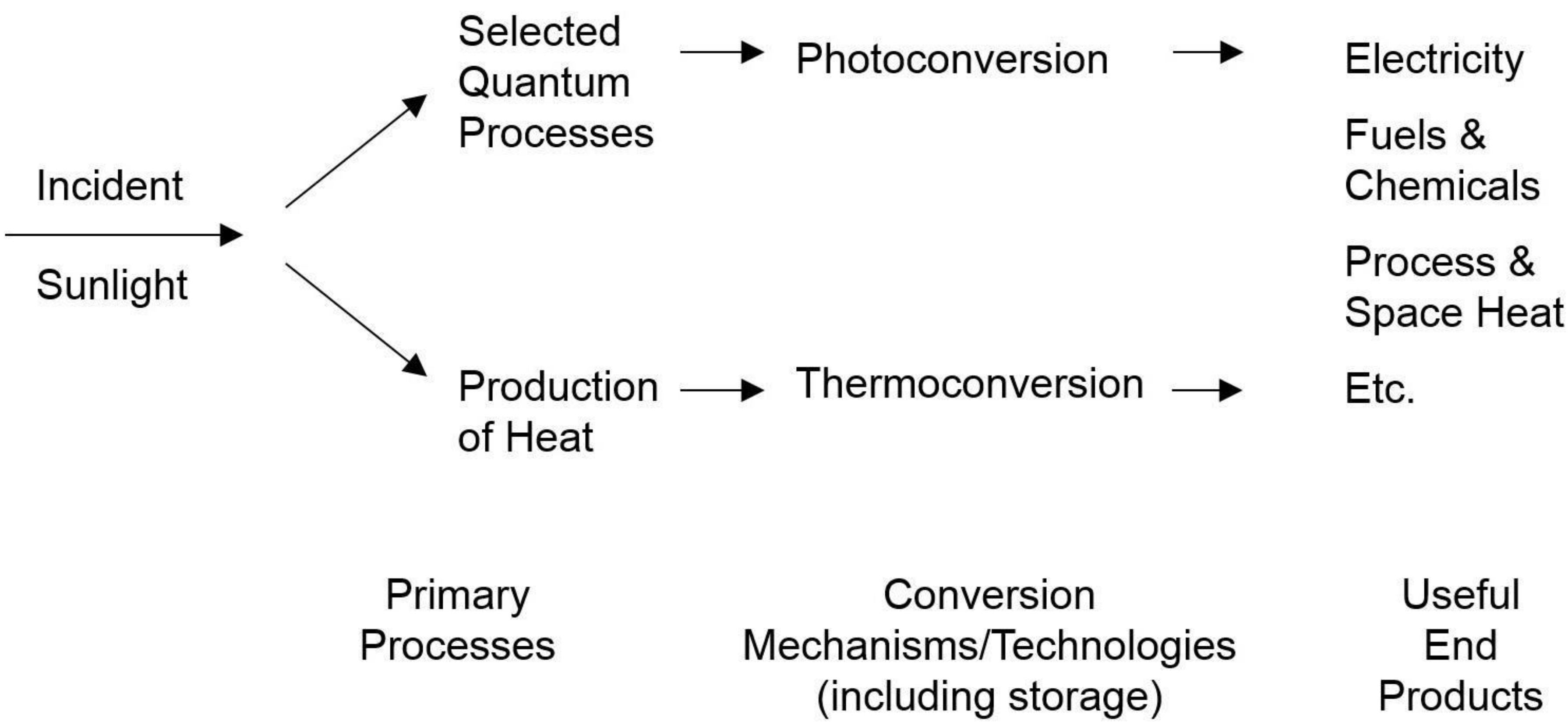
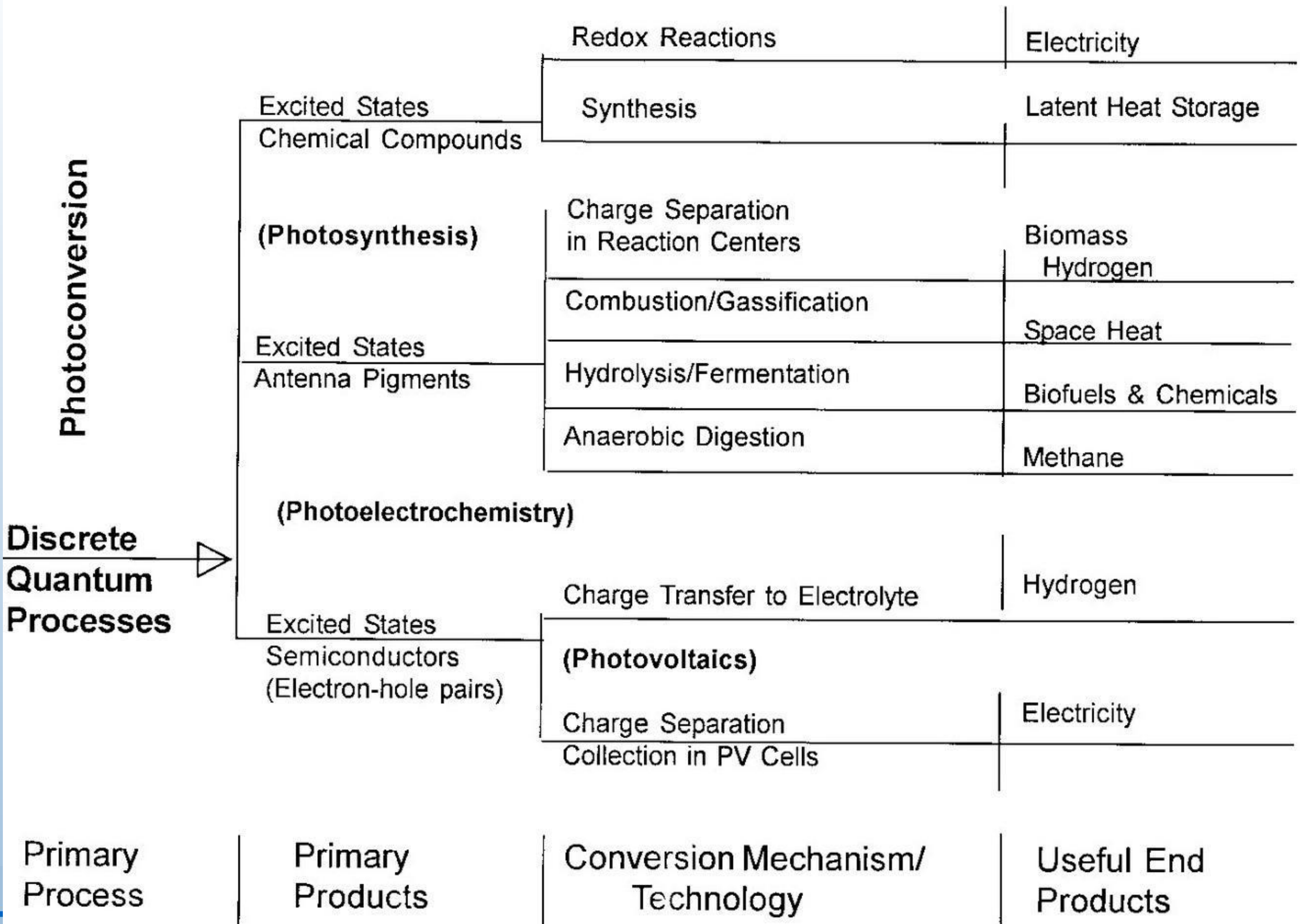
Solar Radiation Processes and Conversion Paths



Detailed Morphology for Solar Thermoconversion Paths

Primary Process	Primary Products	Conversion Mechanism/ Technology	Useful End Products
Production of Heat → **Thermoconversion**	Ocean currents	Turbines	Electricity Shaft Horsepower
	Ocean Thermal Gradients	Closed and Open Cycle Heat Engines	Electricity Sfaft Horsepower
	Hot Fluids, Solids (May require Solar Concentrators)	Thermomechanical Effect	Shaft HP
		Thermoelectric Effect	Electricity
		Various Heat Engines	Electricity, Shaft HP
		Direct Heat Transfer	Process & Space Heat
	Atmospheric Winds	Wave Conversion Devices	Electricity, Shaft HP
		Wind Turbines	Electricity, Shaft HP
	Evaporation/ Precipitation	Salinity Gradients	Electricity, Shaft HP
		Hydroelectric	Electricity

Detailed Morphology for Solar Thermoconversion Paths

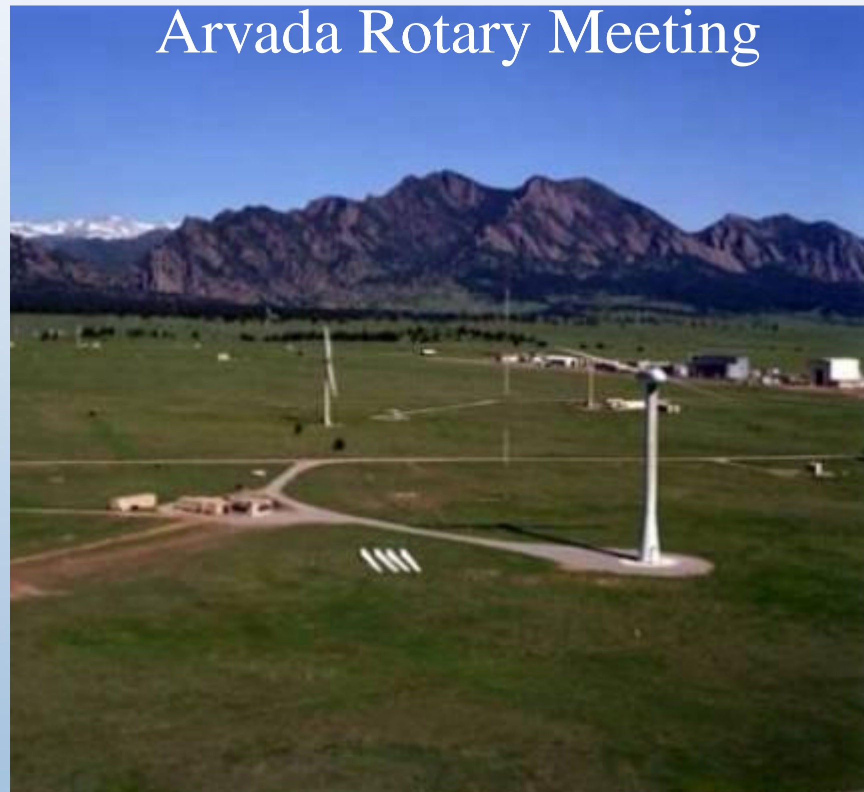


National Wind Technology Center

Jim Johnson

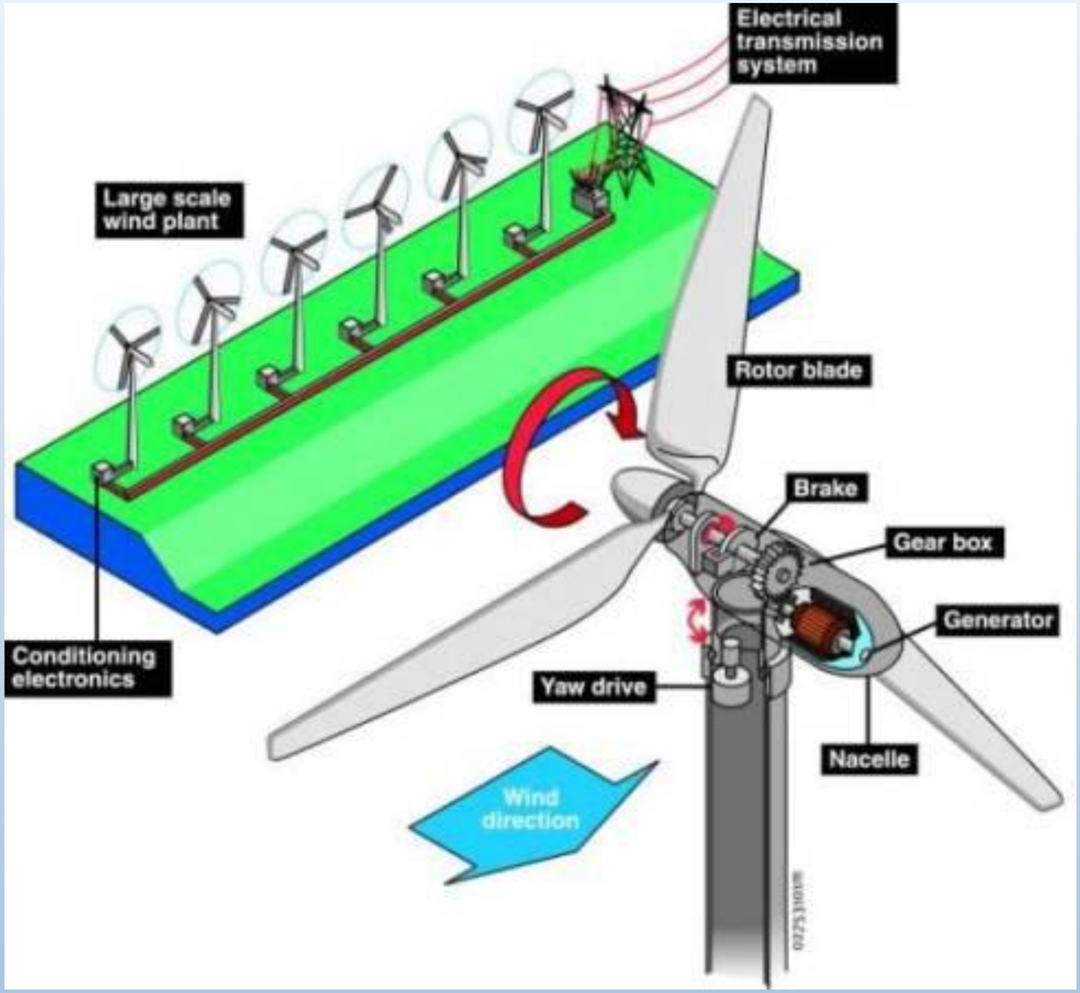
August 27, 2008

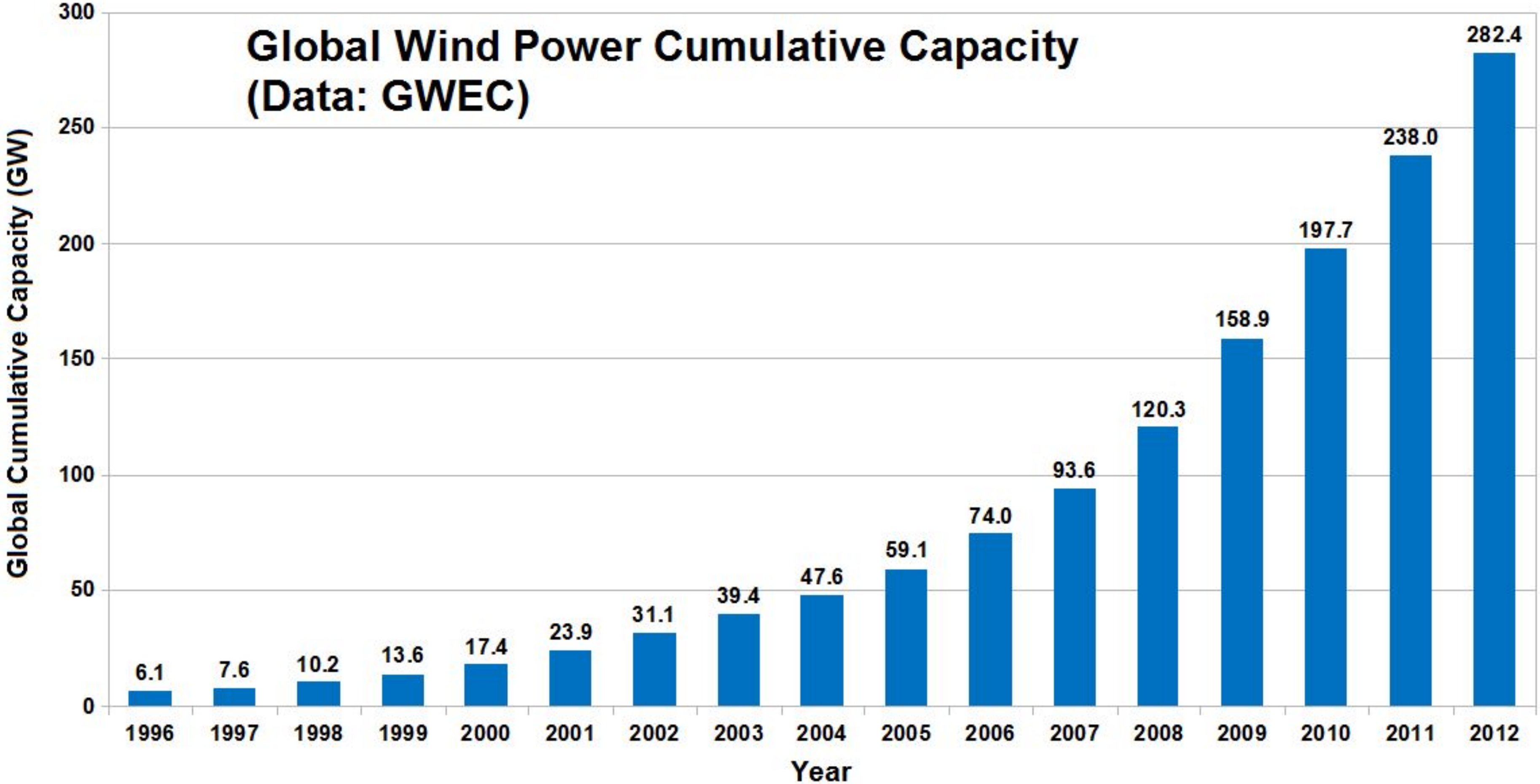
Arvada Rotary Meeting



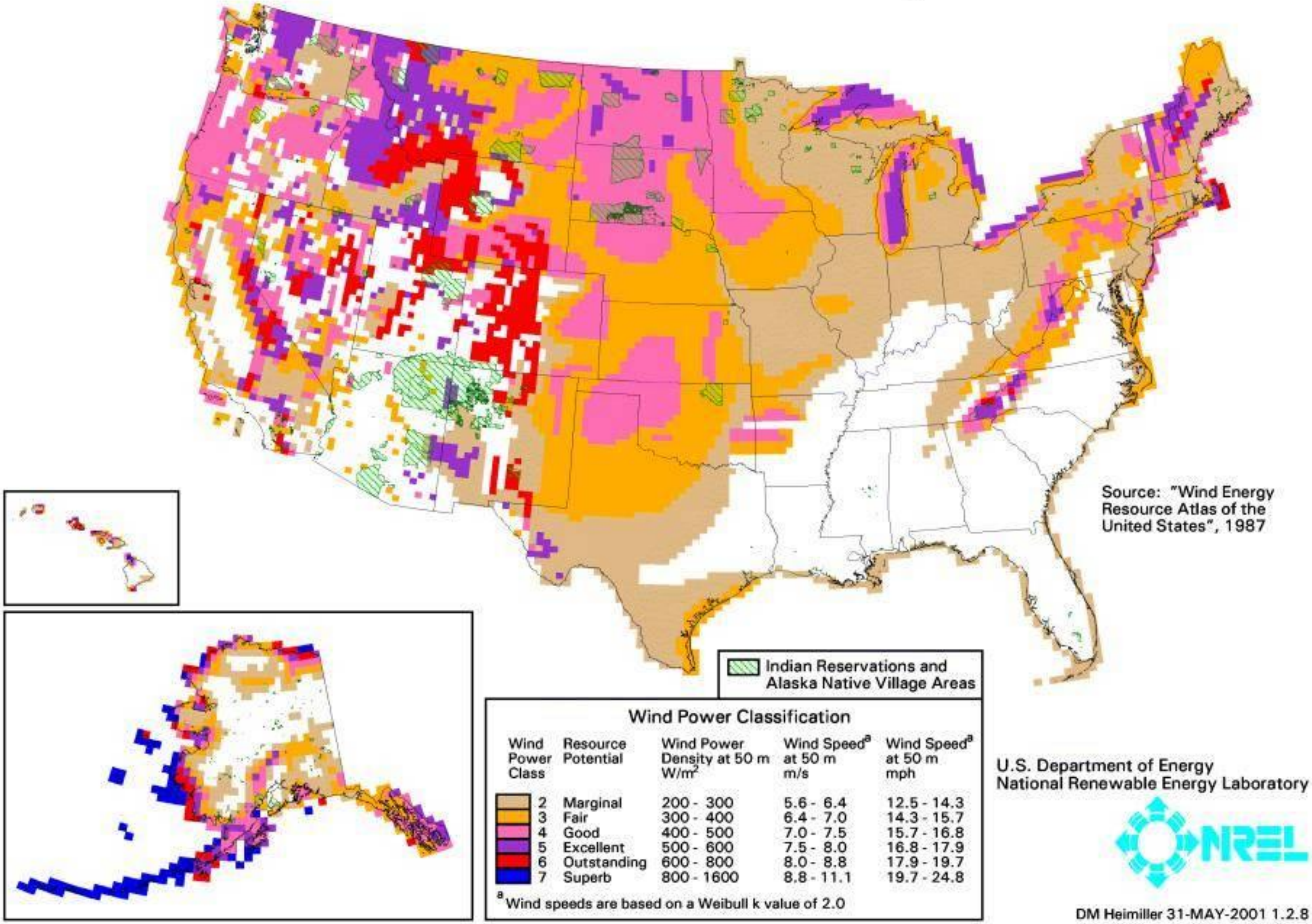
Wind Energy Technology

At it's simplest, the wind turns the turbine's blades, which spin a shaft connected to a generator that makes electricity. Large turbines can be grouped together to form a wind power plant, which feeds power to the electrical transmission system.




