The Florida Advanced Technological Education (FLATE) Center wishes to make available, for educational and non-commercial purposes only, materials relevant to the "EST1830 Introduction to Alternative/Renewable Energy" course comprised of images, texts, facilitator's notes, and other demonstration materials.

This instructional resource forms part of FLATE's outreach efforts to facilitate a connection between students and teachers throughout the State of Florida. We trust that these activities and materials will add value to your teaching and/or presentations.

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Introduction to Alternative and Renewable Energy

EST1830

Florida Energy Systems Consortium

FLATE
FLORIDA ADVANCED TECHNOLOGICAL EDUCATION CENTER

3. Energy Production

3.1 Renewable Energy Technologies

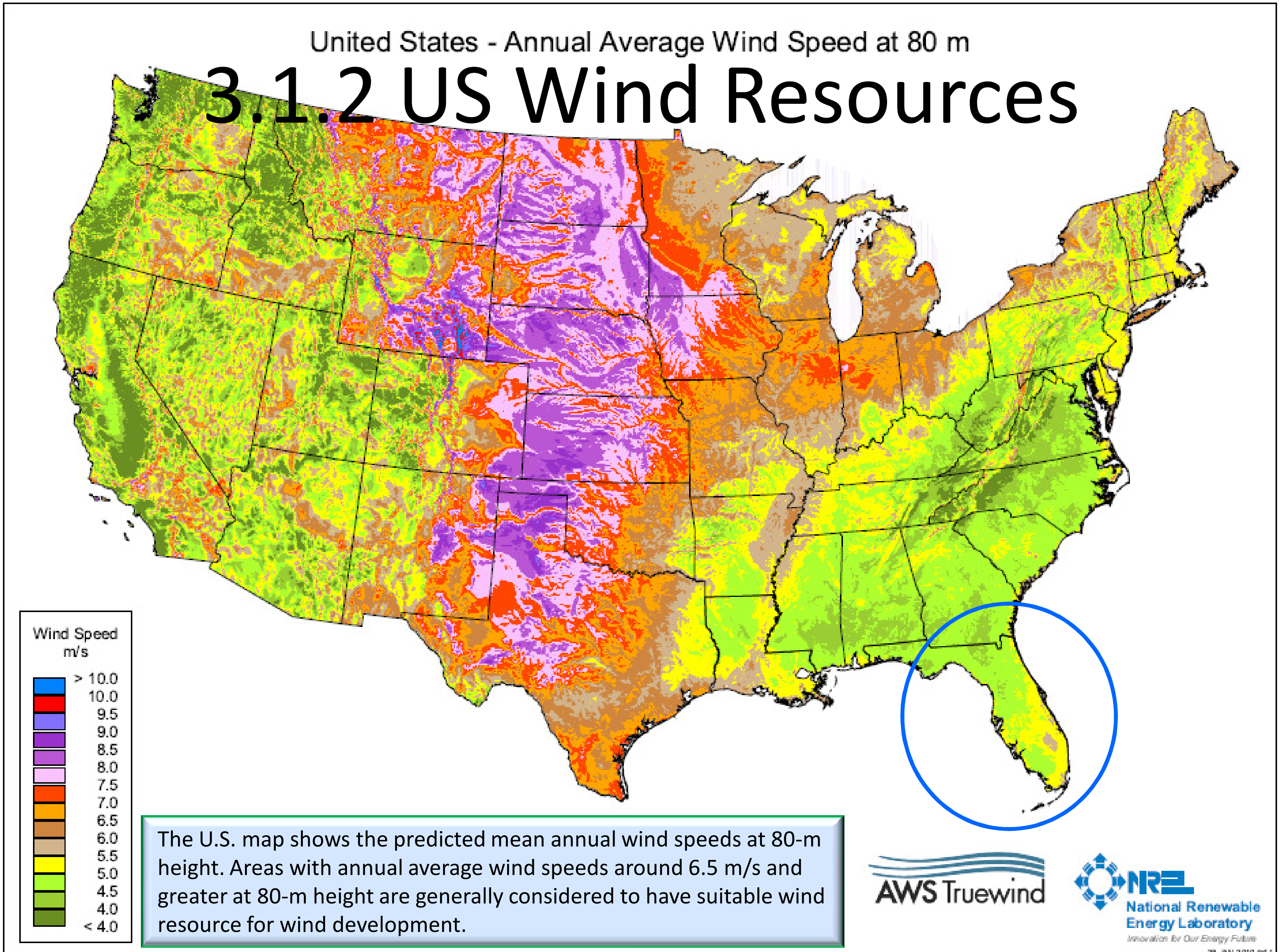
3.1.2 Wind Energy

3. Energy Production

- 3.1.2 Wind
  - 3.1.2a Theory of Operation
  - 3.1.2b Sizes
  - 3.1.2c Types of Turbines

http://www.nrel.gov/data/pix/Jpegs/16707.jpg

3.1.2 US Wind Resources

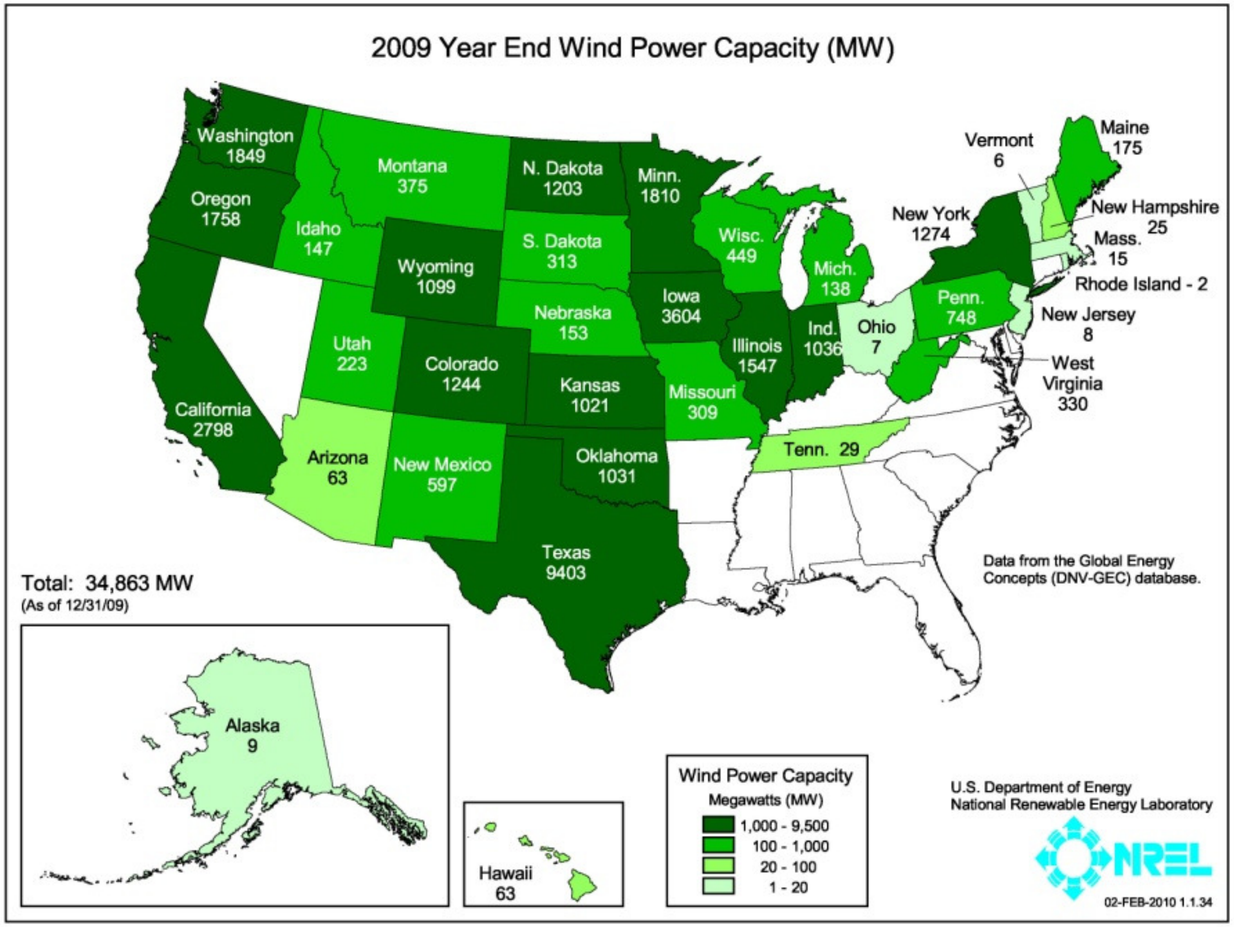


The U.S. map shows the predicted mean annual wind speeds at 80-m height. Areas with annual average wind speeds around 6.5 m/s and greater at 80-m height are generally considered to have suitable wind resource for wind development.

http://www.windpoweringamerica.gov/

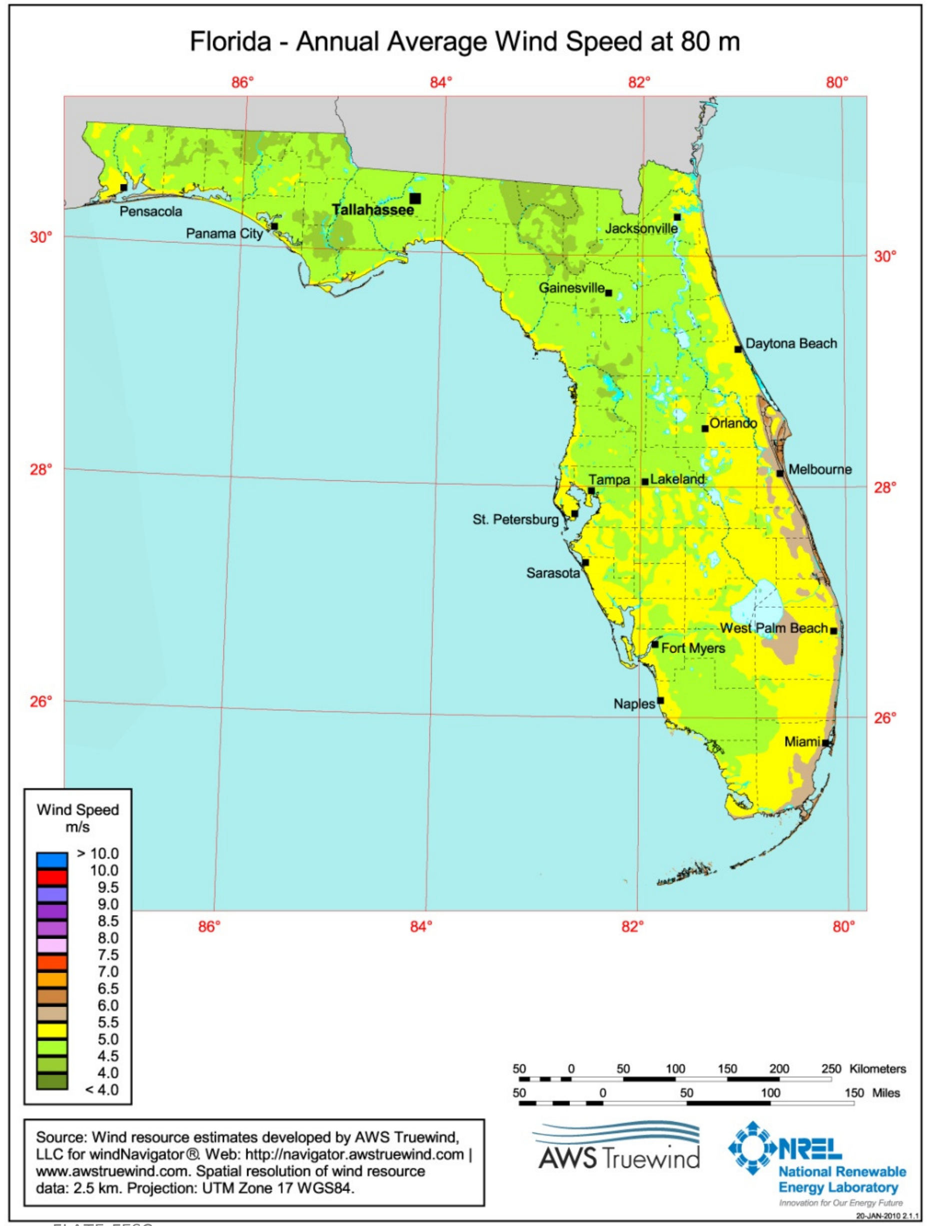
3.1.2 Installed Capacity

- Installed capacity in the US as of year end 2009
- Top five in order of installed capacity
  - Texas
  - Iowa
  - California
  - Minnesota
  - Washington



