°42’58” N and 70°50’30” W. The figure below shows the site location.

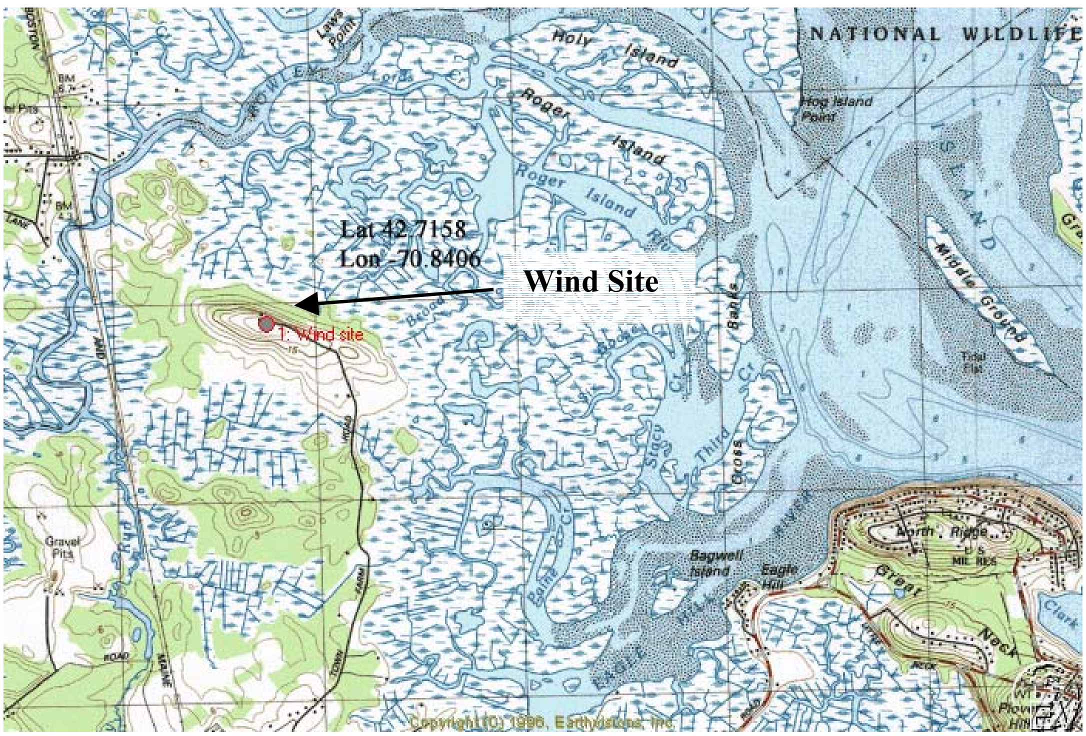


Figure 1- Location of Meteorological Tower

# SECTION 2 - Wind Resource

Wind speed and direction for the site were monitored at 10-minute intervals at three heights over a 12-month period. The average yearly wind speed from June 2003 to May 2004 was found to be 5.14 m/s at the 39 m height with NNW being the predominant wind direction. For estimating the wind energy production, using a particular wind turbine, the wind resource needs to be accurately predicted at the turbine hub height. Hub heights are generally greater than the monitoring heights. Therefore the wind speeds need to be extrapolated to hub heights using a mathematical estimation model. This section describes the various steps followed in estimating the wind resource at the hub height for subsequent use in estimating the wind energy production.

### Long term wind speed

Winds fluctuate over larger time scales of years. One year may be windier than another. To correct the wind speeds for the monitoring period to the long-term wind speeds for the site, comparison is made to the long-term average at a nearby site. For this site comparison was made with long-term data collected from the Logan International Airport. Average wind speed at Logan Airport was found to be 5.04 m/s over the five year monitoring period from June 1999 to May 2004 compared to 4.91 m/s from June 2003 to May 2004. Long-term wind speeds for the site are therefore estimated to be 2.5% higher than the short-term average wind speed over the monitoring period. Long-term average for the current monitoring site can therefore be estimated to be 5.27 m/s at 39 m.

