Wind Power Technology and Finances

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Wind Turbine Basic Types

- Vertical Axis Wind Turbine (VAWT) Good in small spaces but can only extract 50% of energy that a HAWT does. Versions available to 5kW
- Horizontal Axis Wind Turbine (HAWT) Need more space than a VAWT but can extract more energy. Versions > 3mW. Upwind design
- Lots of “smoke and mirror” designs
- Good overview at: http://en.wikipedia.org/wiki/Wind_turbine

Definitions/Conversions

Blade length or turbine diameter:

1 meter = 3.3 feet

Wind Speeds:

1 meter/sec = 2.24 mph

Turbine Power:

1kW (kilowatt)= 1,000 Watts

1MW = 1 million Watts

Energy Production/Consumption:

kWh = kilowatt hours = power x time

(A 100 W light bulb used for 10 hours/day, uses 1 kWh of energy per day or 365 kWh per year)

HAWT Turbine Profiles

	Small	Medium
Energy output (rated)	<100kW (residential are from 2kW – 20kW	100 – 250kW
Rated wind speeds	26-30 mph	30-40 mph
Power Connections	Net metered, 3-phase (net metering is when you offset your electrical usage with the power you produce; excess is sold at a lower price)	3 phase (3 phase is preferred by power companies as it is more efficient)
Blade characteristics	<30 ft blade length/fiberglass	<45 ft blade length/fiberglass
Cut-in speed	6-8 mph	8 mph
Cut-out speed	50-60 mph	50-60 mph

Power Dependencies

•Wind power is determined by average wind speed, air density, area swept by blades, and capacity factor

- Power ~ cube of avg wind velocity
- Power ~ square of rotor length (radius of turbine)
- Power ~ air density – cold air is more dense
- Capacity factor is applied to account for variable wind speed. Actual energy output = rated output x capacity factor (typically 10-40%) x 24hr/day x 365 day/yr

HAWT Wind Turbine

- Large
  - Wind speeds in Carlisle are too low to make economic sense. DOE Wind Resource Atlas assigns Classes 1 – 7, where Class 1 is virtually no wind. Carlisle is in a Class 2 region.
  - Looking for 6.5 m/s (14.5 mph)
  - No 300’ rotors on 400’ towers in Carlisle!!

Carlisle Wind Characteristics

- Raw True winds map data (model-based)
  - 4.0 – 5.5 m/s at 50 meters
  - 9.6 – 12.1 mph at 160 ft
- 66% of the time (over 1 year) winds at 50 meters (~150 ft) blow at an average of 5.3 m/s
- Average wind power density at 50 meters with an average wind speed of 4.9 m/s is 139 Watts/m^2

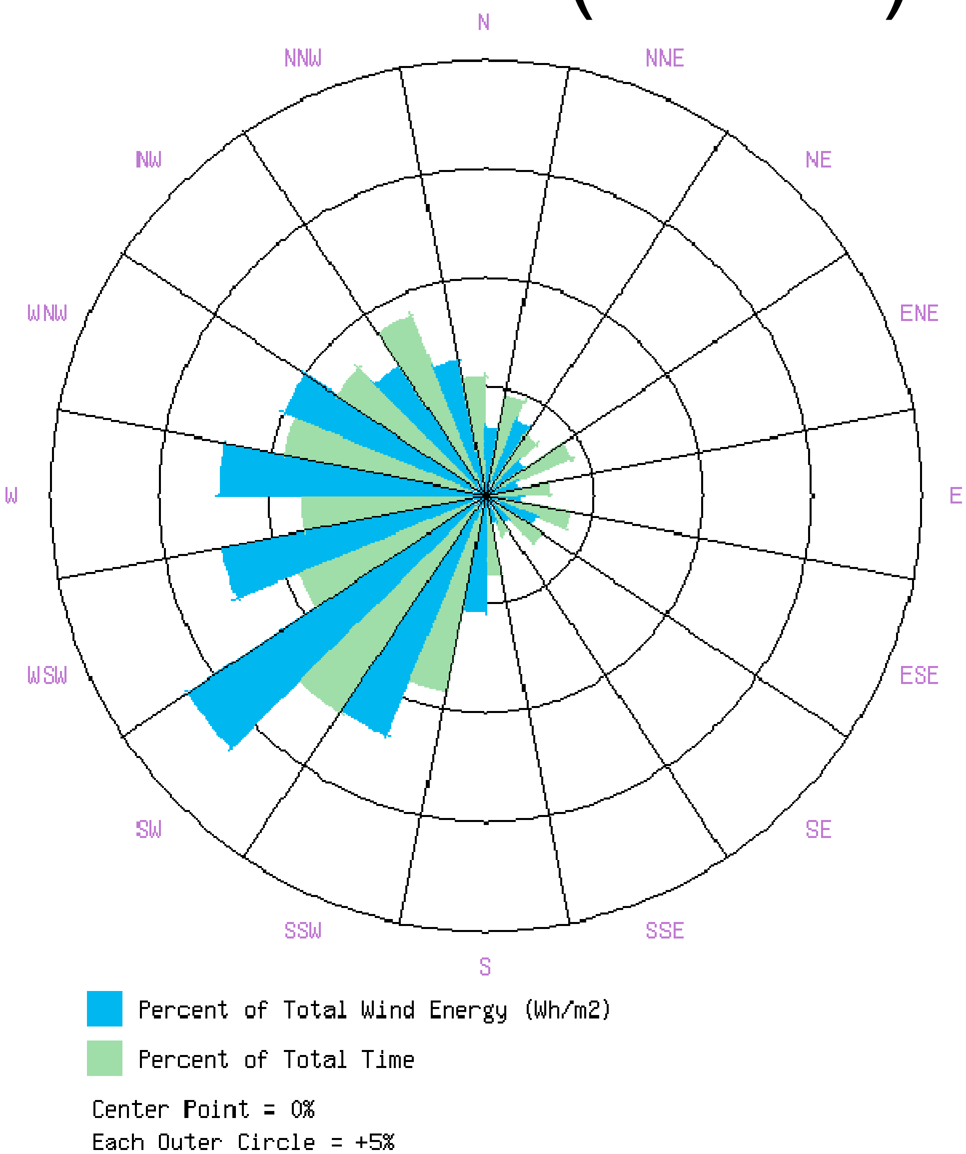
Carlisle Wind Characteristics (cont'd)

