Wind Energy Fundamentals

Wind Diesel 101 Workshop

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Sizes and Applications

Small (≤10 kW)

- Homes
- Farms
- Remote Application

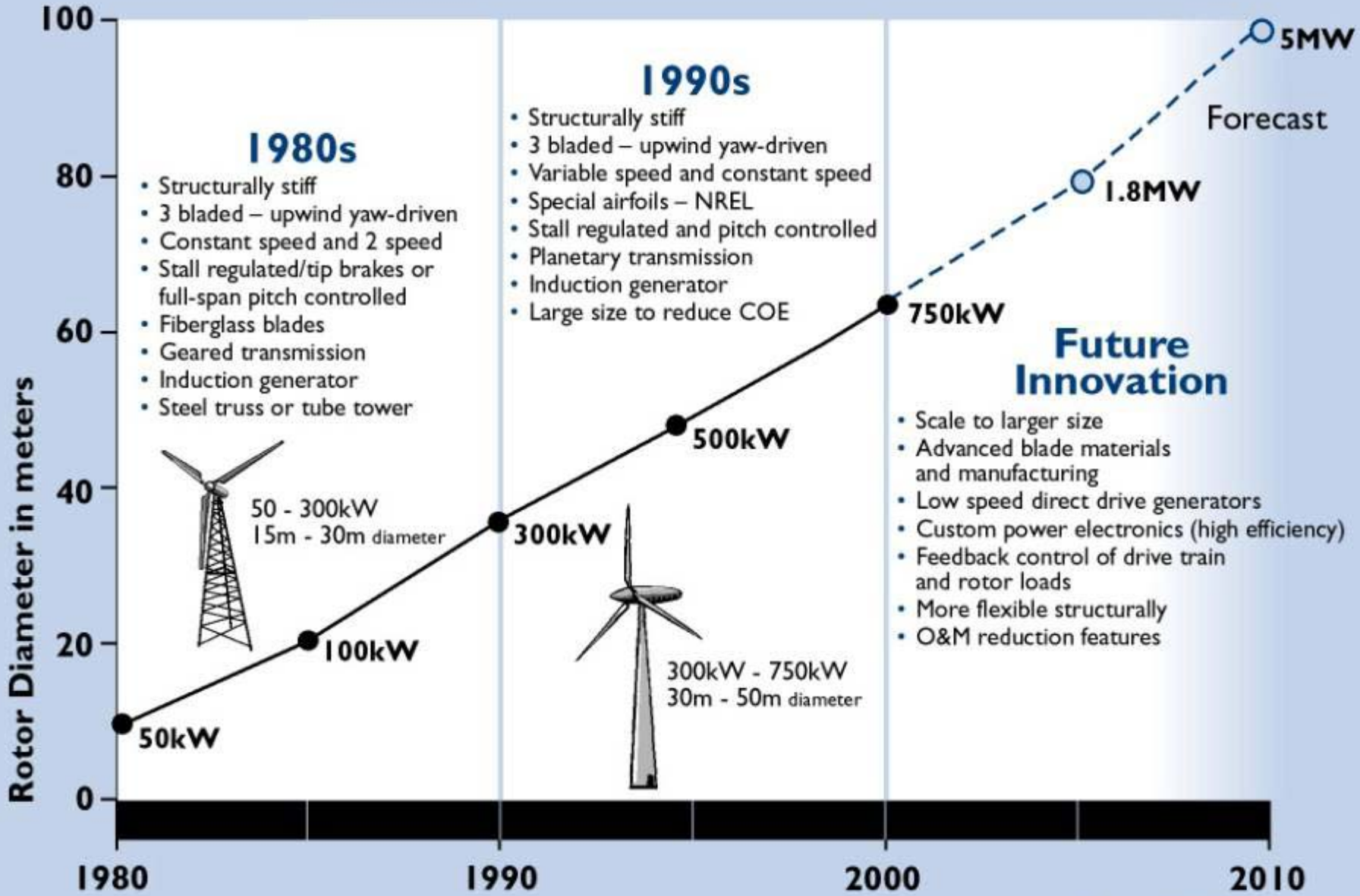
Intermediate (10-250 kW)

- Village Power
- Hybrid Systems
- Distributed Power

Large (660 kW - 2+MW)

