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Why Waste The Wind? A Look into Small Scale Wind Energy

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Why Waste The Wind? A Look into Small Scale Wind Energy

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1. Executive Summary

The human race's dependence on fossil fuels for energy generation has started to cause major changes in the environment. Climate change is a universal issue and it is evident that our current energy schematic is not sustainable. UMass is no different; we must replace fossil fuels with renewable energy. Small scale wind has the potential to be a key component in UMass' future energy portfolio as we begin to implement renewable energy on campus. Strategically placed turbines would produce clean renewable energy, reduce greenhouse gas emissions, and help to decentralize energy dependence on the CHP. Small-scale turbines like the eddyGT (figure 1) are tested technologies that show promise for on-campus applications. These turbines would start shifting UMass energy to renewable sources, and money saved from generating clean energy could be put towards future renewable energy endeavors.



Figure 1:
eddyGT Wind Turbine

The main challenge facing current wind turbines are limited energy production capabilities. High altitude wind turbines address this weakness, accessing stronger and more consistent winds at higher elevations. High altitude wind turbines are still under development and not applicable to campus at this time, but have the potential to be an important renewable energy source down the road.

In order to implement small scale wind energy at UMass, research on wind speeds throughout campus is required. This data will facilitate a determination as to the ideal location and type of small-scale wind turbine to implement on campus. Small-scale wind energy is an ideal starting point to begin to shift away from fossil fuels. (249)

2. Introduction

The human population is experiencing a sustainability crisis. The IPCC Climate Change 2013 report revealed that human influence on the environment is causing warming of the atmosphere and oceans, loss of snow and ice, the rise of global sea levels, and even changes in climate extremes [1]. Our world relies on non-renewable energy sources such as oil, coal, and natural gas, which constitute for 80% of worldwide energy use [2]. The UMass Amherst campus energy infrastructure is no better, relying on natural gas for 81% of our energy demand and generating zero energy from renewable sources [3]. If we want to live up to our Climate Action Plan and reach carbon neutrality by 2050 we must start changing our energy layout, and become a leader in renewable energy [4]. Small-scale wind turbines are the answer to beginning the shift away from fossil fuels towards a sustainable future. Wind turbines are a clean, renewable, energy generation system, and in 2012 were the leading source of US electric generating capacity additions. An investigation of wind speeds on campus is vital to determine if small scale wind energy is feasible and implementable. With this research the ideal location and type of

turbine can be chosen. Once implemented on campus small scale wind turbines will produce renewable energy, cut down our fossil fuel consumption, reduce greenhouse gas emissions, and begin a movement on campus towards a sustainable future. UMass must change its future energy layout and small scale wind turbines are the answer. (249)

3. Wind Turbine Mechanics, with a Focus on Small-Scale Wind

Wind turbines present a viable alternative to fossil fuels, using scientific principles to harness the several hundred terawatts present in atmospheric wind currents [5]. Today, most modern wind turbines use generators to convert the kinetic energy in the wind into electrical power. These turbines range in size and design, from a 1,320 MW farm at the Alta Wind Energy Center in California, to a 3.7 kW windspire farm at Quinnipiac University in Connecticut [6]. Even these small-scale machines can generate electrical power and offset less eco-friendly fuel options.

Wind turbines are a modification of most standard generators (figure 2), utilizing the concept of electromagnetic induction to generate power. Wind turns the blades, spinning a rotor shaft that contains several conducting coils. An electric AC current is passed through these coils inducing another current on stationary coils inside the generator, and this induced current is the electricity output of the turbine [7]. Other turbines, particularly those designed for remote applications, utilize permanent rare-earth magnets [7] that also induce a current as they spin around induction coils. The electric fields in motion induce more current than is required to sustain the field, creating an effective and renewable power source.