3.1.2 Florida Wind

- Not great wind resources in Florida
- ….on land

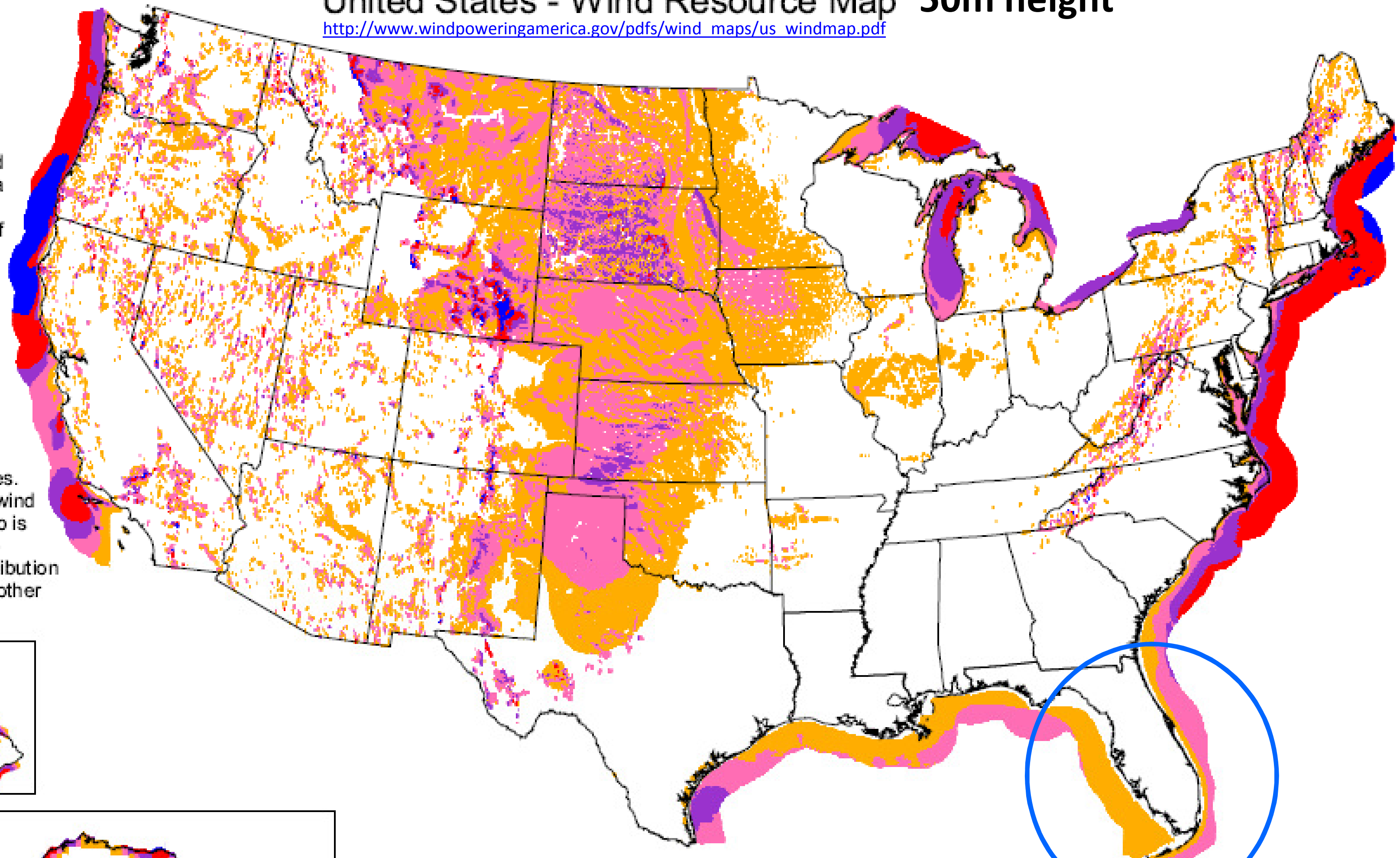


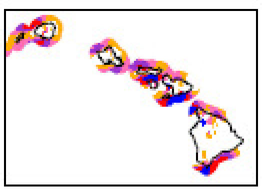
http://www.windpoweringamerica.gov/

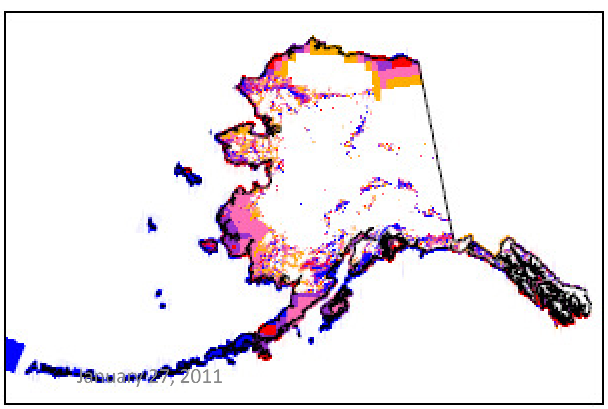
United States - Wind Resource Map **50m height**

http://www.windpoweringamerica.gov/pdfs/wind_maps/us_windmap.pdf

This map shows the annual average wind power estimates at a height of 50 meters. 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.







Wind Power Classification

	Wind Power Class	Resource Potential	Wind Power Density at 50 m W/m^2	Wind Speed[a] at 50 m m/s	Wind Speed[a] at 50 m mph
	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

http://www.windpoweringamerica.gov/

Note the offshore wind resources. Wind farm instead of oil farm?

U.S. Department of Energy
National Renewable Energy Laboratory

06-MAY-2009 1.1.3

3.1.2 Wind Speed Ratings

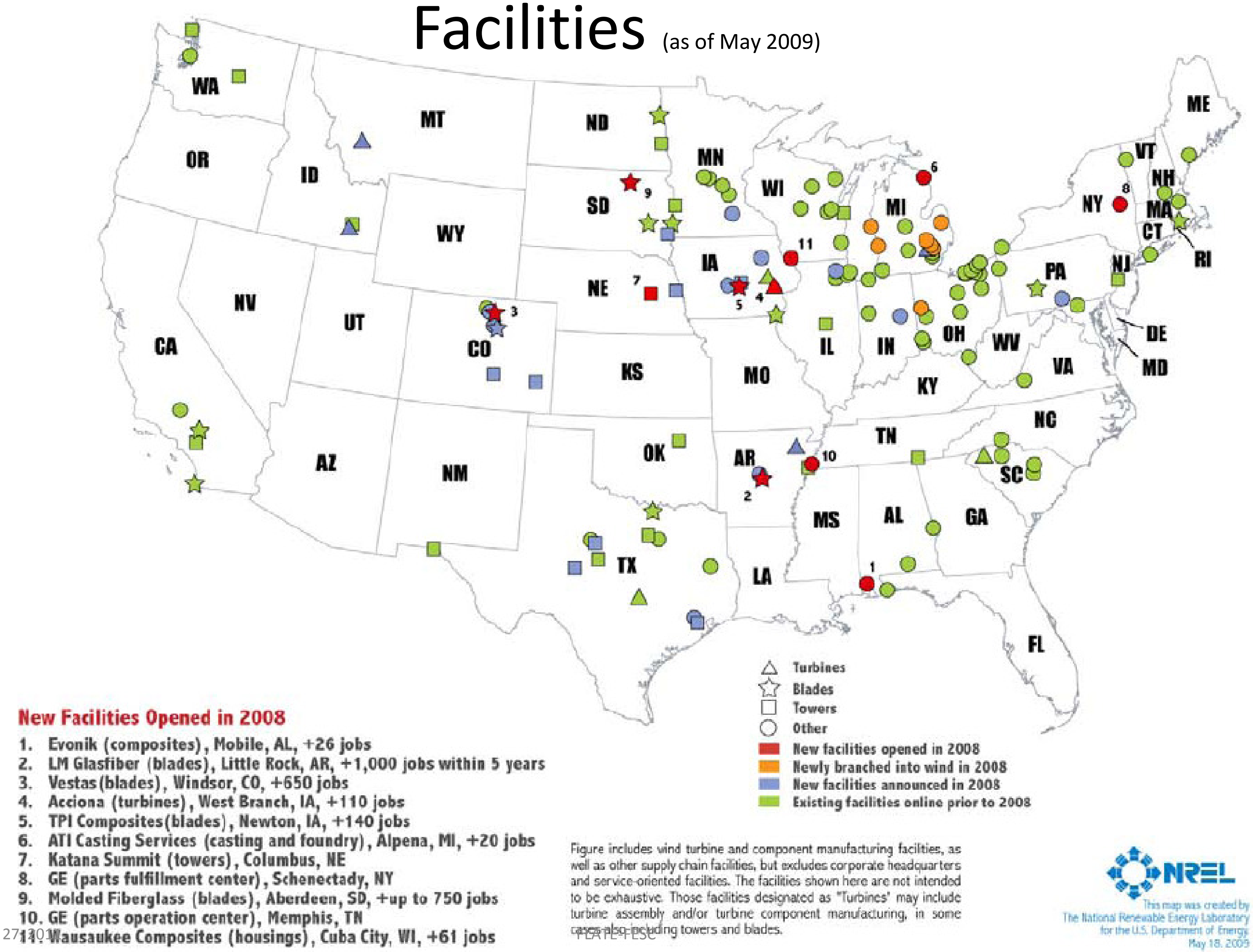
Beaufort Scale of Wind Speed			
BEAUFORT NUMBER	NAME OF WIND	LAND CONDITIONS	WIND SPEED MPH
0	Calm	Calm, smoke rises vertically	<1
1	Light Air	Smoke drifts, indicating wind direction	1-3
2	Light Breeze	Wind felt on face, leaves rustle, flags stir	4-7
3	Gentle Breeze	Leaves and small twigs in constant motion	8-12
4	Moderate Breeze	Small branches move, wind raises dust and loose paper	13-18
5	Fresh Breeze	Smaller trees sway	19-24
6	Strong Breeze	Large branches in motion	25-31
7	Near Gale	Whole trees in motion	32-38
8	Gale	Twigs broken from trees	39-46
9	Severe Gale	Light structure damage	47-54
10	Storm	Trees uprooted, considerable structural damage	55-63
11	Violent Storm	Widespread structural damage	64-72
12	Hurricane	Massive and widespread damage to structure	73-82