### Wind speed at hub height

Wind speed generally increases with height. Thus, a turbine on a higher tower will produce more energy than the same machine on a shorter tower. To determine the energy production of the various candidate turbines, the wind speeds at the hub height for each turbine needs to be estimated. For this study two sample wind turbines with hub heights of 50 m and 80 m were considered. Wind speed changes with height are often represented by the power law relationship:

$$\left(V/V_r\right) = \left(H/H_r\right)^{\alpha}$$

Where,

| | | |
|---|---|---|
| V | = | Wind speed at hub height |
| Vr | = | Wind speed at reference height |
| H | = | Hub height |
| Hr | = | Reference height |
| $\alpha$ | = | Wind shear exponent |

The exponent α, characterizes the amount of wind shear and is a function of the surface roughness and terrain features upwind of the measuring site. Since wind speed was measured at multiple heights, the wind shear, α, can be calculated for each 10-minute averaging period. For example, on 6/1/2003 at 12:00 AM, 10-minute average wind speeds of 3.58 m/s and 3.48 m/s were measured at 39 m and 30 m respectively. Using this, α for the data sample, can be calculated as follows:

$$\alpha = \frac{\ln\left( V_1 / V_2 \right)}{\ln\left( H_1 / H_2 \right)} = \frac{\ln\left( 3.58 / 3.48 \right)}{\ln\left( 39 / 30 \right)} = 0.11$$

This can then be used to estimate the wind speed at, for example, a hub height of 50 m as follows:

$$V = V_r \cdot \left( H / H_r \right)^{\alpha} = 3.58 \cdot \left( 50 / 39 \right)^{0.11} = 3.77 \text{ m/s}$$

Using the method given above, wind speeds at 50 m and 80 m were estimated for each 10-minute time period to give annual average wind speeds of 5.75 m/s and 6.92 m/s respectively. A simpler method of calculating the wind shear from the annual average wind speeds at 39 m and 30 m gives an estimated value of 0.33. Annual average wind speeds using this method were found to be 5.81 m/s and 6.80 m/s at the 50 m and 80 m heights respectively. All estimates include the 2.5% long term wind speed correction factor. The former method, therefore, gives a more conservative estimate for the wind speed at 50 m while giving a higher estimate for the wind speed at 80 m.

These results assume that change in wind speed between 30 m and 39 m characterize the change in wind speed above 39 m. That may very well not be true at this site, given the terrain surrounding the site. Therefore, an additional analysis has been done assuming $\alpha = {}^{1}/_{7}$, to get conservative estimates of wind speed. Power production calculations have been done for these lower wind speed estimates. Estimating wind speeds at higher heights from measurements taken at lower levels is always fraught with uncertainty. However, in general, wind speed and hence power production are found to be higher than those estimated by assuming $\alpha = {}^{1}/_{7}$.

# SECTION 3 - Candidate Wind Turbines

Table 1 lists a few of the utility scale wind turbines available for the US market. These wind turbines are available at multiple hub heights to suit the site requirements. For this report, annual electricity production was estimated for the V47-660 and GE1.5sl turbines at hub heights of 50 m and 80 m, respectively, to give an idea of the generation potential at the monitoring site.

**Table 1 -** Utility scale wind turbines available in US

| Model | Manufacturer | Rated power (kW) | Rotor diameter (m) |
|---|---|---|---|
| FL 250 | Fuhrlander | 250 | 29.5 |
| FL 800 | Fuhrlander | 800 | 48 |
| FL 1000 | Fuhrlander | 1000 | 54 |
| FL 1250 | Fuhrlander | 1250 | 58 |
| GE 1.5s | GE Wind | 1500 | 70.5 |
| GE 1.5sl | GE Wind | 1500 | 77 |
| NM 64C | NEG-Micon | 1500 | 64 |
| NM 82 | NEG-Micon | 1500 | 82 |
| N 62 | Nordex | 1300 | 62 |
| V47-660 | Vestas | 660 | 47 |
| V80-1.8MW | Vestas | 1800 | 80 |

### Estimated electricity production

To estimate the annual electricity produced by the wind turbines, the 10-minute average wind speeds were binned into 0.5 m/s bins. For example all data points for the year with wind speeds between 1.0 and 1.5 m/s were included in one bin. Bins ranged from 0 to 25 m/s wind speeds. The upper limit was chosen as 25 m/s because most wind turbines ‘cut-out’ at wind speeds greater than 25 m/s due to safety reasons. Both the V47-660 and the GE1.5sl have a ‘cut-out’ wind speed of 25 m/s. Similarly ‘cut-in’ speed is the wind speed at which the wind turbine starts electricity production. ‘Cut-in’ speeds for the V47-660kW and the GE1.5sl are 4 m/s and 3 m/s respectively.

