# Hull Wind II: A Case Study of the Development of a Second Large Wind Turbine Installation in the Town of Hull, MA

by

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**ABSTRACT**

Hull, MA, is a remarkable Massachusetts coastal community: since 2001 the town's municipal light plant (HMLP) has owned and operated "Hull Wind I", the largest wind turbine (660 kW) yet installed in the state. That project proved to be so popular that HMLP undertook to develop a second, larger wind turbine project (1.8 MW). This paper provides a description of the process that led to the acquisition of the second turbine, and the details of its successful installation. The "Hull Wind II" project was developed by HMLP, with the assistance of the Renewable Energy Research Laboratory at the University of Massachusetts/Amherst. It was a continuation of the cooperation that led to Hull Wind I. The Hull Wind II project involved the following: 1) community involvement, 2) site selection, 3) resource assessment, 4) foundation selection, 5) economic projections, 6) turbine selection, 7) permitting, and 8) installation. This paper will discuss all of these topics. Community involvement involved outreach activities, public meetings and votes. Site selection involved evaluating a number of sites; a capped landfill was chosen. Resource assessment took advantage of the Hull Wind I experience, nearby data sites, and wind maps. Foundation selection was of particular concern because of the landfill site. A concrete pad, supported by pilings and rock anchor bolts, was chosen. Economic assessment considered both the projected installed cost and the particular situation of HMLP. Turbine selection was by bidding, according to standard town practice. Permitting also involved standard town practice, as well as acquiring state permits. Installation involved a number of issues, because of the nature of the landfill site.

## 1.0 Introduction: Hull Wind II

### 1.1 The Success of Wind in Hull: Effective Community Involvement

The town of Hull is a leader in wind energy implementation in New England. In 2001 it installed the first and largest commercial wind turbine in New England; and in May of 2006 it installed another, much larger turbine on its town landfill. Two elements have allowed this success: a municipally-owned power company whose financial situation made the wind power projects economically feasible; and a citizenry willing to participate actively over a number of years to ensure that the project happened in a way that kept all constituencies satisfied.

### 1.2 Hull, Massachusetts and the Hull Municipal Light Plant

Hull is a town of 10,500 residents. It is located on a peninsula in Boston Harbor. Historic manuscripts refer to the tip of this peninsula as "Windmill Point" as far back as the mid 1820s. These original windmills were built to pump sea water for salt production.

Hull's pursuit of modern wind power began more than 20 years ago, with the 1985 installation of a 40 kW Enertech wind turbine. In 1997, a storm damaged the turbine. In response, a group of citizens encouraged the Hull Municipal Light Plant (HMLP) to replace that machine with a newer one. Three years of study and approvals followed, and in 2001, Hull Wind I (HWI), a Vestas 660 kW turbine was installed close to the site where the Enertech had been. The 47 m diameter turbine supplies approximately 3% of Hull's electricity. This project involved a partnership of HMLP, the Renewable Energy Research Laboratory (RERL) at the University of Massachusetts and the Massachusetts Division of Energy Resources (DOER). More historical and technical details on this subject can be found in Manwell et al. (2004.)

HMLP is a municipal electric utility that has been serving the Town of Hull since 1894. Annual average power demand is approximately 6 MW, corresponding to an annual average energy consumption of 53,000 MWh/yr. Prior to the installation of the wind turbines, all power was purchased wholesale from the New England Power Pool.

Soon after HWI started operating the process to add a second and larger wind turbine began. After four years of study Hull Wind II, a Vestas V80 1.8 MW turbine, went on line May of 2006. Hull Wind II (HWII) will generate about 9% of the town's total energy needs. This paper describes the process that lead to the installation of this second turbine, and the details of its installation.

## 2.0 Site Selection

By the middle of 2002, discussion regarding a second turbine had progressed to the point where HMLP decided to survey the town to see whether the residents were seriously interested in acquiring a second turbine. Thus, a questionnaire was sent out in August of that year asking that question. The response was strongly in favor (95%) and board of HMLP decided unanimously in October 2002 to pursue the project.

### 2.1 Initial Siting

By the beginning of 2003, various options for the location for HWII were being considered. Figure 1 illustrates most of these options. One option was Windmill Point (a.k.a. Pemberton Point), close to where HWI was located. One specific possibility in the vicinity was the former Coast Guard boat house. Another option was Mariner's Park. As part of the investigation of Mariner's Park as well as for use in a preliminary noise study of HWI, RERL installed a meteorological tower. This tower remained on site for approximately two months. During this time, the RERL team also created a number of photosimulations. These illustrated what a second, larger turbine might look like. Some other possible siting options for a second turbine were also introduced. These included Stony Point, the vicinity of the sewer plant and offshore. The landfill (which was eventually chosen) was also an option, but some of the others were still preferred for a variety of reasons. Figures 2 and 3 show photosimulations at Windmill Point and Mariner's Park.