- Central Station Wind Farms
- Distributed Power
- Community Wind

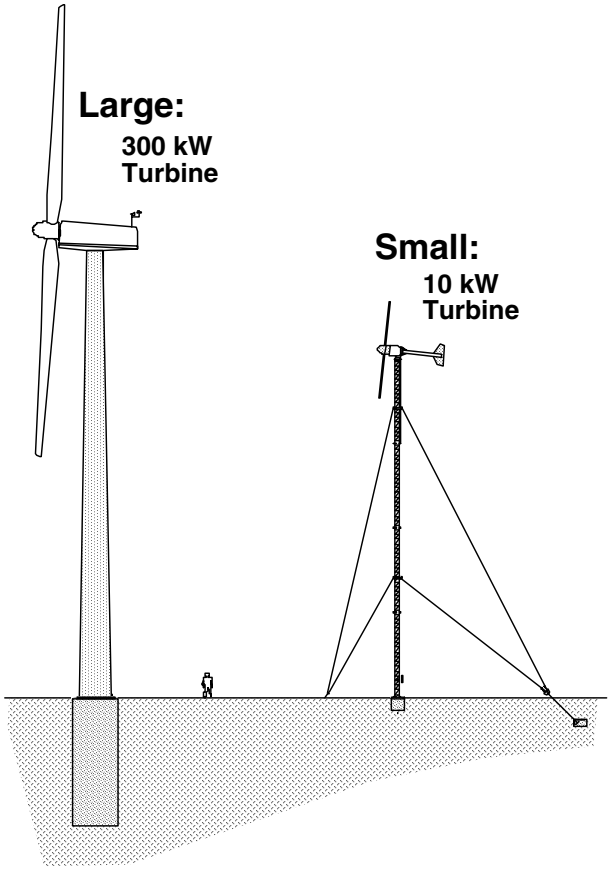
The Evolution of Commercial U.S. Wind Technology



Source: Thresher & Dodge, Wind Energy Journal 1998

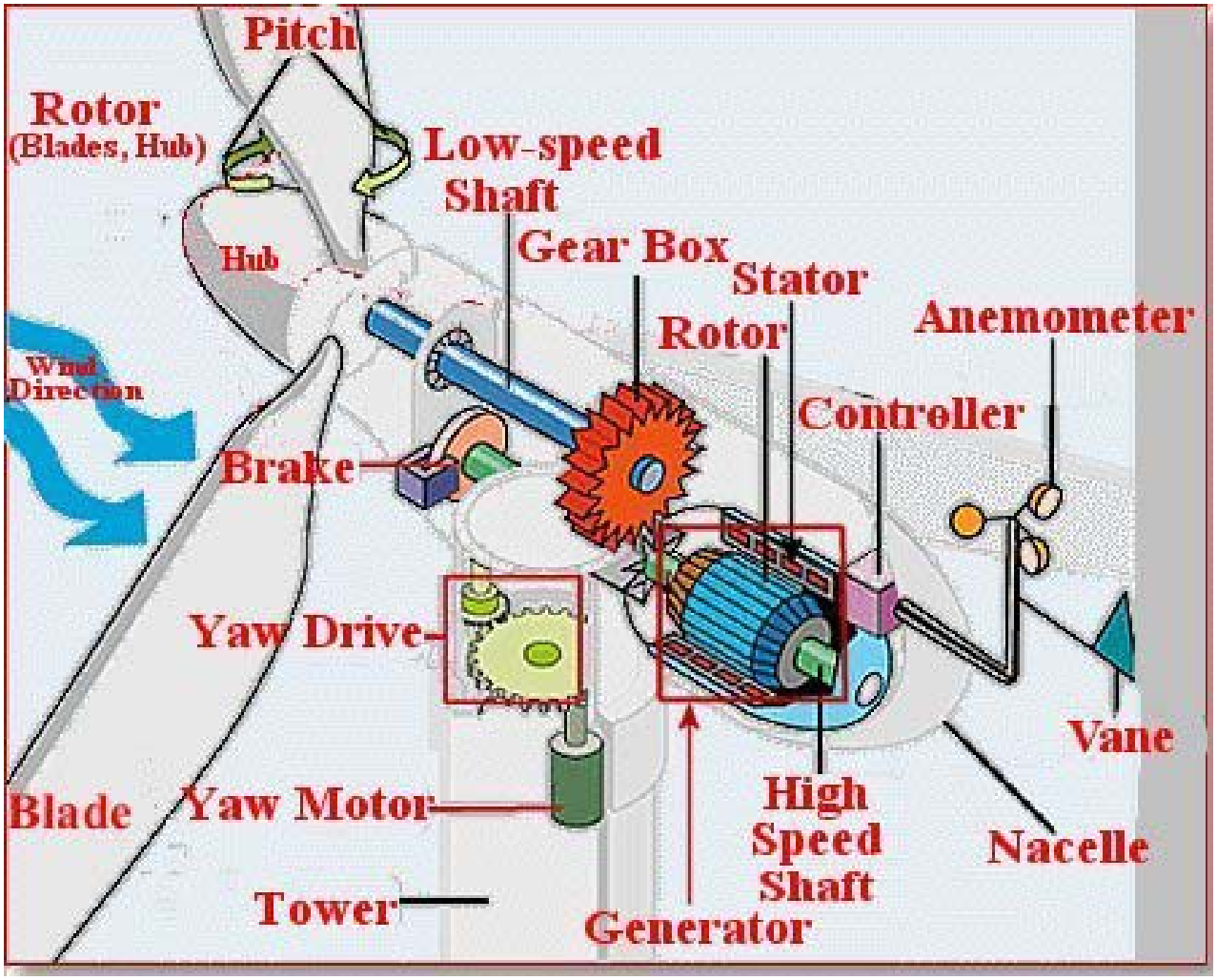
Large and Small Wind Turbines are Different

- **Large Turbines (500-1500 kW)**
  - Installed in "Windfarm" Arrays Totaling 1 - 100 MW
  - $1,000/kW; Designed for Low Cost of Energy
  - Requires 6 m/s (13 mph) Average Sites
- **Small Turbines (0.3-100 kW)**
  - Installed in "Rural Residential" On-Grid and Off-Grid Applications
  - $2,500-5,000/kW; Designed for Reliability / Low Maintenance
  - Requires 4 m/s (9 mph) Average Sites