www.need.org

3.1.2 Installation

http://www.youtube.com/watch?v=eY9EmLV8pnE&feature=player_embedded

3.1.2 Existing and New Wind Manufacturing Facilities (as of May 2009)

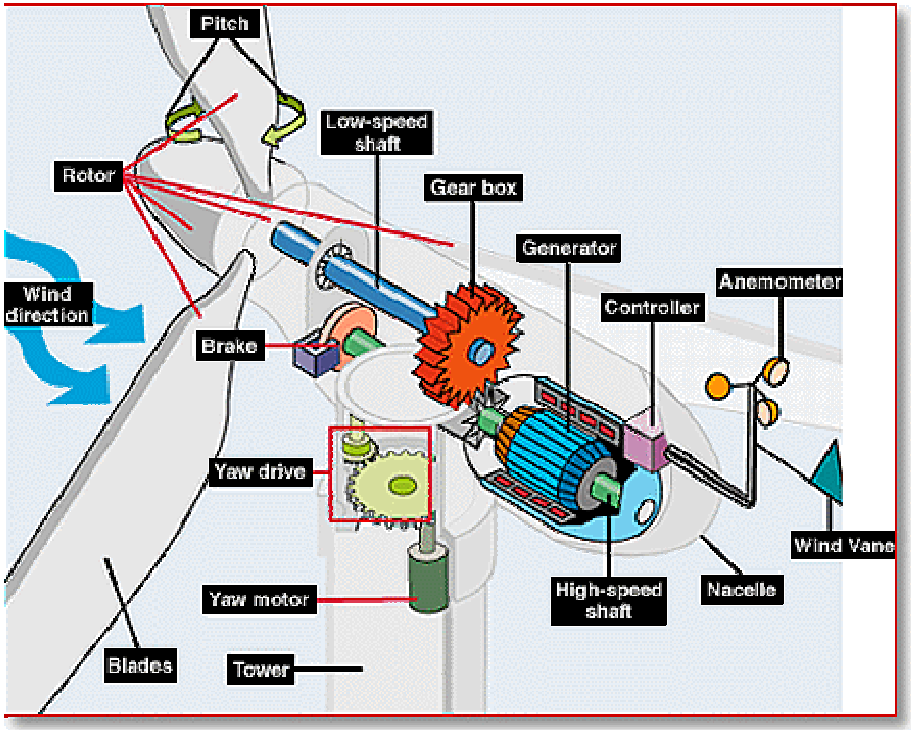


3.1.2 Wind

3.1.2A THEORY OF OPERATION

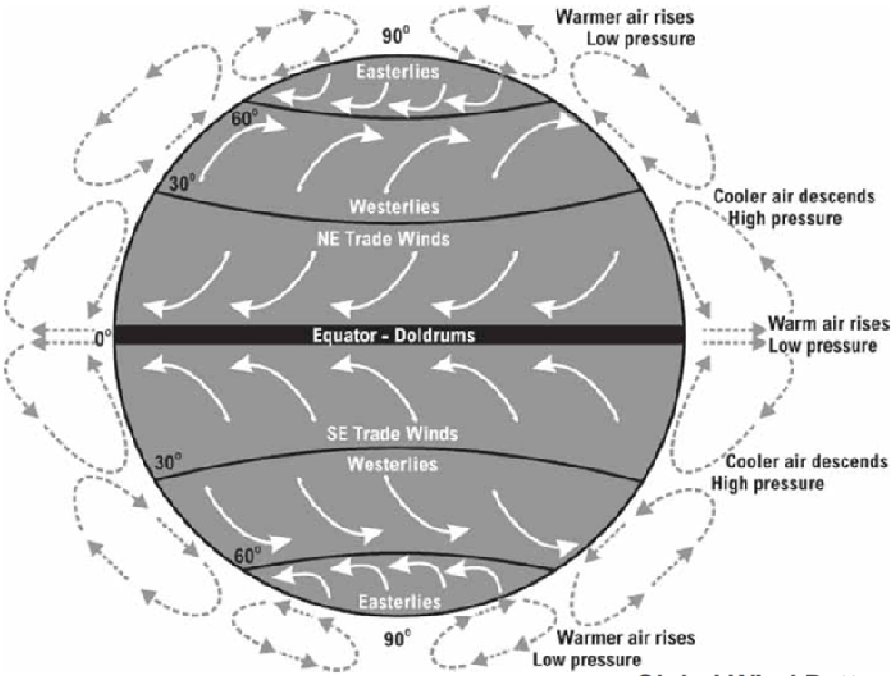
3.1.2a Theory of Operation

(1) http://vimeo.com/13759005



http://www1.eere.energy.gov/windandhydro/wind_animation.html

(2)



3.1.2a Global Wind Patterns

www.need.org

Global Wind Patterns

The equator receives the sun's most direct rays. Here, air is heated and rises, leaving low-pressure areas. Moving to about thirty degrees north and south of the equator, the warm air from the equator begins to cool and sink.

Trade winds Most of the cooling, sinking air moves back to the equator. The rest of the air flows toward the poles. The air movements toward the equator are called trade winds—warm, steady breezes that blow almost continuously. The ***Coriolis Effect***, caused by the rotation of the Earth, makes the trade winds appear to be curving to the west, whether they are traveling toward the equator from the south or north.

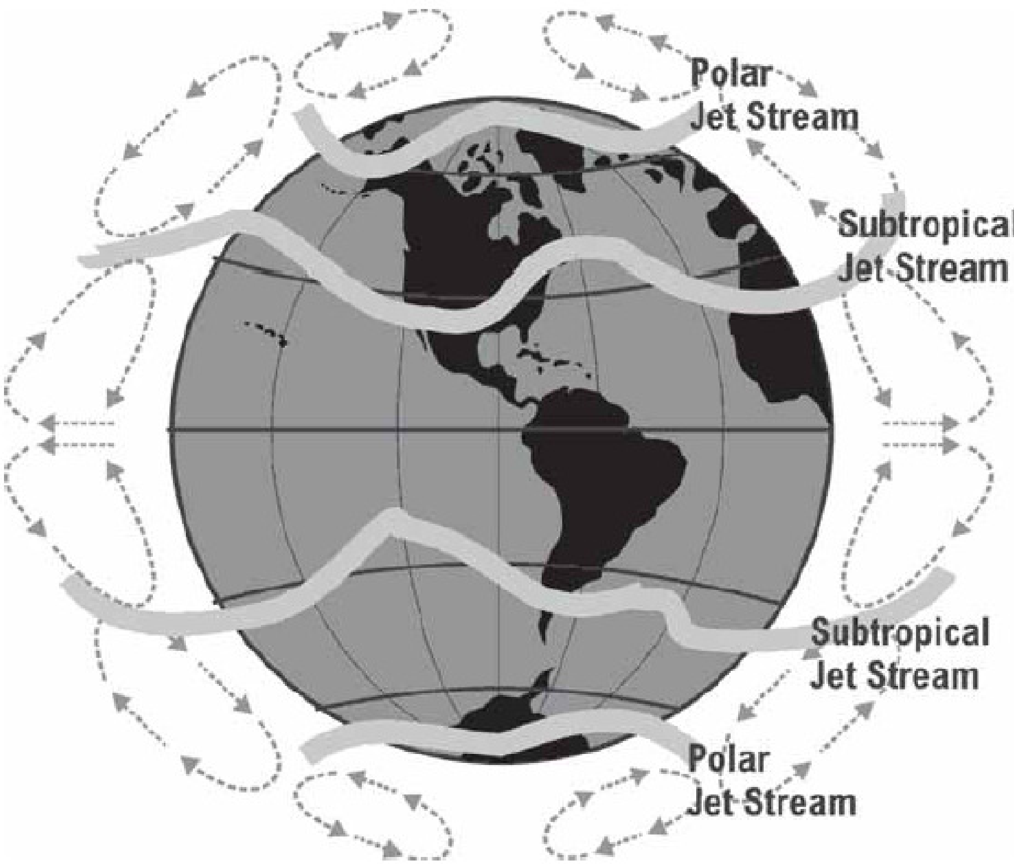
Doldrums The trade winds coming from the south and the north meet near the equator. These converging trade winds produce general upward winds as they are heated, so there are no steady surface winds. This area of calm is called the doldrums.

Prevailing westerlies Between thirty and sixty degrees latitude, the winds that move toward the poles appear to curve to the east. Because winds are named from the direction in which they originate, these winds are called prevailing westerlies. Prevailing westerlies in the northern hemisphere are responsible for many of the weather movements across the United States and Canada. In the U.S., we can look at the weather to our west to see what kind of weather is heading our way.

Polar easterlies At about sixty degrees latitude in both hemispheres, the prevailing westerlies join with polar easterlies to reduce upward motion. The polar easterlies form when the atmosphere over the poles cools. This cool air then sinks and spreads over the surface. As the air flows away from the poles, it is turned to the west by the Coriolis Effect. Because these winds begin in the east, they are called easterlies.

The trade winds, westerlies, and easterlies flow around the world and cause many of the earth's weather patterns.

3.1.2a Jet Streams

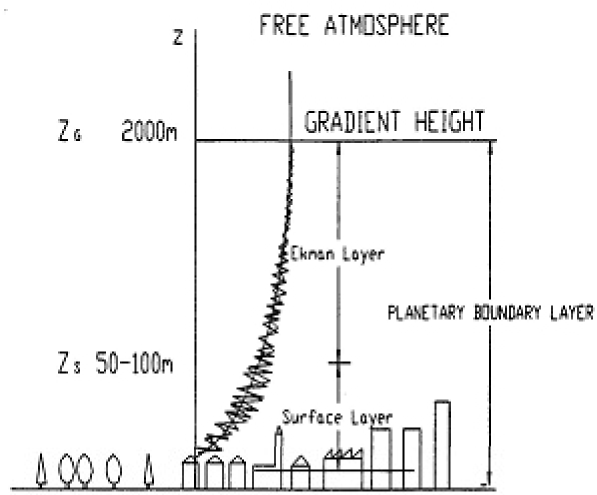


Jet streams The highest winds are the jet streams. The jet streams blow far above the earth where there is nothing to block their paths. Jet streams form more than 9 kilometers (5.6 miles) up in the atmosphere at the boundaries of adjacent air masses with significant differences in temperature.

These fast moving "rivers of air" move 92 kilometers per hour (57 mph) or faster. Jet streams pull air around the planet, from west to east, carrying weather systems with them.

There are also low–level jet streams (100–200 meters in altitude) in some areas that are significant for siting wind turbines.

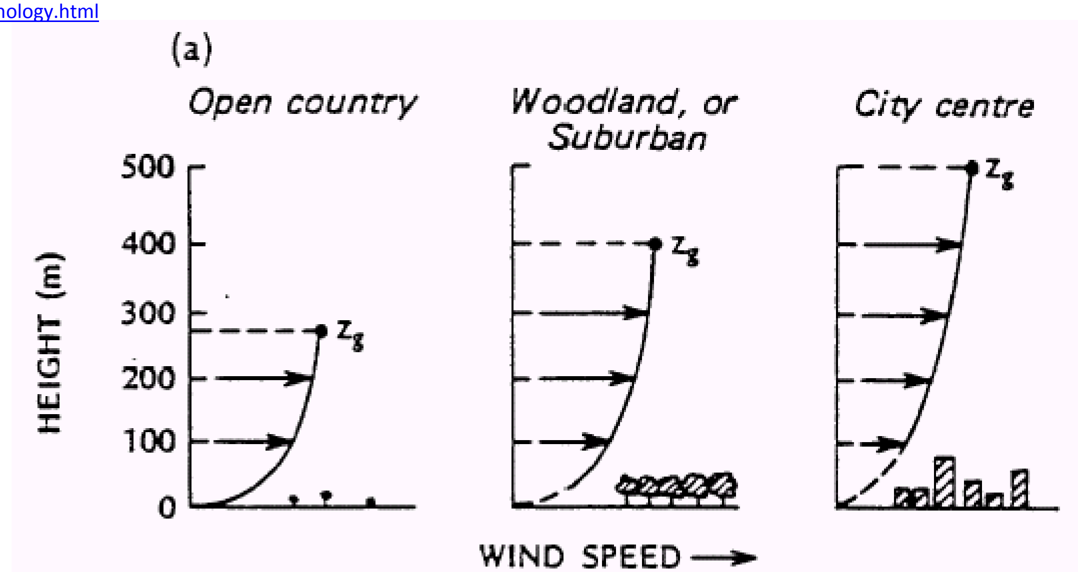
3.1.2a Wind Velocity Gradient



http://www.wind-energy-the-facts.org/en/part-i-technology/technology.html

Surface roughness determines to a certain extent the amount of turbulence production, the surface stress and the shape of the wind profile.

Higher altitudes have faster and smoother wind flows. Closer to the earth friction with earth's surface causes the wind to slow down and become more turbulent.



3.1.2a Wind Velocity Gradient

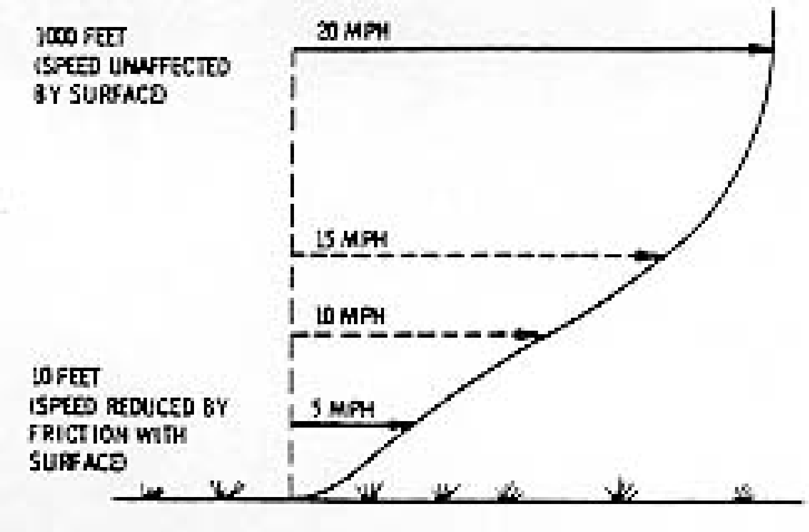
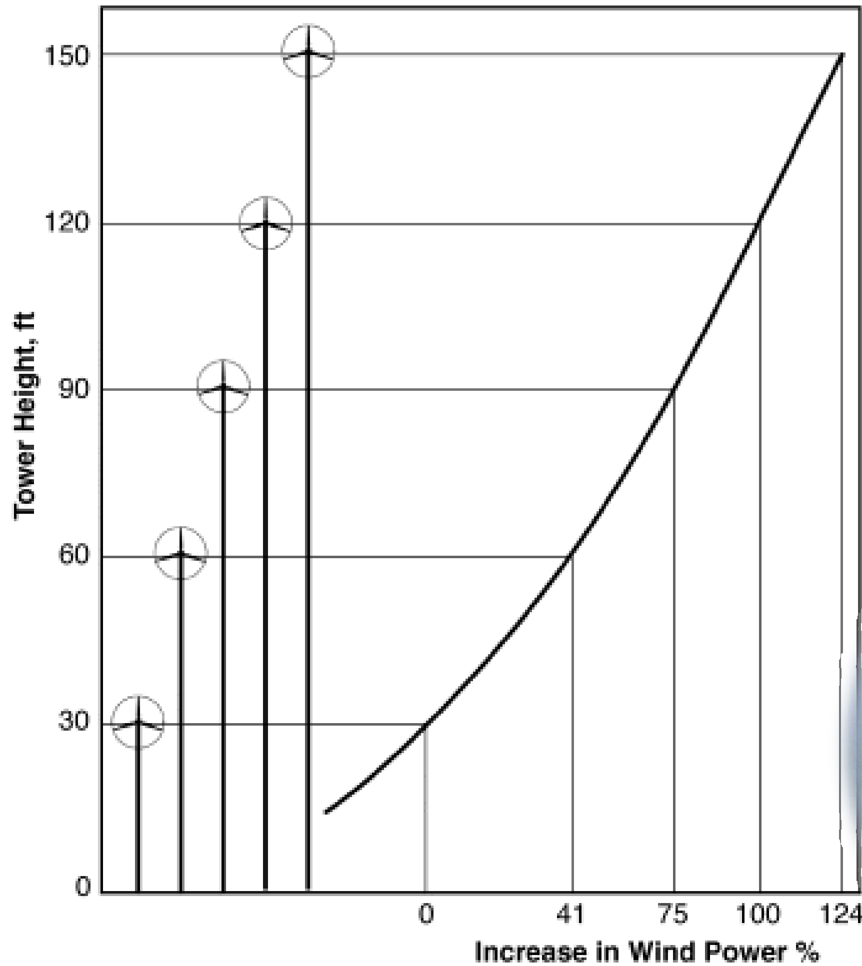