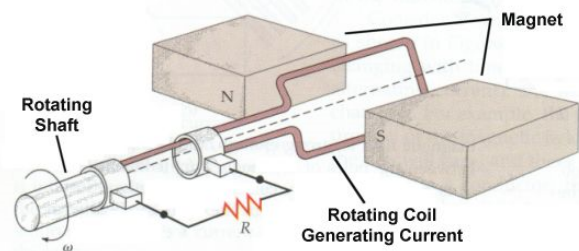


Figure 2: Standard generator

From a power generation standpoint, wind turbines have tremendous potential. Not only does wind increase with altitude, but the physics behind available power in wind flow suggests an incredibly powerful energy source. The potential power present in flowing air is given by the following fundamental equation for wind power density:

$$\delta = \frac{1}{2}\rho V^3 \left[\frac{W}{m^2} \right]$$

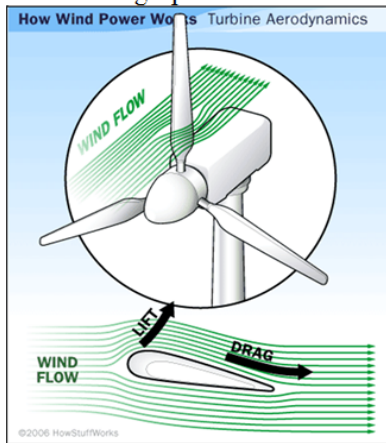
Here, wind power density, δ , is expressed as a function of fluid density, ρ , and velocity (V). Since power density is proportional to wind velocity cubed, even small increases in wind velocity have dramatic impacts on the power that can be harnessed by a turbine.

Contrary to popular belief, it is not the normal force of the wind pushing the blade that causes rotation. Instead, each rotor blade is designed similar to an airplane wing to generate a lift force (figure 3). To do this, the blade is designed such that air on opposite sides will travel

different lengths in the same amount of time and meet again behind the blade. These two wind components will have different velocities, and by Bernoulli's Principle, different pressures. This pressure differential is the origin of the lift force [10]. This style minimizes blade width and allows both wind speed and power generation to be maintained simultaneously, optimizing a turbine's generation capacity.

The two most common styles of wind turbines are horizontal axis and vertical axis turbines. Since wind speed intensifies with altitude and taller towers have access to more potential wind power [8,9], the typical commercial turbine is mounted high above the ground on

Figure 3:
Blade design promotes lift force



a horizontal axis. Most of these commercial turbines have two or three blades and diameters of up to 100 feet [10]. Blades are generally made of fiberglass, plastic, carbon fiber or even wood and are laminated to reduce drag [9]. Additionally, the design and orientation the blades of a horizontal-axis wind turbine (HAWT) are specialized to extract maximum wind energy and therefore require wind blowing perpendicular to the blade's plane. To ensure proper alignment, HAWTs have a yaw mechanism to orient blades perpendicular to wind flow.

The primary alternatives to horizontal axis designs are vertical-axis wind turbines (VAWTs). There are two major designs of VAWTs: Savonius and Darrieus. The Savonius design (figure 4), which is made of 2 or 3 scoops, is a reliable yet inefficient design. In contrast, Darrieus turbines (figure 5) contain multiple airfoil blades that are straight, curved, or helically twisted. These turbines permit the capture of wind omni-directionally, catching wind from all directions and making them ideal for urban settings where wind speeds fluctuate [10]. Also, many VAWTs are compact, smaller in scale, and quieter, enabling them to be located in areas of higher population density.

The mechanics behind these vertically oriented generators are the same as most other turbines. Wind spins the blades, which spin a turbine to generate electricity. VAWTs have a vertical main rotor shaft that leads to a generator located either below the blades or towards the bottom of the shaft. The latter design allows for easy access to the generator for repairs if necessary.

Some notable performance characteristics for VAWTs are Tip Speed Ratio and the Power Coefficient. Tip speed ratio (TSR) is the ratio between the rotational speed of the blades to the actual velocity of the wind. This ratio helps determine the efficiency of the turbine, and varies greatly with different designs. For instance, a VAWT with aerofoil blades can increase optimum TSR by 25-30% because of the generated aerodynamic lift [11]. The Power Coefficient (C_p) is a ratio between the electricity produced by the turbine and the total amount of energy in the wind. Optimizing these values in urban settings is a technological challenge, but new

Figure 4:
Savonius turbine



Figure 5:
Darrieus turbine



studies show emerging designs such as helically twisted blades improve these performance characteristics [12]. For this reason, helix-blade VAWTs are rising in popularity.