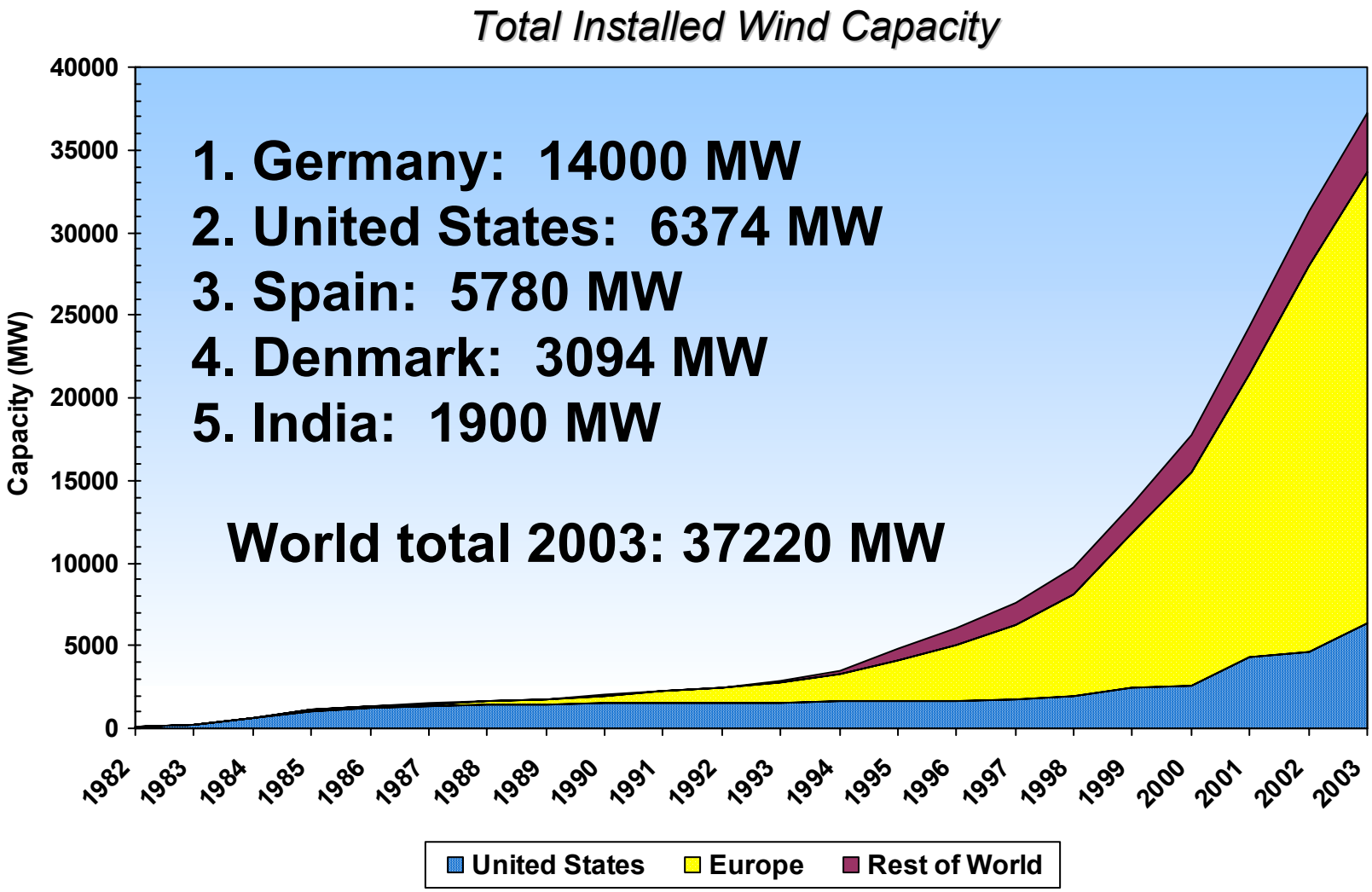


BERGEY WINDPOWER

Turbine Diagram



World Growth Market

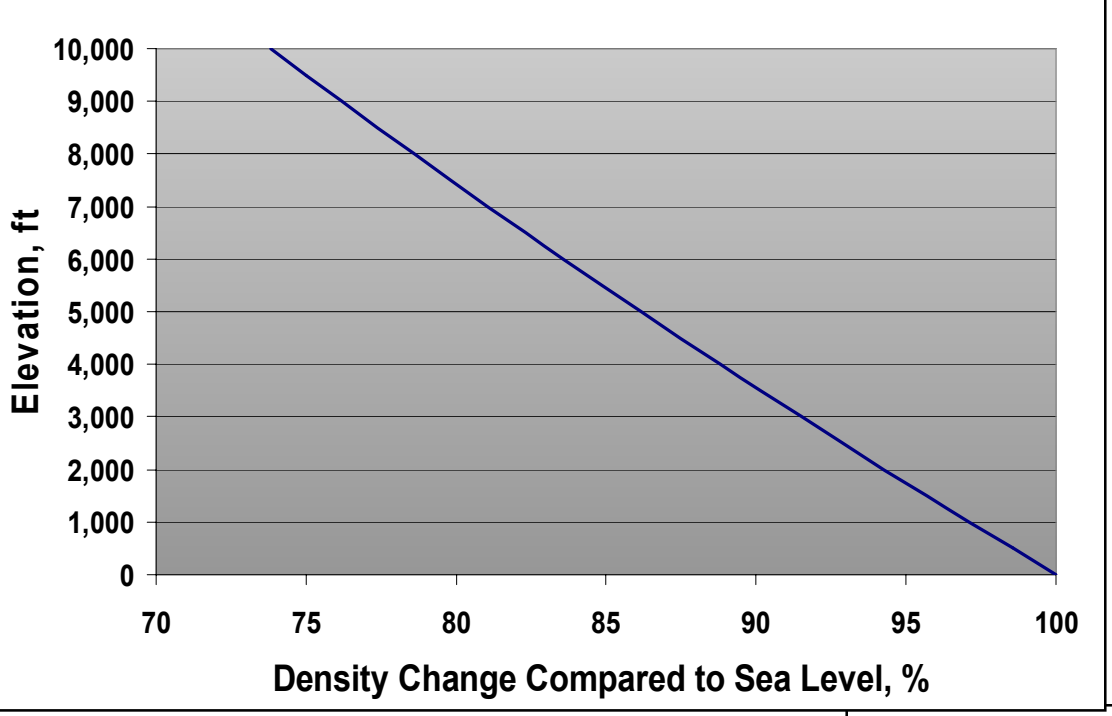