- Factors that increase speed that Carlisle has
  - Gradual rolling hills, open spaces, rivers

- Factors that decrease speed that Carlisle has
  - Trees within 300' of towers. Towers needs about 30' clearance to negate this effect.

- About 20% more wind energy in the winter than summer

Carlisle Wind Characteristics (cont'd)



Most wind power is generated from the NNW – SSW quadrant, which occurs 66% of the time

Generation Calculations

Step 1: Enter the information about your proposed wind energy system in the green boxes.

? <-Mouse over these icons for relevant help

General Information

Name of Person Completing this Form	Tom Dowd/Keith Therrien
Report Date	1/30/2008
Applicant Name	Keith Therrien
Applicant Email Address	keith.therrien@comcast.net
Site Address	78 Berry Corner Lane Carlisle,MA

System Information

? Turbine	Other	
? Tower Height	100	Feet
? Tower Type	Hinged lattice	

Site and Wind Resource Information

? Description	Inland	
? Latitude	42.5200	
Longitude	-71.38	
? Average Annual Wind Speed	4.5	m/s
? Anemometer Height	30	Meters
? Elevation	246	Feet
Distance to Nearest Property Line	60	Feet
? Location of AC Disconnect	Base of tower	
Location of Inverter	Residence basement	

You have selected an unlisted turbine. Please enter the power curve values for your turbine in the table at right. All values must be filled in.

Look up your latitude/longitude

Look up your average wind speed here

Wind Speed (m/s)	Power (kW)
1	0
2	0
3	1.12
4	1.59
5	3
6	4.8
7	6.6
8	8.4
9	11
10	15.5
11	18.5
12	20
13	20
14	20
15	20
16	20
17	20
18	20
19	20
20	20

Rated kW 20

Rated Wind Speed (m/s) 11.6

Go To Step 2

MASSACHUSETTS TECHNOLOGY COLLABORATIVE

Note:

This calculator tool was developed by The Cadmus Group, Inc. on behalf of the Massachusetts Technology Collaborative. It is intended to provide a coarse estimate of production and neither The Cadmus Group, nor MTC, makes any guarantees as to the performance of your particular system.. Factors such as site conditions, changes to manufacturer specifications, and other variables will all affect actual production. The production estimate is based on a Weibull distribution, which can be inaccurate over short periods. We recommend the use of yearly or monthly average wind speeds. The use of shorter time periods may lead to inaccuracies.

For Questions or Comments on this calculator:
PTS@cadmusgroup.com

Step 2: Wind Rose and Roughness/Obstruction Losses

Enter wind frequency numbers in the table below and use pull down menus to describe the roughness of the terrain. If your site has thick vegetation or obstacles, such as forest, near (within 300 feet) of the tower base, estimate the average height of the vegetation. Finally, enter a description (e.g. trees, large barn, etc) in the table below for reference.