Global Wind Power Cumulative Capacity
(Data: GWEC)
Global Cumulative Capacity (GW)
300
250
200
150
100
50
0
6.1
7.6
10.2
13.6
17.4
23.9
31.1
39.4
47.6
59.1
74.0
93.6
120.3
158.9
197.7
238.0
282.4
1996
1997
1998
1999
2000
2001
2002
2003
2004
2005
2006
2007
2008
2009
2010
2011
2012
Year

United States - Wind Resource Map



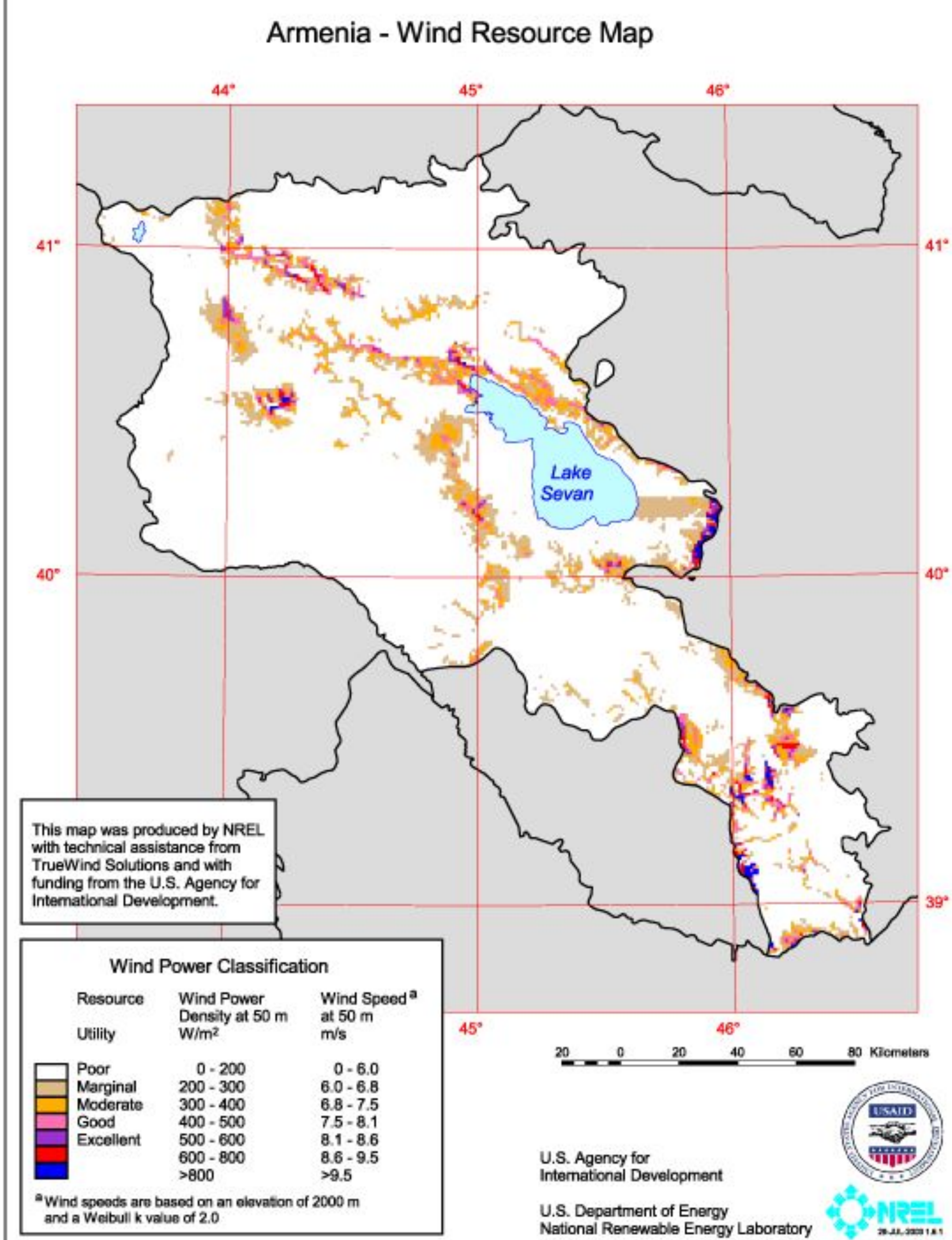
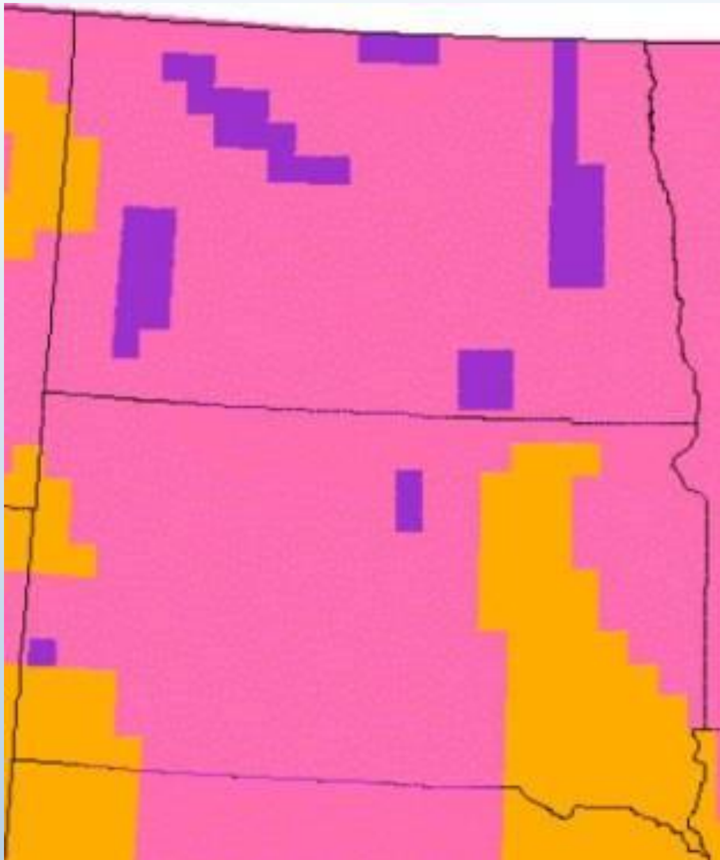

Armenia - Wind Resource Map
44°
45°
46°
41°
40°
39°
Lake Sevan
This map was produced by NREL with technical assistance from TrueWind Solutions and with funding from the U.S. Agency for International Development.
Wind Power Classification
Resource Utility
Wind Power Density at 50 m W/m²
Wind Speed a at 50 m m/s
Poor 0 - 200 0 - 6.0
Marginal 200 - 300 6.0 - 6.8
Moderate 300 - 400 6.8 - 7.5
Good 400 - 500 7.5 - 8.1
Excellent 500 - 600 8.1 - 8.6
600 - 800 8.6 - 9.5
>800 >9.5
a Wind speeds are based on an elevation of 2000 m and a Weibull k value of 2.0
20 0 20 40 60 80 Kilometers
U.S. Agency for International Development
U.S. Department of Energy National Renewable Energy Laboratory
USAID
NREL

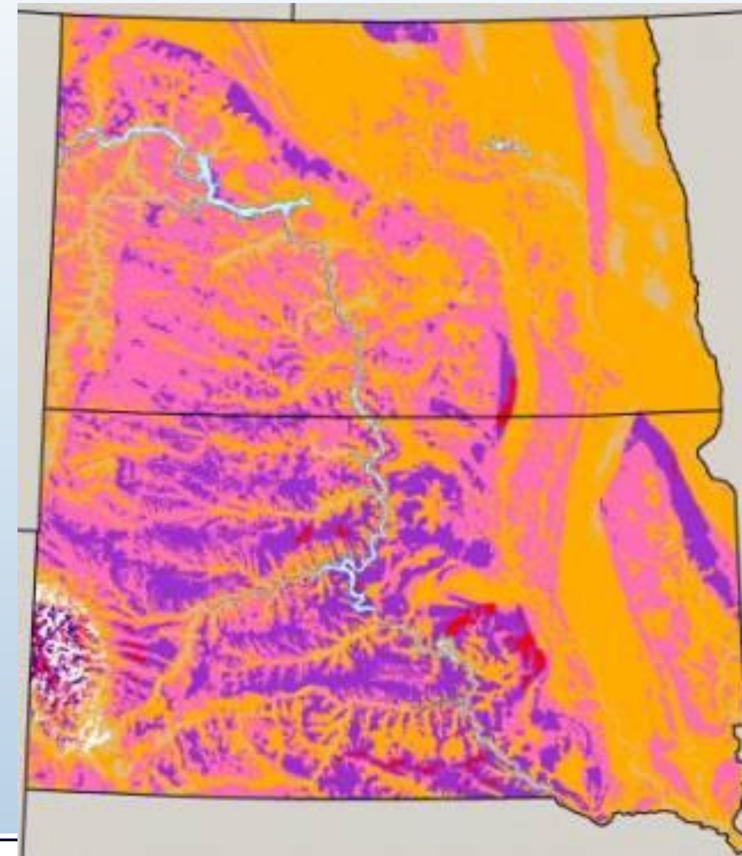
Figure 6-1

Growing to Support the Needs of Industry

Wind Resource Maps for North and South Dakota



1987



2000

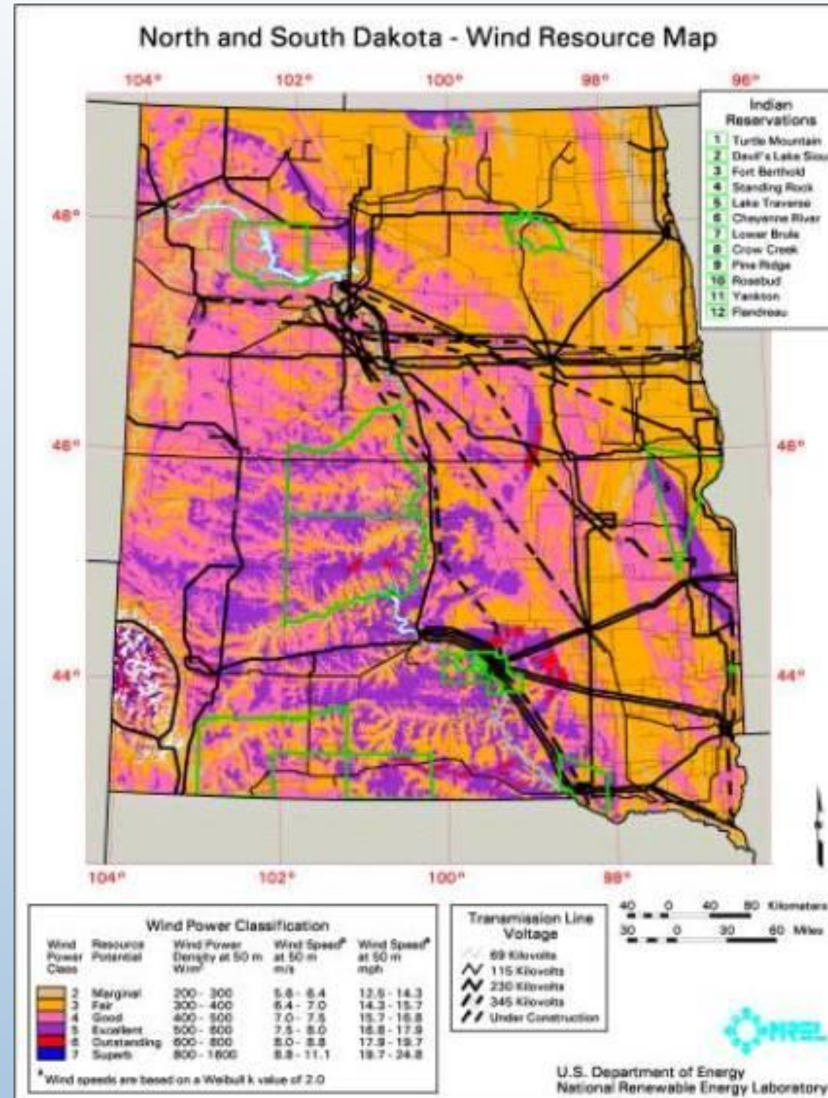
Wind Power Classification

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

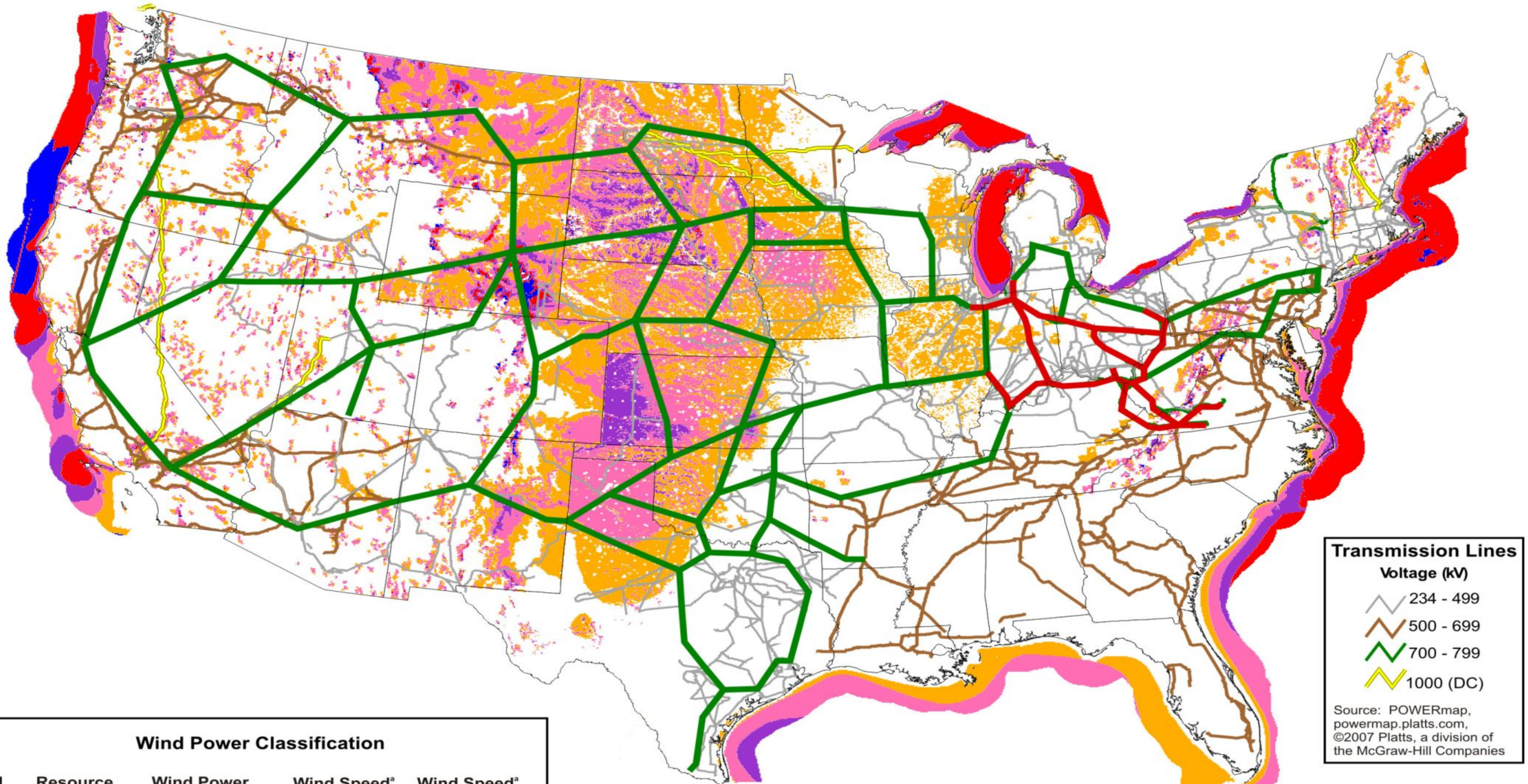
[a] Wind speeds are based on a Weibull k value of 2.0

Wind Resource Mapping

- Identifies most promising areas for wind energy development
- Employs geographic information system technology to create layers of key information
- Used by state energy planners, Indian tribes, and developers
- Approach changing from empirical to numerical modeling techniques
- Forecasting, resource assessment and site specific inflow quantification methods are likely to converge into a single approach



Conceptual Transmission Overlay



Wind Power Classification

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7	Superb	800 - 1600	8.8 - 11.1	19.7 - 24.8

