Wind Energy

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Contents

This open source book contains power points, worksheets, and web links that are useful in teaching wind energy.

CHAPTER 1

Advantages of Wind Energy

- "Wind prices are extremely competitive right now, offering lower costs than other possible resources".
- It offers many environmental advantages compared to its major rival coal generation.
- source: http://www.nrel.gov/docs/fy05osti/37602.pdf.
- https://www.awea.org/falling-wind-energy-costs

Environmental Problems with Coal

- Burning coal causes roughly $60 billion a year in health cost, mostly because of thousands of premature deaths from air pollution according to the National Academy of Sciences.
- Damages average $.032 /KWhr
  source: http://www.nytimes.com/2009/10/20/science/earth/20fossil.html?_r=2&scp=6&sq=coal%20pollution&st=cse

In one year, a typical coal plant generates

- 10,000 tons of sulfur dioxide (SO_2), which causes acid rain

- 10,200 tons of nitrogen oxide (NOx). NOx leads to formation of ozone (smog).
- 720 tons of carbon monoxide (CO)
- 220 tons of hydrocarbons, volatile organic compounds (VOC), which form ozone.

source: http://www.ucsusa.org/clean_energy/coalvswind/c02c.html

Further Info on Environmental Effects of Coal

- Further information on the environmental effects of using coal to generate electricity can be found at http://www.ucsusa.org/clean_energy/coalvswind/c01.html and http://en.wikipedia.org/wiki/Environmental_effects_of_coal

In one year, a typical coal plant generates (continued)

- 170 pounds of mercury, will lead to neurological damage.
- 225 pounds of arsenic
- 114 pounds of lead, 4 pounds of cadmium, and trace amounts of uranium.
- 3,700,000 tons of carbon dioxide (CO2) –as much carbon dioxide as cutting down 161 million trees. Carbon dioxide is a global warming gas.

source: http://www.ucsusa.org/clean_energy/coalvswind/c02c.html

Future of Wind Energy

- Wind suffers from being most available when electricity is least in demand (winter & nights).
- Smart grid applications may make wind more desirable such as charging an electric car during the evening hours

Future of Wind Energy (Continued)

- DOE (Department of Energy) has determined that it is feasible that 20% of the nation's electrical energy could be generated by wind by the year 2030. See 20% Wind Energy by 2030: Increasing Wind Energy's Contribution to U.S. Electricity Supply at http://www1.eere.energy.gov/windandhydro/pdfs/41869.pdf.

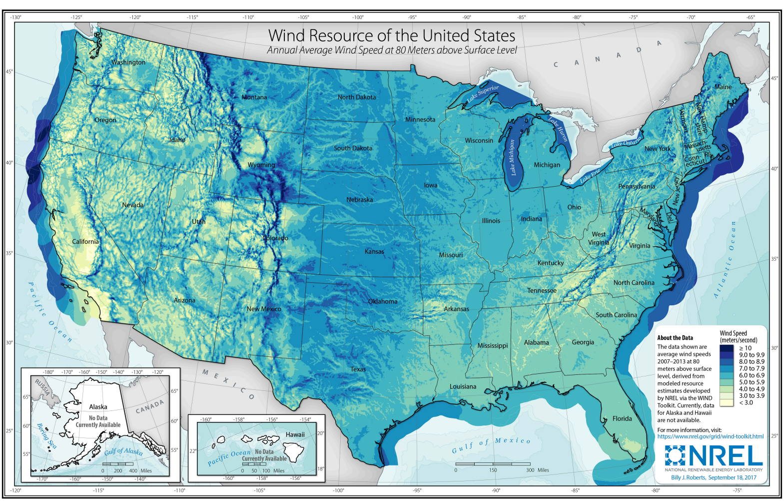
This power point discusses the advantages of wind over other energy sources.

