Wind 101

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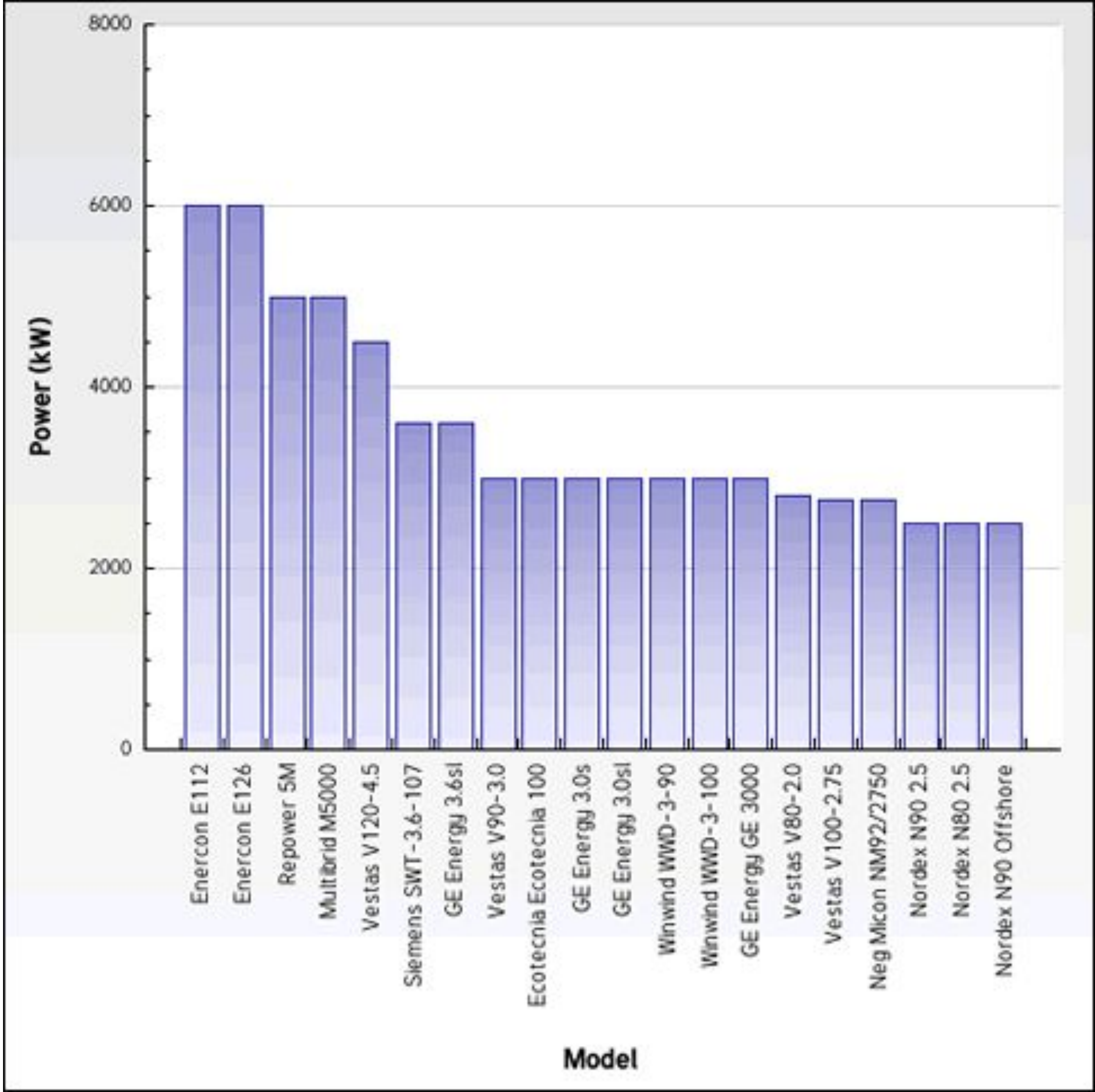
Wind Turbines