The power output of a wind turbine varies with wind speed and every wind turbine has a characteristic power performance curve. It is possible to predict the energy production of a wind turbine with such a curve without considering the technical details of the various components. The power curve gives the electrical power output as a function of the hub height wind speed. Figure 2 gives the power curves for the V47-660 wind turbine.

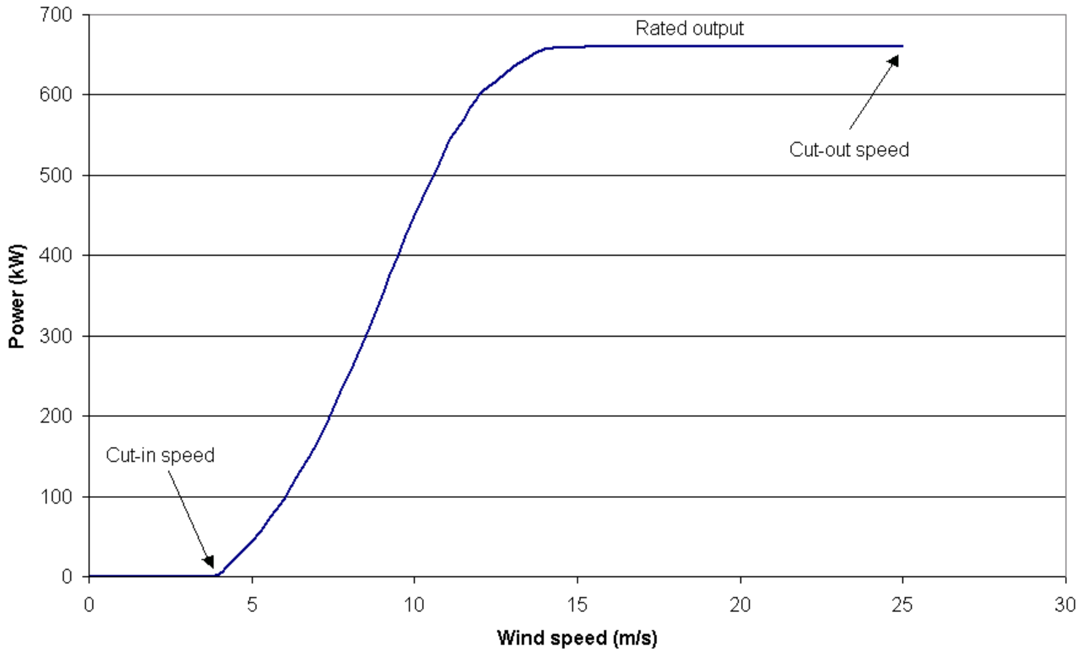


Figure 2 - Power curve for the V47-660

Using the binned wind speed data at hub height and the power curve for the wind turbine, the annual electricity production can be estimated. For example, annual power production by the GE1.5sl for wind speeds between 6.25 m/s and 6.75 m/s at 80 m can be estimated as follows:

$$P_{6.5} = N_{Bin} \cdot WT_{6.5} \cdot {DP_{60}}/{DP_{10}} = 3{,}765 \cdot 326 \cdot {8{,}760}/{52{,}702} = 204{,}013\,\text{KWh}$$

Where,

| | | |
|---|---|---|
| $P_{6.5}$ | = | Power produced by wind speeds from 6.25 m/s to 6.75 m/s at 80 m |
| $N_{Bin}$ | = | Number of data points in the bin |
| $WT_{6.5}$ | = | Power produced by the wind turbine at a wind speed of 6.5 m/s |
| $DP_{10}$ | = | Total number of valid 10-minute wind speeds in the monitoring year |
| $DP_{60}$ | = | Number of hours per year; 8,760 hrs/yr |

The ratio of $DP_{60}$ to $DP_{10}$ is included to obtain the energy production for one year. If hourly averages were used instead of 10-minute averages, this factor would not be used. The total yearly energy production by the GE1.5sl wind turbine can then be calculated as follow:

$$P_{Total} = P_{3.5} + P_{4.0} + .......... + P_{25.0}$$

However, this assumes that the wind turbine is available throughout the year. The availability of modern land based wind turbines is typically between 97% and 99%. Reduced availability is caused by scheduled and unscheduled maintenance and repair periods, power system outages, and control system faults. For this analysis, the estimated electricity production is calculated assuming an availability of 98%. These figures are shown in Table 2. Capacity factor is the ratio of the estimated electricity production to the total production if the wind turbine produces rated power throughout the year.