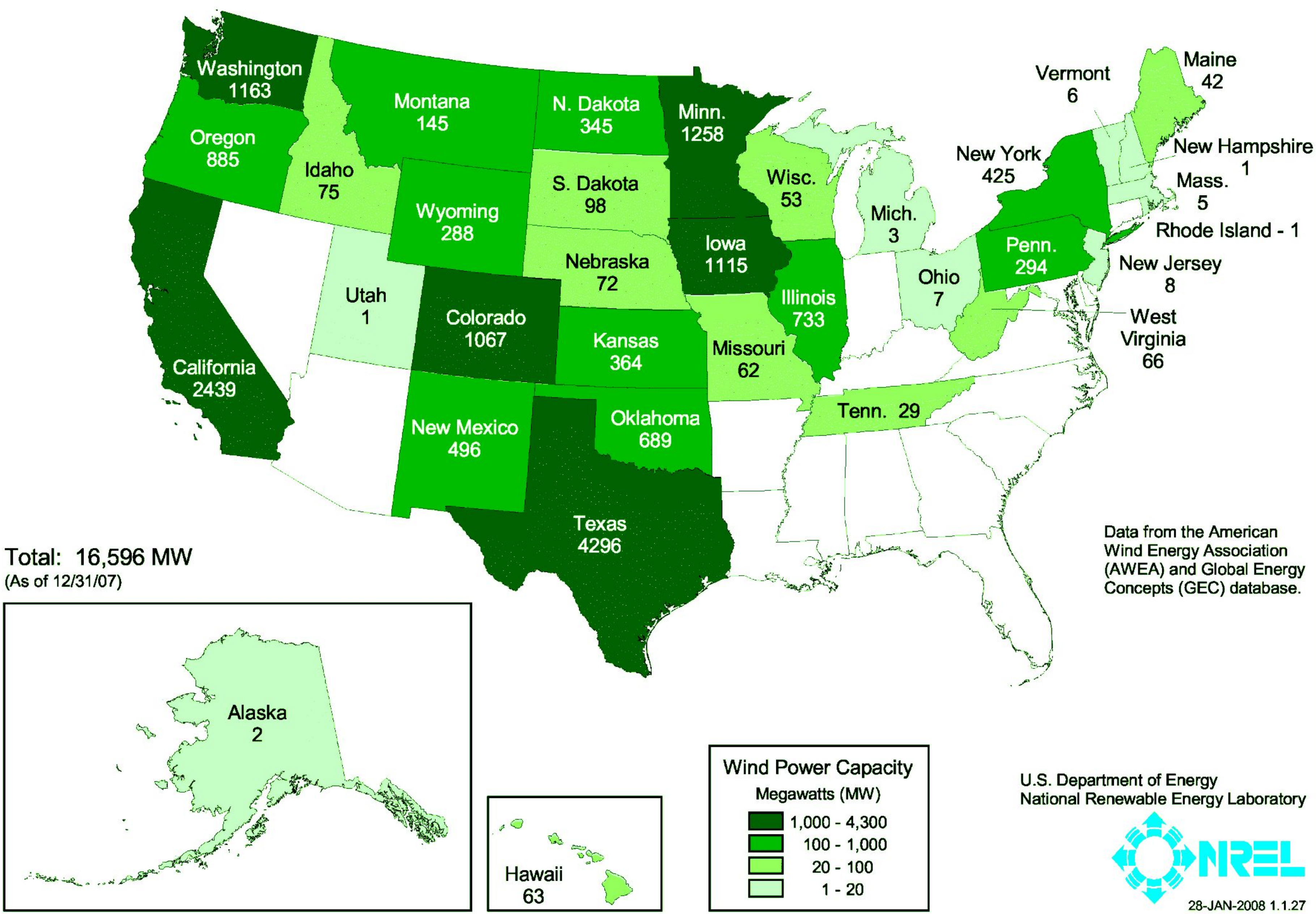
[a] Wind speeds are based on a Weibull k value of 2.0

This map shows the wind resource data used by the WinDS model for the 20% Wind Scenario. It is a combination of high resolution and low resolution datasets produced by NREL and other organizations. The data was screened to eliminate areas unlikely to be developed onshore due to land use or environmental issues. In many states, the wind resource on this map is visually enhanced to better show the distribution on ridge crests and other features.

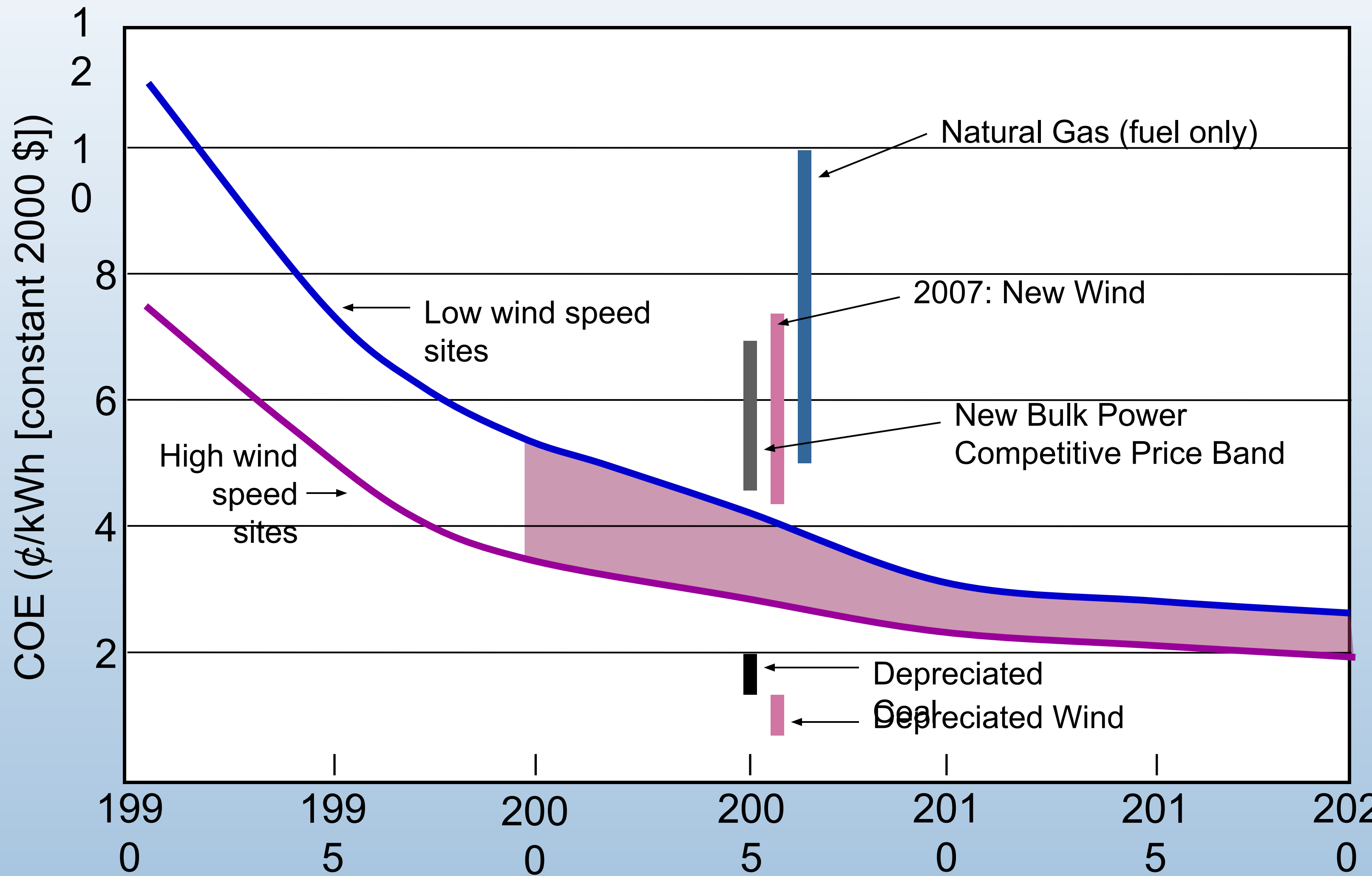
Conceptual 765 kV Network

Existing 765 kV
New 765 kV
AC-DC-AC Link
Source: American Electric Power (AEP)

United States - 2007 Year End Wind Power Capacity (MW)

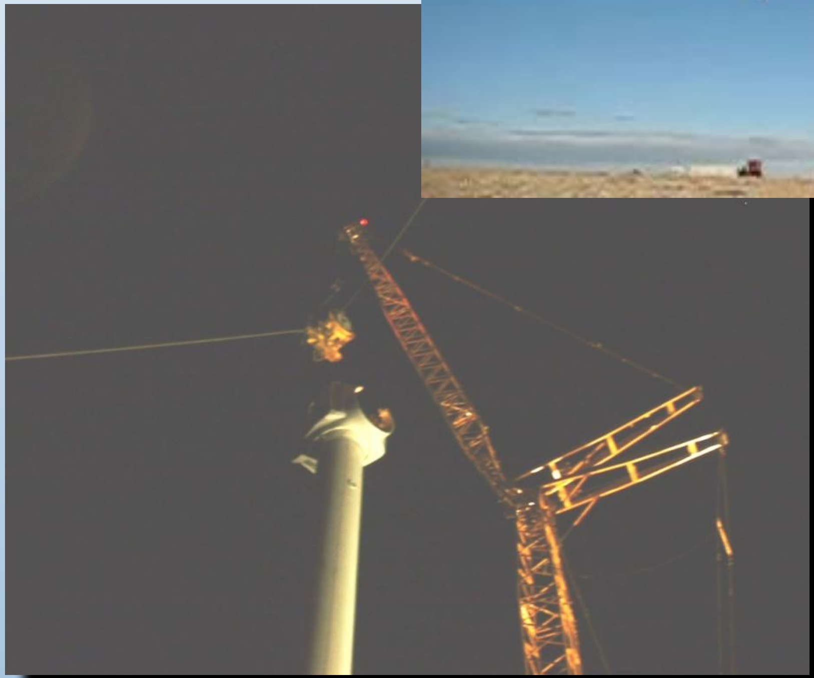


Wind Cost of Energy



NREL National Renewable Energy Laboratory

Clipper LWST Prototype
2.5 MW with 93 m Rotor



Industry's Growing Needs

New Large Blade Test Facilities:

- Boston, MA with Massachusetts Technology Collaborative
- Corpus Christi, TX with University of Houston

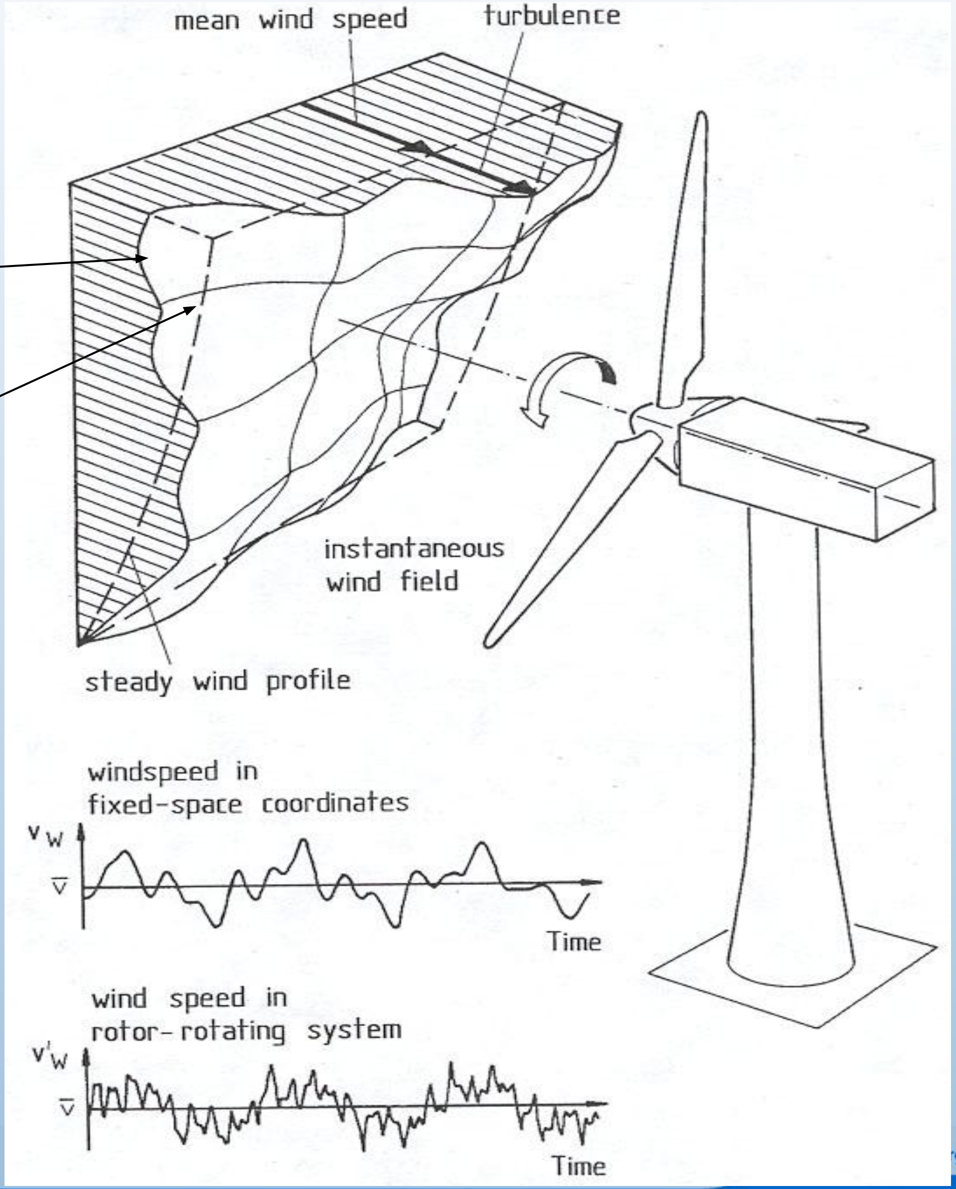
A new 45-meter wind turbine blade was shipped to the NWTC for testing in July 2004.

Dynamic Loading Environment

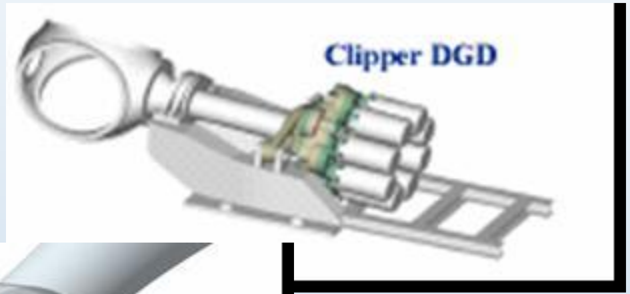
- Wind field = U (y,z,t)