Source: WindPower Monthly

Calculation of Wind Turbine Power

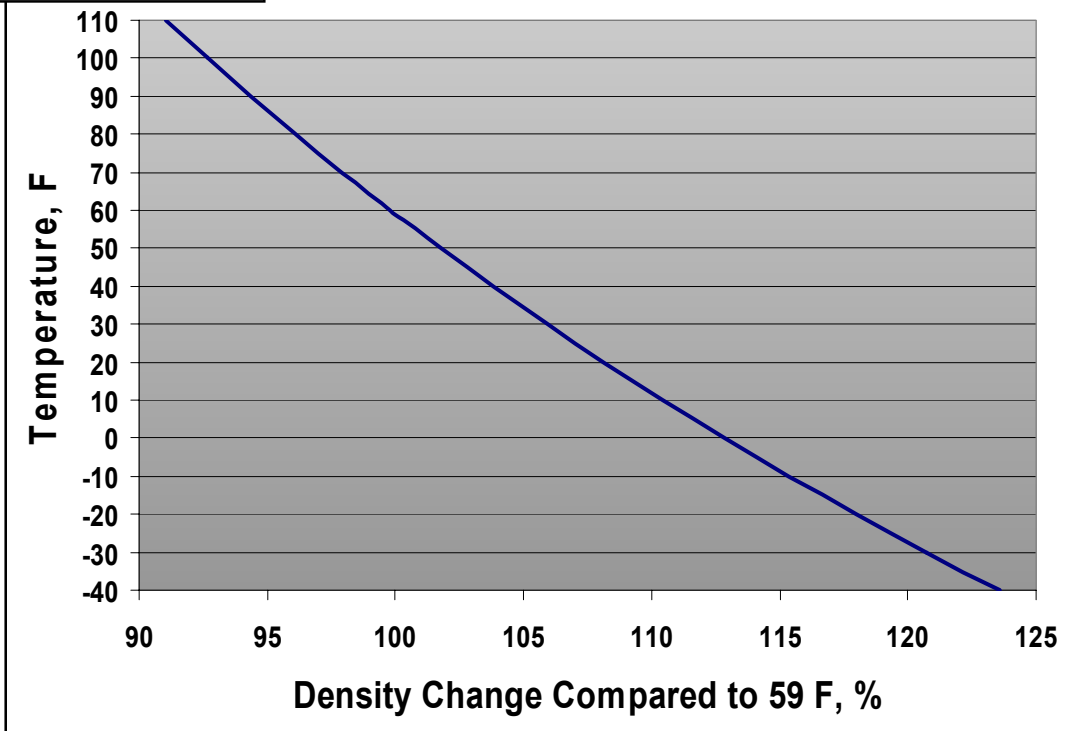
Power from a wind turbine = $C_p \frac{1}{2} \rho A V^3$