- Horizontal Axis, HAWT (all large power turbines are this type)
  - Upwind
  - Downwind
- Vertical Axis, VAWT
  - Good for low wind and turbulent wind (near ground)
- Lift (more efficient that drag type)
- Drag

HAWT

Largest Turbines (Rated Power)



World’s Largest Turbines

- Enercon E-126
    - Rotor diameter of 126 m (413 ft)
    - Rated at 6 MW, but produces 7+ MW

- Clipper (off-shore)
    - Rotor diameter of 150 m (492 ft)
    - Hub Height is 328 ft
    - Rated at 7.5 MW

- Clipper 2.5 MW
  - Hub height 80 m (262 ft)
  - Rotor diameter 99 m (295 ft)
  - 4 PM generators in one nacelle

- 3.28 ft/m

- Vestas 1.65 MW turbines at Ainsworth wind farm
  - Class 5 wind site (avg. wind speed is 19.5 mph)
  - 36 turbines in farm
  - Hub height is 230 feet
  - Rotor diameter is 269 feet
  - Project cost was about $1,355/kW

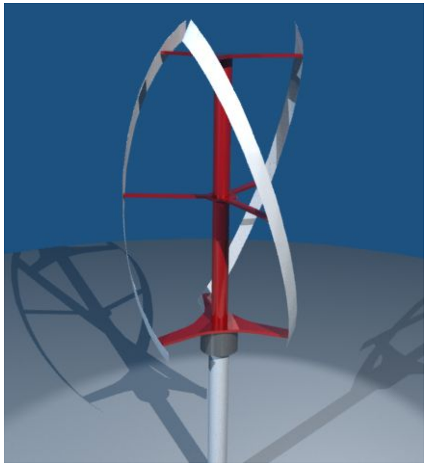
- Bergey Excel 10 kW
  - Hub height 18-43 m (59-140 ft)
  - Rotor diameter 7 m (23 ft)

- 1.8 kW Skystream Southwest Wind Power
  - Hub height is 45 feet
  - Rotor diameter is 12 feet
  - Project cost was about $8,300/kW

VAWT

- 30 m Darrieus

- Helical Twist



Vertical axis turbines

- PacWind Seahawk, 500 W
  - Drag type

- PacWind Delta I,   2 kW
  - Lift type

- Darius turbine, few 10’s kW

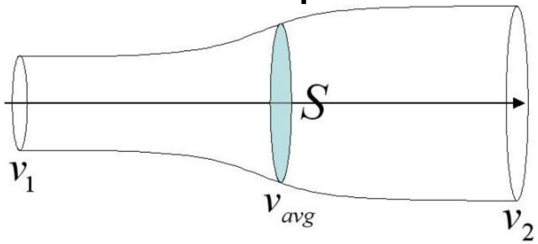
Wind-Turbine Physics

- Power available in the wind

  $P_w = ½ \rho A v^3$ air density, swept area of blades, air velocity

- Power Coefficient, C_p = Rotor Power/Power in Wind

- Betz Limit – theoretical maximum power that can be extracted from the wind is C_p = 16/27 = 0.593 or 59.3%



Physics Continued

- Tip Speed Ratio, λ, is the ratio of the blade-tip speed (linear velocity) to wind speed.

  $\lambda = \Omega R/v$
  - Ω is the angular velocity of the rotor
  - R is the radius of the rotor
  - v is the wind velocity
- The Power Coefficient, C_p, is a maximum (approaches Betz Limit) when the Tip Speed Ratio is in the range of 7.5 to 10.