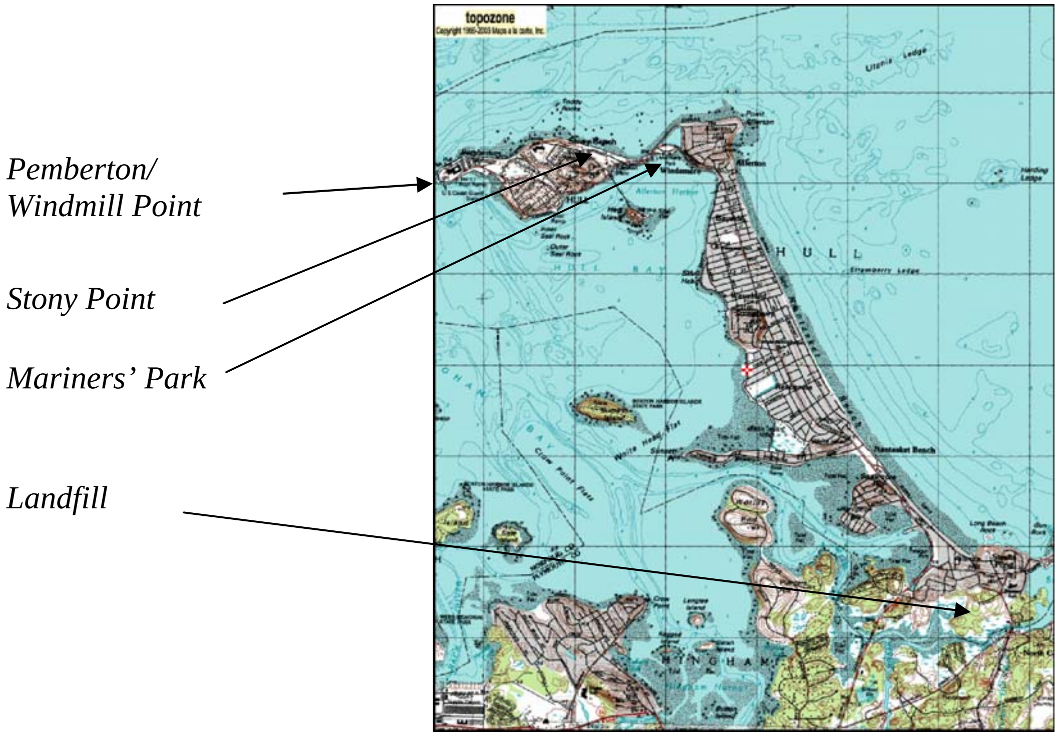


**Figure 1 Options for Siting Hull Wind II**

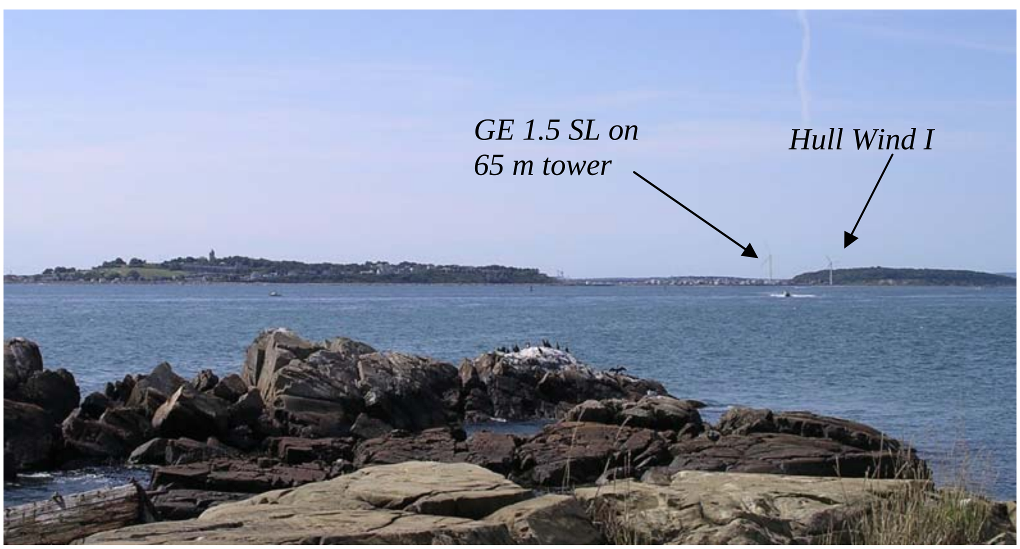


**Figure 2 Photosimulation of a GE 1.5 MW Turbine at Windmill Point**

**Figure 3 Photosimulation of a GE 1.5 MW Turbine at Mariner's Park**

By December, 2003, it appeared that siting the second turbine near the first one on Windmill Point would be the best option, so preparations for installing HWII there continued into 2004. An RFP for the second turbine was prepared; it was issued in March, 2004. The due date for bids was set for early April, 2004. Test borings were also made at the presumed site. The final decision for siting the second turbine, however, was still yet to be made: The HMLP board had agreed that it would be voted on in a town meeting.

In spite of the general support in Hull for a second turbine, there was still some hesitancy among those who lived closest to HWI about having HWII right next to it. This hesitancy eventually led to a special light board meeting at the end of April, 2004. At that meeting there was sufficient concern expressed by residents that the light board in effect withdrew their support of the project. For the time being, the project came to a halt.