Why Wind Energy

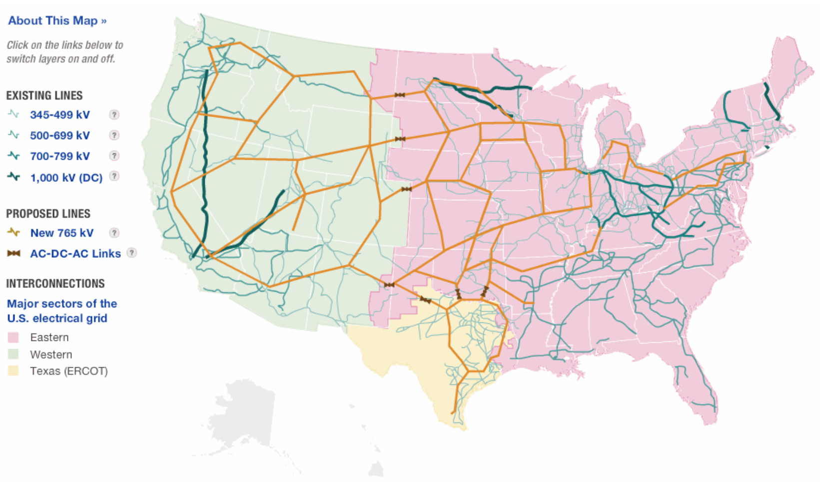
CHAPTER 2

Wind Energy in Iowa

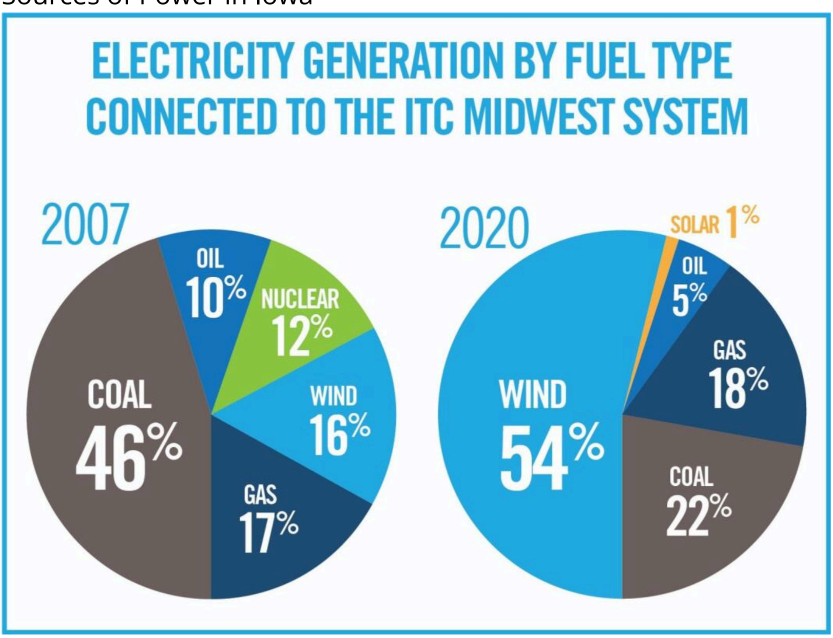
The United States Wind Resource Map



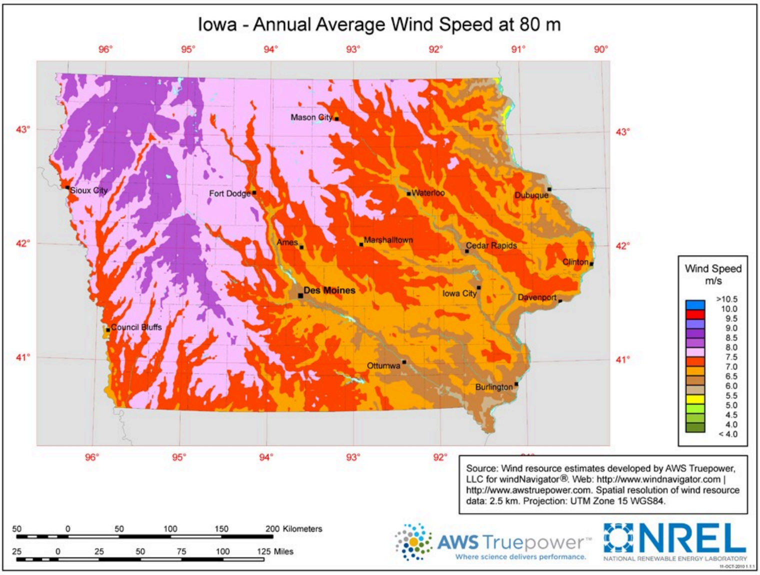
US Electric Grid



Sources of Power in Iowa



Iowa’s Winds Speeds Annually



Iowa Average Wind Speeds by Month

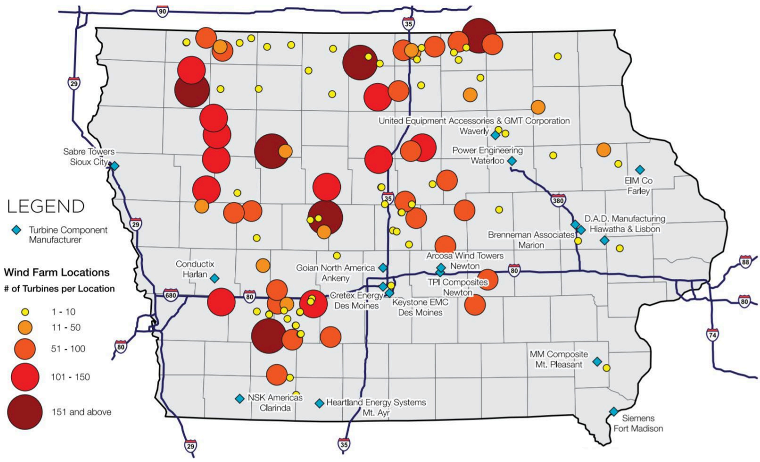
- https://en.wikipedia.org/wiki/Wind_power_in_Iowa
- Note that the lowest outputs are in July & August.

Iowa #2 in Wind Energy Generation

- Iowa is 3rd in the nation in installed capacity
- 36.9% of electrical production in Iowa is from wind.
- 4,145 wind turbines online in the state

source https://www.awea.org/statefactsheets

Wind Turbine Manufacturing and Farms



Iowa is prominent in the national wind industry

- Iowa is 2nd nationally in installed capacity.

http://www.neo.ne.gov/statshtml/205.htm

- Note that MidAmerican Energy (Berkshire Hathaway) is 2nd in the rankings of the largest owner of wind turbines for a utility in the nation. https://www.statista.com/statistics/499486/wind-power-ownership-in-the-us-by-operator/