Physics Continued

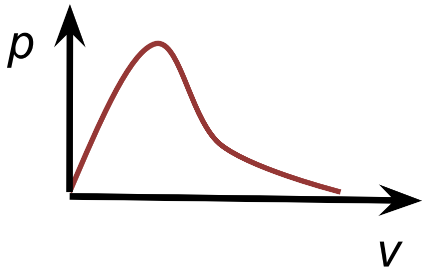
- In Drag-type turbines, the wind velocity relative to the power producing surfaces is limited to the free-stream velocity. This results in a Power Coefficient, C_p, that maximizes at about 0.0815 (much lower than Betz Limit for Lift devices)
- In Lift-type turbines, the relative wind velocity is higher by a factor of up to 10 above the free-stream wind velocity.
  - When considering lift and drag effects, 3 blades is an optimum choice for the number (more blades moves the design closer to the Betz Limit, but is in diminishing return)

Wind Resources

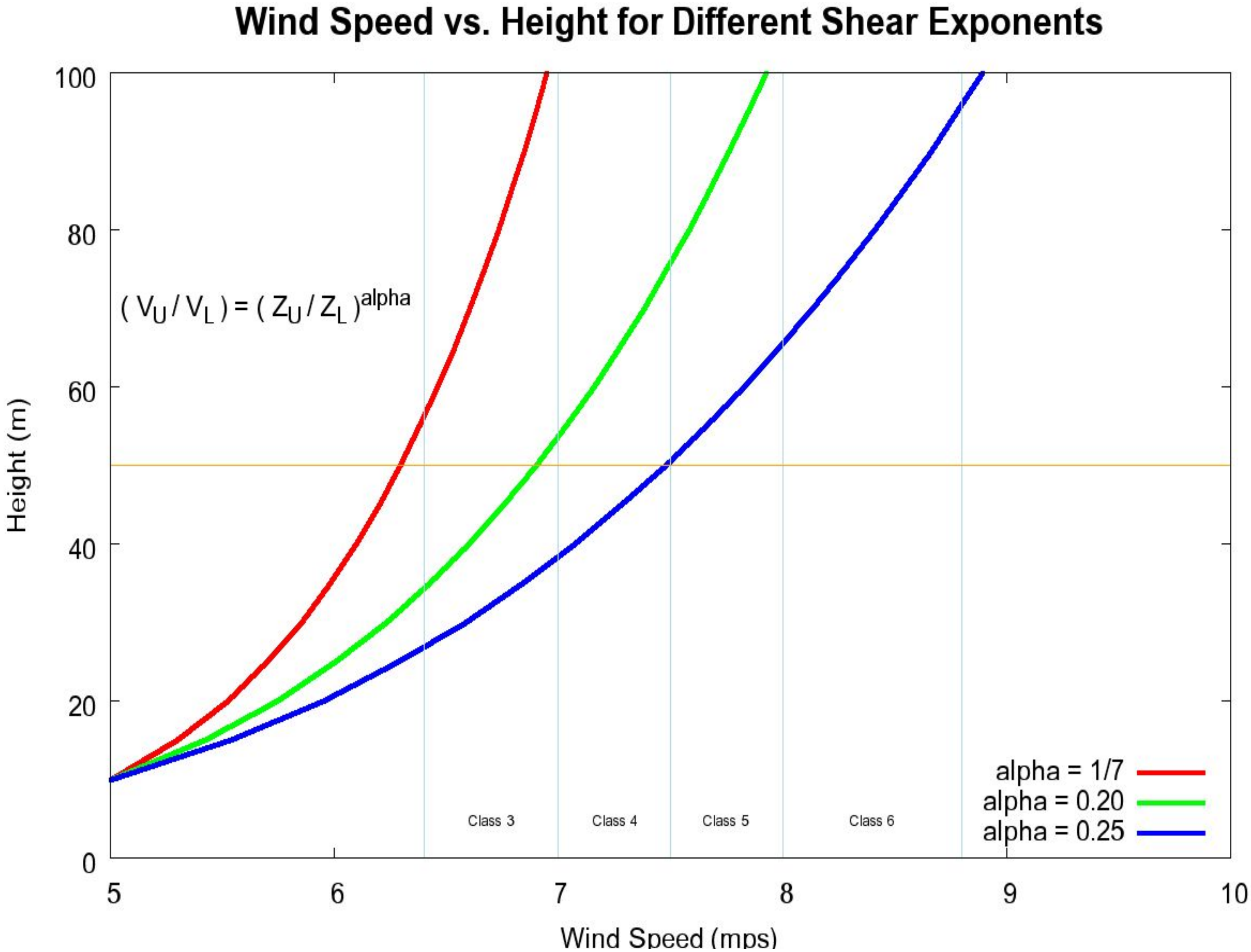
- Probability Distributions
  - Rayleigh
  - Weibull