## 2.2 Final Site Selection

Beginning in May, 2004, the site selection process started over again. One idea discussed was to replace the original 660 kW turbine with a larger one, and then move the smaller one to another site. Possible locations for the smaller turbine included Peddocks Island and the landfill. Peddocks Island lies in Boston Harbor just to the west of Windmill Point. The island is within the borders of Hull, but it is also part of the Boston Harbor Islands National Park. The decision making process regarding whether or not to install a turbine there was not as simple as it was in other locations in Hull. Furthermore, at the time that the turbine was being considered there was no cable connecting the island to the mainland. For these reasons, Peddocks Island was soon rejected as a possible site for relocating HWI.

At this point, the best remaining option was the landfill. Early in the site selection process, the landfill was not seen to be the most promising site. There were two basic reasons for this. First of all, the landfill is located in the part of Hull farthest from the sea (although nothing in Hull is really very far from the water). Thus, it was surmised that the site would not be as windy as some other sites. Second, insofar as majority of the site is covered by a landfill approximately 20 m thick, it was not obvious how a wind turbine could be installed there. One idea was to relocate HWI to a section of the site just to the side of the landfill itself. This would have allowed a conventional foundation to be used, but the spot available was quite a bit lower than the surroundings, and so the original tower of HWI would have been too short. Furthermore, that location was closer than desirable to the nearest residents.

The next option was to actually install a turbine on top of the closed landfill. This option afforded the opportunity to get the rotor relatively high above the surroundings, while still using a tower of moderate height. This was expected to compensate to some degree for the comparatively inland location. On the other hand, the issues and costs associated with building a foundation on the landfill were not well known at the time.

After much additional discussion, it was decided that an attractive option was to leave HWI where it was on Windmill Point, and endeavor to install a larger wind turbine on top of the landfill. (By this time, the bids for the second turbine had been received, and the light board had indicated its preference for a Vestas 1.8 MW turbine on a 60 m tower). Accordingly, HMLP had soil investigations made at the landfill site. A designer of wind turbine foundations (Patrick and Henderson) was commissioned to design a foundation. More detail on the foundation is given in Section 4 of this paper. A photosimulation of a wind turbine installed on the landfill is shown in Figure 4.

**Figure 4 Photosimulation of a Vestas 1.8 MW Turbine on the Landfill**

## 3.0 Resource Assessment and Economics

As should be apparent from the discussion in the previous section, the primary consideration in selecting a site for HWII had to do with its acceptability to the citizens of Hull. The wind resource and the economics were also important, but more in sense of whether the site was adequate, rather than whether it was it the best possible site. The approach that was taken was to consider the likely range of capacity factors and the expected costs of the project and to use those to assess whether the site was "good enough". At the University of Massachusetts, this process has subsequently been further developed into a method known as Streamlined Site Assessment. The major steps of this process are described below.

### 3.1 Wind Speed Estimations

The normal approach to evaluate the wind resource at a site is to install a meteorological ("met") tower, monitor the wind resource for one year, extrapolate to estimate the wind at hub height and use long term data from a nearby long term monitoring site to adjust the estimate up or down (see, for example, Rogers et al., 2006). In the case of HWII a different approach was taken. First of all, the cost to install a met tower on a landfill is much higher than it is most other sites. Second, since HWI had already been in operation for a number of years by the time the landfill was seriously being considered, its capacity factor was known, and by extension its wind resource (even though there was no met tower close to HWI). Third, the general wind conditions were believed to be fairly similar everywhere in Hull, so a turbine installed anywhere where there was good exposure to the wind was not expected to perform too differently from HWI. Fourth, the question to be addressed was whether the project should proceed or not. HMLP was planning to purchase the turbine with its own funds, and would not need to supply data to a financial institution in order to secure a loan. Consequently, if there was good reason to think it should proceed, then there was nothing to be gained by monitoring the site for a year.

On the other hand, some quantitative estimate of the wind resource was still desired, so that a range of possible capacity factors could be estimated, and an economic assessment could be performed. Three methods were used: 1) examination of the AWS Truewind maps (2006), 2) undertaking short term monitoring at the landfill site using a SODAR and 3) estimating the wind resource at the HWI site by reference to its known capacity factor.

The AWS Truewind map for Hull at a height of 70 m is shown in Figure 5. As can be seen, the map estimates that the site of HWI is close to the edge of the dark green and light purple zones, where dark green corresponds to 6.5-7.0 m/s and the light purple corresponds to 7.0-7.5 m/s. The landfill site is in the dark green zone. It is important to note that the hub height of HWI is 50 m, so the wind at hub height could be lower than the AWS Truewind values. In addition, it is not clear if the AWS Truewind map can distinguish the landfill, which is 20 m above the surroundings, so it is not apparent whether 70 m refers to height above the actual ground, or height above the surroundings. In any case, assuming the accuracy of the maps, it may be surmised that the average wind speed at hub height should be at least 6.0 m/s.