Service Area of MidAmerican Energy http://www.google.com/url?sa=i&url=https%3A%2F%2Fwww.midamericanenergy.com%2Fsites%2FSatellite%3Fc%3DPage%26childpagename%3DMEC%252FPage%252FStandardPage%252FLayout%26cid%3D1528308446699%26d%3DTouch%26packedargs%3Dd%253DTouch%26pagename%3DMEC%252FPrimaryWrapper&psig=AOvVaw2EFYmMpqCPLq0RK6ANrLh5&ust=1635536964133000&source=images&cd=vfe&ved=0CAsQjRxqFwoTCPiOs5Lw7fMCFQAAAAAdAAAAABAD

Iowa is prominent in the national wind industry

- https://www.awea.org/manufacturing
- Also, observe the amount of manufacturing in Iowa and bordering states (MN, WI, IL, NE, SD) for wind turbines and components (Figure 18).

This power point covers wind energy in Iowa
Wind Energy in Iowa (power point)
This is a worksheet for the corresponding power point
Wind Energy in Iowa (worksheet)

CHAPTER 3

Theoretical Power of Wind

Kinetic Energy

- KE= ½ mv2, where m = mass & v = velocity

Air's Mass

- m = ρAvt, where ρ= air density A = area through which air passes v = velocity & t= time

Wind Energy

- substituting m = ρAvt into KE= ½ mv^2 results in KE = ½ ρAvtv^2 or wind energy = ½ ρAtv^3

Power

- Energy = Power * time
- Power = Energy/time
- wind energy = ½ ρAtv^3
- wind power = ½ ρAv^3

wind power = ½ ρAv^3

- wind power is directly proportional to the swept area
- wind power is directly proportional to ρ, air density.
- wind power is directly proportional to v^3, air velocity cubed.