- Probability of wind speed occurring between speeds of v_a and v_b is the sum (integral) of $p(v)$ wrt velocity, over the range from v_a to v_b.

Wind Resources



- Probability Distributions, $p(v)$
  - Rayleigh
    - Only need to know mean wind speed, v_{mean}
  - Weibull
    - Need to know 2 parameters, shape factor k, and scale factor c
    - Special case for Weibull Probability Distribution is for $k = 2$ (Weibull becomes a Rayleigh Distribution)



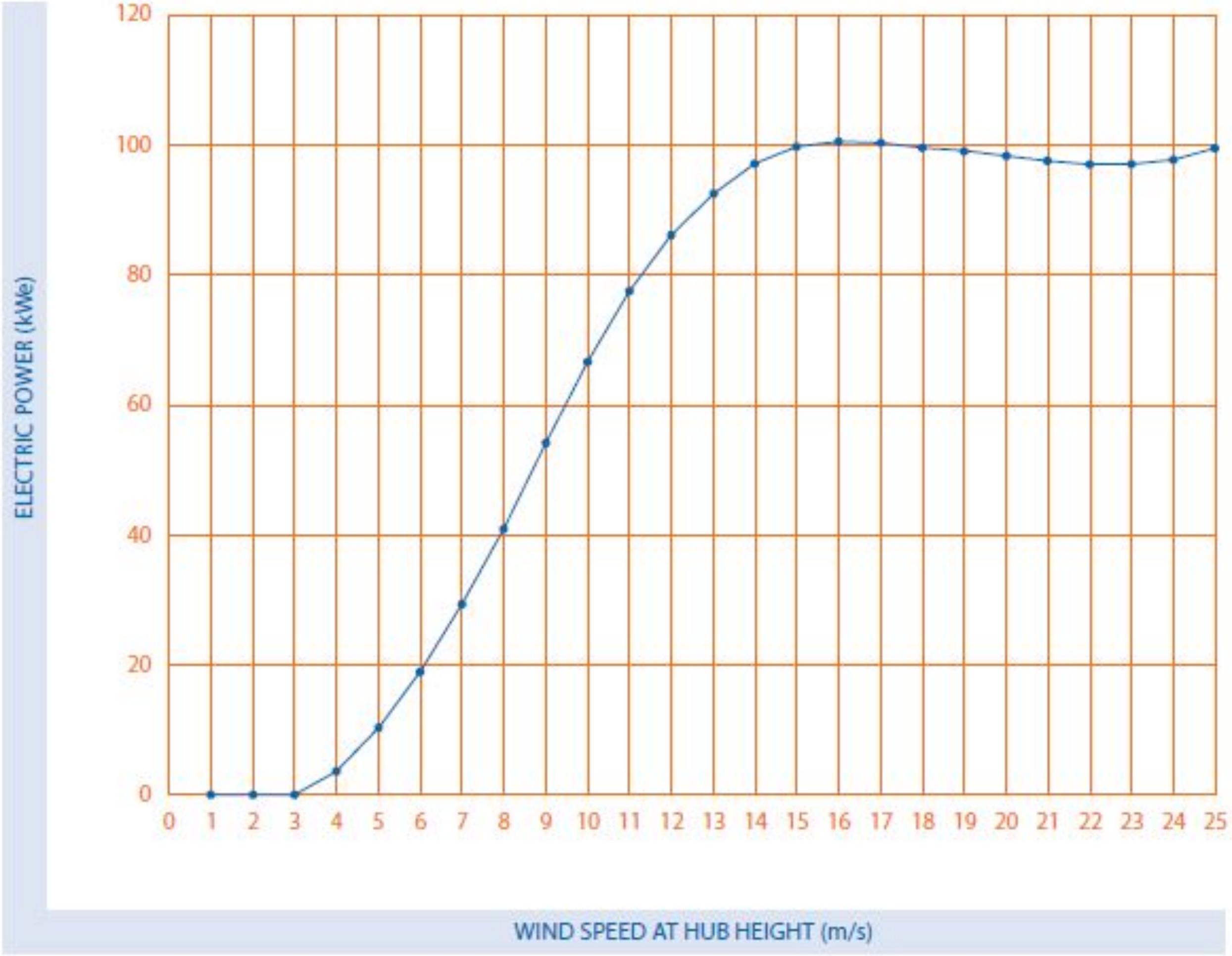
Annual average shear exponents can vary from 1/7 to 0.25, causing considerable uncertainty in vertical extrapolations of wind resource.