**Table 2 -** Estimated electricity production

| | **V47-660** | | **GE 1.5sl** | |
|---|---|---|---|---|
| Hub height (m) | 50 | | 80 | |
| Availability | 0.98 | | 0.98 | |
| Shear | $\alpha = {}^1/_7$ | $\alpha = \alpha_i$ [1] | $\alpha = {}^1/_7$ | $\alpha = \alpha_i$ [1] |
| Estimated annual mean wind speed (m/s) | 5.46 | 5.75 | 5.84 | 6.92 |
| Net Capacity factor | 0.17 | 0.19 | 0.23 | 0.32 |
| Estimated annual production (kWh/yr) | 989,444 | 1,110,929 | 2,996,148 | 4,211,716 |

[1] Shear, $\alpha$, calculated for individual 10-minute averages

# SECTION 4 - Economics

Different methods can be used for the economic analysis of installing a wind turbine at the monitoring site. For this report, the levelized cost of energy from the wind turbine has been calculated. The levelized cost of energy is given by the sum of annual levelized costs for a wind energy system divided by the annual energy production.

## Economic insentives

Two of the major economic incentives that would affect the economic analysis are briefly explained below.

### Renewable Energy Credits (RECs)

The Renewables Portfolio Standard (RPS) is a market-driven policy that recognizes the public benefits of wind, solar, biomass, and geothermal energy, as electricity markets become more competitive [2]. The policy is intended to ensure that a minimum amount of renewable energy be included in the portfolio of electricity resources serving a state and increases that amount over time. The RPS for promotion of renewables took effect in Massachusetts in April 2002. According to the RPS,

> "The total annual sales of each Retail Electricity Product sold to Massachusetts End-Use Customers by a Retail Electricity Supplier shall include a minimum percentage of electrical energy sales with New Renewable Generation Attributes." [3]

Starting with a minimum of 1% in 2003, the minimum increases by 0.5% per year from 2004 to 2009. After 2009, the minimum standard shall increase by 1% per year until the Massachusetts Division of Energy Resources suspends the annual increase. Wind energy qualifies as a new renewable.

With RPS, the environmental attributes of electricity are unbundled from electricity itself. This is done using Renewable Energy Credits (RECs) which are central to the RPS. A REC is a tradable certificate of proof that one MWh of electricity has been generated from a renewable source. The RPS requires all electricity suppliers to demonstrate, through ownership of RECs, that they have supported an amount of renewable energy generation equivalent to some percentage of their total annual kWh sales. For example, if the RPS is set at 5%, and a supplier sells 100,000 MWh in a given year, the supplier would need to possess 5,000 RECs at the end of that year. If the suppliers did not generate the stipulated electricity from renewables, they might be able to fulfill part or all of their portfolio requirements by purchasing RECs, in effect, 'rebundling' them with 'brown' power[2].

[2] Electricity generated from non renewable power sources

There are companies which facilitate trading of RECs. One such company is Evolution Market LLC. According to the company's market report, the last REC was traded at $49.25/MWh [4]. Hence this figure is used as the value of a REC.

**Renewable Energy Production Incentive (REPI)**

The Renewable Energy Production Incentive (REPI) was introduced in the Energy Policy Act of 1992 as part of an integrated strategy to promote generation and utilization of electricity from renewable energy sources. This program provides financial payments for electricity produced and sold by new renewable energy facilities. Eligible electric production facilities are those owned by state and local government entities (such as municipal utilities) and not-for-profit electric cooperatives that started operations between October 1, 1993 and September 30, 2003 [5]. Qualifying facilities (which use solar, wind and forms of geothermal and biomass) are eligible for annual incentive payments of 1.5 cents per kilowatt-hour (1993 dollar and indexed for inflation) for the first ten-year period of their operation, subject to availability of annual appropriations in each Federal fiscal year of operation. The REPI expired on September 30, 2003. Recently, the house and senate approved the Production Tax Credit (PTC). The PTC will extend the tax credit retroactively from January 1, 2004 to December 31, 2005. The status of REPI is not known. Even if the REPI has been approved, it needs to be ascertained if the wind plant owner qualifies to receive the incentive.

## Other Economic Parameters

Table 3 lists the other economic parameters used in the analysis.