The advantages of a twisted helix turbine style lies in their ability to mitigate the effects of variable and turbulent winds. In general, maximizing a turbines production requires operation at the most efficient TSR [12]. Maintaining this ideal TSR is difficult in unsteady wind conditions, and is a process requiring adjustments in the turbine’s rotational velocity. This concept is challenging in practice. The twisted helix turbine reduces the effects of such variable winds by creating multiple “angles of attack” (the incident direction) for oncoming wind, and by allowing different TSR’s along a given blade. With these variances, changes in wind conditions have less dramatic effects on the turbine and facilitate more consistent energy production [12]. (946)

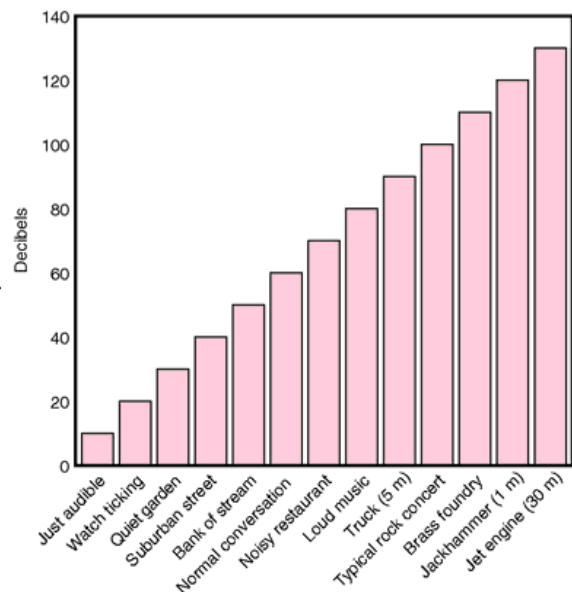
4. Comprehensive Analysis of Small-Scale Wind

Small-scale wind turbines are often publicly overshadowed by large wind farms, but are ideal for both residential and commercial use and should be taken advantage of here on the UMass Amherst campus. With the installation of wind power, UMass can generate clean renewable energy, cut down greenhouse gas emissions, and begin to change the current fossil fuel driven energy layout towards a more sustainable future.

After comparing multiple commercially available small-scale wind turbines, their average power output was found to range from 3kW-5kW [13-15]. These can produce between 5,000 kWh to 9,000 kWh per tower annually, by increasing tower quantity you can increase energy production [16]. The problem is that the energy generated is minimal in comparison to the campus energy needs. For instance four 5kW wind turbines annually produce around 36,000 kWh, which is only 0.0283% of UMass’s 127 million kWh total power usage [17]. Small-scale wind turbines would still make an impact when applied in the right circumstance; four 5 kW wind turbines could substitute 14% of Moore Hall’s electricity demands [17]. By bringing renewable energy to campus we are creating clean energy and beginning a shift away from fossil fuels towards a sustainable future.

Environmentally, wind energy is a great way to reduce carbon emissions and other harmful air pollutants. On average, one megawatt of wind energy reduces 2,600 tons of carbon dioxide [18,19]. Despite their promise though, some negative environmental impacts do exist

Figure 6:
Decibel Scale (for comparison)



from wind turbine material production. Water pollution results from polymer production and the excavation of steel, copper, and aluminum [20]. There are also carbon emissions from production, transportation and installation of turbines that amount to 0.02-0.04 lbs/kWh [21], however this amount is still far less than emissions associated with natural gas production, UMass' main source of fuel, which produces an estimated 0.6-2.0 lbs/kWh [21]. Another environmental impact of wind turbines are bird and bat collisions, caused by pressure differences from spinning rotor blades [21]. Before installation, an assessment must be done on impacts to local habitat and protected species. Damage to habitats will be minimal on campus if the installation process and environmental assessments are conducted properly. The positive environmental impacts of wind turbines are a major selling point.