Wind Turbine Output Power

- The average output power, $P_{Turbineavg}$, from the turbine is the sum (integral) of the product of the turbine's power curve, $P_{pwrcurve}(v)$, and the wind speed probability density function, $p(v)$.
- One quick measure of turbine performance is to assume an ideal turbine where $C_p = 16/27$ (Betz Limit) and an efficiency, $\eta = 1$, and a Rayleigh distribution of wind speeds.
  - Calculation of $P_{Turbineavg}$ gives the 1-2-3 equation:
    - $P_{Turbineavg} = \rho(2D/3)^2(v_{avg})^3$
      - ➢ ρ is air density, D is rotor diameter, v_{avg} is average wind speed

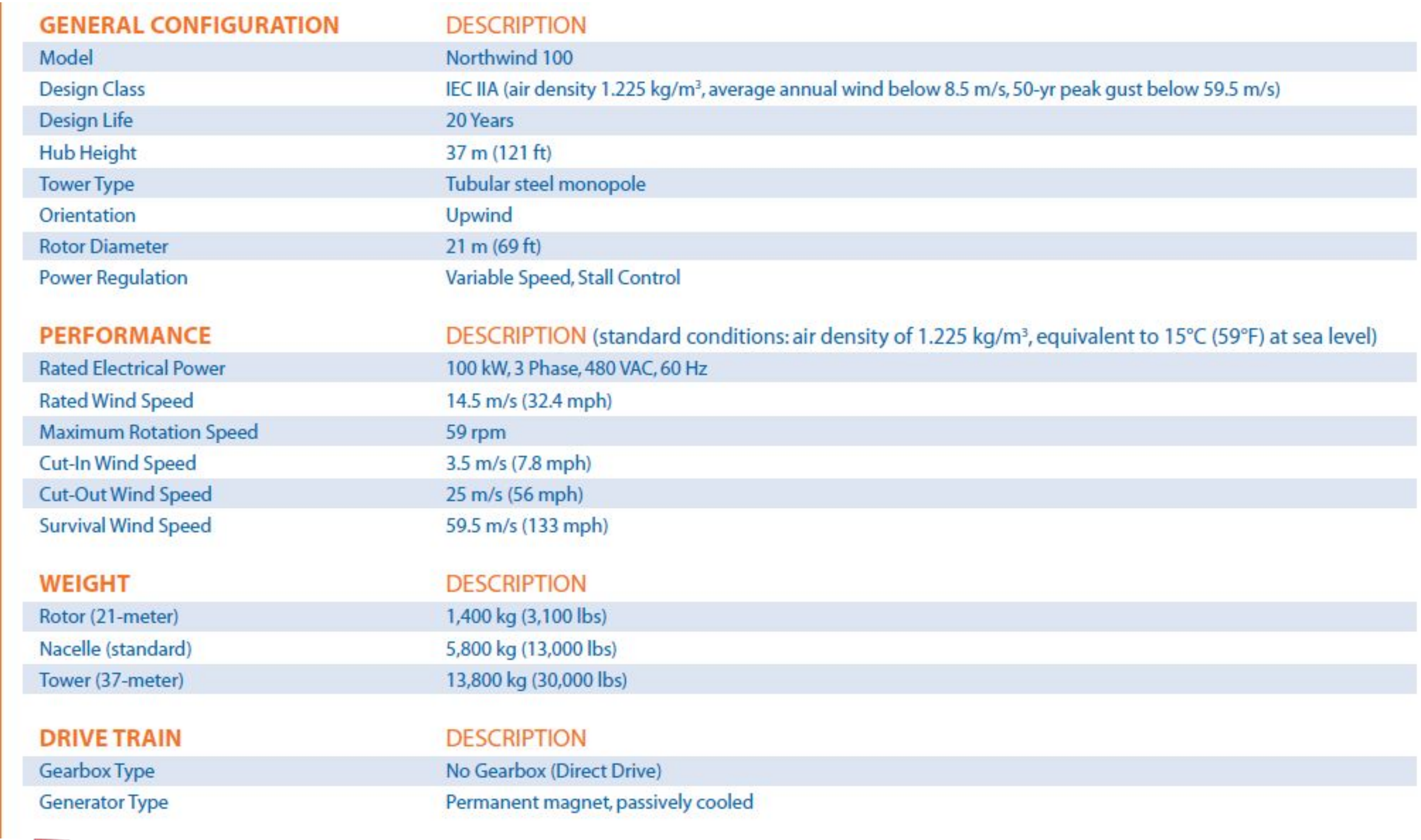
POWER CURVE: 21-METER ROT0R

Standard Density (1.225 kg/m^3)



WIND SPEED (m/s)	POWER (kWe)
1	0
2	0
3	0
4	3.7
5	10.5
6	19.0
7	29.4
8	41.0
9	54.3
10	66.8
11	77.7
12	86.4
13	92.8
14	97.3
15	100.0
16	100.8
17	100.6
18	99.8
19	99.4
20	98.6
21	97.8
22	97.3
23	97.3
24	98.0
25	99.7

Northwind 100