Clipper Wind: wind power ∝ swept area

- Swept area = πr^2 or $\pi(d/2)^2$ where d is the diameter
- The blade length or radius of the Clipper Wind Liberty 2.5 MW Wind Turbine (C100) is 48.8 meters and a rotor diameter of 100meters
- The swept area = $\pi(d/2)^2 = \pi(100\text{meters}/2)^2$ = 7854m^2 (industry uses this method) however,
- With blade length only swept area = $\pi(r/2)^2 = \pi(48.7\text{m}/2)^2$ = 7,451m^2

Acciona Energy: wind power ∝ swept area

- swept area = πr^2 or $\pi(d/2)^2$ where d is the diameter
- The blade length or radius of the AW-82/1500 Wind Turbine is 40.3 meters and the diameter is 82m
- The swept area = $\pi(d/2)^2 = \pi(82\text{meters}/2)^2$ = 5281m^2 (industry uses this method) however,
- With blade length only swept area = $\pi r^2 = \pi(40.3\text{m})^2$ = 5,102 m^2

Wind power ∝ ρ (air density)

- air density decreases with increases in altitude (for the same wind velocity a turbine is more efficient in Iowa than in the mountains)
- air density decreases with increases in temperature (wind turbines are more efficient in the winter than summer)
- Try this air density calculator

Wind power ∝ v^3

- **Velocity is the most important** contributor to wind power
- Example:
- If when v = 5.25 m/s,
  the wind power is 187.5 kW, then
- When v = 10.5 m/s,
  the wind power is 1500 kW

This is an **8x increase in power for a 2x increase** in velocity

CHAPTER 4

Power from Wind

Theoretical Wind Power

- Energy = Power * time
- Power = Energy/time
- wind energy = ½ ρAtv^3
- wind power = ½ ρAv^3

Betz Factor

- The ratio of practical power to the power in the wind is called the Betz Factor
- Betz Factor = 16/27 = 0.593

Practical Wind Power

- wind power = ½cpρAv^3
- where cp = 0.593 for wind turbines using the lift (not drag) Betz Factor

Clipper Wind: Actual Power Curve
http://www.google.com/url?sa=i&url=http%3A%2F%2Fwww.twinkletoesengineering.info%2Fwind_turbine.html&psig=AOvVaw3osFzuX0gqcuntJ8Y-7e2P&ust=1635538624308000&source=images&cd=vfe&ved=0CAsQjRxqFwoTCPCs_bP27fMCFQAAAAAdAAAAABAD
Clipper Wind: Actual Power Curve

- Any power generated by the turbine will be significantly less than ½cpρAv3.
- This is a result of losses in converting mechanical to electrical power, friction, etc.

Clipper Wind: Actual Power Curve

- power = ½cpρAv3
- For example at v = 10m/s, theoretical power = ½(0.593)*(1.2 kg/m3)*(7854m2)*(10m/s)3 = 2.79 MW
- At 10 m/s, Actual Power ≅ 1800 kW = 1.8 MW
- Efficiency = 64%

Clipper Wind: Actual Power Curve

- At 5 m/s, Power ≅ 225 kW
- At 10 m/s, Power ≅ 1800 kW
- This is an 8x increase as expected by wind power ∝ v3

Clipper Wind: Actual Power Curve

- After 10 m/s,

wind power ∝ v3 will not accurately predict the power.

- This is due to the generator and other mechanical components of the turbine being unable to increase power output proportional to the wind velocity

Clipper Wind: Actual Power Curve

- The cut-out wind velocity of this turbine is 25m/s
- The constant output of power between 13m/s and 25 m/s is achieved through pitch control

Clipper Wind – Pitch Control

- Pitch control allows the blade of each turbine to be oriented in a manner to maximize wind power prior to 2.5MW on the Liberty 2.5 MW Wind Turbine.
- Once the output reaches 2.5 MW, pitch control will be used to limit the power from the wind in order to maintain a constant 2.5MW output from the generator.

Theoretical Power from the Wind (power point)
Practical Power from the Wind (power point)
Power from the Wind (work sheet)

CHAPTER 5

HAWT vs. VAWT

HAWT – Horizontal Axis Wind Turbines

- The axis is of rotation is parallel to the ground.
- These are the most common type of turbines.
- Operates on lift principle

VAWT – Vertical Axis Wind Turbines

- This is an image of a Darrieus wind turbine.
- “Eggbeater” turbine is another name.
- It is one type of vertical axis turbine since its axis of rotation is vertical to the ground.
- Have not been very successful commercially
- Operates on lift principle

VAWT – Vertical Axis Wind Turbines

- H-Rotor is another type of VAWT

- It is a vertical axis turbine since its axis of rotation is vertical to the ground.
- It can self-start
- Have not been very successful commercially
- Operates on lift principle