FIGURE 2. Effect of Surface Friction on Low-Level Wind

Higher means stronger, smoother wind

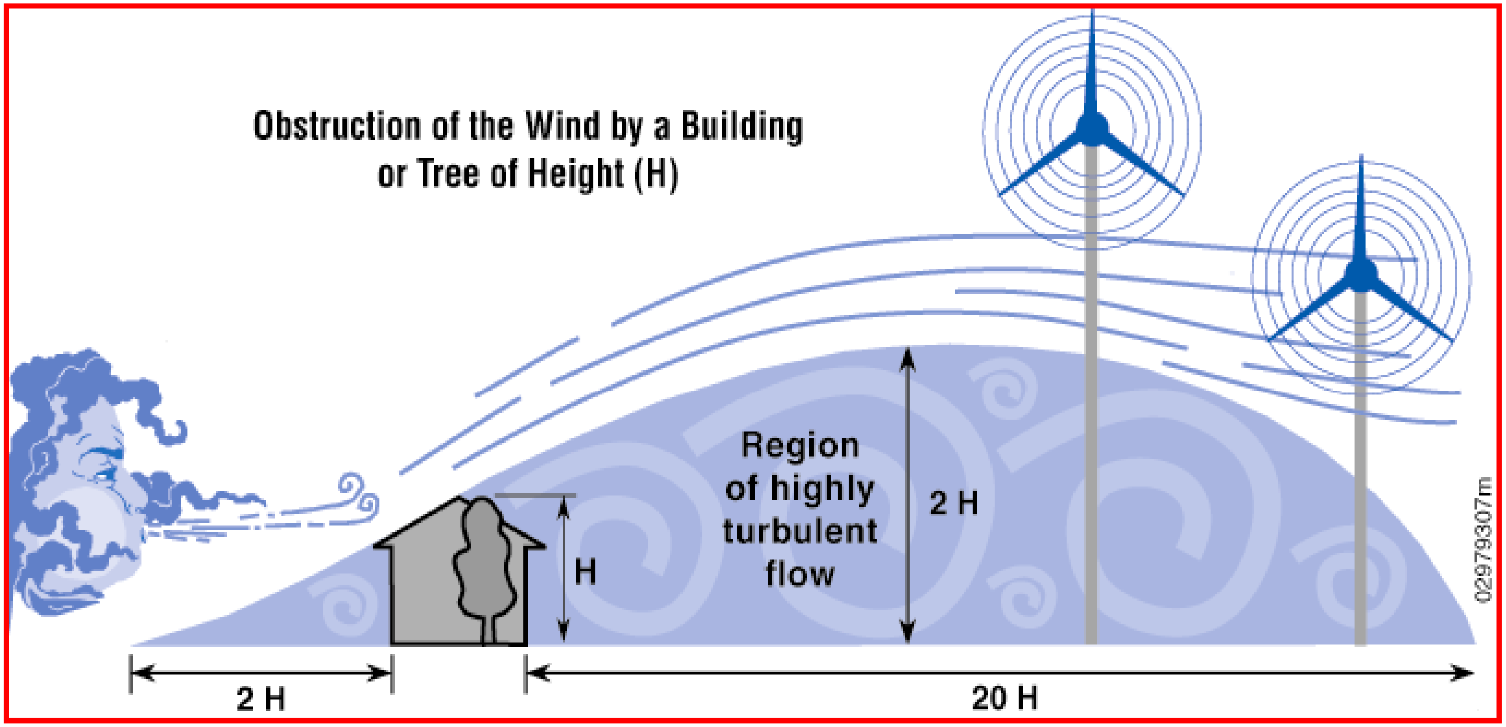
Richard Lawrence, National Wind Technology Center, NREL, http://www.kidwind.org/students_teachers/powerpoints_teachers.php

3.1.2a Wind Velocity Gradient



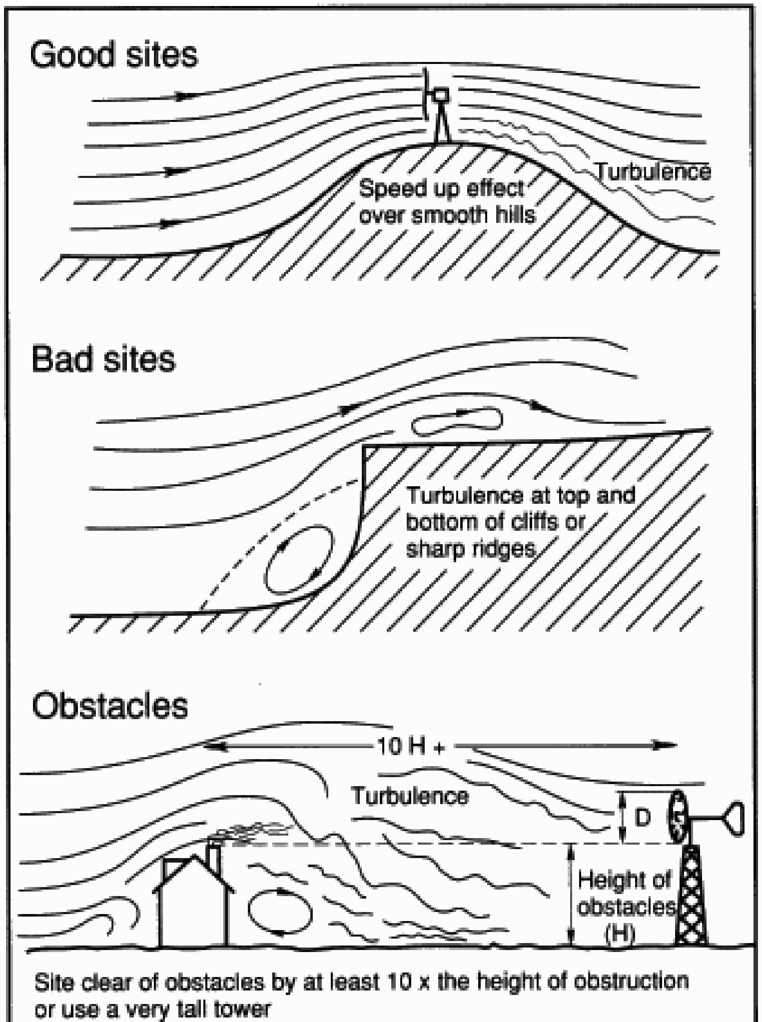
Richard Lawrence, National Wind Technology Center, NREL, http://www.kidwind.org/students_teachers/powerpoints_teachers.php

3.1.2a Wind Turbine Placement



Joe Rand,The Kidwind Project,St. Paul, MN, http://www.kidwind.org/students_teachers/powerpoints_teachers.php

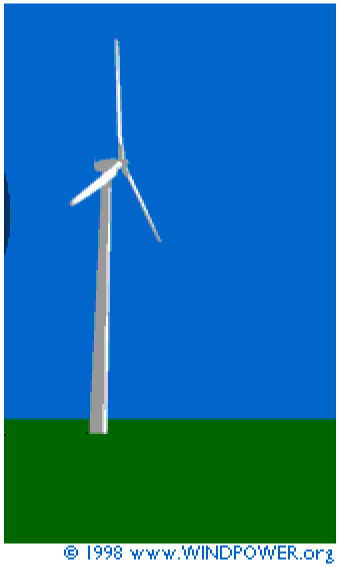
3.1.2a Wind Turbine Placement



Joe Rand,The Kidwind Project,St. Paul, MN, http://www.kidwind.org/students_teachers/powerpoints_teachers.php

Flow over hills and obstacles

3.1.2a Kinetic Energy in the Wind



Kinetic Energy = Work = ½mV²

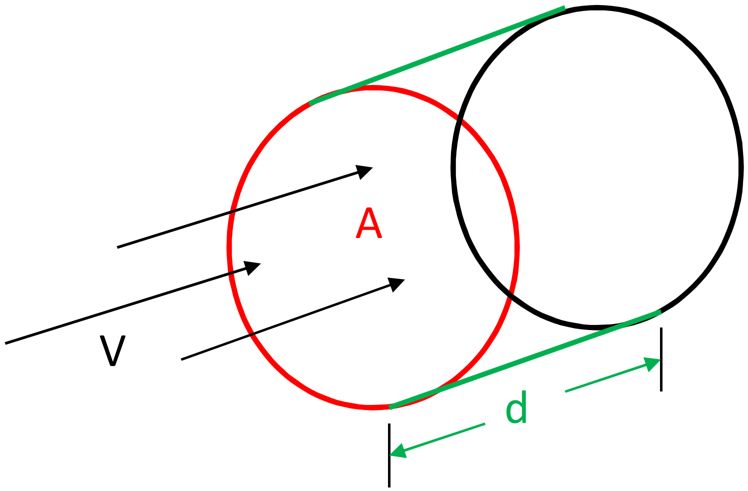
Where:
M= mass of moving object
V = velocity of moving object

What is the mass of moving air?

m= density (ρ) x volume (Area x distance)

m= ρ x A x d

m= (kg/m³) (m²) (m)
m= kg



Walt Musial, National Wind Technology Center, NREL, http://www.kidwind.org/students_teachers/powerpoints_teachers.php

3.1.2a Power in the Wind

Power = Work / t

= Kinetic Energy / t

$= \frac{1}{2} mV^2 / t$

$= \frac{1}{2}(\rho A d)V^2/t$

$= \frac{1}{2}\rho A V^2 (d/t)$

$= \frac{1}{2}\rho A V^3$

d/t = V

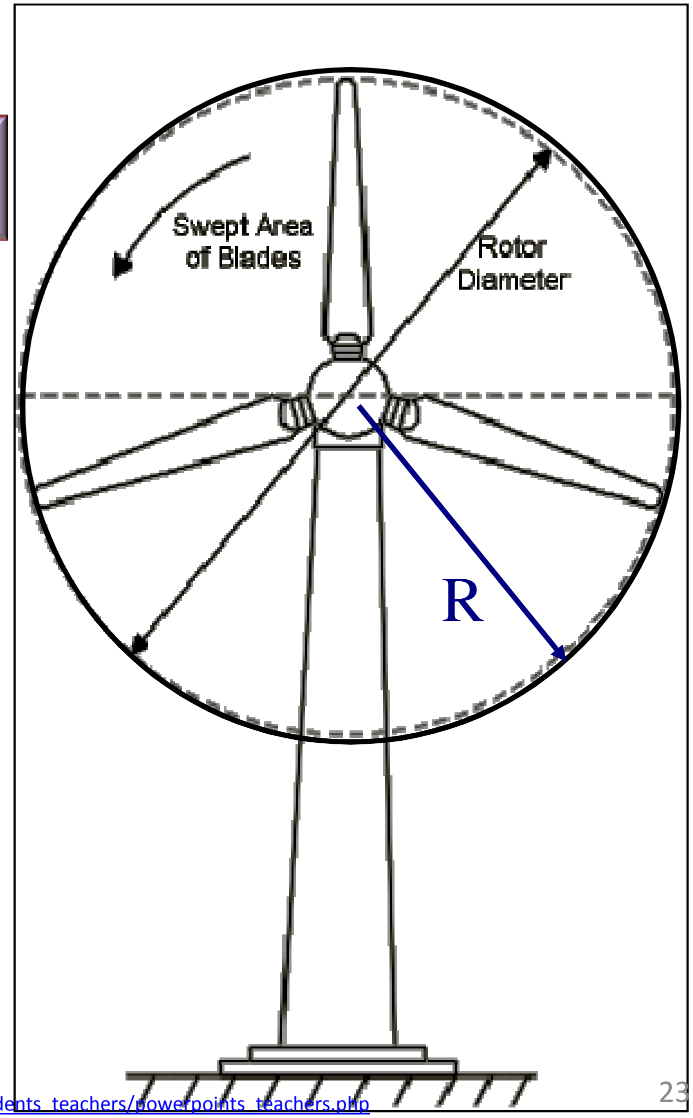
Power in the Wind = $\frac{1}{2}\rho A V^3$

Walt Musial, National Wind Technology Center, NREL, http://www.kidwind.org/students_teachers/powerpoints_teachers.php

3.1.2aCalculation of Wind Power

Power in the Wind = $\frac{1}{2}\rho A V^3$

- Effect of air density, ρ
- Effect of swept area, A
- Effect of wind speed, V



Swept Area: $A = \pi R^2$
Area of the circle swept by the rotor (m^2).