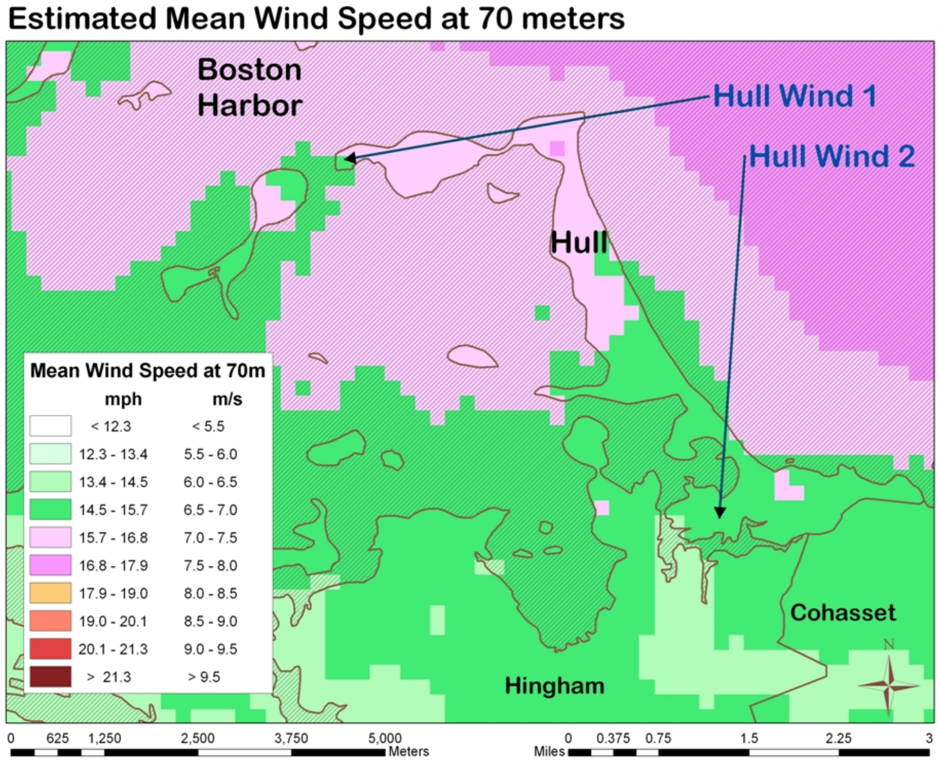


**Figure 5 AWS Truewind Wind Map of Hull and Near Vicinity**

In an attempt to confirm the AWS Truewind estimates, a SODAR was placed on top of the landfill and used to gather data from October 17 to November 17, 2005; see Walls, Rogers, and Manwell (2005). Figure 6 shows the SODAR in operation. Data was gathered for a range of heights from 5 m (using a conventional anemometer on a short mast) to 160 m. The data from the 60 m level was compared with simultaneous data from a met tower operated by RERL on Thompson Island, also in Boston Harbor, but approximately 14 km away. Long term wind data is also available from the Thompson Island met tower; that data was used to estimate the long term wind speed from the short term comparisons. Based on the available data, it was concluded that the long term average wind speed at 60 m above the landfill should be approximately 7.0 m/s. This value is within the bounds of the AWS Truewind estimate, although at the high end. A shear profile was also prepared, illustrating the measured wind speeds at various heights. This shear profile is shown in Figure 7. It is noteworthy that the wind speed drops significantly at heights below 60 m.

**Figure 6 RERL SODAR Operating at Hull Landfill**

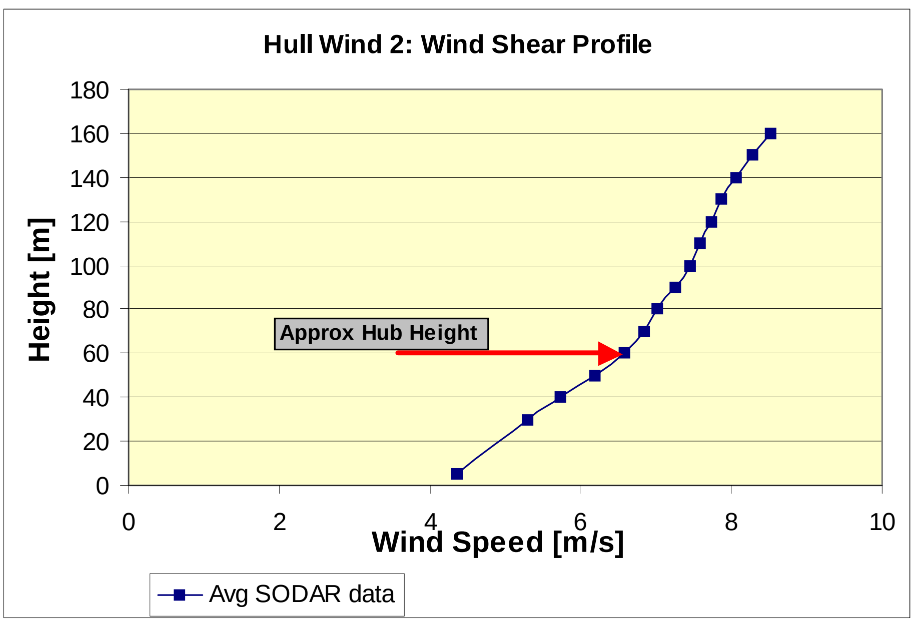


**Figure 7 Measured Wind Shear Profile at Hull Landfill**

One final estimate of the wind speed in Hull was obtained by taking advantage of the known capacity factor of HWI. Over the last several years, the average capacity factor has been approximately 0.27. Assuming that the wind follows a Rayleigh distribution (as does Thompson Island data), and applying the UMass Wind Engineering Minicodes (Manwell, Rogers, and McGowan, 2000), it was estimated that the mean wind speed at HWI was 6.4 m/s.