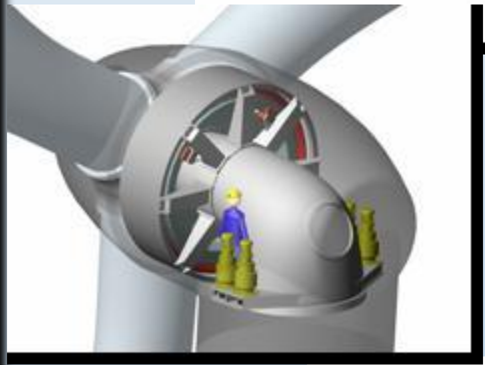
- Steady wind shear superimposed

- Rotational sampling effect increases effective wind fluctuations

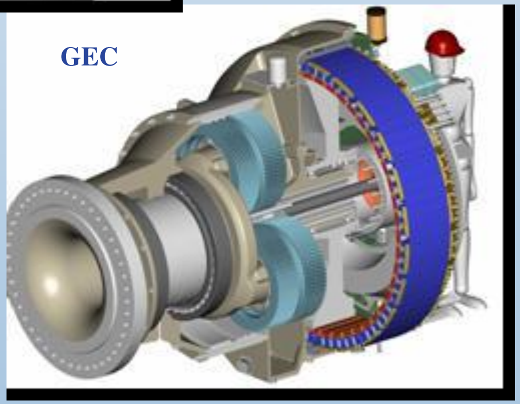


Advanced Drivetrain R&D



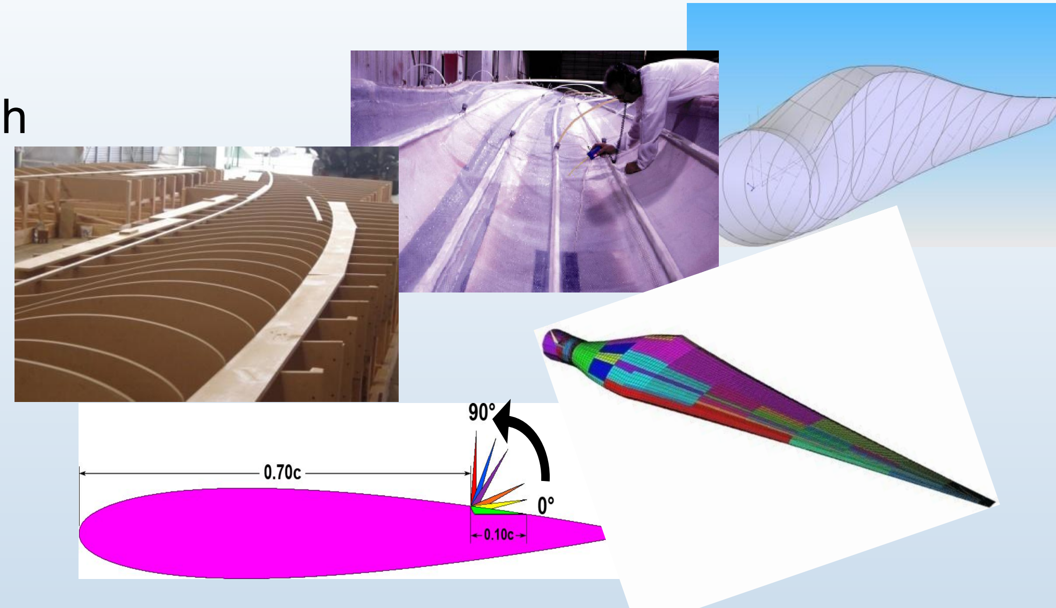


Tomorrow



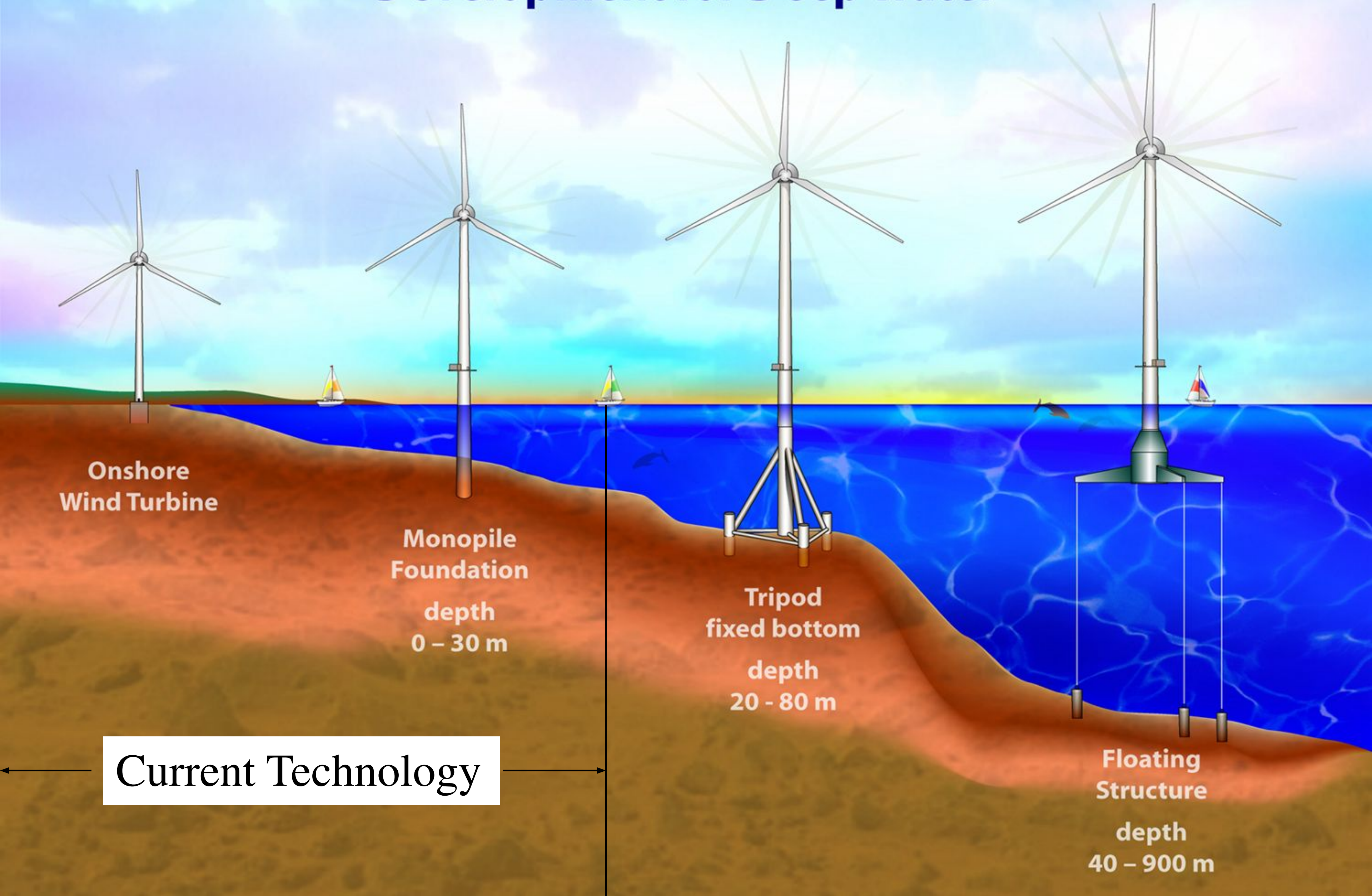
Land Based Technology Improvement Options

- **Advanced Rotor Technology**
- Extended rotor architectures through **<u>load control</u>**
- Incorporate advanced materials for hybrid blades
- Cyclic & independent blade pitch control for load mitigation
- Sweep and flap twist coupled architectures
- Light weight, high TSR with attenuated aeroacoustics

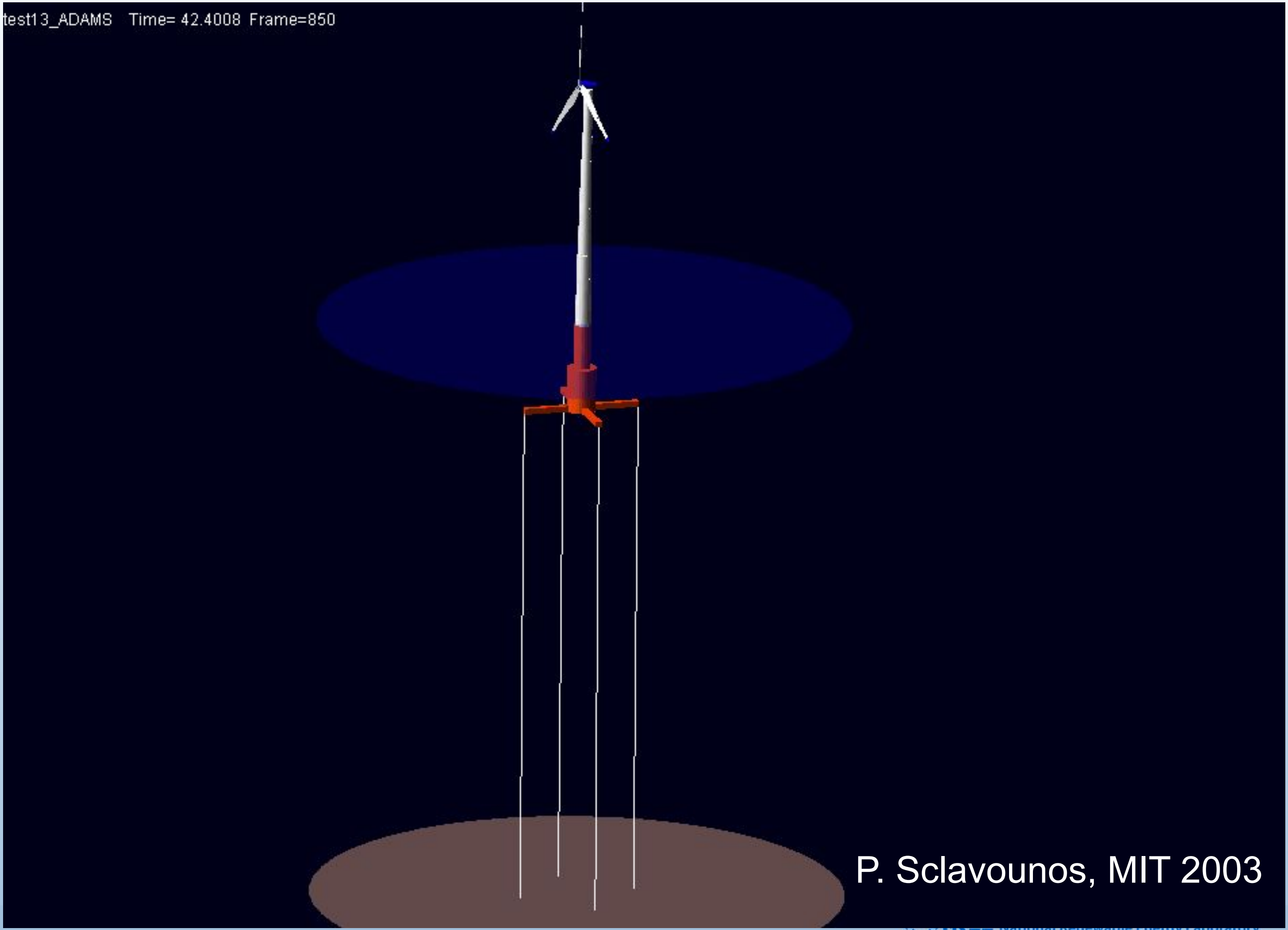


- **Power Train Enhancements**
- Permanent Magnet DD Architectures
- Split load path multi-stage generation topologies
- Reduced stage (1-2) integrated gearbox designs
- Convoloid gearing for load distribution

Offshore Wind Turbine Development for Deep Water



MIT ADAMS Model



Arklow Banks Windfarm
The Irish Sea

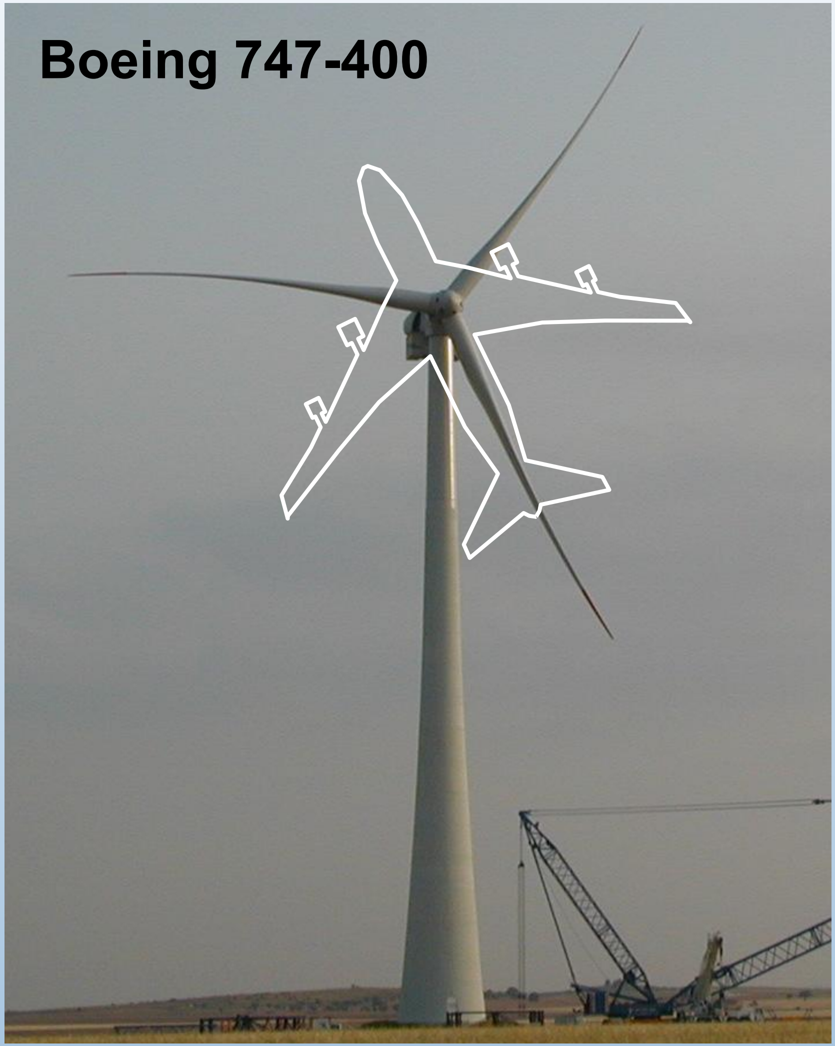
Enercon Offshore Prototype

Enercon 4.5MW 112 meter rotor

440 metric tonnes

GE Wind Energy
3.6 MW Prototype

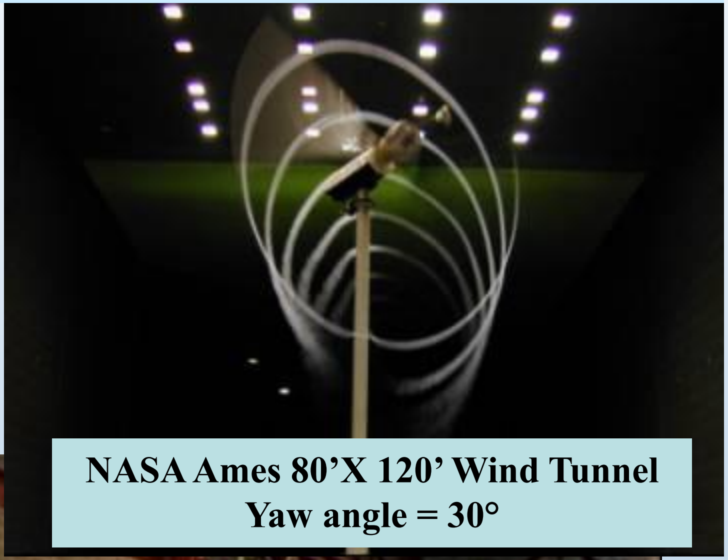
- **Design concept similar to offshore GE 1.5 / 70.5**
- **Offshore GE 3.6 MW 104 meter rotor diameter**
- **Offshore design requirements considered from the outset:**
  - **Crane system for all components**
  - **Simplified installation**
  - **Helicopter platform**



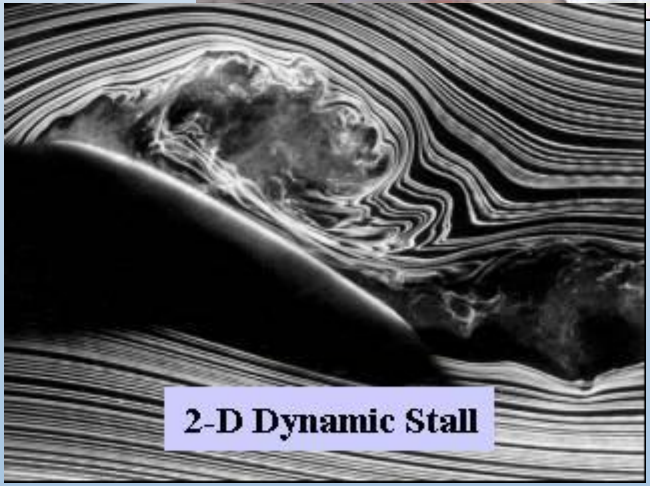
NREL's National Wind Technology Center Research and Development

Basic & Applied Research & World-Class Testing Facilities

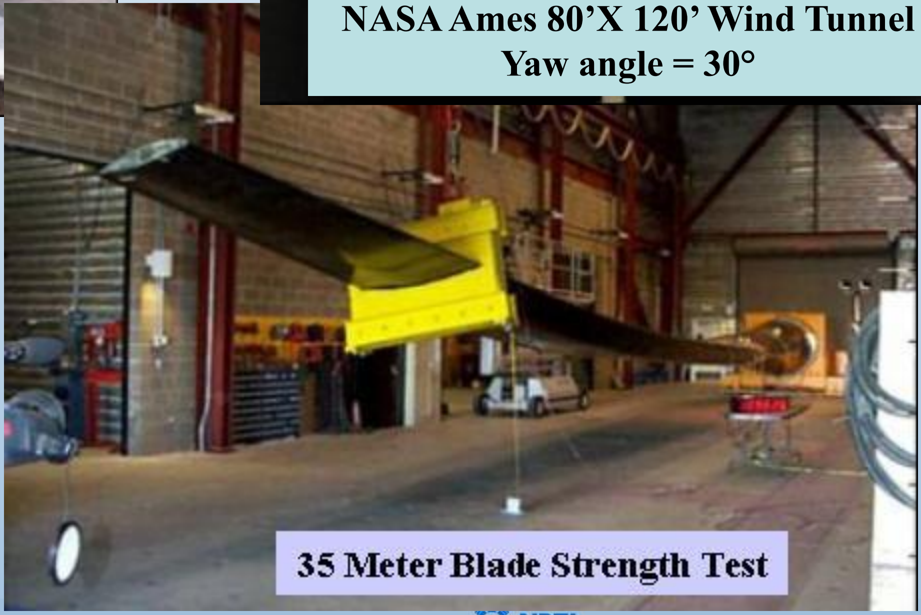
GE Wind Energy
1.5 MW Drive Train



NASA Ames 80'X 120' Wind Tunnel
Yaw angle = 30°



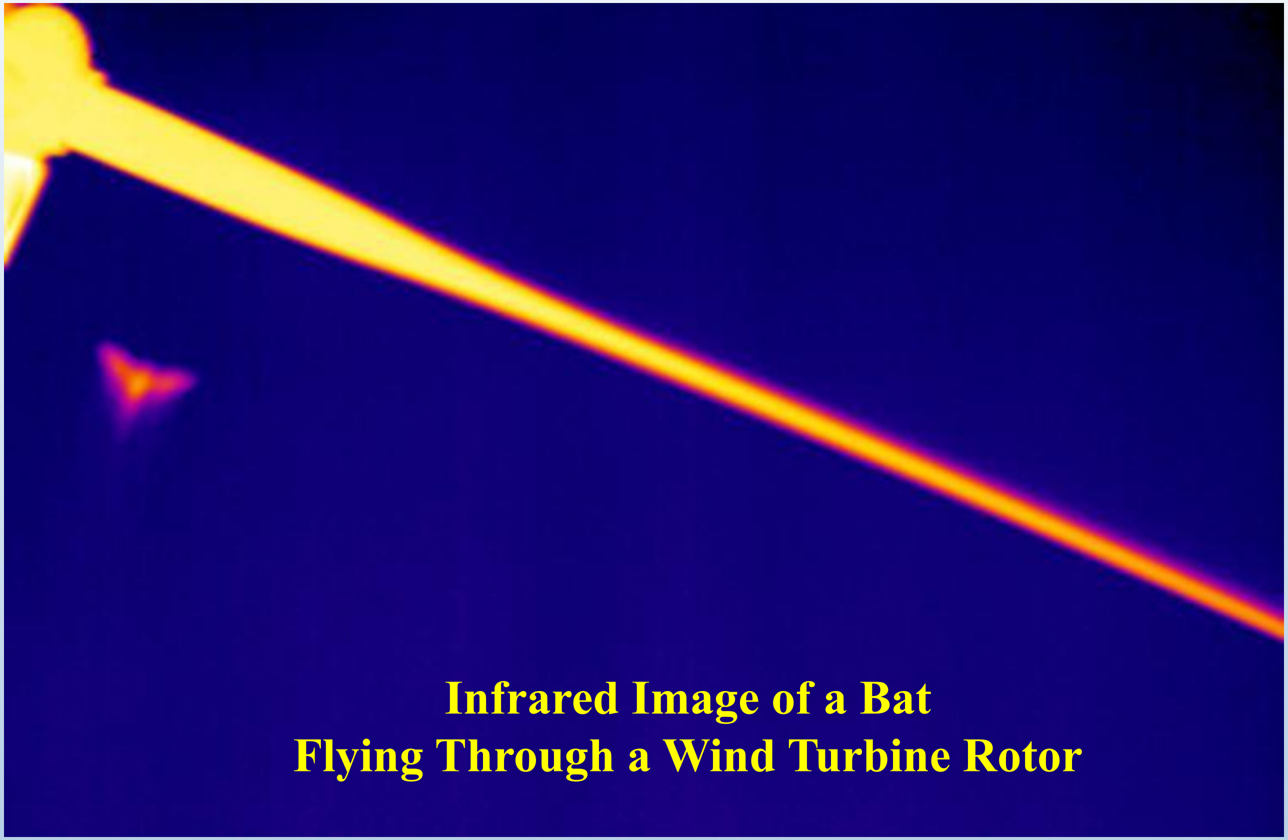
2-D Dynamic Stall



35 Meter Blade Strength Test

Multi-Stakeholder Wildlife Research

- **National Wind Coordinating Committee**
- **Bat & Wind Energy Cooperative**
- **Grassland Shrub Steppe Species Collaborative**



Jason Horn, Boston University

Wildlife-Related Research

- Data suggest the most significant avian wind-turbine interaction problem in the U.S. is in the Altamont WRA.
- Generally speaking, avian issues can be managed at future wind farm developments by careful site selection.
- Two guidance documents have been adopted by the NWCC: (1) *Permitting of Wind Energy Facilities,* and (2) *Metrics and Methods for Avian Studies.* These two documents serve as guidance for siting and development of new wind farms in the U.S.
- Some current NWCC Wildlife Workgroup activities include developing: (1) a companion document focused on Methods and Metrics for Studying the Impacts of Wind Power on Nocturnal Species; (2) a protocol for investigating displacement effects of wind facilities on grassland songbirds; and, (3) a toolbox of potential mitigation options.