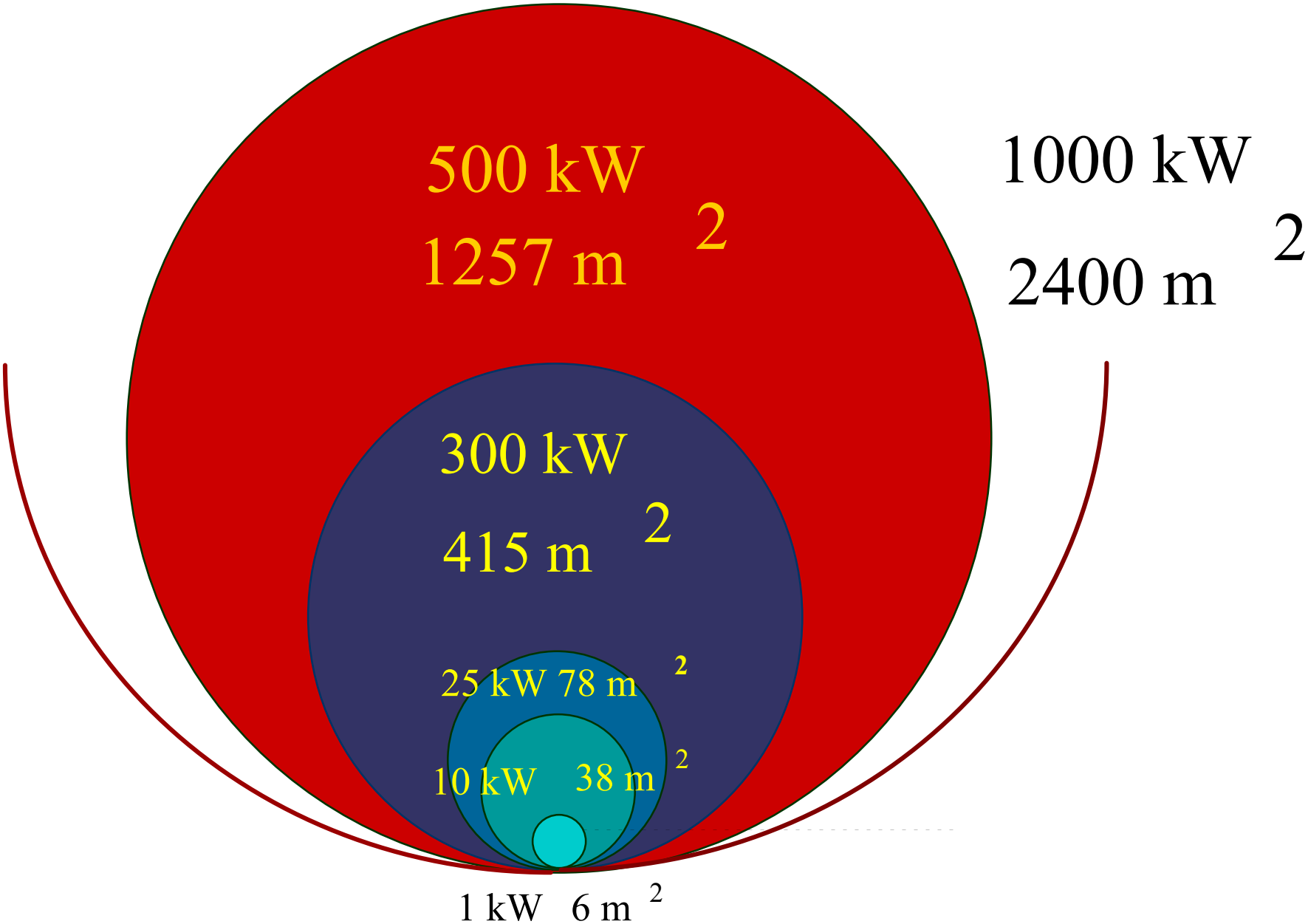
- Effect of wind speed, V
- Effect of rotor diameter on swept area
  $A = Pi\ D^2 / 4$
- Effect of elevation and temperature
  on air density, ρ
- Limits on power coefficient (efficiency):
  $C_p = 0.2 - 0.4$ (theoretical max = 0.59)