Return to Step 1

Units Feet

Wind Direction	Frequency (Percent)	Terrain Roughness	Height of Nearby Obstacles	Description of Terrain/Obstacles
N	5.50%	Rough	50	Trees (tower on top of ridge)
NNE	4.70%	Rough	50	Trees (tower on top of ridge)
NE	3.40%	Rough	50	Trees (tower on top of ridge)
ENE	4.30%	Rough	50	Trees (tower on top of ridge)
E	3.00%	Rough	50	Trees (tower on top of ridge)
ESE	4.10%	Rough	50	Trees (tower on top of ridge)
SE	3.10%	Rough	24	Residence
SSE	2.00%	Rough	50	Trees (tower on top of ridge)
S	3.70%	Rough	50	Trees (tower on top of ridge)
SSW	9.20%	Rough	50	Trees (tower on top of ridge)
SW	12.10%	Rough	50	Trees (tower on top of ridge)
WSW	9.40%	Rough	50	Trees (tower on top of ridge)
W	8.50%	Rough	50	Trees (tower on top of ridge)
WNW	9.50%	Rough	50	Trees (tower on top of ridge)
NW	8.30%	Rough	50	Trees (tower on top of ridge)
NNW	9.00%	Rough	50	Trees (tower on top of ridge)

Proceed to Wind Technical Worksheet

Generation calculation (cont'd)

Wind Technical Worksheet	
Total wind system size (AC watts): *(rated output for industry comparison purposes, e.g., the Bergey XL.1 would be 1,000 watts or 1 kW)* **20 kW**	Wind speed required for rated output (meters per second): **11.6 m/s**
Inverter location: **Residence basement**	Location of AC disconnect switch: **Base of tower**
Tower type: *Lattice*	Tower location (Degrees) **42.52 Lat -71.38 Long**
Hub/tower height (meters): **30.5 m**	Distance to nearest property line from base of turbine (meters): **18 m**
Average annual wind speed at hub height (meters per second): **4.1 m/s**	Source of average annual wind speed: ***AWS TrueWind Maps***
Est. annual Production (kWh): **22650 kWh/year**	Summarize methodology and source for estimated production: **Calculator developed by The Cadmus Group, Inc. on behalf of the Massachusetts Technology Collaborative**

Note: Truewinds adjusts wind speed and wind power output downward to account for site conditions such as roughness, and obstacle height (trees) and increases hub height to avoid turbulence.

Feasibility Studies

- Feasibility studies should be required for community based facilities where capital investment is higher than for residential installations.
- Feasibility studies for community scale cost ~ $30 – $70K (before rebates) and should include:
  - Wind resource assessment (is there enough wind to generate enough wind power throughout the year?)
  - Site and design selection and optimization
  - Environmental impact study
  - Economic feasibility analysis (financing, dependencies, ROI)
  - PR plan (how to involve the community)
  - Review of applications and permits
- Feasibility for residential should include a third party site visit and validation of site selection and design by qualified, impartial expert (e.g. not an installer).

Feasibility Studies (cont'd)