Taking all available information into account, it was therefore concluded that the wind speed at hub height of HWII should be in the range of 6.0-7.0 m/s and could be modeled with a Rayleigh distribution.

With the wind speed estimates from the previous analysis, a range of capacity factors was derived. This was also done using the UMass Wind Engineering Minicodes referred to above. The wind speed range was extended down to 5.5 m/s to include the lowest values believed to be possible. Under these assumptions, the calculated capacity values ranged from a low of 0.2 to a high of 0.34. It should be noted that the actual capacity factor could be lower than these estimates due to: 1) a turbine availability of less than 100% and 2) relatively high wind shear below 60 m (see Figure 7).

### 3.2 Economic Evaluation

An economic evaluation was performed next, with a particular attention to the worst plausible case. The total cost of the project was projected to be $3,000,000. The major costs were the wind turbine itself and the foundation. Other costs include geotechnical studies, foundation engineering, legal assistance, transportation, crane and installation. A breakdown of the major costs is shown in Table 1.

| **Item** | **Cost** |
|---|---|
| Wind Turbine | $1,800,000 |
| Foundation | $850,000 |
| Other | $350,000 |
| **Total** | **$3,000,000** |

**Table 1 Cost Breakdown For Hull Wind II.**

In addition to the initial capital cost of purchasing and installing the wind turbine, there were known annual recurring costs. These are summarized in Table 2.

| **Item** | **Recurring Cost** |
|---|---|
| Maintenance Contract | $25,000 |
| Insurance | $16,000 |
| **Total** | **$31,000** |

**Table 2 Recurring Costs for Hull Wind II**

Three types of economic analysis were performed. These included 1) a simple payback analysis, 2) a cost of energy analysis, and 3) a net “profit” analysis. The methods used are described in Manwell, McGowan, and Rogers (2003) and implemented in the UMass Wind Engineering Minicodes described previously.

The simple payback period is found from the total installed cost divided by the net annual value of the energy produced. This was based on the estimated capacity factor, the value of the electricity, and the recurring annual costs. The value of the electricity itself to Hull is $0.10/kWh, since that is what they would pay for the electricity that they would otherwise buy. A range of payback periods for mean wind speeds ranging from 5.5 to 7.0 m/s is shown in Figure 8. As can be seen they vary from 6 to 11 yrs, depending on the wind speed. Based on the wind resource assessment, it is apparent that the payback period should be less than 9 years and probably shorter.

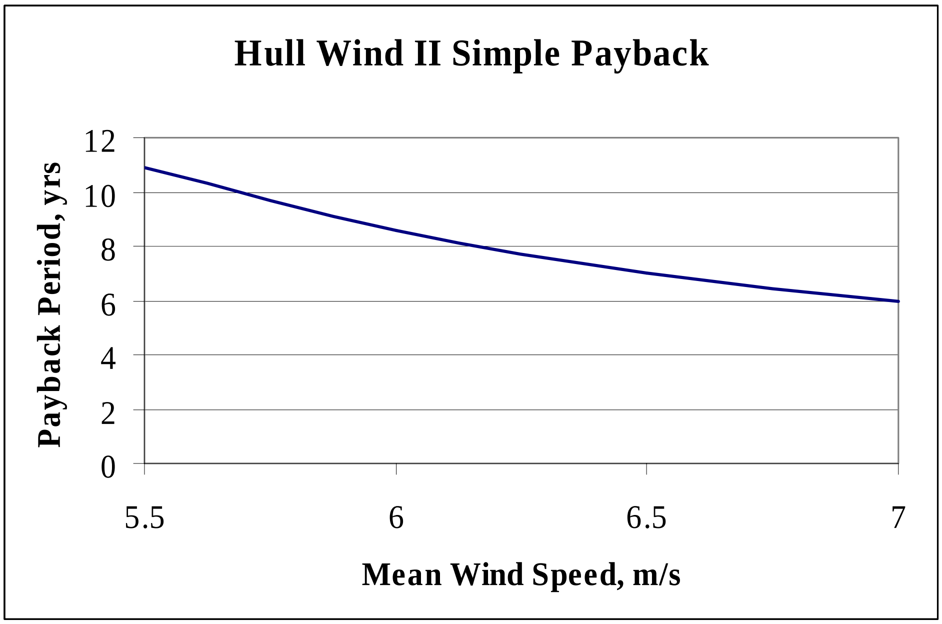


**Figure 8 Simple Payback Period for Hull Wind II**

The cost of energy (COE) analysis is more detailed than the simple payback analysis. It takes into account various economic parameters, such as a possible loan for the wind turbine, inflation, and discount rate. Plausible values for each of these parameters were chosen for a "base case" analysis. These are illustrated in Table 3. The COE analysis does not directly consider Massachusetts renewable energy credits (REC's) or federal renewable energy production incentives (REPI), but these may be used in comparing the relative cost of the energy to the value of the energy. They are also included in Table 3. The results of the COE are illustrated in Figure 9 for the same range of wind speeds as for the simple payback.