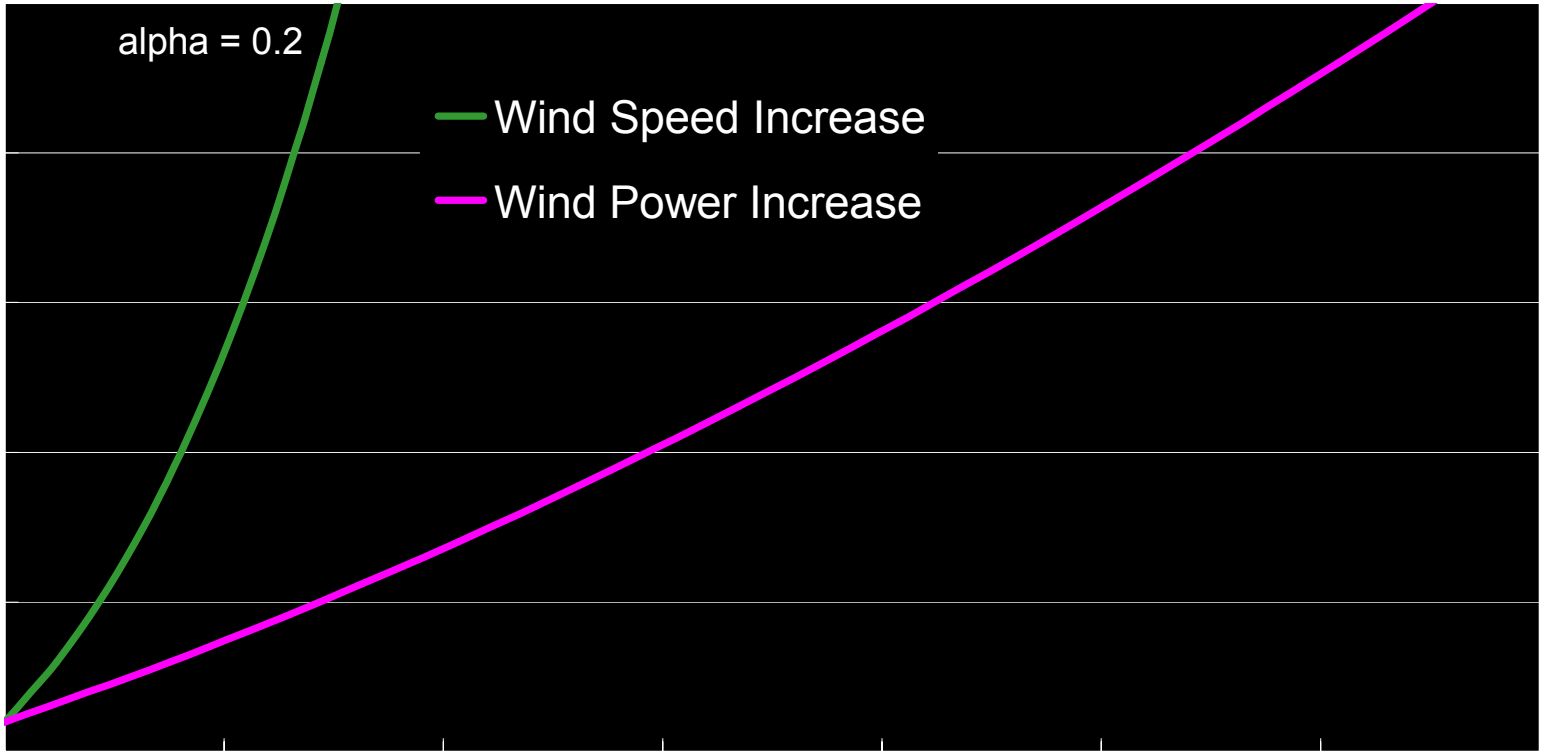
Air Density Changes with Elevation

Air Density Changes with Temperature




500 kW
1257 m 2
1000 kW
2400 m 2
300 kW
415 m 2
25 kW 78 m 2
10 kW 38 m 2
1 kW 6 m 2

Wind Speed and Power Increase with Height Above the Ground



Wind Power Classes

Small Wind Turbine Productivity Estimates*

Wind Power Class	Productivity per m² of swept area** (kWh/year)	Wind Power Density at 33 ft (10 m) (W/m²)	Wind Speed at 33 ft (10 m) (mph)	Wind Speed at 33 ft (10 m) (m/s)
1	< 350	<100	< 9.8	< 4.4
2	350 - 500	100 - 150	9.8 - 11.5	4.4 - 5.1
3	500 - 610	150 - 200	11.5 - 12.5	5.1 - 5.6
4	610 - 690	200 - 250	12.5 - 13.4	5.6 - 6.0
5	690 - 770	250 - 300	13.4 - 14.3	6.0 - 6.4
6	770 - 880	300 - 400	14.3 - 15.7	6.4 - 7.0
7	880 -1170	400 -1000	15.7 - 21.1	7.0 - 9.4

* Estimates are based on different models and sizes of wind turbines assuming a tower height of 80 ft (24 m).

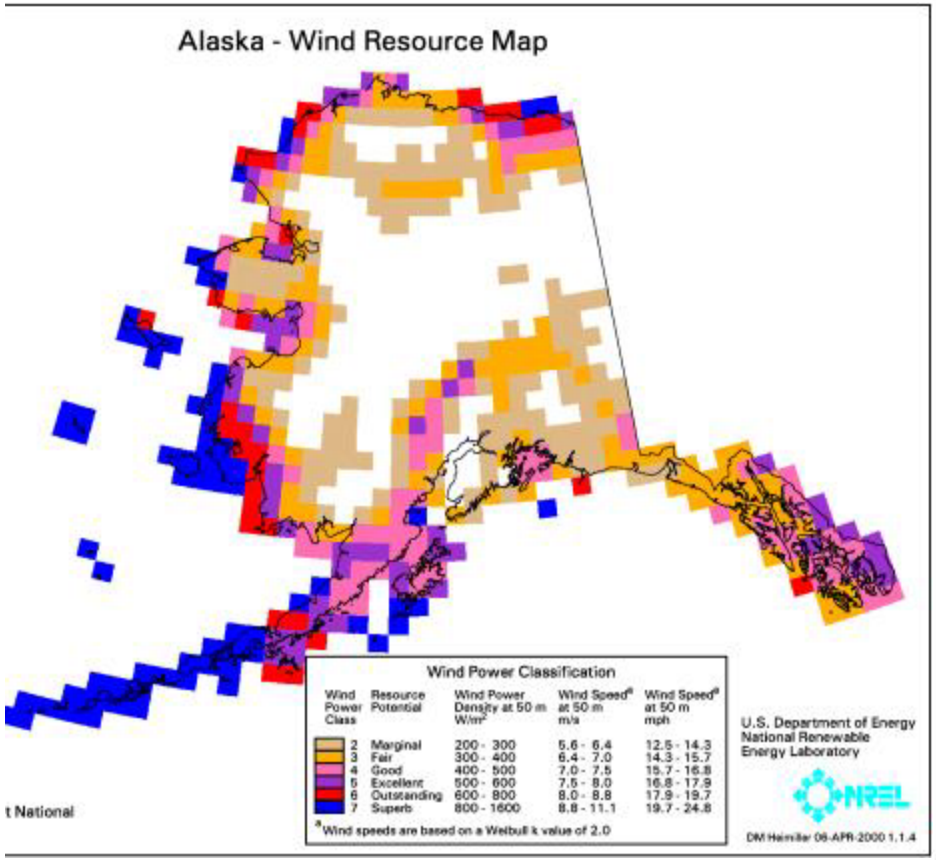
** For systems of different sizes, multiply the estimated productivity by the total swept area of the turbine.