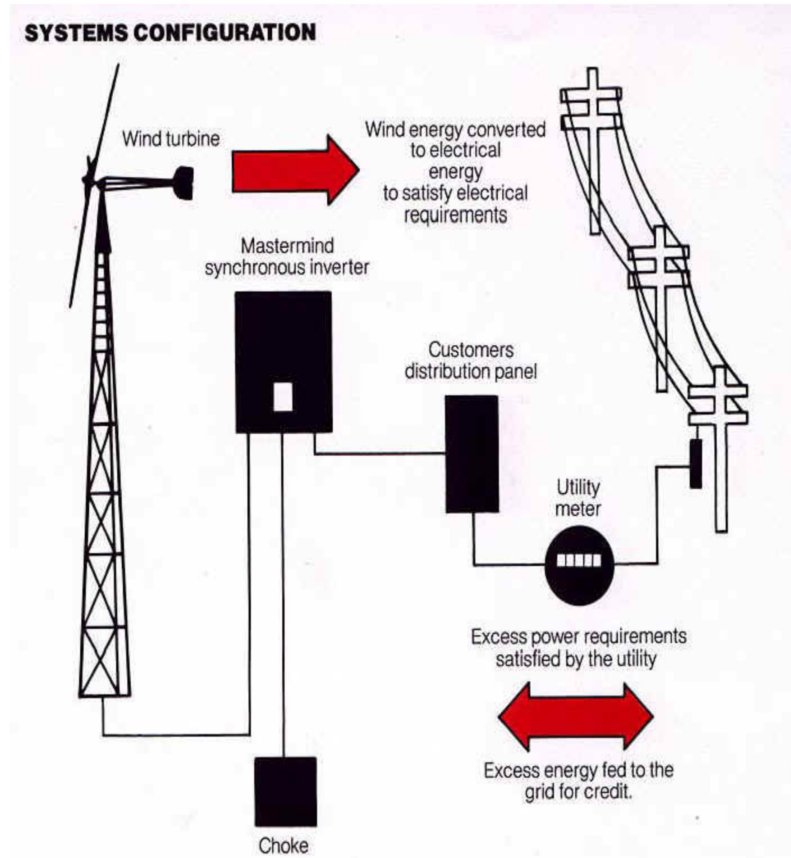
- Economics of projects (ROI and revenue) are highly dependent upon accurate wind data (small errors have large impact on power calculations).
  - Wind speeds are highly site specific, especially due to Carlisle modest avg wind speeds, and tree cover.
  - Wind power assessment includes the setup of temporary met tower(s) to gain accurate average wind speed/direction & air density over a year.*
- All applications should require the presentation of wind data.
  - Residential sites may only need modeled data (such as from TrueWinds**), however wind measurement may be required depending upon location
  - Community scale requires additional measurement at the actual site.

* *Met tower consists of a ~50 – 100 m pole that carries an anemometer for speed and direction, and a logger for data collection*

** *TrueWinds data is model-based and is accepted by MTC which provides $ grants*

Net Meter Hookup

- NSTAR allows up to 60kw simple net metering hookup
- NSTAR requires UL 1741 compliant inverters for net metering hookup
- NSTAR pays back $.07 per excess kWhr. Might go to over $.11kWh



Electrical Contingencies

- Wind turbines must have automatic turn-off in the case of power outages to avoid ‘islanding’
- Voltage and frequency of generated power (e.g. power quality) must be in phase with that of the utility grid (IEEE standards – UL 1741 for NSTAR)
- In 21 years since utilities have been required to allow small wind systems to interconnect with the grid there have been no liability claims relating to electrical safety.
- NSTAR does not require insurance coverage for turbines <60kW

Carlisle Energy Requirements and Carbon Numbers

- Average house uses ~1000kWh/month
- With a Groundwater heat pump of COP = 3, required load is doubled to 2000kWhr/month
- With plug in cars ??? Have no data on this.
- Typical residential turbine keeps over 200 tons out of the atmosphere over its life span.

Turbine Maintenance

- O&M is low for residential scale; most components sealed in today's technology
- Small residential units at most require greasing of drives every 6 months (tighten bolts, check electrical connection, corrosion, blade wear, etc.) and replacement of bearings and blades every 10 years. Cost is minimal for servicing ~$500/yr; $0 for do-it-yourselfers
- Most towers are purchased with hinges to make lowering simple for maintenance or safety reasons (e.g. during hurricanes)

Funding and Subsidies – Small (<10kW)

- MTC (Mass Technology Collaborative) is the entity that administers SRI funds (for wind, solar and hydro):
  - $3.6 million of rebates per year through 2010
  - Grants of up to $50K for design & construction
  - For consumer sited renewable projects
  - First come first serve grants, monthly awards
- State personal income tax credit (minimal)
- Exempt from property tax (only the value of project) and sales tax
- Federal rebates for wind expired in Jan 08 – more to come?????

Funding and Subsidies – Large (>10kW)

- MTC administration of LORI funds (for wind, solar and hydro):
  - $7 million of rebates (pending approval), semi-annual awards
  - Competitive solicitation & evaluation
  - Grants of up to $40K for feasibility studies (with 15% cost share)
  - Design capped at $100K or 75% of actual
  - Construction capped at $400K or 75% of actual
  - Added rebates for affordable housing, green buildings, systems made in MA, public buildings
  - Technical and business services, wind monitoring equipment, etc offered to cities and towns interested in exploring renewables
  - MTC Green Power Partnership purchases Renewable Energy Certificates (RECs) to create guaranteed revenue streams that facilitate project financing.
- Federal incentives for solar and fuel cell but not wind (could change)