| Item | Value |
|---|---|
| Down payment fraction | 20% |
| Interest rate | 3%/yr |
| Inflation rate | 2%/yr |
| Discount rate | 2% |
| Electricity value | $0.10/kWh |
| REC's value | $0.04/kWh |
| REPI value | $0.02/kWh |
| REC's, REPI period | 10 yr |

**Table 3 Assumptions Used in Cost of Energy Analysis of Hull Wind II**

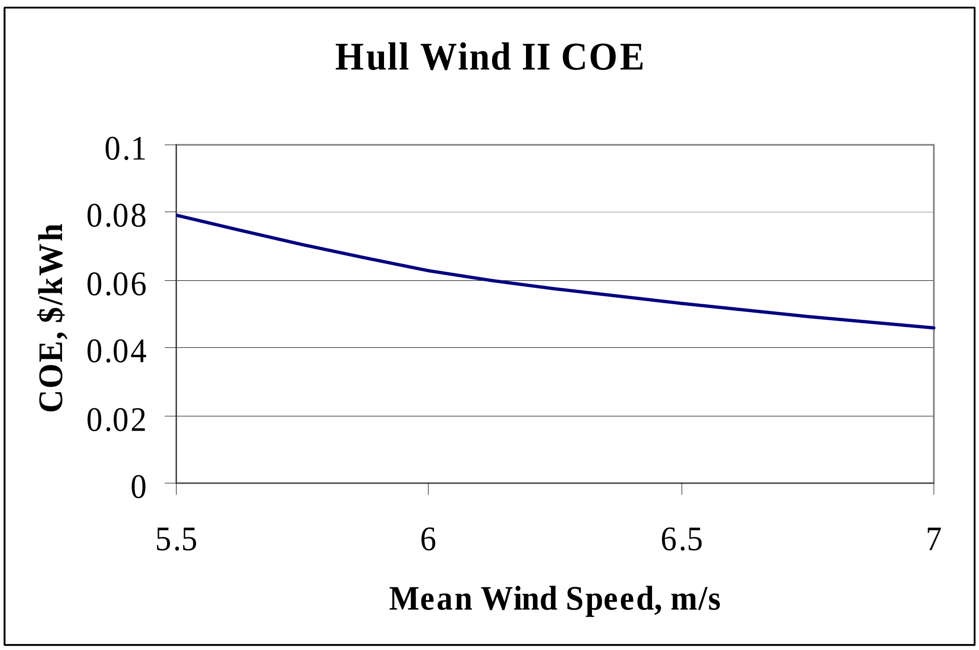


**Figure 9 Cost of Energy Analysis for Hull Wind II**

The third part of the economic analysis considered the net "profit" to the Town of Hull from owning and operating the wind turbine. Quotes are used around profit, because as a public entity HMLP does not really make a profit. The "profit" represents the present value of the surplus of the total value of the electricity produced in excess of the cost of owning and operating the turbine, over the lifetime of the project. The "profit" takes into account the REC's and the REPI mentioned above. The "profit" from Hull II for the same range of wind speeds is illustrated in Figure 10.

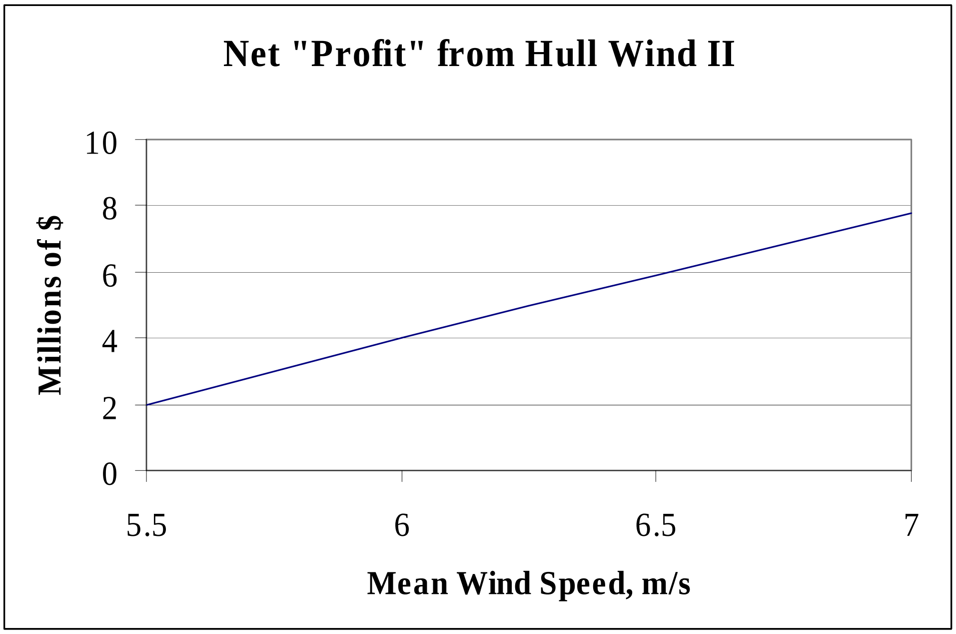


**Figure 10 Net "Profit" from Hull Wind II**

As can be seen, even in the worst case considered, the cost of energy from the wind turbine would be less than the value of the electricity, even if REC's and REPI were not taken into account. Furthermore over the life of the project, HMLP would reap a substantial "profit". The latter should be at least greater than $2 million and quite possibly in excess of $6 million.