Wind Power Classification

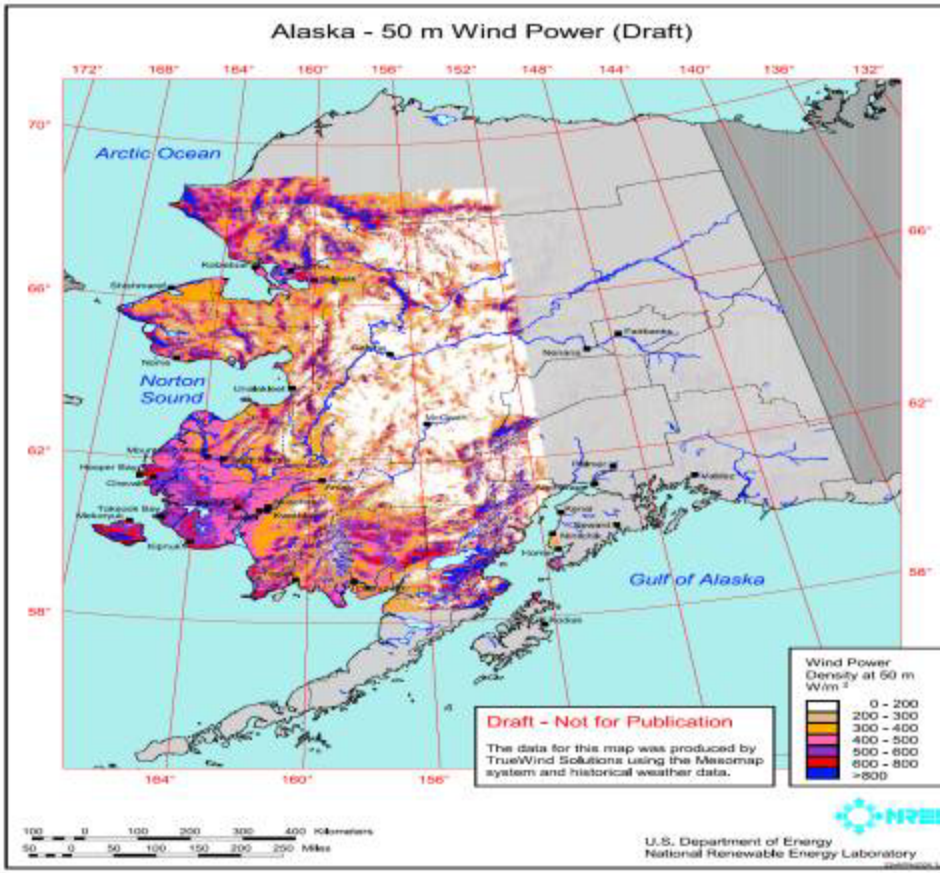
Wind Power Class	Resource Potential	Wind Power Density at 50 m W/m²	Wind Speed[a] at 50 m m/s	Wind Speed[a] at 50 m mph
2	Marginal	200 - 300	5.6 - 6.4	12.5 - 14.3
3	Fair	300 - 400	6.4 - 7.0	14.3 - 15.7
4	Good	400 - 500	7.0 - 7.5	15.7 - 16.8
5	Excellent	500 - 600	7.5 - 8.0	16.8 - 17.9
6	Outstanding	600 - 800	8.0 - 8.8	17.9 - 19.7
7	Superb	800 - 1600	8.8 - 11.1	19.7 - 24.8

[a] Wind speeds are based on a Weibull k value of 2.0

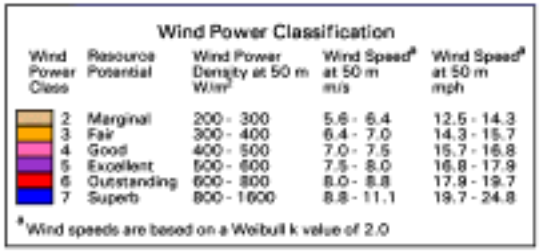
Comparison of Digital Wind Map from 1987 U.S. Wind Atlas and New (2004) High-Resolution (200-m^2) Alaska Wind Map



1987



2004



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Wind Economics - Determining Factors

- Wind Resource
- Financing and Ownership Structure
- Taxes and Policy Incentives
- Plant Size: equipment, installation and O&M economies of scale
- Turbine size, model, and tower height
- Green field or site expansion