Low Wind Speed Technology – Significance to U.S. Wind Industry

Current Status of Wind Technology:

- Wind Technology has matured over 25 Years
- Availability now reported at 98-99%
- Certification to international standards for new turbine designs helps avoid "major failures"
- Current designs produce electricity for 5-8 cents/kWh at Class 6 wind sites (15 mph or higher average wind)

Low Wind Speed Technology Innovations for the future:

- Larger-scale 2 to 5 MW, with rotors diameters to 120 meters
- Flexible, thin high-speed rotors
- Extendable rotor concepts
- Hybrid glass-carbon rotors
- Load feedback control systems
- Custom designed low-speed, permanent-magnet generators
- Self-erecting tall tower designs, 85 to 100 meters tall
- Offshore wind turbines
- Wind/hydrogen production

Top Ten Wind Turbine Manufacturers

Installed capacity, annual market share in 2010

- Vestas 14.8%
- Sinovel 11.1%
- GE Wind Energy 9.6%
- Goldwind 9.5%
- Enercon 7.2%
- Suzlon Group 6.9%
- Dongfang Electric 6.7$
- Gamesa 6%
- Siemens Wind Power 5.9%
- United Power 4.2%

In 2016

http://www.energydigital.com/top10/3705/Top-10-Wind-Turbine-Suppliers

- 10. Nordex Germany 3.4%
  9. Ming Yang China 3.7%
- 8. United Power China 3.9%
  7. Gamesa Spain 4.6%
  6. GE U.S. 4.9%
  5. Sulzon Group India 6.3%
  4. Siemens Germany 8.0%
  3. Enercon Germany 10.1%
  2. Goldwind China 10.3%
  1. Vestas Denmark 13.2%

  Vestas is the world's only global energy company dedicated entirely to wind power and it definitely shows. With more than 60 GW installed worldwide, Vestas is the biggest name in the wind industry. Vestas also experience on its side, as it's been around since 1898. Committed to sustainability and a healthier planet, Vestas doesn't look like it's giving up its top spot anytime soon.

In 2016

- 10. Nordex
  Germany
  3.4%
  Nordex has been supplying wind turbines since 1985. Just two years after its founding, the company installed the largest series wind turbine in the world at the time. The company saw large growth in the 1990s, entering the MW class in 1995. Nordex is still a world leader in wind, with its focus on reliability, quality ongoing service, and wide range of offerings.
- 9. Ming Yang
  China
  3.7%
  The largest private wind turbine manufacturer in China (but the 5th largest in the country), Ming Yang is a major player in the world of wind. Founded in 2006, the company is relatively new—its first turbines went into production in 2007. The company's stock skyrocketed earlier this year, with it getting major support from Chinese power companies. While it hasn't quite hit the same highs, Ming Yang remains a leader in wind.
- 8. United Power
  China
  3.9%
  United Power is a state-owned Chinese wind company which has been a world leader for several years. The company, which is headquartered in Beijing, has several subsidiaries underneath it. The company has a diverse turbine portfolio, allowing it to deploy its turbines in a variety of settings.
- 7. Gamesa
  Spain
  4.6%
  Gamesa is a big name when it comes to wind. The company has 30,000 MW installed in 45 countries and offers comprehensive maintenance and service for 19,500 MW worth of turbines. Its two biggest markets are its home country of Spain and the burgeoning energy market of China. Gamesa is very internationally focused, as 88% of its sales come from outside of Spain. Also unique to the country is its partnership with universities, in which it looks to academic to recruit and retain the best staff it can.
- 6. GE
  U.S.
  4.9%
  GE is majorly focused on innovation within the wind industry. It's also very proud of its turbines, in which its 2-3 MW platform produces the highest annual energy yield in its class. With more than 16,500 turbines deployed worldwide, it's no surprise that GE is one of the largest wind companies out there.
- 5. Sulzon Group
  India
  6.3%
  Sulzon views itself as more than a wind company; it believes it is a champion of the renewable energy movement. As well as leading the charge for wind in India, the company operates on 6 continents—all except Antarctica. Also notable about Sulzon is its wide range of turbine size, from 600 kW to its 6.15 MW offshore turbine.
- 4. Siemens
  Germany
  8.0%
  One of the most recognizable names in wind, Siemens offers solutions for both on and offshore wind projects. The biggest focus for Siemens is driving down costs of wind turbines. They aim to make renewable energy viable without subsidies. Siemens is also fully committed to their turbines, acting as its caretaker for its whole life cycle to ensure it's always running optimally.
- 3. Enercon
  Germany
  10.1%
  Enercon is a company that believes in value. Whether it's its customers, service, shareholders, or employees, Enercon defines excellence as the value placed in them. The company is highly focused on delivering projects on time and error-free. Still, quality is king for Enercon and it's not something it's willing to compromise.
- 2. Goldwind
  China
  10.3%
  Goldwind is an older wind company, having been founded in 1998. Since then, it's grown massively and has an installed 19 GW around the globe. The company is looking to expand internationally, though it already has operations on all 6 continents. Goldwind is aiming for the number 1 spot on the list and believes it will get there by setting aggressive goals for itself—and it believes it can meet them.
- 1. Vestas
  Denmark
  13.2%
  Vestas is the world's only global energy company dedicated entirely to wind power and it definitely shows. With more than 60 GW installed worldwide, Vestas is the biggest name in the wind industry. Vestas also experience on its side, as it's been around since 1898. Committed to sustainability and a healthier planet, Vestas doesn't look like it's giving up its top spot anytime soon.

Wind Power
(Basic Analyses)

- Kinetic Energy: ½ mV^2; m-mass; V-velocity
- Wind Power: Energy/time = (1/2) (mass flow) $(velocity)^2$

  mass flow = density of air x area swept x velocity of air = ½ ρAV^3

* However, turbine power $P(T)=1/2\ \rho\ C_p AV^3$ where maximum of C_p is known as the Betz limit = 16/27

Wind Power, cont'd.

- $P(T) = \frac{1}{2}\rho C_p A(ref) V^3$

ρ = air density f(z, T, humidity)

- V = f(x,y,z,t) = <V> + v(fluctuating)
- Cp = f[C(L), C(D), α, drive train, generator]
- Where C(D) is blade drag coefficient
- C(L) is blade lift coefficient α is angle of attack

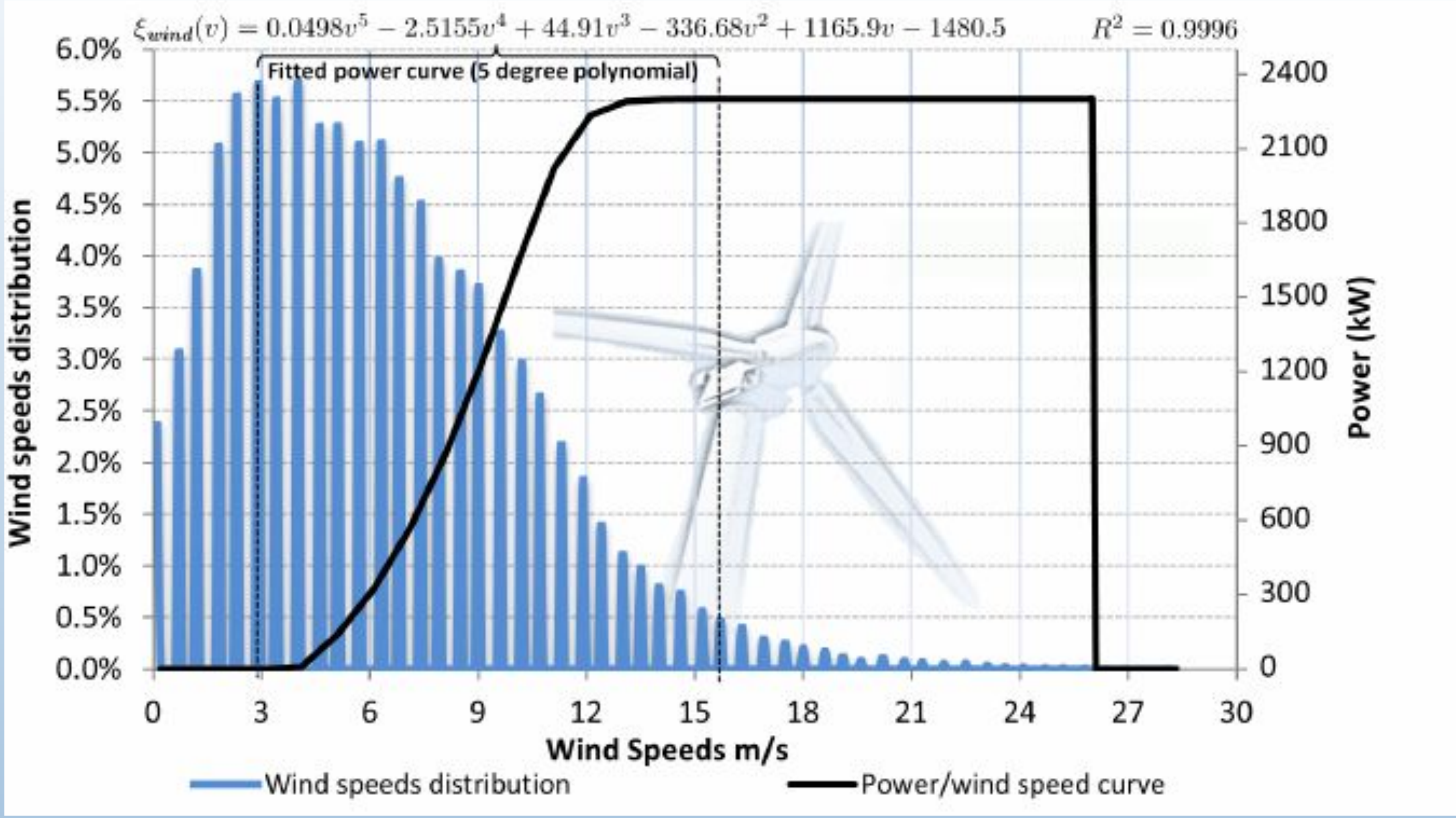
Wind Power, cont'd.

The science and technology of wind power includes:

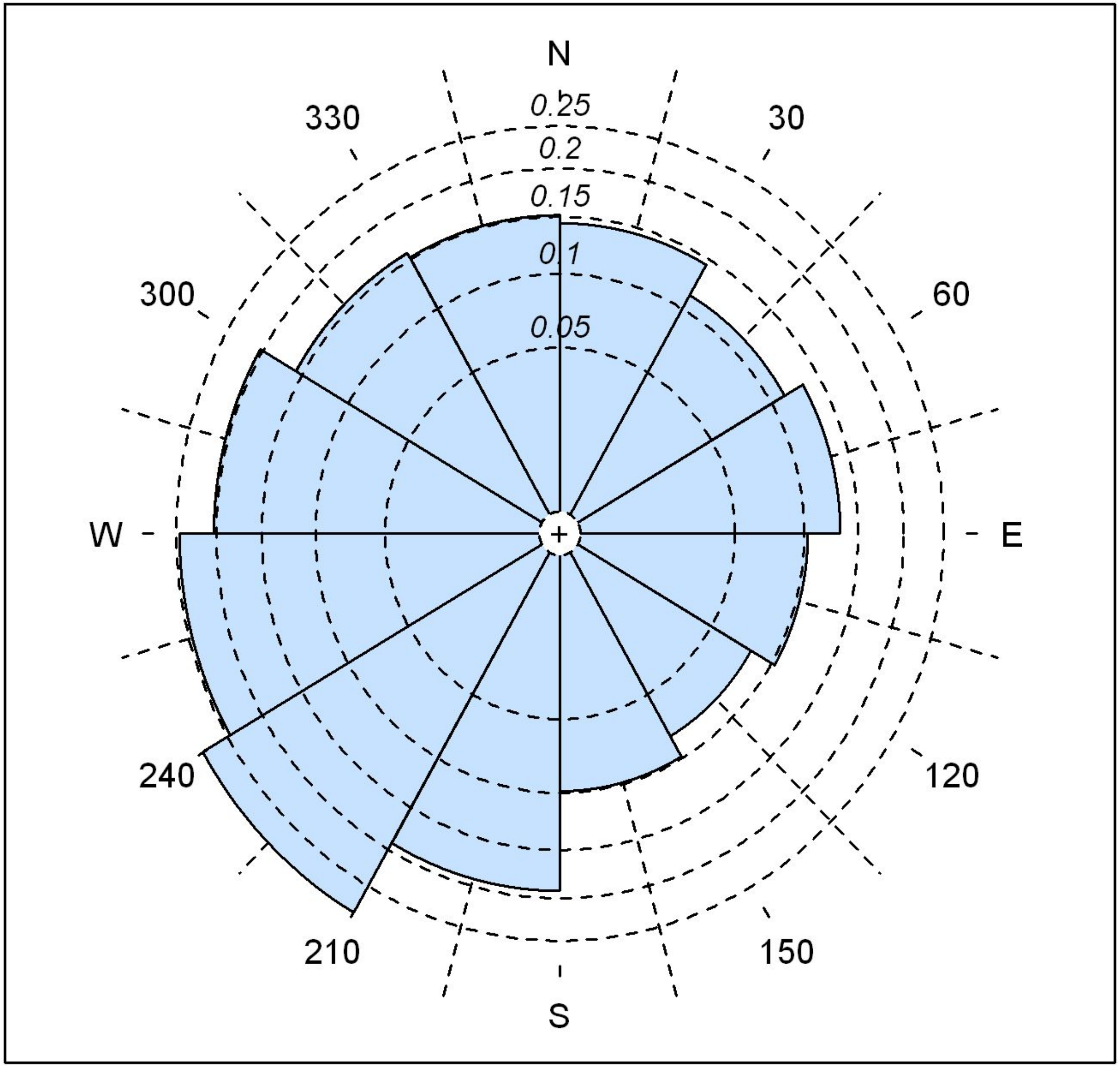
- aerodynamics/fluid mechanics
- Material science
- Meteorology
- Mechanical design
- Power engineering
- Controls

Add to these economics; aesthetics; environmental sciences.

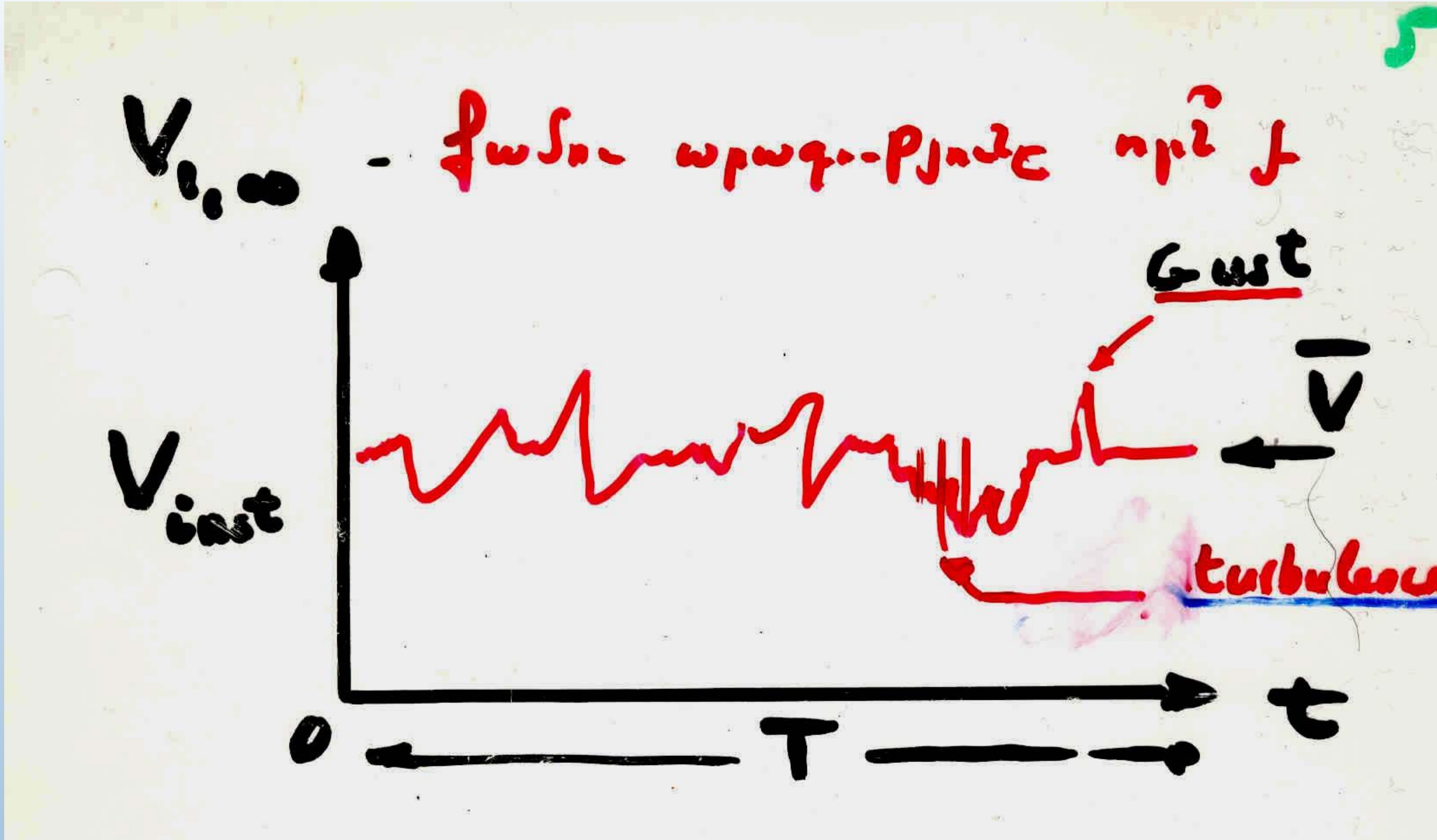
Theoretical and Actual Wind Power Curves