A small-scale wind turbine is an investment, and therefore the risks involved in purchase must be weighed against potential rewards. For small-scale turbines, the primary risk arises in the high expense of installation. Small-scale turbine prices range considerably with purchase and installation costs depending on location, terrain, manufacturer, and turbine power ratings. Excluding maintenance and installation costs, the Bornay 6000 would initially cost \$12,307 [22]. We would see a return on investment after 3.35 years operating at 50% of its 6kW rated output, and in 6.7 years we will have raised enough money to purchase an additional turbine [23]. As long as a turbine meets expectations, these savings almost guarantee a net profit. Using this business plan, we can use the money raised by our initial investment and purchase additional turbines, expanding renewable energy on campus.

Small-scale wind turbines hold up remarkably when faced with issues of social equity. In general, smaller designs allow for safe, low-profile energy production that has direct benefits to those impacted. In addition to the energy and environmental benefits discussed earlier, turbines serve as symbols to educate communities about renewable and sustainable energy. Turbine integration will also result in a more localized energy networks, for instance reducing the UMass campus dependence on Central Heating Plant and WMECO operation. Also, purchasing turbines from local businesses such as Aeronautical Windpower or Turning Mill Energy boosts local economy.

One major issue that wind turbine projects have had is noise production. At a distance of 300 meters, your average large scale wind turbine has a sound pressure of 43 dB(A) [24]. This is comparable to an air conditioner (for more comparisons, see figure 6). Small scale turbines with the production of 1-10 kW eliminates this problem, as they have a maximum noise output of 30-40 dB(A) at only 100 meters away [25,26]. This is critical due to the fact that these turbines would be on campus where noise pollution is unacceptable.

Small-scale wind turbines have the potential to make a resounding effect on the UMass campus. If implemented they would produce clean energy, reduce carbon emissions, educate the public, and serve as a symbol of UMass's dedication towards sustainability. (743)

5. Technology of the Future - Altaeros' BAT

Wind is a tremendous source of energy if it can be harnessed correctly. However, most conventional wind turbines cannot reach altitudes where wind velocity is strong and consistent. The tallest wind turbines tend to be outrageously expensive or intrusive. High altitude wind energy addresses this limitation, and has grasped the attention of many scientists by being one of the largest untapped natural resources. Professors Cristina Archer and Ken Caldeira of the Carnegie Institute for Science at Stanford University stated in a 2009 journal article that, “the total wind energy in the jet streams is roughly 100 times the global energy demand” [27]. Understanding this, companies worldwide are racing to build and perfect airborne wind turbines, with hopes to harness this valuable renewable energy in the near future.

Figure 7: The BAT, by Altaeros



Designed by Altaeros Energies out of MIT the BAT, or Buoyant Airborne Turbine (see figure 7), is a high altitude wind turbine, which uses aerospace technology to capture strong consistent winds that are beyond the reaches of conventional turbines. The BAT is flown at altitudes as high as 600 meters, while commercial turbines only reach 120 meters. Wind speeds are on average 2 to 3 times faster and more consistent at the altitude’s reached by the BAT [28]. Increased wind power density is directly related to power generation, and high altitudes measure greater wind speeds far more consistently.

In order to reach high altitudes, the BAT operates similar to a blimp. The outer shell is composed of an industrial fabric filled with helium gas, which lifts the turbine to different heights. The shell does not need a yawing system because it is designed with tails and wings to automatically align with the wind.

Capturing wind energy is perhaps the most traditional part of the BAT’s design, utilizing a fairly standard turbine. This turbine is a conventional 3-blade horizontal axis wind turbine (HAWT) mounted in the center of the shell. The blades are connected to a shaft that goes through an induction generator. High rotational speeds achieved at higher altitudes cut out the need for a gearbox, greatly reducing weight.

Energy generated from the BAT is transmitted down to the ground using the BAT’s tether system. These tethers, three high strength cables connecting the BAT to its ground station, act as transmission wires in addition to structural components. The tethers are used to adjust the elevation of the turbine in order to maximize electricity generation, as well as pull the wind turbine down in the event of inclement weather.

The tethers connect to a ground station, which acts as a base for the BAT. It holds an autonomous control system that operates a winch system to control the BAT’s altitude, in addition to rotating the base to prevent the tethers from tangling. The electricity sent through the

tethers is conditioned at the ground station, and then distributed to the grid. The ground station is also portable, enabling the BAT and its components to be housed and transported on a large truck. This allows the BAT to shift locations, so it can move in the event of poor wind conditions.