Key Deployment Issues for Wind Power

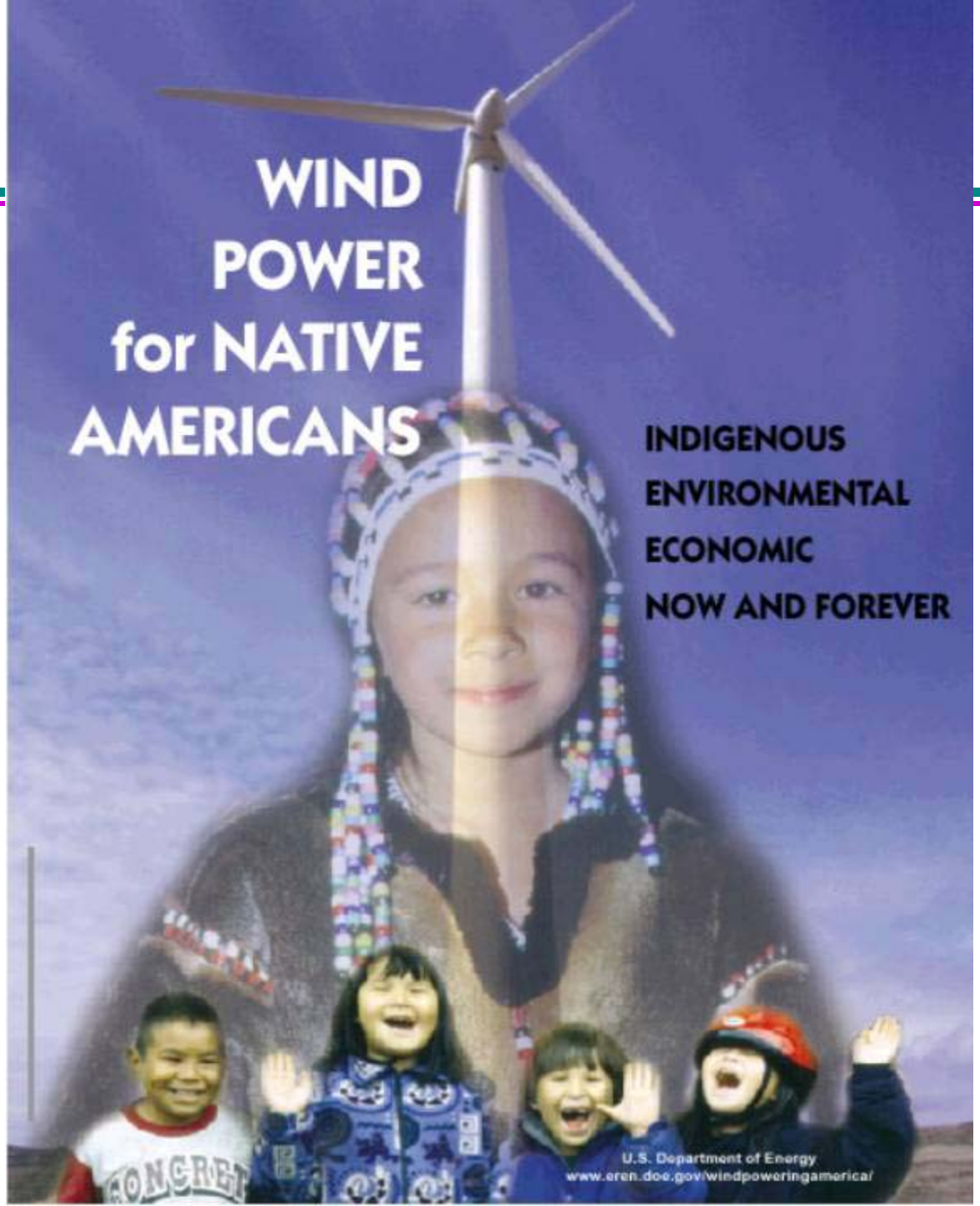
- System Economics
- Permitting and Siting
  - Visual
  - Noise
  - Avian interaction
  - Land use
- Institutional Delivery
- Wind-diesel: construction equipment and timing

The Wind Project Development Process

- Site Selection
- Land Agreements
- Wind Assessment
- Environmental Review
- Economic Modeling
- Interconnection Studies
- Permitting
- Sales Agreements
- Financing
- Turbine Procurement
- Construction Contracting
- Operations & Maintenance

Rosebud, SD

- Turbine Size: 750 KW
- Turbine Manufacturer: NEG Micon
- Turbine Owner: Rosebud Sioux Indian Reservation (Commissioned March 2003)
- PPA: Basin Electric
- Green Tags: Native Energy, US Air Force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www.eren.doe.gov/windpoweringamerica/

"It is becoming clear that wind energy will play a major role in the national generation mix. In Kotzebue, Alaska, wind energy provides between 5%-7% of the total energy needs and we plan to add more. There are potentially 70 to 90 communities that could reduce their energy costs by adding wind energy. This makes it extremely important for utilities to learn all they can about wind's ability to provide safe, reliable, cost-effective electricity to their members."

Brad Reeve, General Manager, Kotzebue Electric Association

Carpe Ventum

www.windpoweringamerica.gov