The overall conclusion it that even under the most conservative assumptions, Hull Wind II should be an economically viable project.

## 4.0 Wind Turbine Foundation Details

The intent to install Hull Wind II on a top of a closed landfill presented an unusual siting situation. Landfills have been proposed previously as sites for wind turbines, because 1) they are often relatively far from residences and 2) it is often of interest to put the land to some other use, especially after the landfill has been closed. In fact there have been turbines installed at landfills, but these have been to the side of the waste pile and not on top. To the best of our knowledge, there have been no other wind turbines installed on top of a closed landfill in the United States.

The fundamental problem with installing a wind turbine on a landfill is that the waste pile itself does not provide a very good support for the turbine's foundation. There are a number of approaches that could be taken to circumvent this problem, but the most straightforward is to build the foundation pad on pilings. The piles would be driven through the landfill to solid rock beneath, so there would be no need to rely on the waste itself for support. This was in fact the solution eventually chosen for Hull. It must be noted, however, that such a solution would not necessarily be suitable for other landfills. First of all, this method takes advantage of bedrock beneath the landfill. If there were no bedrock close to the bottom of the waste pile, another solution would be needed. Second, many newer landfills have a liner underneath them, whereas older landfills, such as Hull's, do not. If there were a liner, it might not be permissible to drive a piling through it, because to do so would introduce the possibility of leakage of liquid waste out of the landfill, and perhaps into the groundwater. So again, if the landfill has a liner, some different method to support the foundation would have to be found. Most closed landfills do have membrane caps, and particular care must be taken to restore the cap after construction. Dealing with the cap, however, is much easier than dealing with a liner, which is quite inaccessible.

### 4.1 Soil Investigation

A geotechnical investigation at the landfill was carried out in the fall of 2004. The purpose was to determine the characteristics of the landfill and the bedrock underneath it in sufficient detail that a foundation could be designed. The geotechnical investigation was carried out by SEA Consultants, Inc. (Dubanowitz and Wright, 2004). A test boring was made down to a depth of 16.2 m (73 ft) below the surface. The study revealed that for a depth of approximately 18.3 m (60 ft) below the surface, the land fill consisted of mixed solid waste material. This waste "consisted of dark brown/gray partially-decomposed waste (garbage/refuse) mixed with varying quantities of coarse to fine widely-graded sand with trace amounts of silt and fine gravel. The waste contained paper, metal, plastic, wood, glass and other miscellaneous debris that is characteristic of municipal solid waste. Unknown obstructions were encountered intermittently throughout the waste layer."

The top of the bedrock was encountered just under the landfill. The upper 15 cm (6 inches) consisted of meta-sedimentary rock, apparently argillite. The remainder of the rock was a coarse grained meta-conglomerate. Laboratory tests were then carried out on the rock samples. These tests determined the density, the compressive strength and the shear strength of the rock. These values were then used in the foundation design.

### 4.2 Foundation design

As previously mentioned, it was decided to support the wind turbine on a piled foundation, in which the piles were driven through the landfill to bedrock below. These piles were actually hollow pipe. They were capped at the leading end so that they would not be filled up with trash as they were driven through the waste pile. Once the pipes were driven, rock anchor bolts were lowered through the pipes and then drilled and grouted into the rock. The designer of the foundation was Patrick & Henderson a firm with considerable experience in wind turbine foundation.

Details of the foundation are shown in Figure 11. Some features of note include the following:

1) A 6.1 m (20 ft) wide by 1.8 m (6 ft) deep square reinforced concrete pad was used to support the turbine itself. Typically this pad would have been octagonal, but it simplified the landfill cap restoration to have it square.

2) The rock anchor bolts were lowered through the pipe piles to the bedrock, then drilled 4.5 m (15 ft) into the bedrock. The anchor bolts were hollow, allowing grout to be pumped through them down to the bedrock. The grout locks the anchor bolts to the bedrock. The anchors are also protected from corrosive substances in the landfill. After the rock anchor bolts were in place, the pipes were filled with concrete to enhance their compressive strength. At the other end, the rock anchor bolts pass through the concrete pad. Nuts were threaded onto the bolts and tightened to an appropriate torque. The anchor bolts are in tension, with the pipes "sandwiched" in compression between the concrete pad and the bedrock. Within the concrete pad is a steel ring, or "embedment plate" which holds the tower bolts in place. A template was used on the top of the pad during the pouring of the concrete to keep the bolts aligned so that they would match the

holes in the lower tower section when it was lowered on to the pad. Figure 12 shows a photograph of the foundation construction.

3) A flexible linkage was installed between the turbine base and the switchgear pad, whose foundation does not go down to bedrock.