**Table 3 -** Economic parameters

| **Economic parameters** | |
|---|---|
| Down payment | 20% |
| Loan interest rate | 5.0% |
| Discount rate | 3.00% |
| General inflation rate | 2.00% |
| Period of loan | 20 years |
| System life | 20 years |
| Operation & Maintenance (O&M) | $0.015/kWh |

## Results of preliminary economic analysis

Table 4 lists the levelized costs of energy using a single V47-660 and GE1.5sl wind turbine. The turbine cost figures are estimates from similar community scale installations. The actual cost figures for the monitored site can vary slightly from the figures used. The V47-660 and GE1.5sl were used because they are popular wind turbine models. Economic analysis was carried out using the more conservative estimate of energy production obtained by using $\alpha={}^{1}/_{7}$. The levelized cost of energy,

$COE_L$, is given by the sum of annual levelized costs for the wind energy system, including operation and maintenance costs, divided by the annual energy production [6].

$$COE_L = \frac{\sum(\text{Levelized Annual Costs})}{\text{Annual Energy Production}}$$

**Table 4 -** Cost of electricity

| **Wind turbine** | **V47-660** | **GE1.5sl** |
|---|---|---|
| Total installed cost ($) | 750,000 | 1,635,000 |
| $COE_L$ | 5.73 ¢/kWh | 4.51 ¢/kWh |

The value of electricity from the wind turbine is what the owner can expect to get for a unit of electricity sold. Table 5 lists the assumed values of the different parameters that contribute to the total value of electricity and the levelized value of electricity obtained by applying the incentives for varying periods of time. This analysis has been carried out for different time periods because of uncertainty in the value of RECs over time and the applicability of REPI. Thus, while the RECs may be presently trading at 4.95 ¢/kWh, there is no assurance that this will be their rate in future. Similarly, there is uncertainty with the REPI since it depends on the availability of annual appropriations in each federal fiscal year of operation. The value of electricity sold will be same for both the turbines. Total revenue generation will however be different for the two turbines depending up on their total electricity generation.

**Table 5 -** Value of electricity generated

| *Parameters* | |
|---|---|
| Value of electricity sold to grid | 3.50 ¢/kWh |
| Value of REC | 4.95 ¢/kWh |
| Value of REPI | 1.80 ¢/kWh |
| Annual escalation for values above | 2.0% |
| *Total levelized value of electricity sold (¢/kWh)* | |
| 1. Including RECs for 5 years | 4.36 |
| 2. Including RECs and REPI for 5 years | 4.80 |
| 3. Including RECs for 10 years | 5.51 |
| 4. Including RECs for 10 years and REPI for 5 years | 5.94 |
| 5. Including RECs and REPI for 10 years | 6.36 |

When the levelized value of electricity is less than the levelized cost of electricity, the project is not profitable over its lifetime of 20 years. When the value is greater than the cost, the net present value of revenue generation over the project lifetime can be calculated. A sample calculation for the V47-660, when both the RECs and REPI are applied for 10 years, is shown below.

$$NPV = \left(VOE_L - COE_L\right) \cdot E_{yr} \cdot N_{yr} \cdot C = (6.36 - 5.73) \cdot 989{,}444 \cdot 20 \cdot {}^{1}\!/_{100} = \$124{,}670$$

Where,

| | | |
|---|---|---|
| NPV | = | Net present value of revenues over the project lifetime of 20 years |
| $VOE_L$ | = | Levelized value of electricity from the wind turbine; ¢/kWh |
| $COE_L$ | = | Levelized cost of electricity from the wind turbine; ¢/kWh |
| $E_{yr}$ | = | Yearly electricity generation by the wind turbine; kWh/yr |
| $N_{yr}$ | = | Project lifetime; 20 years |
| C | = | Conversion factor; ¢ to $ |

# SECTION 5 - Environmental, Regulatory and Public Acceptance Issues

The development of a wind project can involve multiple agencies including developers, landowners, utilities, the public, and various local, state and federal agencies. The time period from the initial planning to the plant operation can vary from one to two years or more. Permits are required from multiple government agencies and can take up to 12 months or more. This section lists some of the permitting considerations and public acceptance issues that may need to be addressed. Not all the listed considerations apply to all the projects. For further details please refer to the Permitting of Wind Energy Facilities prepared by the Siting Subcommittee of the National Wind Coordinating Committee [7].