Walt Musial, National Wind Technology Center, NREL, http://www.kidwind.org/students_teachers/powerpoints_teachers.php

Example – Calculating Power in the Wind

Power in the Wind = ½ρAV³

$V = 5$ meters (m) per second (s) m/s

$\rho = 1.0\ kg/m^3$

$R = .2\ m$ >>>> $A = .125\ m^2$

Power in the Wind = $\frac{1}{2}\rho AV^3$

$= (.5)(1.0)(.125)(5)^3$

$= 7.85$ Watts

Units

$= (kg/m^3) \times (m^2) \times (m^3/s^3)$

$= (kg\text{-}m)/s^2 \times m/s$

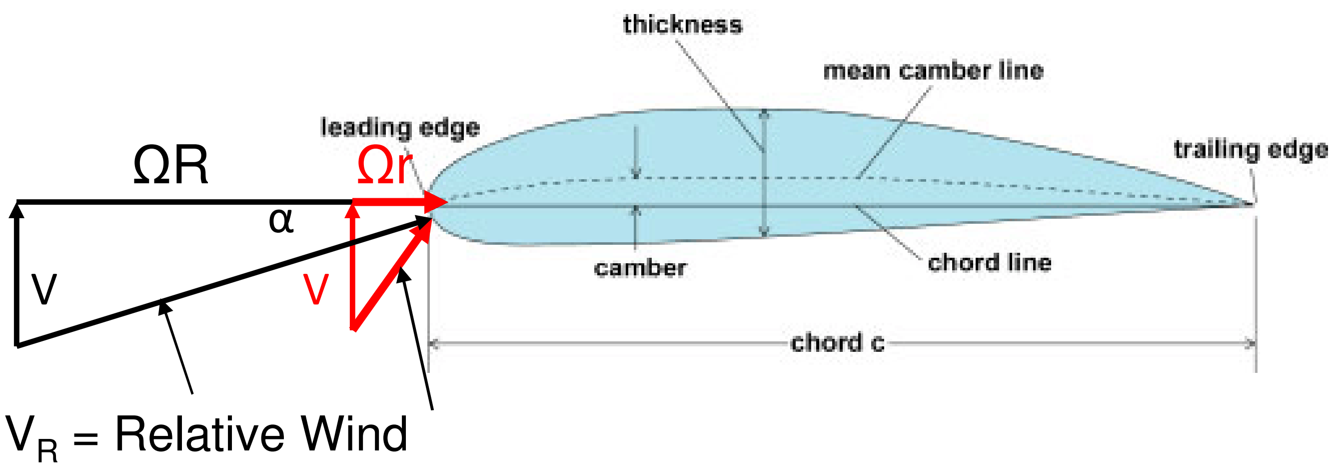
$= N\text{-}m/s =$ Watt

$(kg\text{-}m)/s^2 =$ Newton

Walt Musial, National Wind Technology Center, NREL, http://www.kidwind.org/students_teachers/powerpoints_teachers.php

Airfoil Nomenclature

Wind turbines use the same aerodynamic principals as aircraft, but blades are not the same design

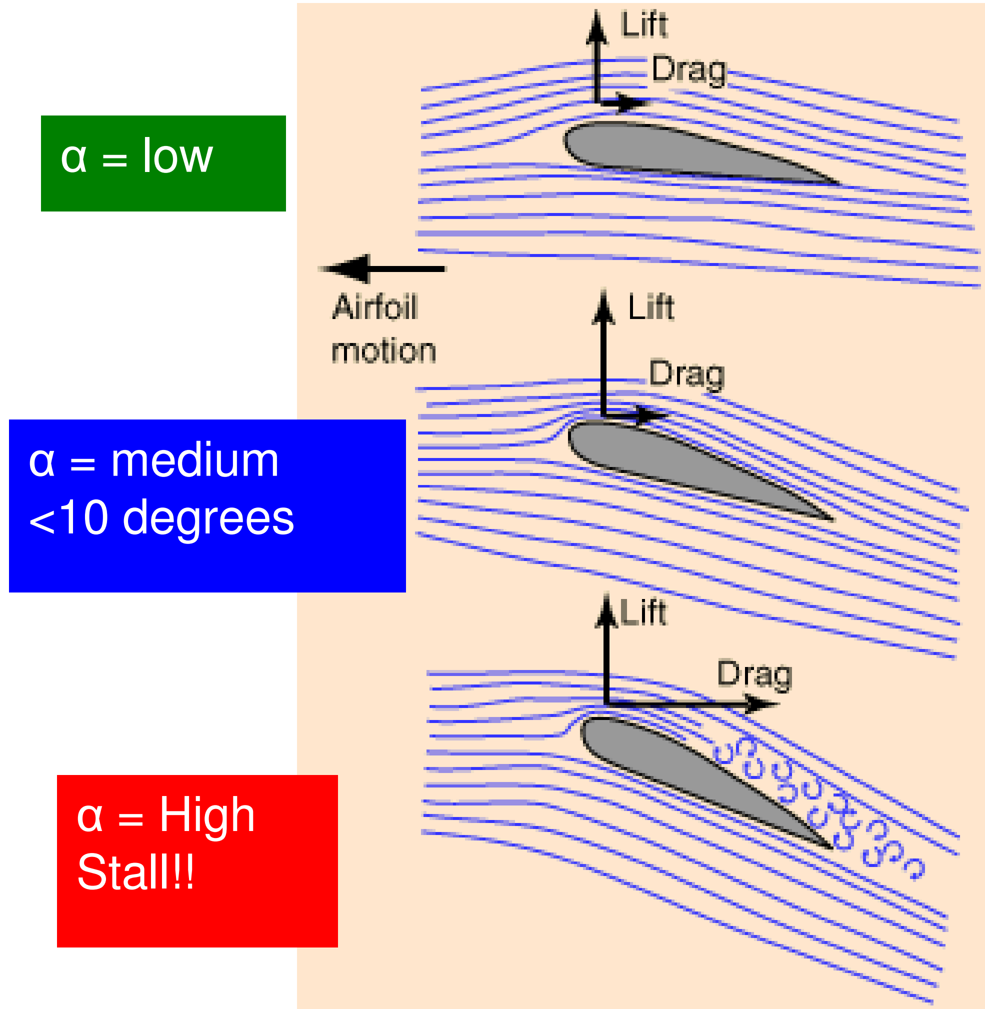


α = angle of attack = angle between the chord line and the direction of the relative wind, V_R .

V_R = wind speed seen by the airfoil – vector sum of V (free stream wind) and ΩR (tip speed).

Airfoil Behavior

- The ***Lift Force*** is perpendicular to the direction of motion. We want to make this force BIG.
- The ***Drag Force*** is parallel to the direction of motion. We want to make this force small.

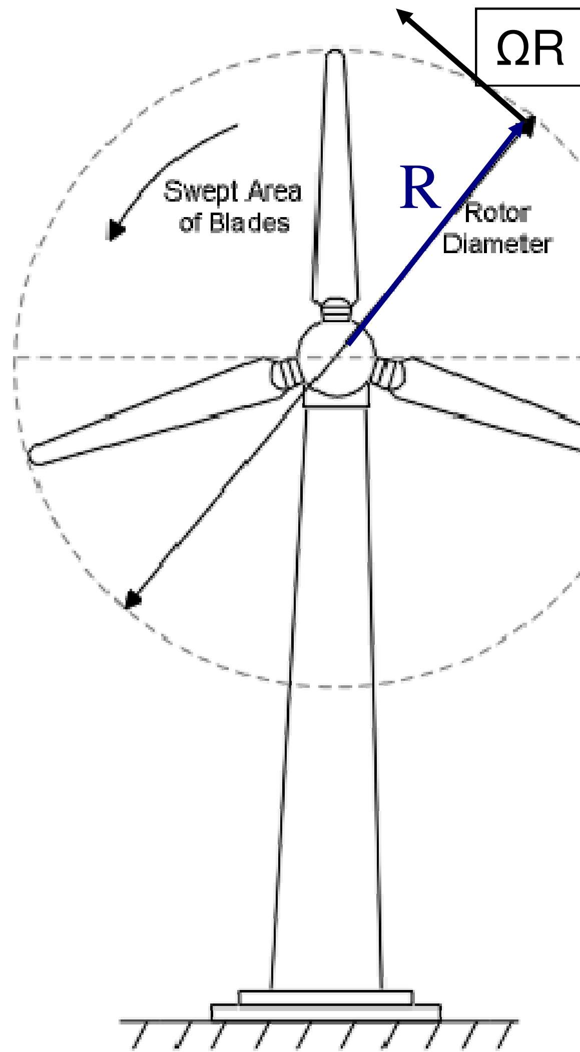


3.1.2a Tip-Speed Ratio

Tip-speed ratio is the ratio of the speed of the rotating blade tip to the speed of the free stream wind.

There is an optimum angle of attack which creates the highest lift to drag ratio.

Because angle of attack is dependant on wind speed, there is an optimum tip-speed ratio



$$TSR = \frac{\Omega R}{V}$$

Where,

Ω = rotational speed in radians /sec

R = Rotor Radius

V = Wind "Free Stream" Velocity

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3.1.2 a Wind Turbine Power

Power from a Wind Turbine Rotor = $C_p ½ \rho A V^3$

- C_p is called the ***power coefficient***.
- C_p is the percentage of power in the wind that is converted into mechanical energy.

All wind power cannot be captured by rotor or air would be completely still behind rotor and not allow more wind to pass through.

Theoretical limit of rotor efficiency is 59% (Betz limit)

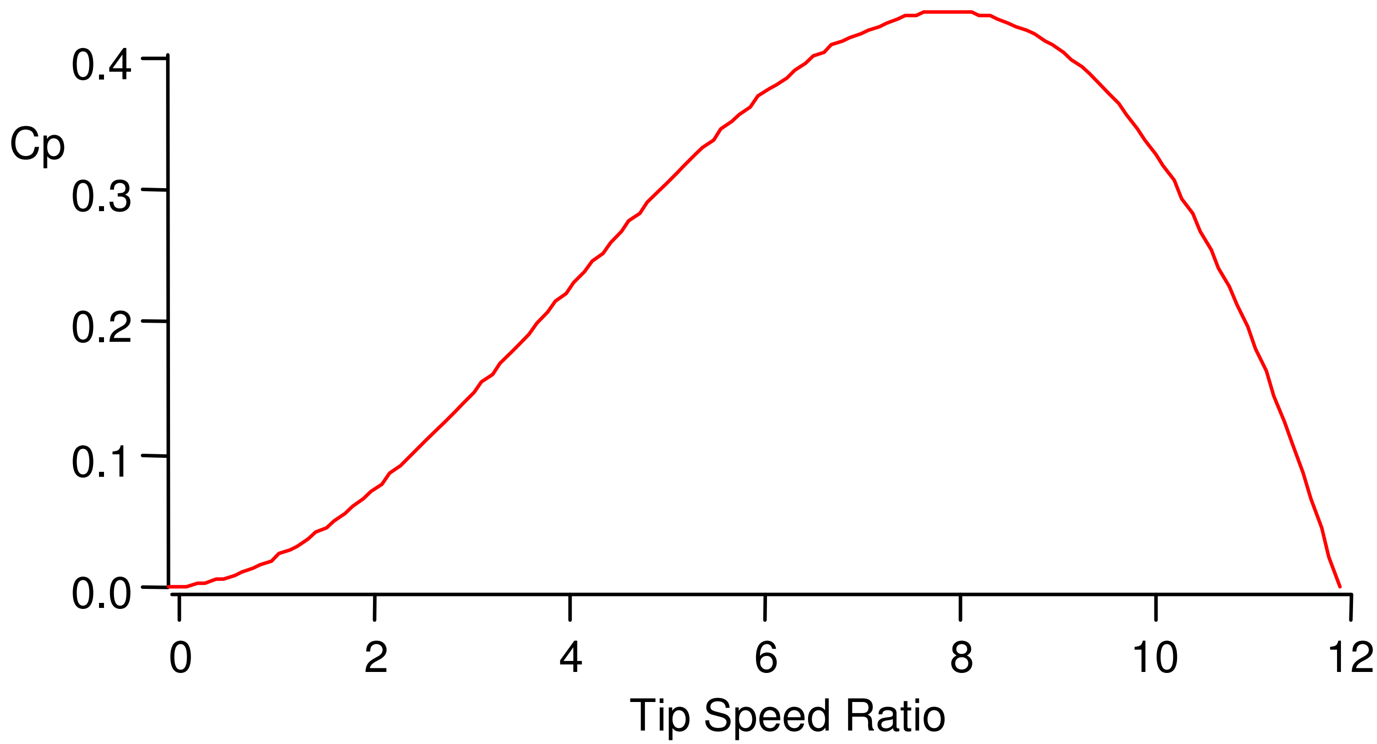
- Most modern wind turbines are in the 35 – 45% range

What is the maximum amount of energy that can be extracted from the wind?