More details on the foundation may be found in Wright (2005).

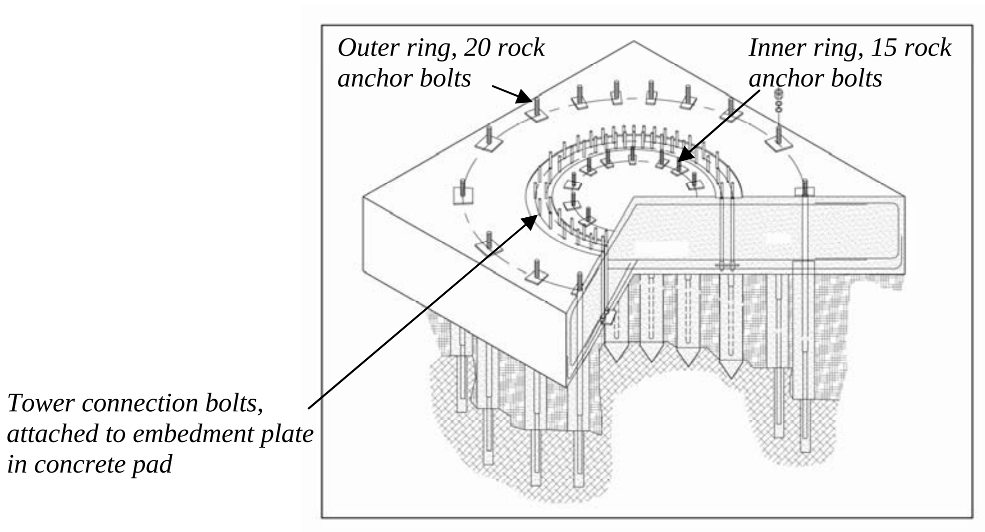


**Figure 11   Hull Wind II Foundation Details (Figure: Patrick & Henderson)**

**Figure 12 Piles and Rock Anchor Bolts for Hull Wind II Foundation**

# 5.0 Permitting, Installation & Operation

## 5.1 Permitting

There were a number of legal and permitting issues to be addressed before the turbine could be installed. These initially included: 1) HMLP's gaining use of the site, 2) consent from Hull's Conservation Commission, 3) obtaining a Post Closure Permit from the Department of Environmental Protection (DEP).

In addition, during the process, some residents from the adjoining town of Hingham objected to the possibility of wind turbine being installed in their vicinity. They requested that the Massachusetts Environmental Policy Act (MEPA) Office require a "fail-safe" review of the project. Furthermore, a local conservation group, the Weir River Park Estuary Committee requested that attention be given to the possible effect of the proposed wind turbine on migratory birds.

Most of the legal and permitting activities proceeded fairly smoothly. The Conservation Commission provided a letter of approval in December, 2004. Ownership of the landfill site was transferred from the town of Hull itself to HMLP in January, 2005. By March, MEPA had concluded that no fail safe study was needed. The final version of the Post Closure Permit, taking into account a number of details on the foundation, was completed in June, 2005. The final approval from DEP was obtained in September.

In addition, arrangements were made with Weir River Park Estuary Committee to undertake a study of the effect of the wind turbine on birds and to facilitate other programs of the Committee.

The Federal Aviation Administration (FAA) issued a "Determination Of No Hazard To Air Navigation" to this project in November of 2004, soon after the site and the turbine size was established (Federal Aviation Administration, 2004).

## 5.2 Installation

The installation of Hull Wind II is illustrated in Figures 13 -19. The figures and the captions are self explanatory.

**Figure 13 Blades Arriving in Boston Harbor (Photo: Malcolm Brown)**


**Figure 14 Nacelle Arriving in Quincy Harbor (Photo: Mark Brennan)**


**Figure 15 Nacelle Installation**


**Figure 16 Hub Installation**

**Figure 17    Blade Lifting Process**

**Figure 18 First Blade Installation**


**Figure 19 Hull Wind II Installation Completed**

## 6.0 Conclusion & Lessons Learned

The conclusions and lessons learned on the Hull Wind II are summarized below. Of high importance, the first large wind turbine, HW I, was successful and popular. It led directly to the second wind turbine. A municipal electric company such as HMLP is an ideal host for a wind turbine project of this type. They are familiar with electricity and since they are owned by the town that they serve, the residents feel that the turbine is "theirs" as well. Because the value of the electricity is high and guaranteed (and considerably higher than it would be if the electricity were sold into a wholesale market), the unusually high cost of the foundation could be borne by the project.

- Success of Hull One
- Local champions
- Municipal electric company – ideal host
- Guaranteed value of energy
- Clear public benefit
- Adequate wind resource
- Non-restrictive regulations
- Opportunities for meaningful public input
- Reputable and responsive turbine supplier
- Municipal electric utility that was an active participant in the process
- Available site
- Qualified and experienced partners

## 7.0 Acknowledgements

We would like to acknowledge the active participation of the residents of Hull, the financial support of the U. S. Department of Energy, Region 1 Office, and the Massachusetts Technology Collaborative for their assistance in the purchase of the SODAR which was used in the resource assessment.

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