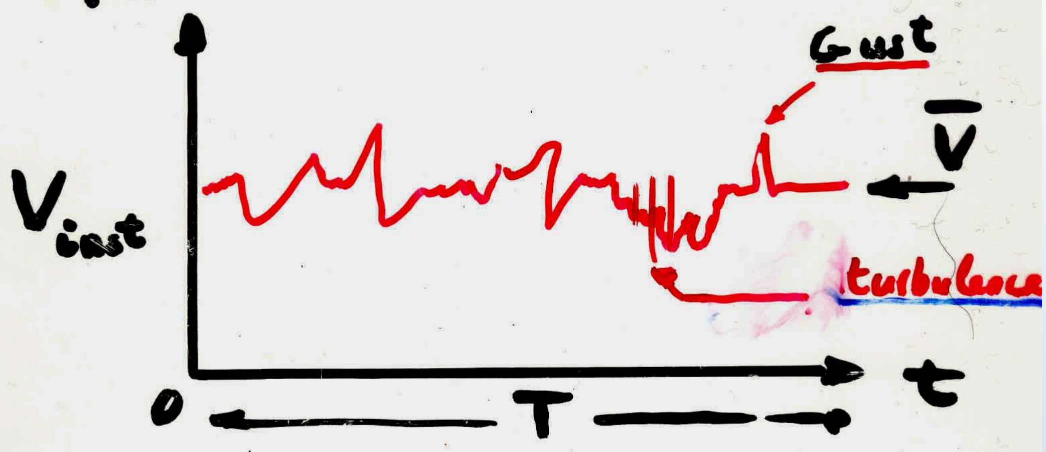
Wind direction distribution



Instantaneous Wind Speed Sketch



Instantaneous Wind Speed Sketch



T – Period where variations are typical

θ – Time over which measurements are averaged

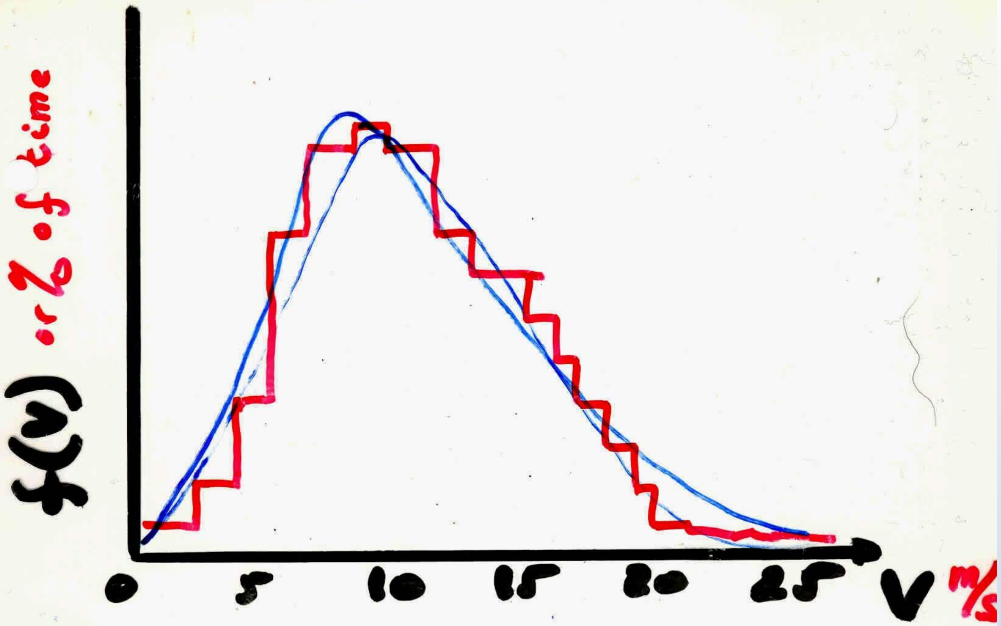
τ – sampling time (interval between successive samples)

$$\overline{V^3} = \frac{1}{T}\int_0^T V^3 \, dt$$

{real time axis

$$\overline{V^3} = \int_0^\infty V^3 f(V, A, B) \, dV$$

{probable time axis



f(v) - Lognormal; Weibull; Gamma
[illegible] Rayleigh.

$$f_{Weibull}(V;A,B) = \frac{A}{B}\left(\frac{V}{B}\right)^{A-1} \exp\left[-\left(\frac{V}{B}\right)^{A}\right]$$

[illegible]

$f(v) = 0$ when $V = 0$

$f(v) \rightarrow 0$ when $V \rightarrow \infty$

$$\int_0^\infty f(v)\,dv = 1$$

Statistical Distribution of Wind Power

Weibull Statistics

6 WIND-SPEED STATISTICS

The speed of the wind is continuously changing, making it desirable to describe the wind by statistical methods. We shall pause here to examine a few of the basic concepts of probability and statistics, leaving a more detailed treatment to the many books written on the subject.

One statistical quantity which we have mentioned earlier is the average or arithmetic mean. If we have a set of numbers u_i, such as a set of measured wind speeds, the mean of the set is defined as

$$\bar{u} = \frac{1}{n}\sum_{i=1}^{n} u_i \tag{15}$$

The sample size or the number of measured values is n.

Another quantity seen occasionally in the literature is the *median*. If n is odd, the median is the middle number after all the numbers have been arranged in order of size. As many numbers lie below the median as above it. If n is even the median is halfway between the two middle numbers when we rank the numbers.

In addition to the mean, we are interested in the variability of the set of numbers. We want to find the discrepancy or deviation of each number from the mean and then find some sort of average of these deviations. The mean of the deviations $u_i - u$ is zero, which does not tell us much. We therefore square each deviation to get all positive quantities. The *variance* σ^2 of the data is then defined as

$$\sigma^2 = \frac{1}{n-1}\sum_{i=1}^{n}(u_i - \bar{u})^2 \tag{16}$$

The term n - 1 is used rather than n for theoretical reasons we shall not discuss here[2].

The *standard deviation* σ is then defined as the square root of the variance.

$$\text{standard deviation} = \sqrt{\text{variance}} \tag{17}$$

Example

Five measured wind speeds are 2,4,7,8, and 9 m/s. Find the mean, the variance, and the standard deviation.

$$\bar{u} = \frac{1}{5}(2+4+7+8+9) = 6.00 \text{ m/s}$$

$$\sigma^2 = \frac{1}{4}[(2-6)^2 + (4-6)^2 + (7-6)^2 + (8-6)^2 + (9-6)^2]$$
$$= \frac{1}{4}(34) = 8.5 \ \ \mathrm{m^2/s^2}$$
$$\sigma = \sqrt{8.5} = 2.92 \ \ \mathrm{m/s}$$

Wind speeds are normally measured in integer values, so that each integer value is observed many times during a year of observations. The numbers of observations of a specific wind speed u_i will be defined as m_i. The mean is then

$$\bar{u} = \frac{1}{n}\sum_{i=1}^{w} m_i u_i \qquad (18)$$

where w is the number of different values of wind speed observed and n is still the total number of observations.

It can be shown[2] that the variance is given by

$$\sigma^2 = \frac{1}{n-1}\left[\sum_{i=1}^{w} m_i u_i^2 - \frac{1}{n}\left(\sum_{i=1}^{w} m_i u_i\right)^2\right] \tag{19}$$

The two terms inside the brackets are nearly equal to each other so full precision needs to be maintained during the computation. This is not difficult with most of the hand calculators that are available.

Example

A wind data acquisition system located in the tradewinds on the northeast coast of Puerto Rico measures 6 m/s 19 times, 7 m/s 54 times, and 8 m/s 42 times during a given period. Find the mean, variance, and standard deviation.

$$\bar{u} = \frac{1}{115}[19(6) + 54(7) + 42(8)] = 7.20 \ \text{m/s}$$

$$\sigma^2 = \{\frac{1}{114}[19(6)^2 + 54(7)^2 + 42(8)^2 - \frac{1}{115}[19(6) + 54(7) + 42(8)]^2\}$$

$$= \frac{1}{114}(6018 - 5961.600) = 0.495 \ \text{m}^2/\text{s}^2$$

$$\sigma = 0.703 \ \text{m/s}$$

2.7 WEIBULL STATISTICS

There are several density functions which can be used to describe the wind speed frequency curve. The two most common are the *Weibull* [15–17] and the *Rayleigh* functions. For the statistically inclined reader, the Weibull is a special case of the Pearson type III or generalized gamma distribution, while the Rayleigh [or *chi with two degrees of freedom* (chi-2)] distribution is a subset of the Weibull. The Weibull is a *two-parameter* distribution while the Rayleigh has only *one parameter*. This makes the Weibull somewhat more versatile and the Rayleigh somewhat simpler to use. We shall present the Weibull distribution first.

The wind speed u is distributed as the Weibull distribution if its probability density function is

$$f(u) = \frac{k}{c}\left(\frac{u}{c}\right)^{k-1} \exp\left[-\left(\frac{u}{c}\right)^{k}\right] \qquad (k > 0, u > 0, c > 1) \qquad (2.30)$$

We are using the expression exp (x) to represent e^x.

This is a two-parameter distribution where c and k are the *scale parameter* and the *shape parameter*, respectively. Curves of $f(u)$ are given in Fig. 2.16, for the scale parameter $c = 1$. It can be seen that the Weibull density function gets

Weibull Density Function for Scale Parameter c = 1

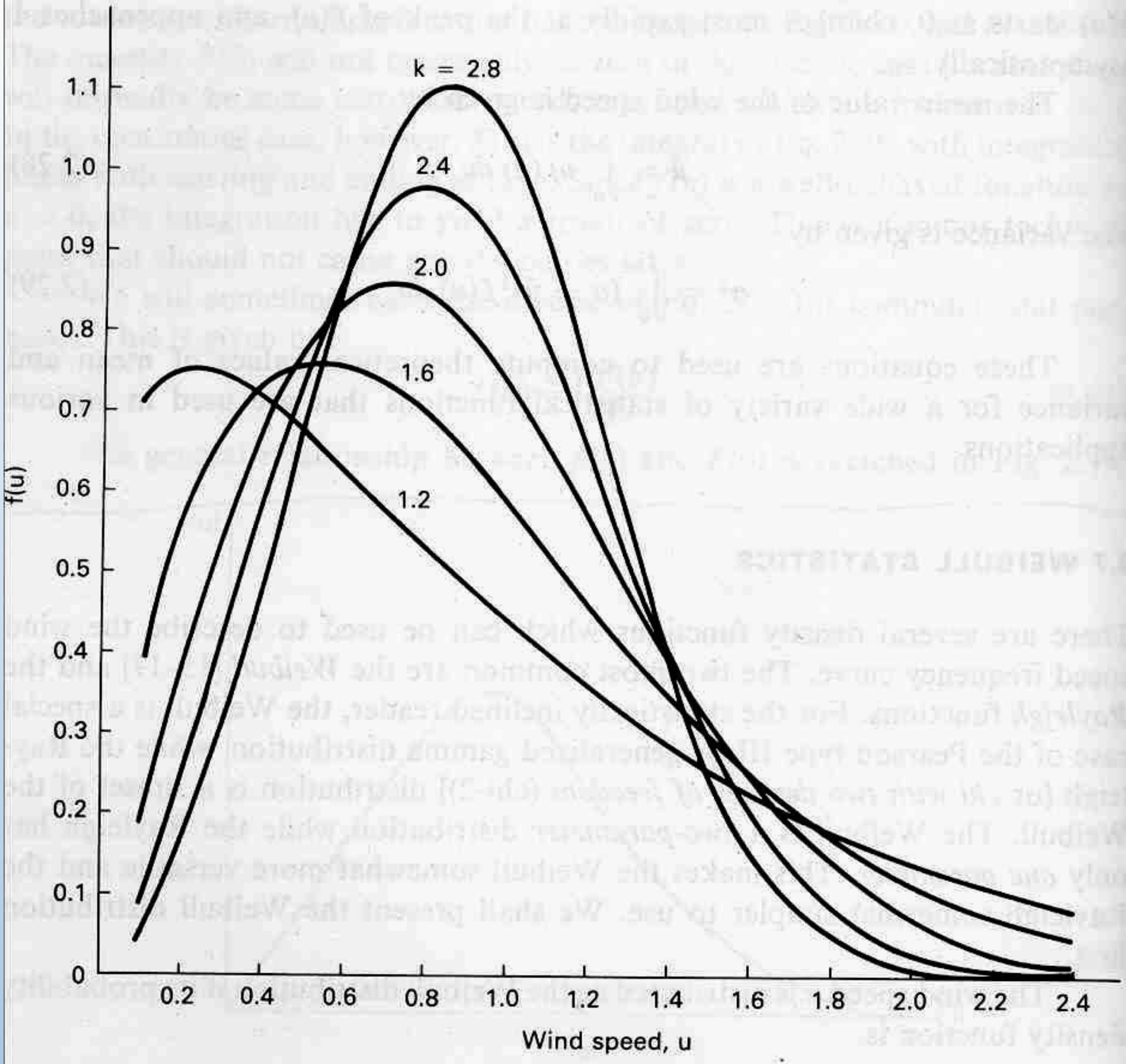
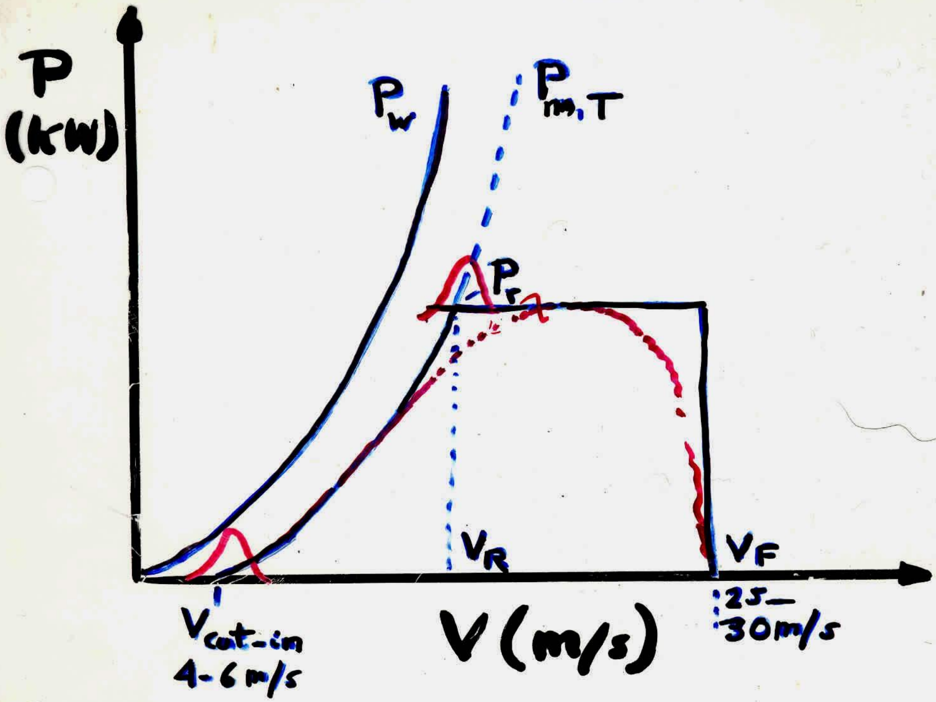


Figure 2.16 Weibull density function $f(u)$ for scale parameter $c = 1$.

Theoretical and Actual Wind Power Curves



- C_p - effect
- actual vs theoretical curve
- effect of velocity distribution
- rpm of turbine
- gusts

$P_r = C_{p_r}\,\eta(\text{Transmission})\,\eta(\text{generator})\,\frac{\rho}{2} A \bar{V}_R^3$

$P_r = 0 \quad (V < V_c)$ and $V > V_F$

$P_r = a + bV^k \quad (V_c < V < V_R)$

$P_r = P_r$ for $(V_R < V < V_F)$

The Betz Limit

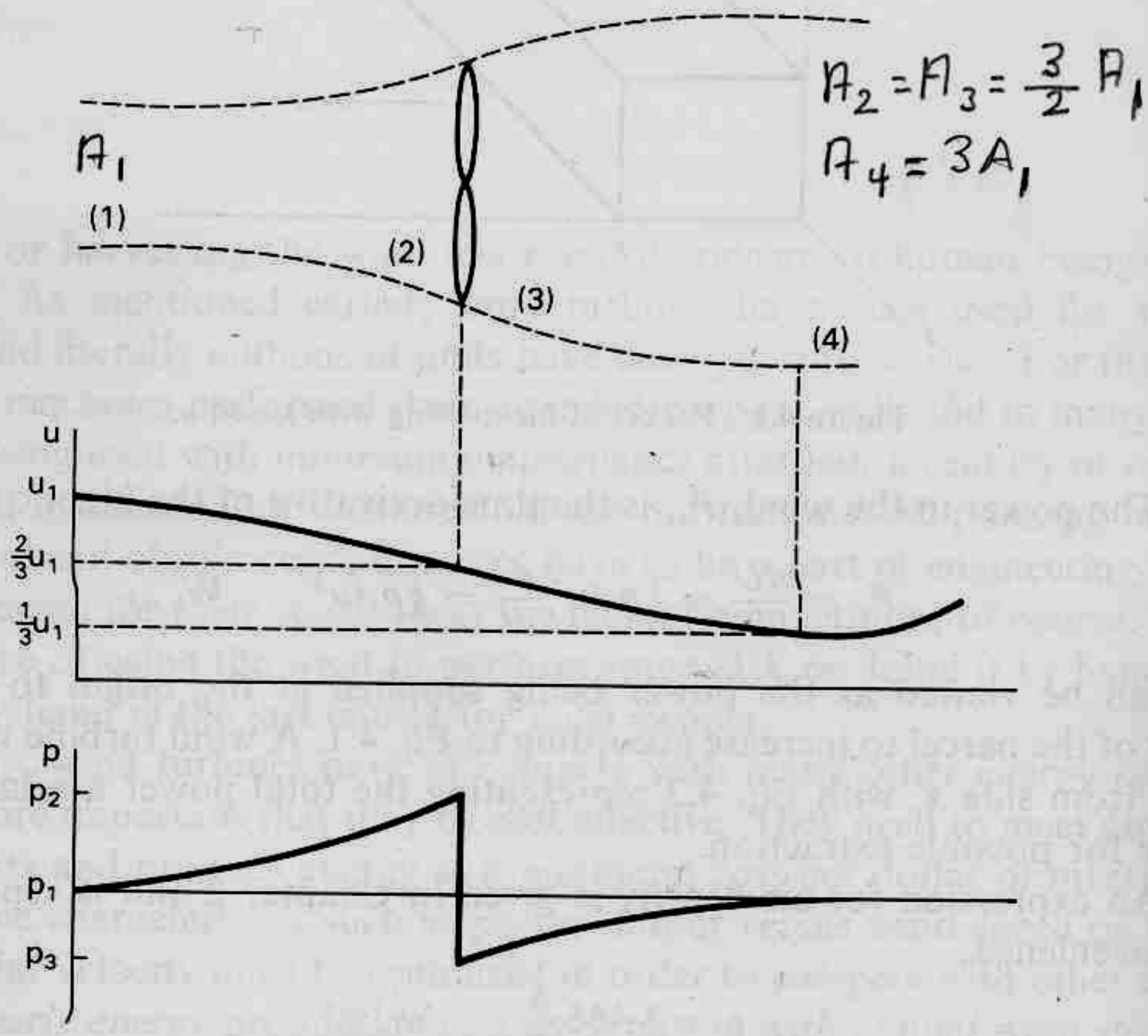


Figure 4.2 Circular tube of air flowing through ideal wind turbine.