Walt Musial, National Wind Technology Center, NREL, http://www.kidwind.org/students_teachers/powerpoints_teachers.php

Performance Over Range of Tip Speed Ratios

- Power Coefficient Varies with Tip Speed Ratio
- Characterized by Cp vs Tip Speed Ratio Curve



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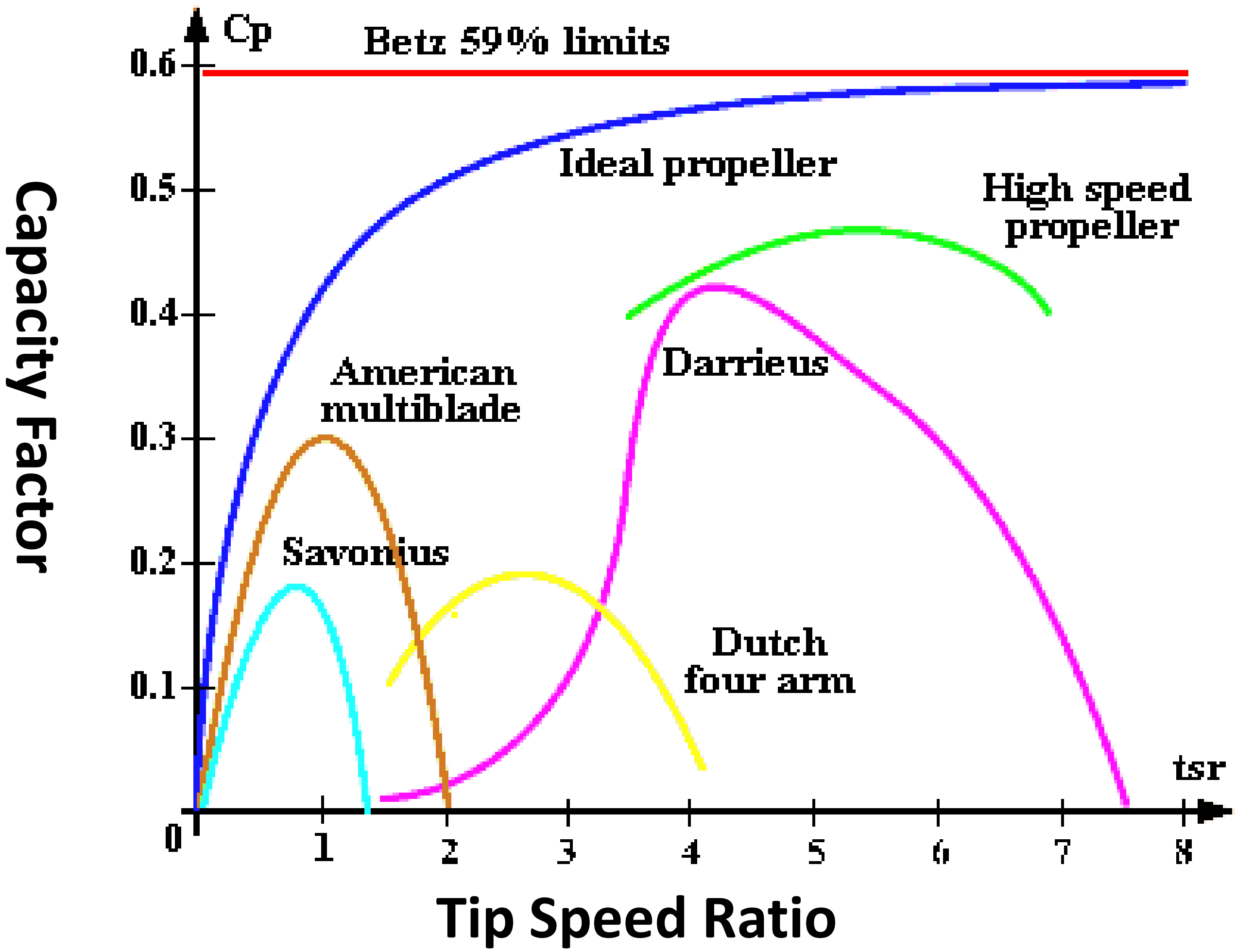
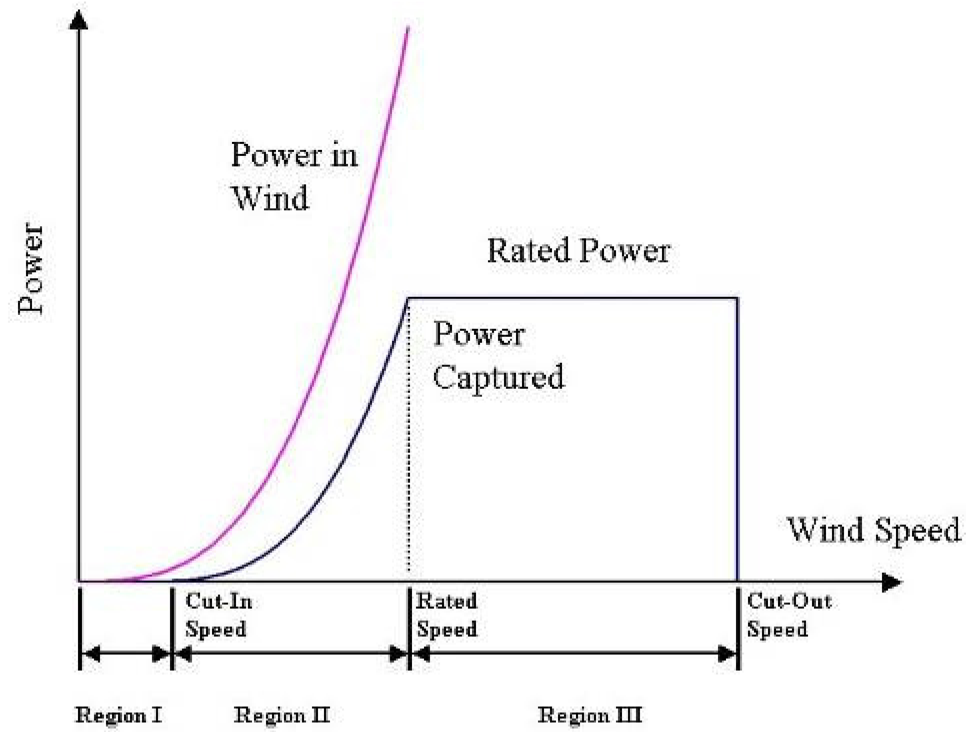
3.1.2 a Wind Turbine Power



Richard Lawrence, National Wind Technology Center, NREL, http://www.kidwind.org/students_teachers/powerpoints_teachers.php

Energy Production Terms

- *Power in the Wind* = $1/2\rho AV^3$
- *Betz Limit* - 59% Max
- *Power Coefficient* - C_p
- *Rated Power* – Maximum power generator can produce.
- *Capacity factor*
  - Actual energy/maximum energy
- *Cut-in* wind speed where energy production begins
- *Cut-out* wind speed where energy production ends.



Typical Power Curve

3.1.2 Wind

3.1.2B TURBINE SIZES

3.1.2b Types of Electricity Generating Windmills

Small (≤10 kW)
- Homes
- Farms
- Remote Applications

(e.g. water pumping, telecom sites, icemaking)

Intermediate (10-250 kW)
- Village Power
- Hybrid Systems
- Distributed Power

Large (250 kW - 2+MW)
- Central Station Wind Farms
- Distributed Power

Joe Rand,The Kidwind Project,St. Paul, MN, http://www.kidwind.org/students_teachers/powerpoints_teachers.php

3.1.2b 1.5MW Turbine

Rotor blades:
- Shown feathered
- Length, 37-m

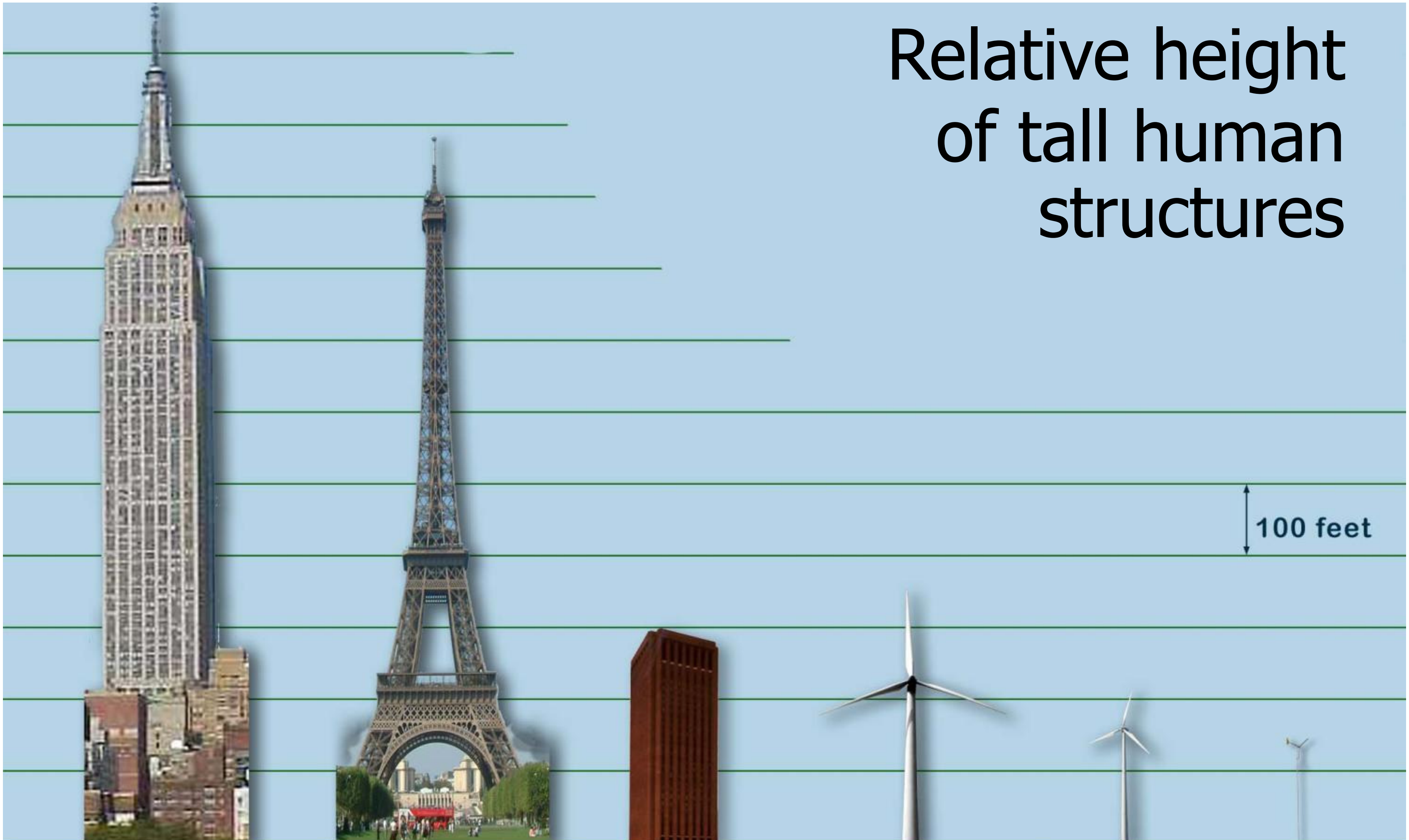
Rotor Hub

Nacelle enclosing:
- Low-speed shaft
- Gearbox
- Generator, 1.5 MW
- Electrical controls
- Blade pitch controls