VAWT – Vertical Axis Wind Turbines

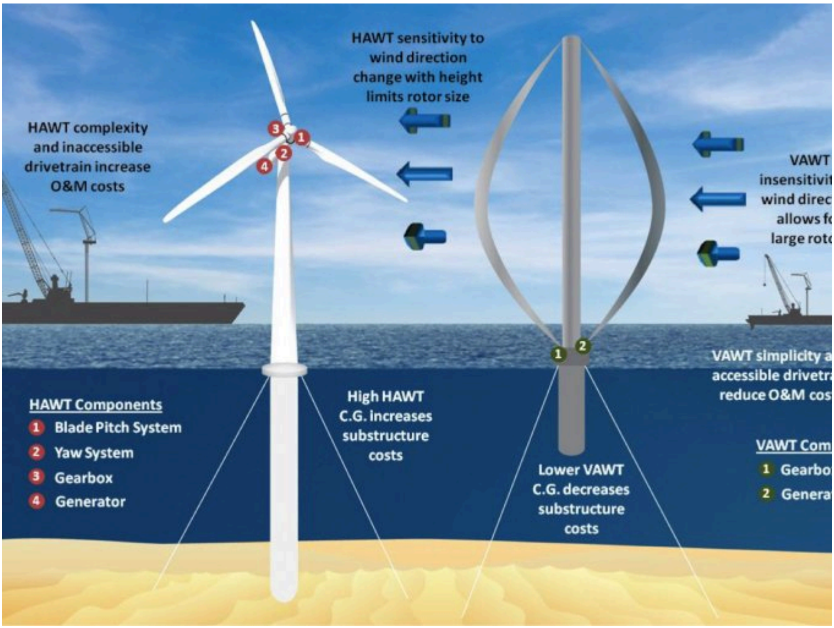
- Savonius is another type of VAWT
- It is a vertical axis turbine since its axis of rotation is vertical to the ground.
- It can self-start
- Have not been very successful commercially
- Operates primarily on drag principle

Lift vs. Drag

- Lift turbines can theoretically capture 59% of the wind (Betz Limit)
- Drag turbines can theoretically capture 15% of the wind
- Drag turbine requires more material

source: Gipe, Paul. Wind Power. White River Junction, VT: Chelsea Green Publishing Company, 2004.

HAWT vs. VAWT



HAWT vs. VAWT

- HAWT – ADVANTAGES
    - The wind is stronger at greater heights. A HAWT can be placed at heights to take advantage of

strong winds.
    - Good performance & reliability
    - Self-starting
    - Commercially successful
- VAWT – DISADVANTAGES
    - The wind is weaker at ground level and there is more turbulence at ground level due to obstructions.
    - Notorious for poor reliability since the lift forces reverse direction every revolution.
    - Darrieus' design can't be self-starting unless orientated properly.

HAWT vs. VAWT

- HAWT – DISADVANTAGES
    - Difficult to service due to height. In most models, a crane is needed to install a new generator or drivetrain.
    - Needs yaw system to track the wind.
- VAWT – ADVANTAGES
    - Generator & drivetrain is at ground level so that it is easier to service.
    - It is omnidirectional so it does not need gears & controls to track the wind.

Horizontal Axis vs. Vertical Axis Turbines what are the advantages and disadvantages of each.

HAWT vs VAWT (power point)

HAWT_vs_VAWT (work sheet)

CHAPTER 6

Why Are Turbine Blades in Groups of 3?

Why are turbine blades in groups of 3?

- A condition called chatter occurs when a turbine with two blades attempts to yaw.
- This condition occurs because the moment of inertia of a blade is significantly greater when it is horizontal than when it is vertical to the ground.

Moment of Inertia for the blade when horizontal

- The moment of a two-blade system when it is horizontal to the ground is given by

1/12 ML2 where M is the mass and L is the length of both blades.

- If an AW-1500 turbine had only two blades, the moment of inertia when the blades are horizontal would be 1/12(11,560 kg)(80.6 meters)2 = 6.26 x 106 kg-meters.

Moment of Inertia for the blade when vertical

- The moment of a two-blade system when it is perpendicular to the horizon is given by
- 1/2 Mr2 where M is the mass and r is the radius of one of the blades.
- If an AW-1500 turbine had only two blades, the moment of inertia when the blades are vertical would be 1/ 2(11,560 kg)(1 meter)2 = 5,780 kg-meters2.
- Note the 1-meter radius of a blade is an estimate and the blade is not a true cylinder, but this is a useful model.