Turbine Payback - Residential

- Project costs (~$2 - $8 per installed Watt):
  - about $55k for a 10kW (Bergey @ $5,500/W cost) or $75k for a 20kW unit (Jacobson at $3,800/W cost)
- MTC rebate (~$2/installed Watt):
  - $20K for 10kW, $40K for 20kW
- The net cost (after MTC rebate):
  - $35K for 10kW, $35K for 20kW
- For household using 1,000kWh/mo, wind speeds at 50m of 4.1m/s:
  - Payback on 10kW unit is about 12 years and on 20kW unit is about 9 years given current electric rates ($.19/kWh in avoided cost and $.07/kWh for NStar purchase)

Turbine Payback –Residential <u>w/ Heat Pump</u>

- Project costs:
  - $75k for a 20kW unit
  - $25,000 for a groundwater heat pump (estimate)
- MTC rebate ($2.25/installed W for wind):
  - $45K for 20kW
- For household using 1,000kWh/mo electricity, 1,000 gal/yr fuel oil, wind speeds at 50m of 4.1m/s:
  - Payback on 20kW unit is about <u>7 yrs</u> given current electric rates ($.19/kWh in avoided cost and $.07/kWh for NStar purchase, average of $5,000 fuel cost/yr avoided) *Note gas and propane avoided costs differ

Environmental Impact

- Birds - Modern wind turbines kill on average one to two birds per turbine, per year
- Wind energy development's overall impact on birds is extremely low (<1 of 30,000) compared to other human-related causes such as power lines, buildings, communications towers, traffic, and house cats
- Bat collisions have not been measured but appear to be no worse than bird collisions

Source – Renewable Energy Research Lab, U. Mass Amherst

Environmental Impact

- Noise - at winds speeds around 4-7 m/s + the noise from the wind in leaves, shrubs, trees, etc. will mask any sound from wind turbines.
- Sound intensity decreases with the square of the distance from the sound source.
- From a distance of several hundred feet, large turbines can be compared to the sound level of a refrigerator ~52-55 dba. (Residential units <20kw generate < 55 dba at 100’ from unit at ground level*)

Source – Renewable Energy Research Lab, U. Mass Amherst

* Sources - *Contemporary Problems in Appropriate Technology Residential Wind Turbines and Noise Emissions By Ernest V. F. Hodgson, WTIC Jacobs 31/20 Wind*

Environmental Impact

- Rotor Safety – Material fatigue properties are an important consideration in wind turbine design and materials selection
- During the expected 20-30+ year life of a wind turbine, many of the components will need to be able to endure 4×10^8 fatigue stress cycles.
- Wind turbines located in the northeast should be rated for loads to reflect possible icing.

Source: Danish Wind Industry Association

Environmental Impact

- Icing Issues – blade flexion inhibits the formation of ice during operation; most ice throw occurs during start up.
- Vibration sensors act to stop operation if load imbalance is detected from ice formation (usually ice does not distribute evenly over surfaces)
- Rime ice is the exception to the above – in this case vibration will not occur. The best security is to halt operation during forecasts of icing.

Real Estate Value

- Statistical evidence does not support a contention that property values within the view shed of wind developments suffer or perform poorer than in a comparable region.
- In several cases the property values in the view shed actually go up faster than values in the comparable region

- *Source: Renewable Energy Policy Project – Analytical Report May 2003*

Case Study 1

- At least 2 residential wind turbines are operating successfully in Hamilton, MA since 2003
- Population density ~500 per mi^2
- Avg wind speed 5.2 m/s, 174 W/m^2
- Hub is 72 ft tall – no dead birds
- Hamilton Bylaws:

http://www.hamiltonma.gov/Zoning%20Bylaw%20posted%20Sept.%202006.pdf

- Already 5 states prohibit local zoning laws from small wind prohibitions

Source: US DOE – Small Wind Electric Systems – Massachusetts Guide, MTC NE Wind Map

Case Study 2

- 50kw Entegrity EW-15 in Essex, Ma. Population density ~230 per mi^2 . Under construction. LORI grant.
- Avg wind speed 6.2 m/s
- Site is wooded on top of hill with about 50’ canopy.
- Tower is 100’ lattice
- ZBA special permit because there were no bylaws

Source: US DOE – Small Wind Electric Systems – Massachusetts Guide, MTC NE Wind Map

Further Reading

- http://www.eere.energy.gov/windandhydro/windpoweringamerica/ne_projects.asp inventories wind projects in NE
- US DOE Small Wind Electric Systems – MA Consumer's Guide
- US DOE Annual Report on U.S. Wind Power Installation, Cost and Performance Trends: 2006 (PDF 2.5 MB)
- http://www.awea.org/faq/wwt_environment.html
- http://www.awea.org/resources/resource_library/index.html#DocumentsandReports