The Betz Limit

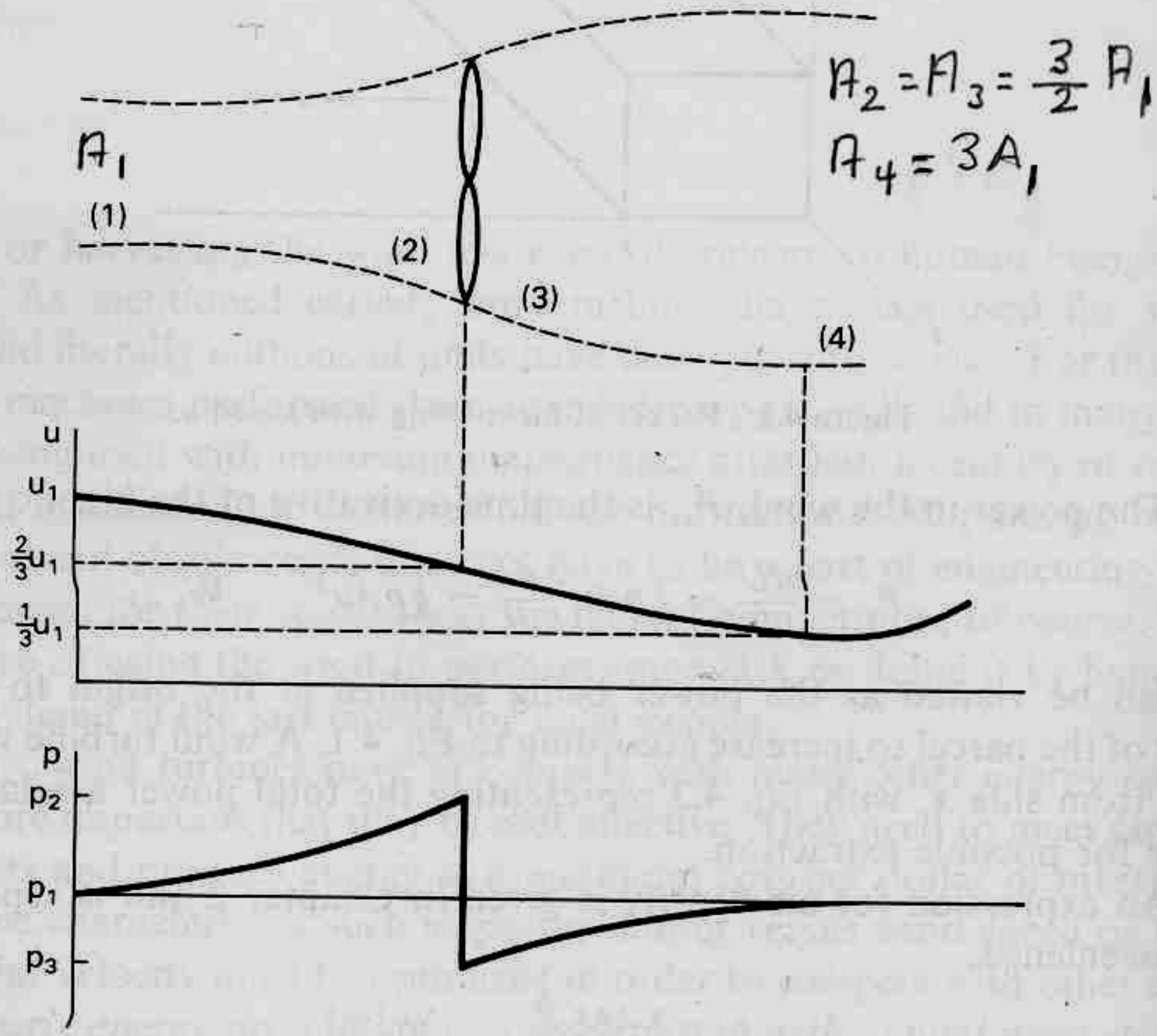
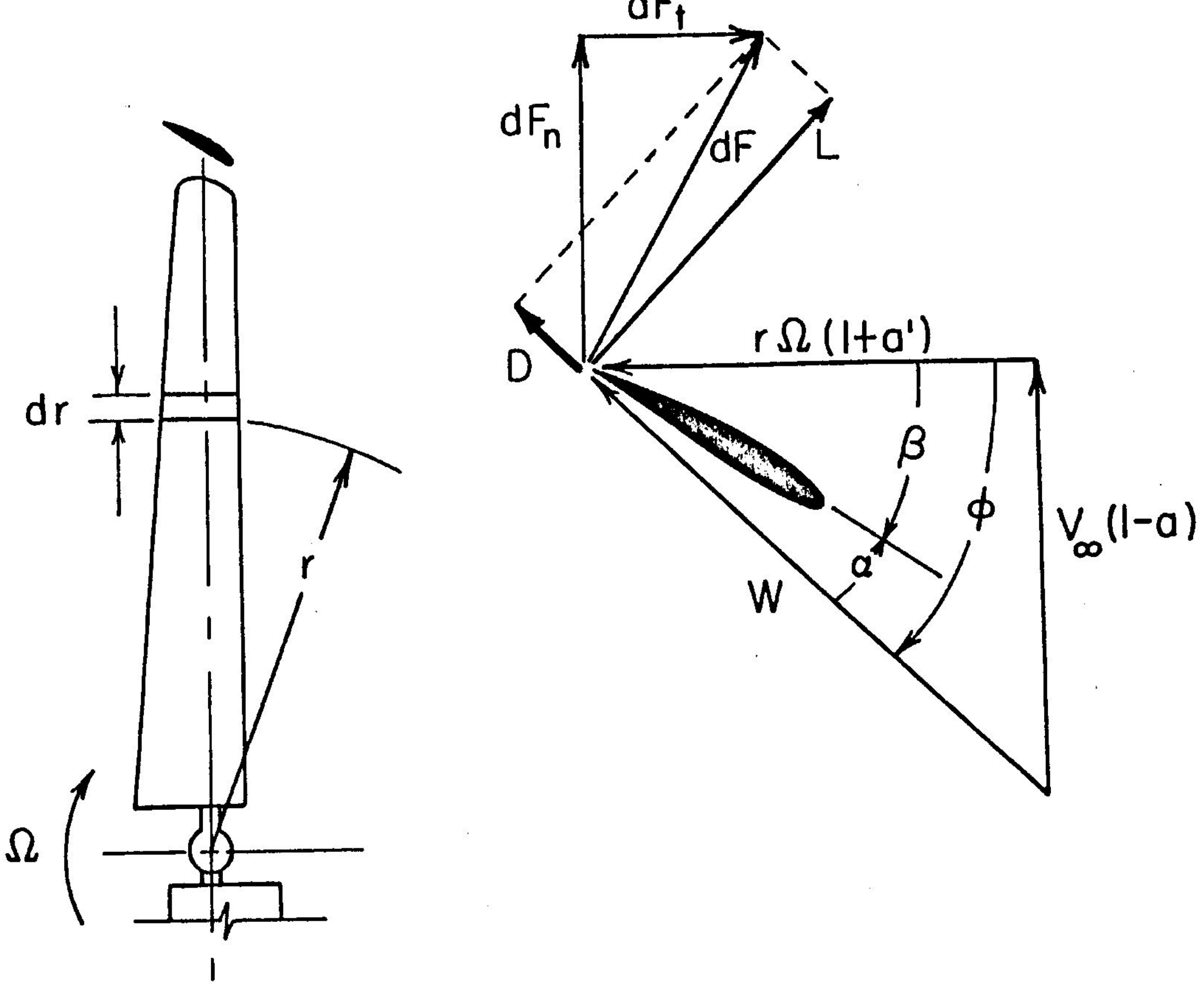


Figure 4.2 Circular tube of air flowing through ideal wind turbine.



dr
r
Ω
dF_t
dF_n
dF
L
D
$r\Omega(1+a')$
β
φ
α
W
$V_\infty(1-a)$

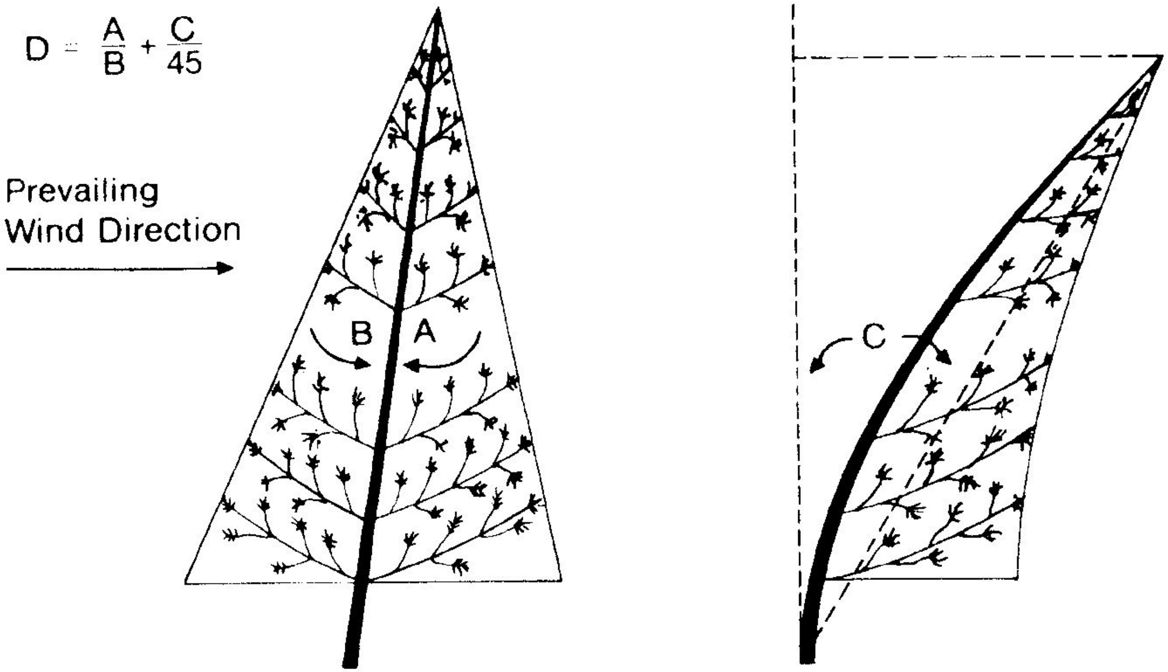
Wind Power (siting)

Summary of Features of Suitable Site

- High annual average wind speed (consult local National Weather Service Station)
- No tall obstructions upwind for a distance depending on the height
- Top of smooth well-rounded hill (with gentle slopes) on flat plain or island in a lake or sea
- Open plain, open shoreline
- Mountain gap that produces a funneling

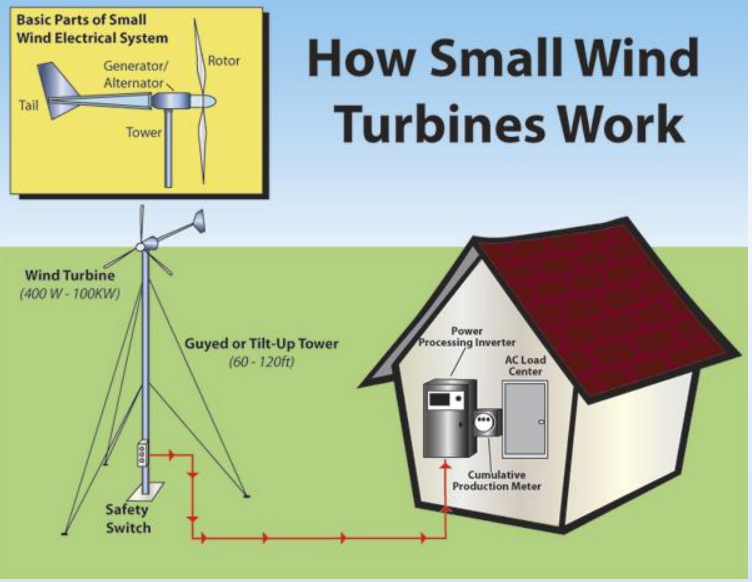
- The wind turbines are categorized into classes, corresponding to the average wind speed areas that they are designed for, see also fig. 22, thus area classes range from Class 1 - 200 W/m2 or less at 50 m height - to Class 7, 800 ÷ 2000 W/m2. Most of the large wind farms are sited for Class 3 or higher geographical areas, although Class 1 area will be of the most interest for architects. Wind turbines are classified by the wind speed they are designed for, from class I to class IV, with A or B referring to the turbulence.

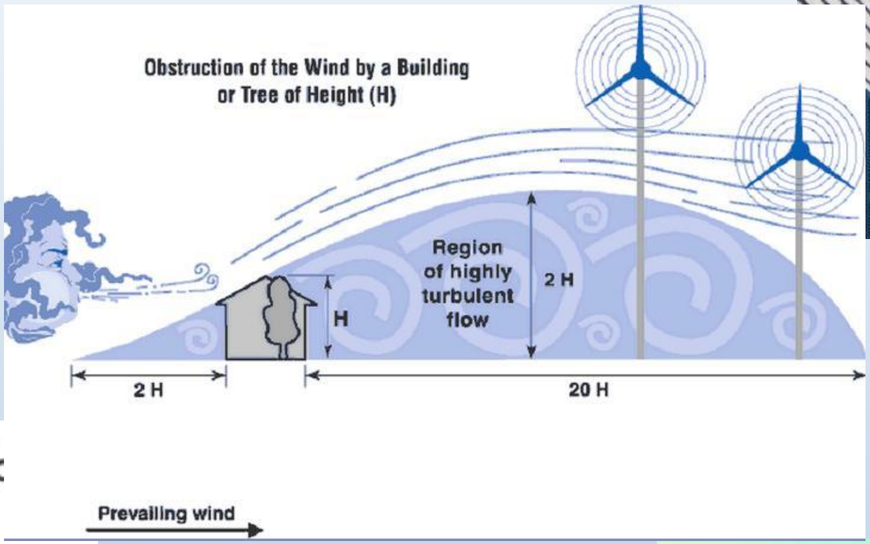
- Necessary to remember that the efficiency of the wind turbines are restricted by Betz Limit, approximately equal to 59%. Usually wind turbines are fulfilling only about 65-85% of this range, thus it is accepted to talk about coefficient of Performance – COP, and not efficiency. Thus the most turbines have COP of 0.65 – 0.85.

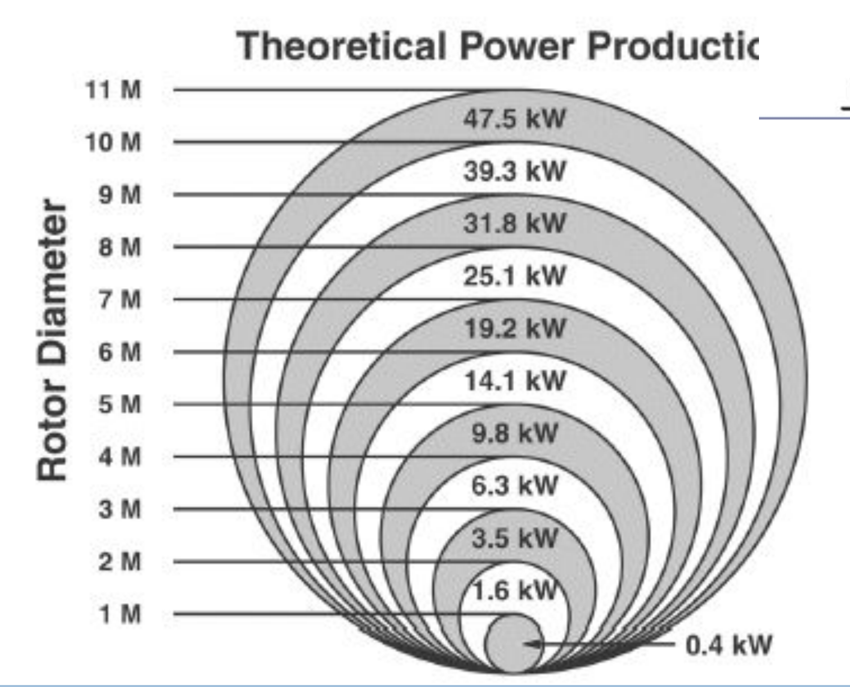


Source: Hewson, E.W.; Wade, J.F.; Baker, R.W. 1977 (June). *Vegetation as an Indicator of High Wind Velocity*. (Prepared for the Energy Research and Development Administration by Oregon State University, Corvallis, OR.)

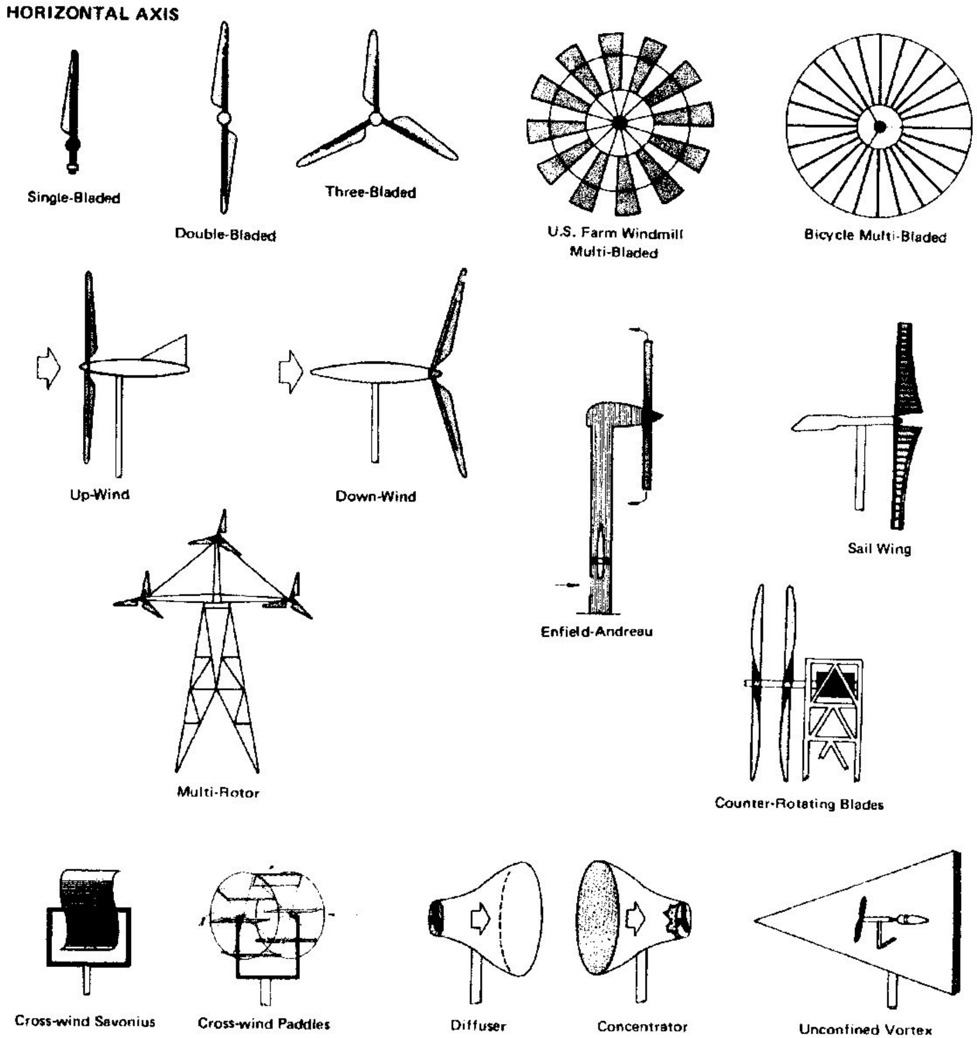
Figure 2-16. Deformation Ratio Computed as a Measure of the Degree of Flagging and Throwing