In addition to these main components, the BAT has many other features that set it apart from the competition. The BAT's mobile design allows for power generation in remote communities, offgrid industries, and disaster relief. The BAT can also serve as a unique platform to expand Internet, phone and weather services. In emergency situations, whether it be a puncture identified by a pressure sensor or a rotor malfunction, the BAT is automatically programmed to slowly retract and safely land.

Commercial wind turbines are often challenged with the issue of environmental collateral damage, killing birds and bats that fly near the rotor blades. Most wildlife casualties result from barotrauma with rotor blades creating strong pressure differences in the air, causing the lungs of birds and bats to explode [29]. The high operating altitude and shape of the BAT help prevent birds from flying too close to the turbine and experiencing barotrauma. Avoiding these environmental obstacles significantly curtails possible opposition to the turbines and improves their ultimate goal of improving sustainability.

The Altaeros BAT and all new age turbines that harness the power of high altitude wind are the future of wind energy. The power that lies in high altitude winds is something that we must take advantage of in order to reduce our demand of fossil fuels. This new technology has the potential to change the world's energy layout. (742)

6. How the BAT Measures Up

Despite wind power's inherent renewability as an energy source, it accounts for only 1% of the energy used in the United States [30]. This is best explained by the prohibitive costs of installing wind turbines, limited locations of optimal conditions, and public opposition to wind power projects due to environmental concerns or aesthetic objections. Solutions must be less expensive, less intrusive, and more effective at capturing wind than current designs. To this end, high altitude wind energy solutions- such as Altaeros' BAT- improve upon energy generation magnitudes, present lower cost alternatives, and increase the technology's distance from society

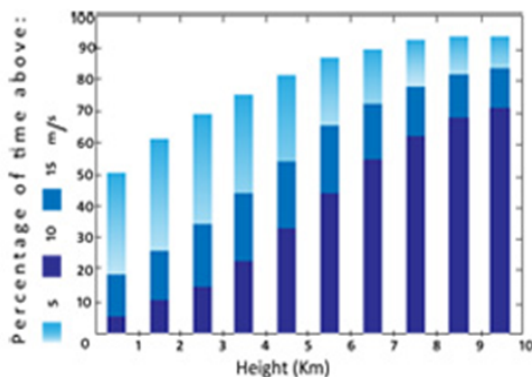


Figure 8:
Dependability of High-Altitude Wind as a Resource

to minimize collateral effects.

High-altitude wind turbines have even more potential than regular turbines due to the prevalence of faster, more consistent winds at higher altitudes. The fundamental power equation, given in section three, states that power density is proportional to wind velocity cubed. An Altaeros Press Release, and wind velocity increases substantially with altitude gains

between 80 and 500 m [27]. The BAT has been shown to work at heights of 150 m, and is scheduled to reach heights of 300 m during the Alaska Demonstration Project [31] announced last month. At these altitudes, the BAT can take advantage of much higher wind velocities.

According to Katherine Tweed of the IEEE Spectrum, the BAT has a power capacity of about 30 kW [36]. This is roughly the power consumed by 12 homes. Relating this figure to UMass' power consumption, we see this would power less than 1% of campus. This major con would discourage its implementation on campus.

Environmentally, wind turbines often impose threats to birds and bats, but the BAT's design helps reduce bird and bat casualties. The BAT's rotor blades are encased within a shell, reducing chances of collision or barotrauma [34]. Also, at 10 m in diameter the BAT's rotor blades are small compared to 90 m commercial rotor diameters, and therefore decrease collision risks. Additionally, pollution is caused by the excavation of steel used in existing turbine structures, where the process releases heavy metals and chemicals into water supplies. Airborne wind turbines use significantly less material than commercial turbines, reducing steel excavation pollution.

An environmental restraint on the BAT is its dependence on helium. The shell is filled with helium, which has a low density that lifts the turbine. Once helium is released into the environment it escapes into space, making it a finite resource [32]. Other airborne turbines do not use buoyant technology, and operate more like kites to stay suspended [33]. Helium supplies are not currently limited, but potential future shortages may be a problem for buoyant turbines.