Tower, 80 m

Minivan

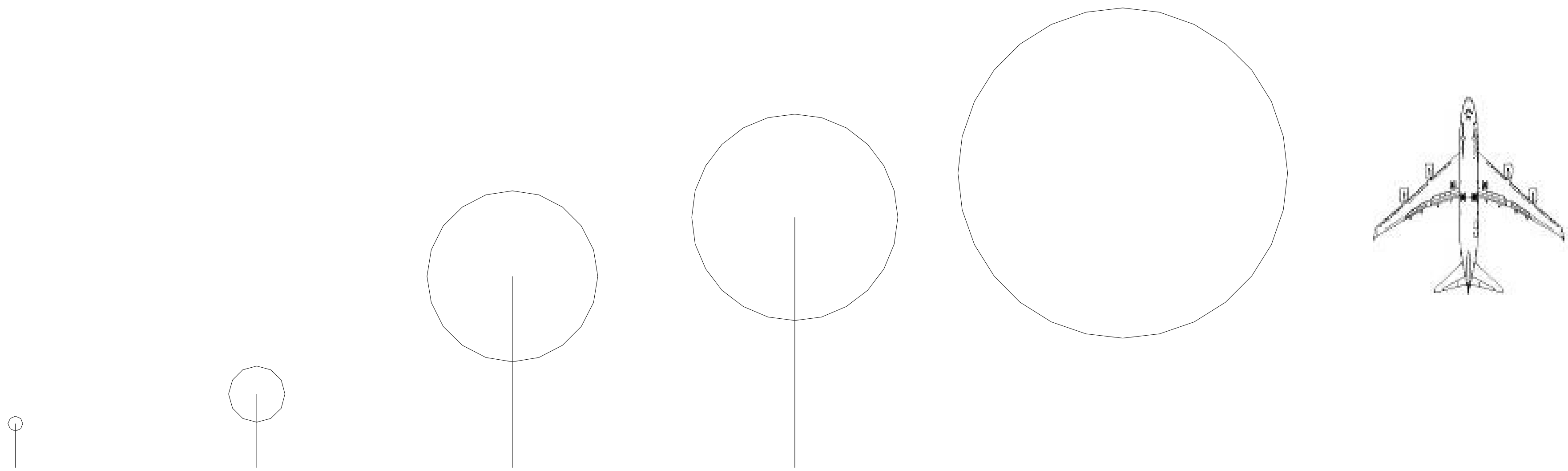
Relative height of tall human structures



Empire State	Eiffel Tower	Umass Library	1.5 MW Turbine	Medium Turbine	Farm Turbine
1250′	986′	297′	356′	212′	142′
381 m	301 m	90 m	109 m	65 m	43 m
		28 stories	--------------*examples*	-------------------	

http://www.kidwind.org/students_teachers/powerpoints_teachers.php

3.1.2b Wind Turbine Technology



North Wind HR3
rating: 3 kW
rotor: 5 m
hub height: 15 m

North Wind 100
rating 100 kW
rotor: 19.1 m
hub height: 25 m

Lagerwey LW58
rating: 750 kW
rotor: 58 m
hub height: 65 m

Enercon E-66
rating: 1800 kW
rotor: 70 m
hub height: 85 m

Enercon E-112
rating: 4000 kW
rotor: 112 m
hub height: 100 m

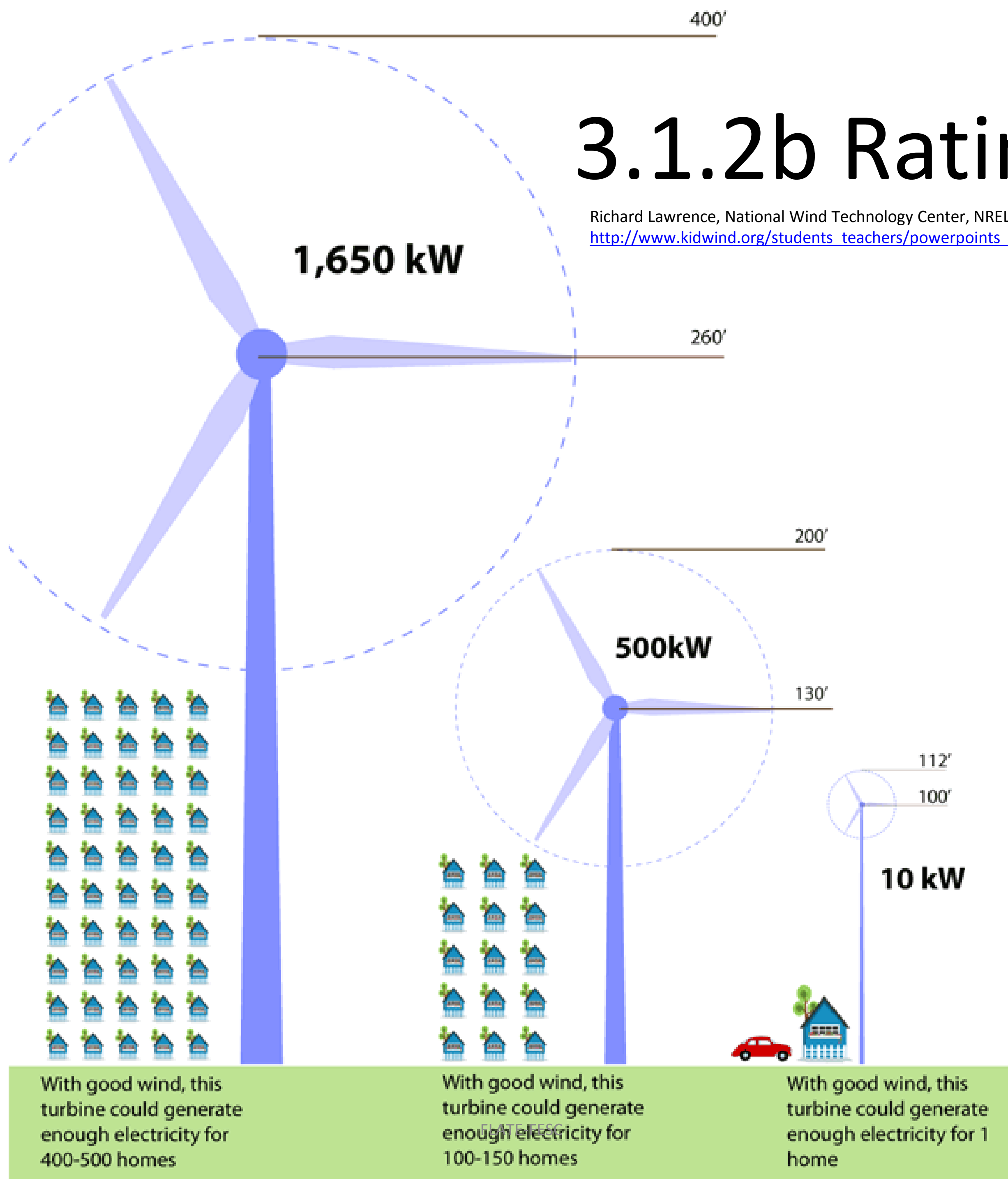
Boeing 747
wing span: 69.8m
length: 73.5 m

Comparative Scale for a Range of Wind Turbines

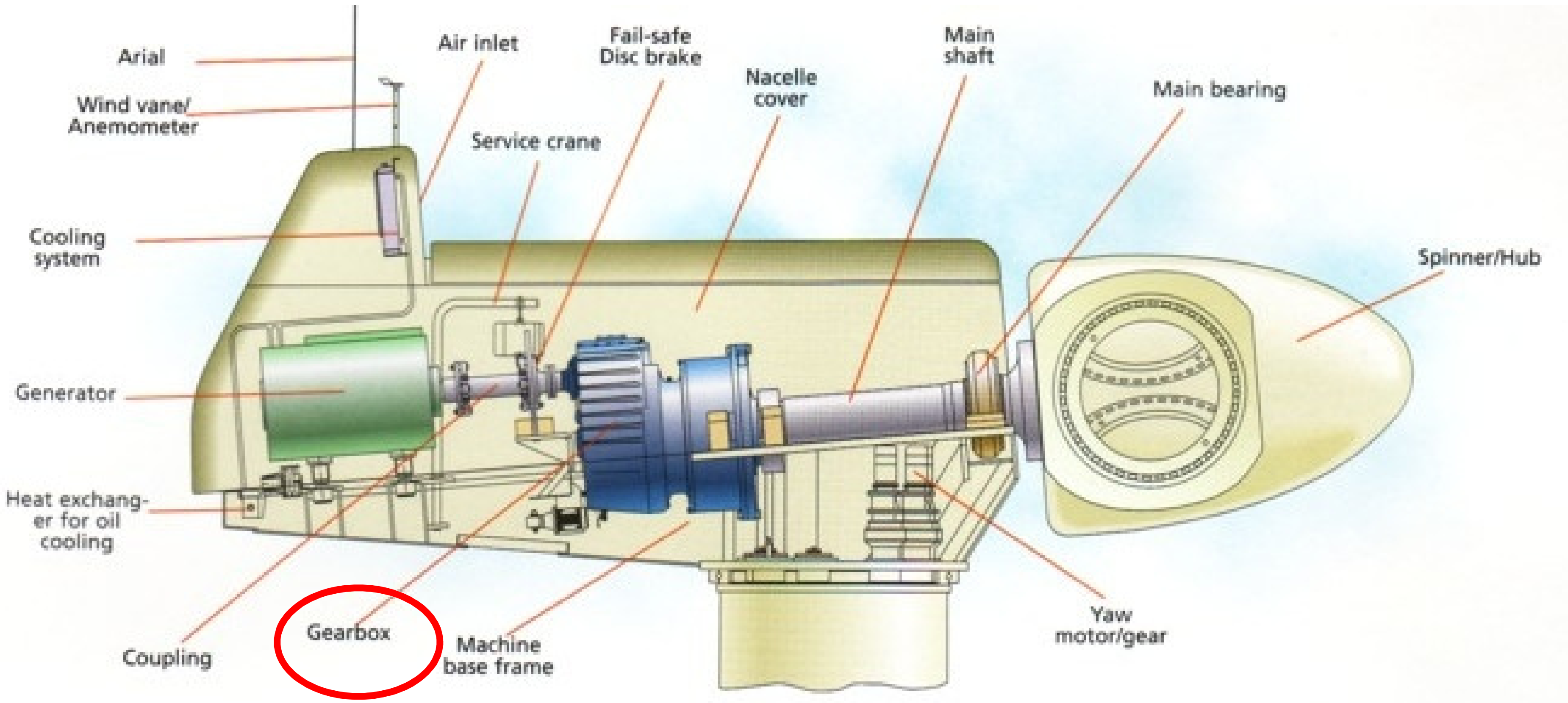
Joe Rand,The Kidwind Project,St. Paul, MN, http://www.kidwind.org/students_teachers/powerpoints_teachers.php

3.1.2b Ratings

Richard Lawrence, National Wind Technology Center, NREL,
http://www.kidwind.org/students_teachers/powerpoints_teachers.php