GENERAL CONFIGURATION	DESCRIPTION
Model	Northwind 100
Design Class	IEC IIA (air density 1.225 kg/m^3, average annual wind below 8.5 m/s, 50-yr peak gust below 59.5 m/s)
Design Life	20 Years
Hub Height	37 m (121 ft)
Tower Type	Tubular steel monopole
Orientation	Upwind
Rotor Diameter	21 m (69 ft)
Power Regulation	Variable Speed, Stall Control

PERFORMANCE	DESCRIPTION (standard conditions: air density of 1.225 kg/m^3, equivalent to 15°C (59°F) at sea level)
Rated Electrical Power	100 kW, 3 Phase, 480 VAC, 60 Hz
Rated Wind Speed	14.5 m/s (32.4 mph)
Maximum Rotation Speed	59 rpm
Cut-In Wind Speed	3.5 m/s (7.8 mph)
Cut-Out Wind Speed	25 m/s (56 mph)
Survival Wind Speed	59.5 m/s (133 mph)

WEIGHT	DESCRIPTION
Rotor (21-meter)	1,400 kg (3,100 lbs)
Nacelle (standard)	5,800 kg (13,000 lbs)
Tower (37-meter)	13,800 kg (30,000 lbs)

DRIVE TRAIN	DESCRIPTION
Gearbox Type	No Gearbox (Direct Drive)
Generator Type	Permanent magnet, passively cooled