How Small Wind Turbines Work
Basic Parts of Small Wind Electrical System
Generator/ Alternator
Rotor
Tail
Tower
Wind Turbine
(400 W - 100KW)
Guyed or Tilt-Up Tower
(60 - 120ft)
Power Processing Inverter
AC Load Center
Cumulative Production Meter
Safety Switch

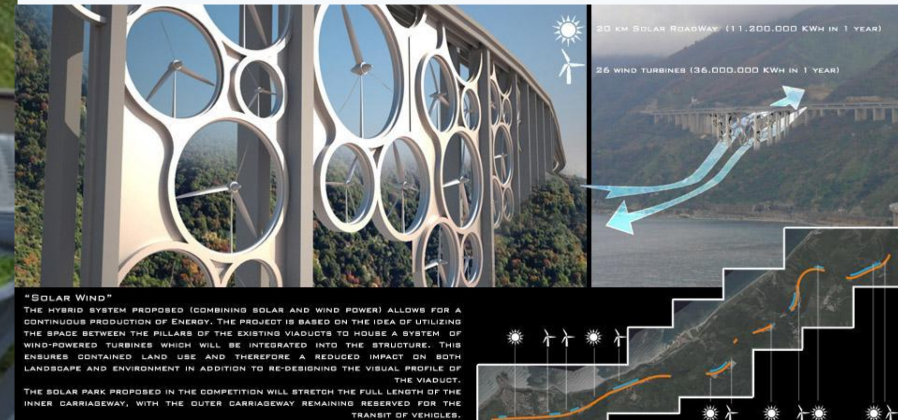

Obstruction of the Wind by a Building or Tree of Height (H)
Region of highly turbulent flow
2 H
H
2 H
20 H
Prevailing wind


Theoretical Power Productic
Rotor Diameter
11 M
10 M
9 M
8 M
7 M
6 M
5 M
4 M
3 M
2 M
1 M
47.5 kW
39.3 kW
31.8 kW
25.1 kW
19.2 kW
14.1 kW
9.8 kW
6.3 kW
3.5 kW
1.6 kW
0.4 kW

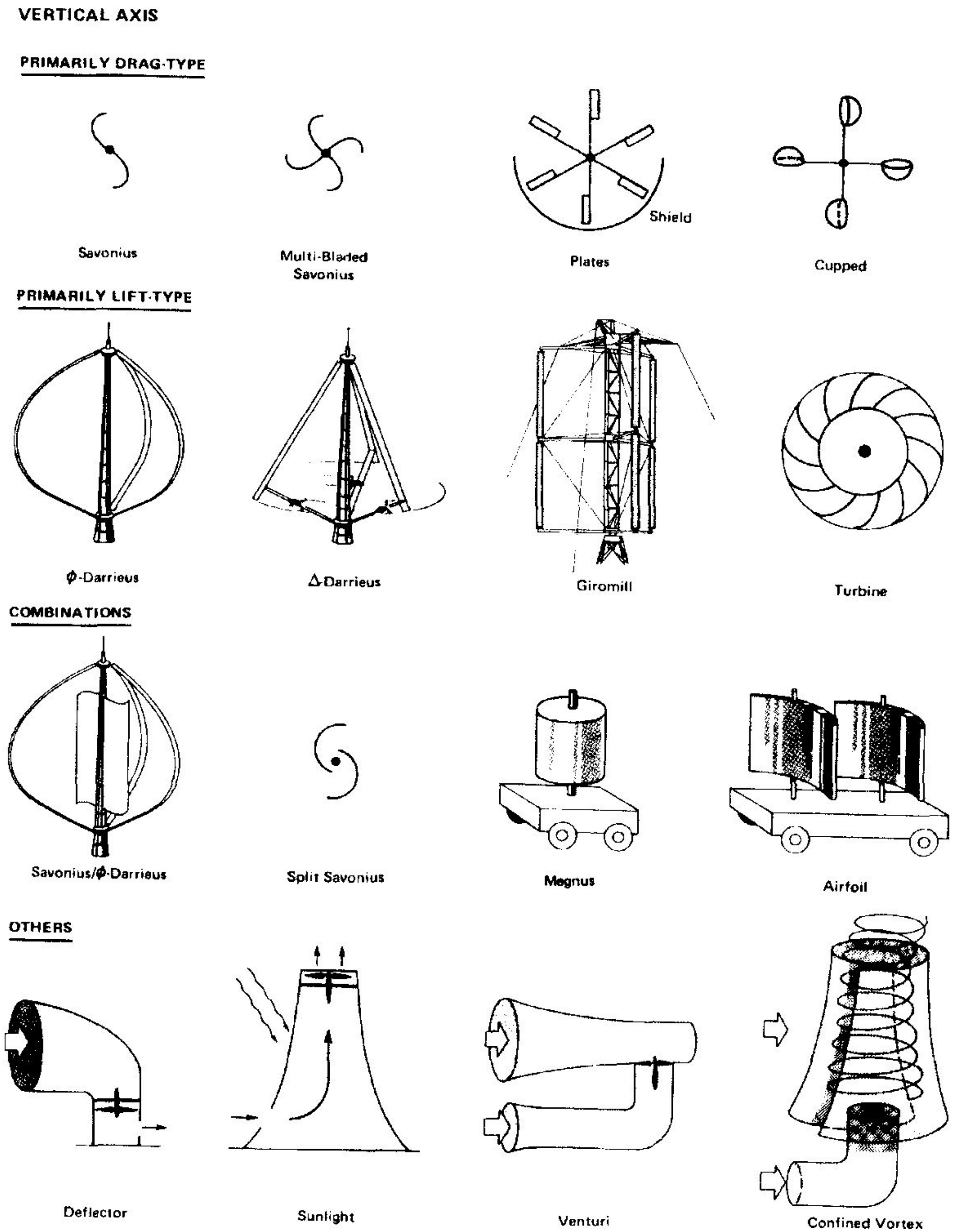
TAXONOMY


HORIZONTAL AXIS
Single-Bladed
Double-Bladed
Three-Bladed
U.S. Farm Windmill Multi-Bladed
Bicycle Multi-Bladed
Up-Wind
Down-Wind
Enfield-Andreau
Sail Wing
Multi-Rotor
Counter-Rotating Blades
Cross-wind Savonius
Cross-wind Paddles
Diffuser
Concentrator
Unconfined Vortex

Bahrain world trade center with wind integrated turbines. Center opened in 2008, is a better example of sustainable inspiring architecture. The construction of the twin towers is one of the best eco-friendly building in the world. The building has three wind turbines with a total capacity of 680 KW.



A bridge that repurposes abandoned viaducts, produces energy AND looks futuristically sleek? Yes, it can be true, and it is Italy's proposed Wind Turbine Viaduct called "Solar Wind." Southern Italy is dotted with unused viaducts, and rather than spending $50 million to tear them down, town officials near Calabria held a competition called "Solar Park South," open to designers and engineers asking them to come up with an environmentally conscious way to re-use the existing structures.

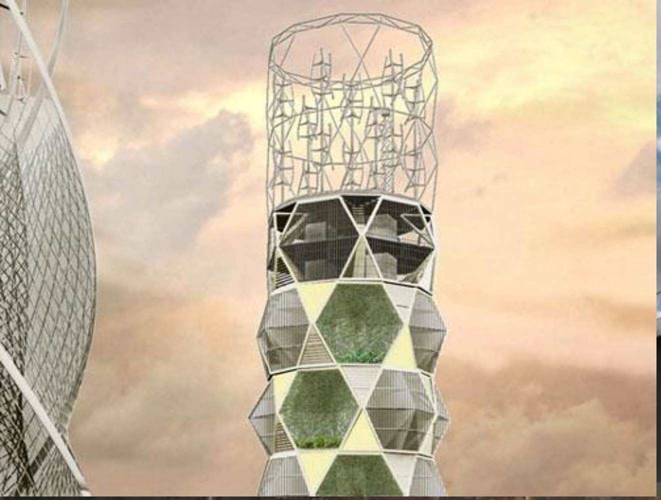
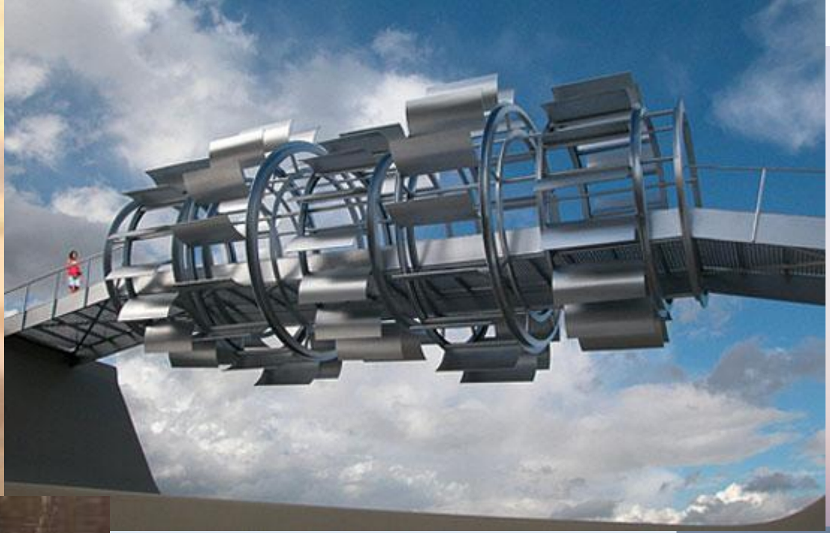

VERTICAL AXIS
PRIMARILY DRAG-TYPE
Savonius
Multi-Bladed Savonius
Shield
Plates
Cupped
PRIMARILY LIFT-TYPE
ϕ-Darrieus
Δ-Darrieus
Giromill
Turbine
COMBINATIONS
Savonius/ϕ-Darrieus
Split Savonius
Magnus
Airfoil
OTHERS
Deflector
Sunlight
Venturi
Confined Vortex



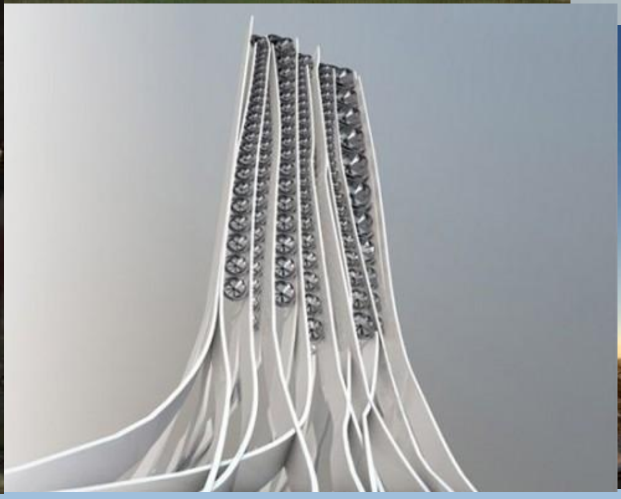


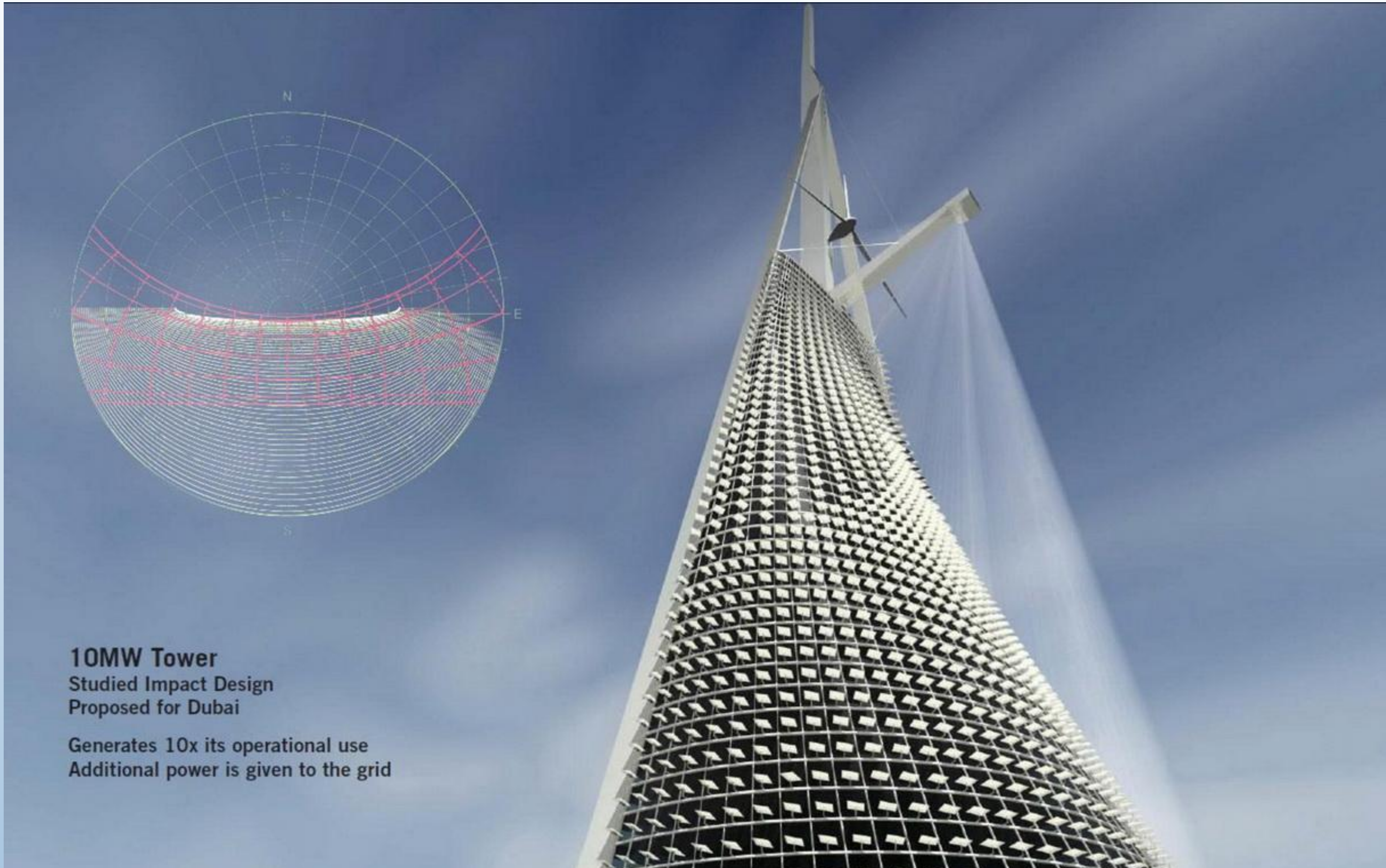




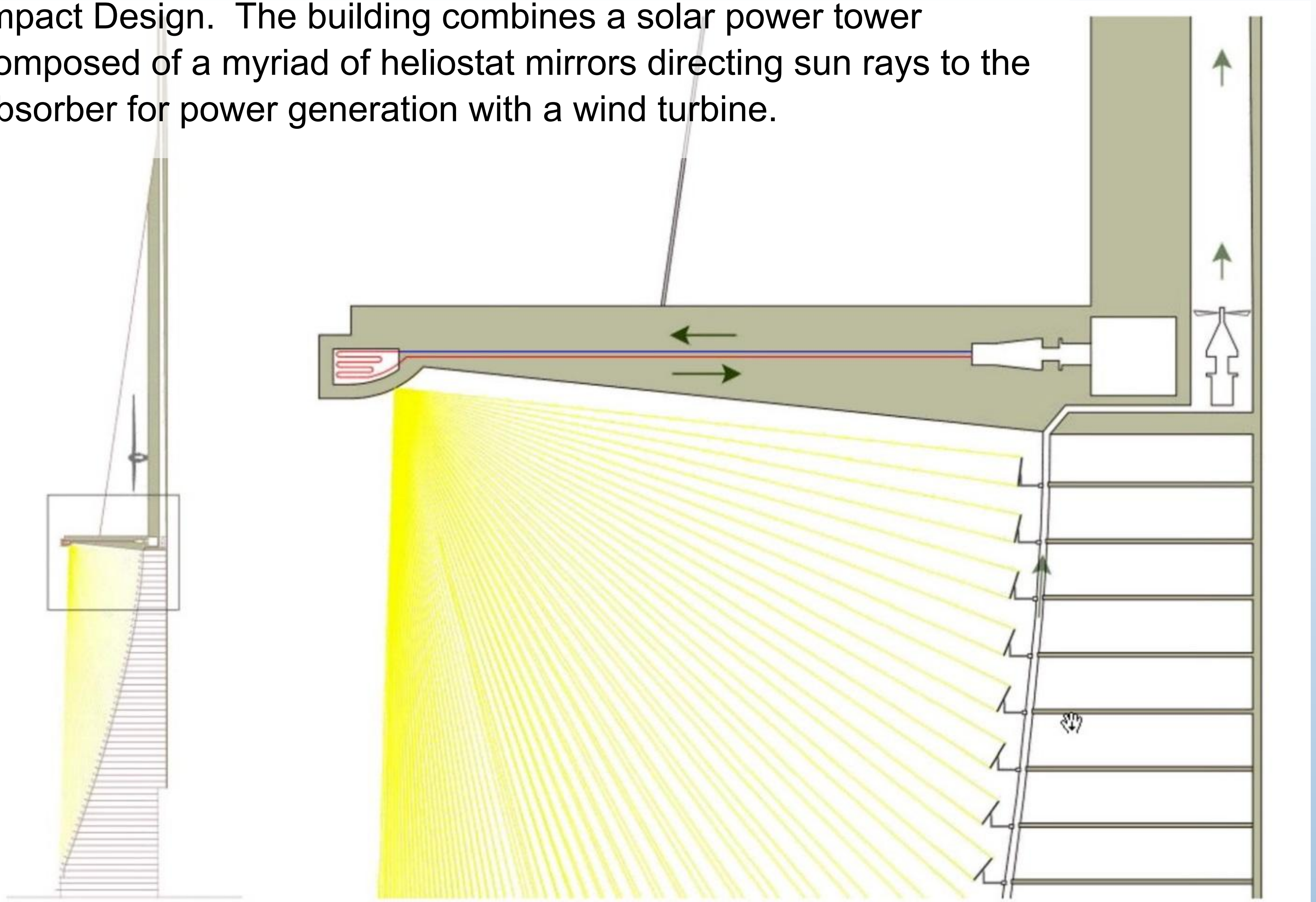








N
E
S
10MW Tower
Studied Impact Design
Proposed for Dubai
Generates 10x its operational use
Additional power is given to the grid

An interesting work by Robert Ferry, founding partner of Studied Impact Design. The building combines a solar power tower composed of a myriad of heliostat mirrors directing sun rays to the absorber for power generation with a wind turbine.



Homework - Wind

- A wind-data acquisition system located at Kahuku Point, Hawaii, measures 8 m/s 24 times, 9 m/s 72 times, 10 m/s 85 times, 12 m/s 48 times, and 13 m/s 9 times during a given period. Find the mean, variance, and standard deviations.
- A turbine is rated at 100 KW at 16 m/s and 50 KW at 12 m/s. The area is 200m^2. Compute the rated overall efficiency η at each rating when ρ =1,294 kg/m^3.
- Derive Betz Limit formula.