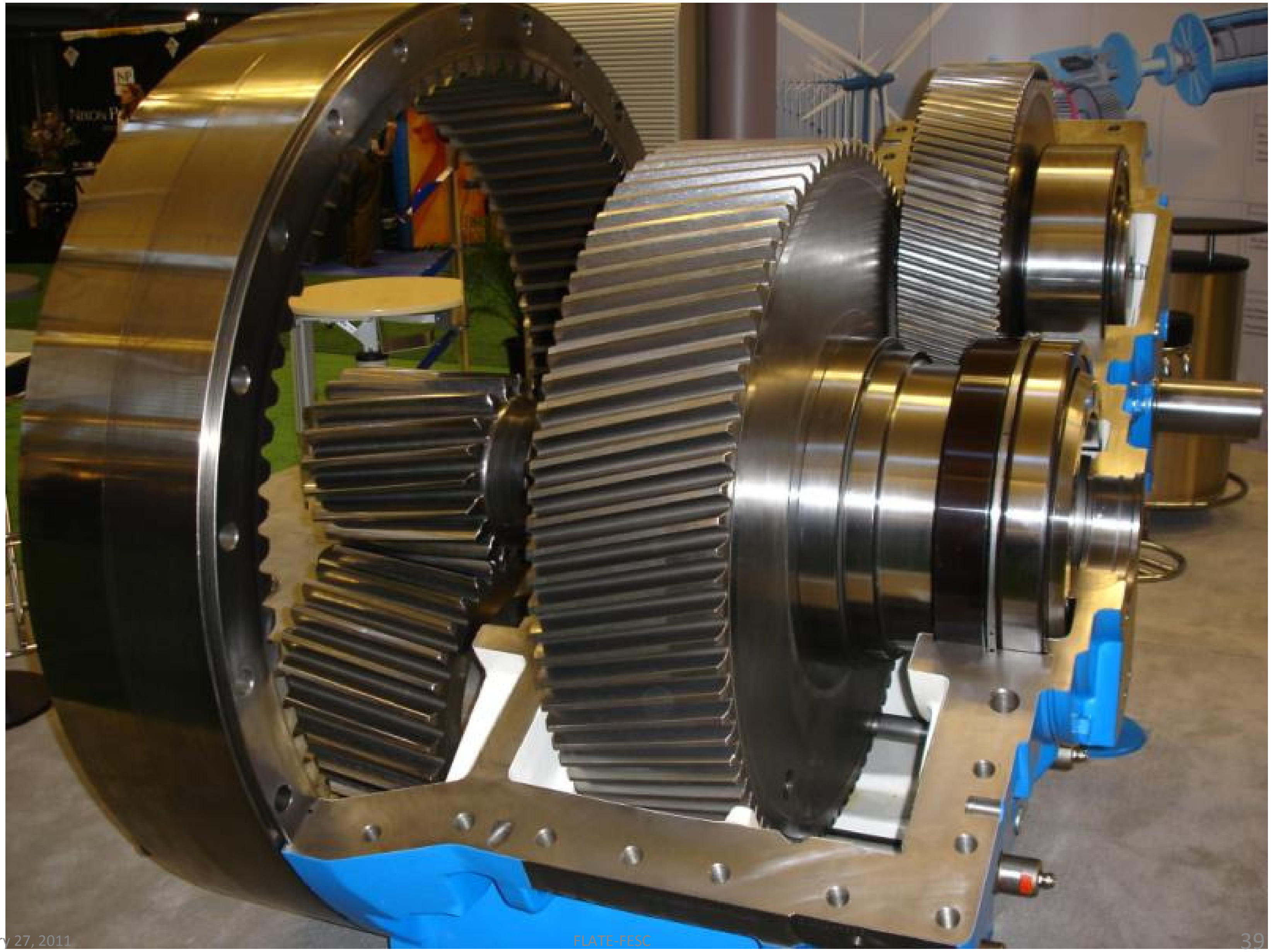


3.1.2b Wind Turbine Technology



Joe Rand,The Kidwind Project,St. Paul, MN, http://www.kidwind.org/students_teachers/powerpoints_teachers.php

3.1.2b Gearbox

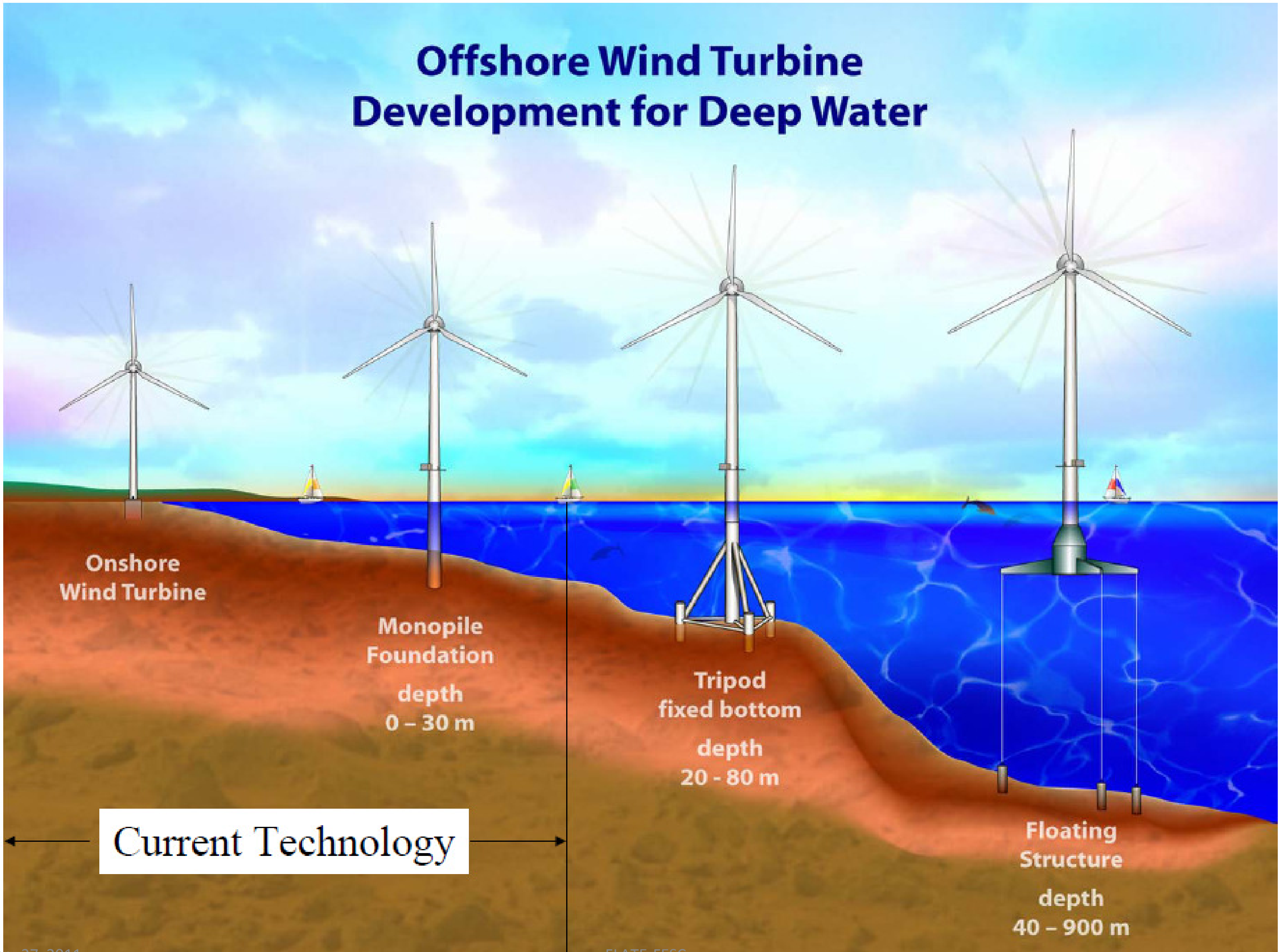


Joe Rand,The Kidwind Project,St. Paul, MN, http://www.kidwind.org/students_teachers/powerpoints_teachers.php

3.1.2b Blades

http://www.mywindpowersystem.com/wp-content/uploads/2010/01/wind-turbine-blades.jpg

3.1.2b Wind Turbine Technology



http://ocsenergy.anl.gov/guide/wave/index.cfm

3.1.2 Wind

3.1.2C TURBINE TYPES

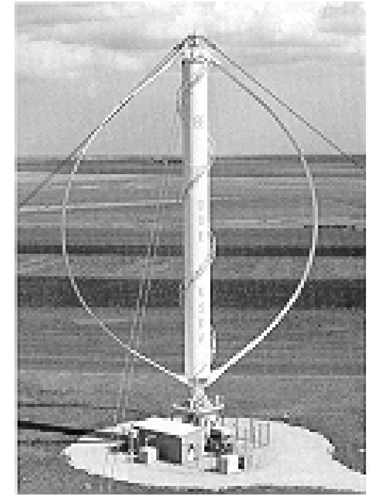
Orientation

Turbines can be categorized into two overarching classes based on the orientation of the rotor

Vertical Axis **Horizontal Axis**

Joe Rand,The Kidwind Project,St. Paul, MN, http://www.kidwind.org/students_teachers/powerpoints_teachers.php

Vertical Axis Turbines



Advantages

- Omnidirectional
  - Accepts wind from any angle
- Components can be mounted at ground level
  - Ease of service
  - Lighter weight towers
- Can theoretically use less materials to capture the same amount of wind

Disadvantages

- Rotors generally near ground where wind poorer
- Centrifugal force stresses blades
- Poor self-starting capabilities
- Requires support at top of turbine rotor
- Requires entire rotor to be removed to replace bearings
- Overall poor performance and reliability
- Have never been commercially successful

Joe Rand,The Kidwind Project,St. Paul, MN, http://www.kidwind.org/students_teachers/powerpoints_teachers.php

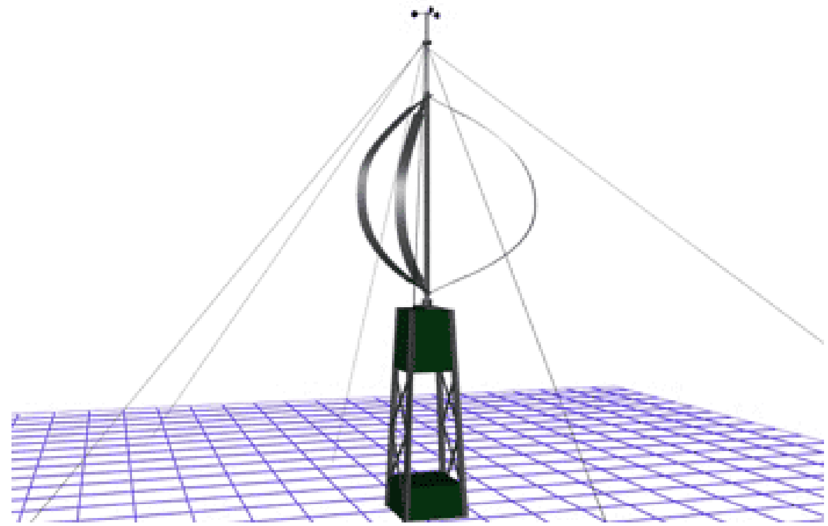
Lift vs Drag VAWTs

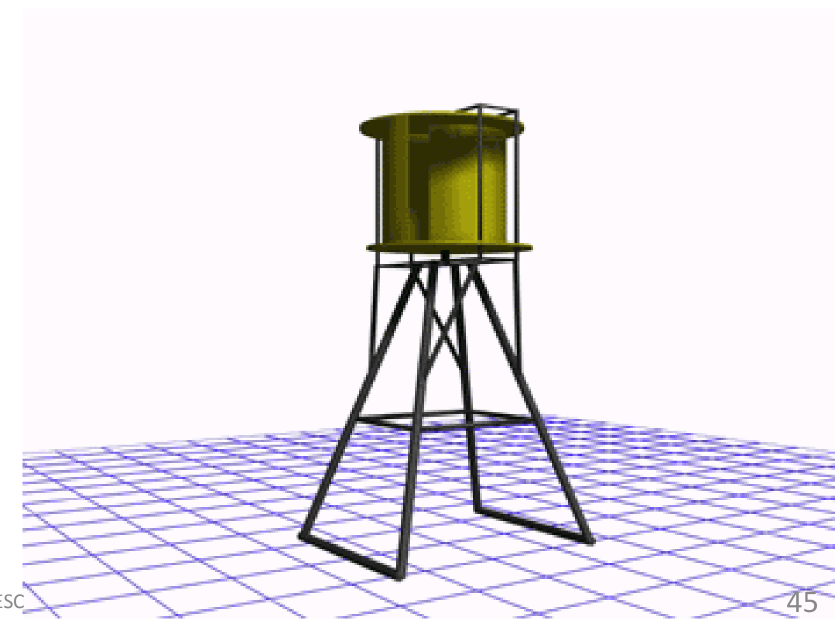
Lift Device "*Darrieus*"

- Low solidity, aerofoil blades
- More efficient than drag device

Drag Device "*Savonius*"

- High solidity, cup shapes are pushed by the wind
- At best can capture only 15% of wind energy





Joe Rand,The Kidwind Project,St. Paul, MN, http://www.kidwind.org/students_teachers/powerpoints_teachers.php

VAWT's have not been hugely commercially successful, yet…

Every few years a new company comes along promising a revolutionary breakthrough in wind turbine design that is low cost, outperforms anything else on the market, and overcomes all of the previous problems with VAWT's. They can also usually be installed on a roof or in a city where wind is poor.


WindStor


Wind Spire

EnviroEnergies

Joe Rand,The Kidwind Project,St. Paul, MN, http://www.kidwind.org/students_teachers/powerpoints_teachers.php

Vertical Axis Turbines

Notice: As of May 15th, 2010 Windterra closed down all operations.

ECO 1200 1.2 kW Vertical Axis Wind Turbine

Vertical Axis Turbines

- What do you think about this turbine?
- Is it hype or will it work?
- What are some advantages and disadvantages to its operation?
- What do you think the payback period will be?

http://www.youtube.com/watch?v=xWKNMt9rsIA&feature=player_embedded