The BAT's economic implications are dependent upon the application, but perhaps the most obvious drawback is the substantial price tag. The \$1.3 million 30kW BAT prototype being installed in Alaska averages slightly less than \$45,000 per kW, which is starkly contrasted with traditional small-scale turbines, where installation costs range from \$3,000-8,000 per kW [35]. Despite this, two facts should be noted. First, the BAT's portability eliminates the risk of permanent installation in unfavorable wind conditions. Second, this \$1.3M cost is for a prototype. Prices should diminish if the BAT proves effective and becomes commercially manufactured. This is a future technology afterall.

Location is another key in economic scope. Current expectations set Alaskan energy costs at about \$0.18 per kWh [36], half that paid currently by beneficiaries. This is more expensive than UMass' current rates, set at \$0.14 in 2012 [23]. That being said, a BAT purchase by UMass eliminates this cost. Unfortunately at current prototype prices, return on investment would take 50 years, which is not a feasible option.

The BAT is an equitable investment in many regards. Altaeros Energies is a local company based out of MIT in Boston. Supporting them correlates to supporting local businesses and jobs. An important aspect of Altaeros' research is that they are helping to access the large untapped renewable resource of high altitude wind. These powerful winds have significant energy potentials and Altaeros is one of the first working towards capturing them.

After further research high altitude wind turbines have a promising future. Although the BAT does not produce the quantity of energy we expected it still has many pros and is a start for the future of high altitude wind turbines. Further research and development of this technology will only improve in performance and decrease in cost making it a formidable future technology. (741)

7. Conclusion

There are many small scale wind turbine designs, each with advantages and disadvantages. Horizontal-axis turbines extract energy from the wind very efficiently, but are limited in urban settings due to their yawing system. Vertical-axis turbines capture wind from all directions, and work more efficiently in variable wind conditions. Performing research on campus to accurately determine wind patterns will allow us to choose the turbine most fit for the UMass campus.

Small-scale wind turbines are environmentally responsible, generating clean and renewable electricity. Wind energy potential may seem minimal in comparison to UMass's cumulative energy consumption, but when used to offset energy usage in residence halls or individual buildings we see they have a considerable impact. Most small scale wind turbines have a payback period less than 15 years [23], and the money saved after this period can be used to buy more turbines, accelerating renewable energy production.

The lack of energy output of wind energy in comparison to other available energy sources is a major problem. High altitude wind can solve this problem though, as wind energy density is proportional to velocity cubed. High altitude wind turbines, such as Altaeros' BAT, can reach heights of 500 m, where wind speeds can be several times greater than speeds on the ground [28,31]. This technology is still in the developing stages, but shows promise to be a large contributor to our world's future energy layout.

Once we conduct necessary research to quantify the wind energy potential on campus, we can choose the most effective turbine to optimize energy output and minimize the payback period. Obtaining this data is crucial to assessing the viability of wind energy on campus. There are many wind tunnels throughout campus that are created when wind is compressed between buildings. If future research shows these wind tunnels to be a significant wind resource, we can exploit this occurrence to our advantage when installing turbines.

UMass claims to be a leader in sustainability, and the Climate Action Plan projects the Amherst campus to be carbon neutral by 2050 [4]. If wind energy is currently too expensive for a full-scale switch, a gradual start down the path of clean energy must be adopted immediately. Wind energy, the fastest growing renewable energy, needs to be a part of UMass's energy portfolio. (375)

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Figure 1: <http://www.enviroprosolutions.ca/images/eddyGT.png>

Figure 2: <http://www.realityunknown.com/wp-content/uploads/2011/06/electrical-generator.jpg>

Figure 3: <http://static.ddmcdn.com/gif/wind-power-wind-flow.gif>

Figure 4:

<http://www.greenenergyreporter.com/wp-content/uploads/2012/06/Savonius-3-Blade-Wind-Turbine.jpg>

Figure 5: http://sync.nl/wp-content/postpics/f_479.jpg

Figure 6: <http://img.tfd.com/mk/D/X2604-D-04.png>

Figure 7: Alteros Energy (2014) The Buoyant Airborne Turbine.

<http://www.alterosenergies.com/bat.html>

Figure 8: High Altitude Wind Energy (2006) Omnidea

http://www.omnidea.net/hawe/project_motivation.html