### Noise

Wind turbines generate noise from multiple mechanical and aerodynamic sources. As the technology has advanced, wind turbines have become much quieter. Under most conditions modern turbines generate primarily broad-band sound levels, no higher than those of a moderately quiet room, at distances of 750 to 1000 ft. (about 230-300 m) [7]. In Massachusetts, the Department of Environmental Protection (DEP) regulates noise emissions as a form of air pollution. The regulation includes two requirements, First, any broadband sound source is limited to raising noise levels no more than 10 db(A) over ambient baseline sound level. The ambient baseline is defined as the sound level that is exceeded 90% of the time, the L90 level. Second, “pure tones”, defined here as an octave band, may be no greater than 3 dB(A) over adjacent octave bands. All readings are measured at the property line and at the nearest inhabited building. An appropriate noise assessment study in this situation should contain the following four major parts of information [8].

1) A survey of the existing ambient background noise levels.
2) Prediction (or measurement) of noise levels generated by the turbines(s) at or near the site.
3) Identifying a model for sound propagation.
4) Comparing calculated sound pressure levels from the wind turbines with background sound pressure levels at the locations of concern.

### Visual impacts

The visual appearance of a wind turbine depends on its apparent size, color, number of blades and tower type. The general consensus is that a wind turbine should be unobtrusive in character. The smaller the apparent size, the less obtrusive the turbine would be. Apparent size is a function of distance and the actual size of an object. Thus, the farther the turbine is from residential areas the less the visual impact of the turbine will be. The colors of the turbine need to fairly neutral, so the machine does not ‘jump out’ into the foreground of a view. However, most modern wind turbines are of heights that bring them into airspace regulated by the Federal Aviation Authority (FAA). Thus lighting and possibly markings may be required on certain portions of the turbines installed in a wind project. Requirements may be more stringent if the proposed site is located near an airport. Federal regulations require markings on all objects over 200 ft tall (60 m).

A valuable tool for the assessment of the potential visual impact of the project is the preparation of visual simulations, which superimpose the wind turbine on the existing landscape. By using these simulations installation site and/or turbine layout can be adjusted (in case of multiple wind turbines) so as to minimize the potential visual impact and be acceptable to the public.

**Land Use**

Many federal, state and local agencies set guidelines for the development and use of lands within their jurisdictions. These are intended to ensure that there is sufficient land available for various uses, that adjacent uses are compatible, and that there is an orderly transition between differing types of used [7]. Wind project developers should contact the land use agencies regarding their plans early in the project planning process. A proposed project which is inconsistent with the existing land use plans and policies may still be approved if the permitting agency grants a variance.

**Avian Impact**

As with other tall structures, birds can collide with wind turbines. The movement of the blades adds to the potential of striking birds, although it is not known whether this increases avian mortality compared to other tall structures. Avian mortality has been a cause of concern at some sites. Therefore it may be required to conduct an environmental impact study on the local bird population. Unless the turbine is sited along an avian flyway or a nesting area, this is typically not a major concern. A tubular tower will have less impact on bird populations than a lattice tower, as the former lacks perching sites that might otherwise attract birds. Pre-stressed concrete towers, due to their external ladder, are also less desirable in that regard. A developer who is aware of protected or sensitive species within an area may choose to alter the siting plan to minimize the impact.

**Electromagnetic Interference (EMI)**

Early wind turbine designs were reported to have affected the reception of TV broadcasts. While some early wind turbine designs did have problems with EMI. The EMI problem was often due to the materials used to make the blades, namely conductive metals. None of the machines mentioned earlier use metal blades. The small quantity of metal used for lightning protection and bolting to the hub does not appear likely to cause reception problems.

## References


[1] Boston North Cities and Towns (2004), Website http://www.masstourist.com/nshore.htm

[2] American Wind Energy Association, Organization website, http://www.awea.org

[3] Department of Energy Resources (DOER), Massachusetts (2004), Renewable Energy portfolio Standard, Organization website, http://www.mass.gov/doer/

[4] Evolution Markets LLC (2004), Company website, http://www.evomarket.com/

[5] Energy Efficiency and Renewable Energy, United States Department of Energy (2004), Organization website, http://www.eere.energy.gov

[6] J.F. Manwell, J.G McGowan, A.L. Rogers (2002), Wind Energy Explained, John Wiley & Sons Ltd.

[7] The Permitting of Wind Energy Facilities (2002), National Wind Coordinating Committee, Website http://www.nationalwind.org/pubs/permit/permitting2002.pdf

[8] Rogers, A.L., Manwell, J.F. (2004), Wind Turbine Noise Issues, Renewable Energy Research Laboratory, University of Massachusetts, Website http://www.ceere.org/rerl/publications/whitepapers/WindTurbineNoiseIssues.pdf