The Difference in Moment of Inertia

- For a hypothetical 2 blade setup, the horizontal moment of inertia would be 6.26 x 10^6 kg-meters^2, and when vertical would be 5,780 kg-meters2.
- The horizontal moment is over 1,000 times greater than the vertical moment.
- This difference causes chatter

3 Blades to the rescue!

- For 3 blades, the moment of inertia is always the same since the x and y components of all the blades balance out each other at any point in its rotation.

CHAPTER 7

Components of a Wind Generator

Pitch – refers to the angle of the blade

- The pitch can be changed to increase or decrease the rotational velocity

Brake – is used to stop rotation

- On the Acciona AW-1500 turbine, the brake is a single disk.

Low Shaft Speed

- On the Acciona AW-82/1500 turbine, the low-speed shaft rotates at a max of 16.7 rpm.

High Shaft Speed

- On the Acciona AW-82/1500 turbine, the high-speed shaft rotates at 1320 rpm.

Gearbox

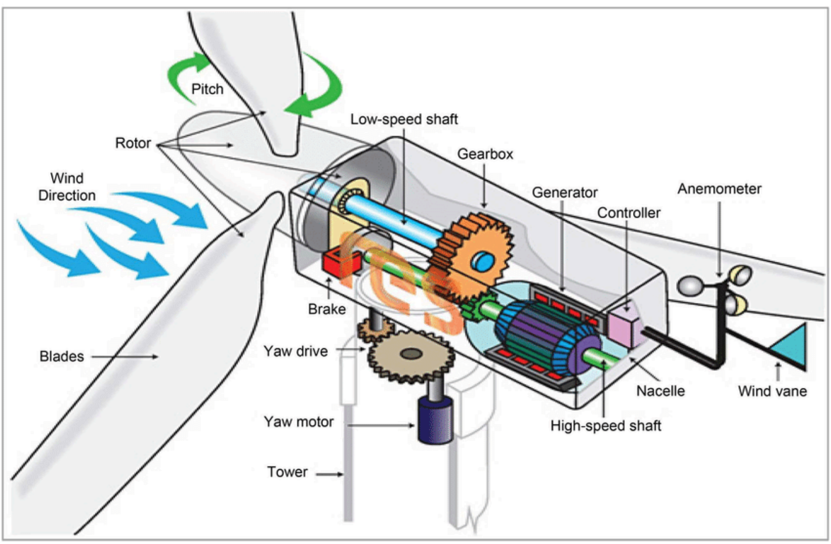
- On the Acciona AW-82/1500 turbine, the gearbox ratio is 1:78. For every 1 revolution of a blade, the generator spins 78 times.

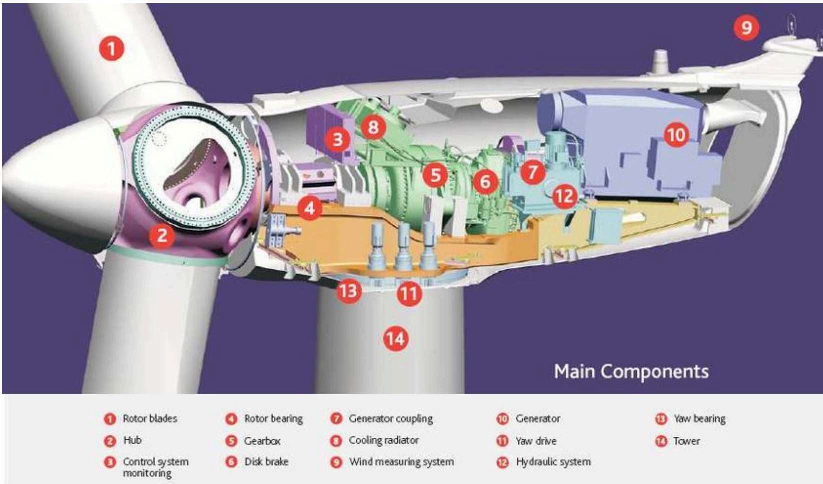
Nacelle

- The nacelle is the covering that encloses the generator, gears, brakes, etc.

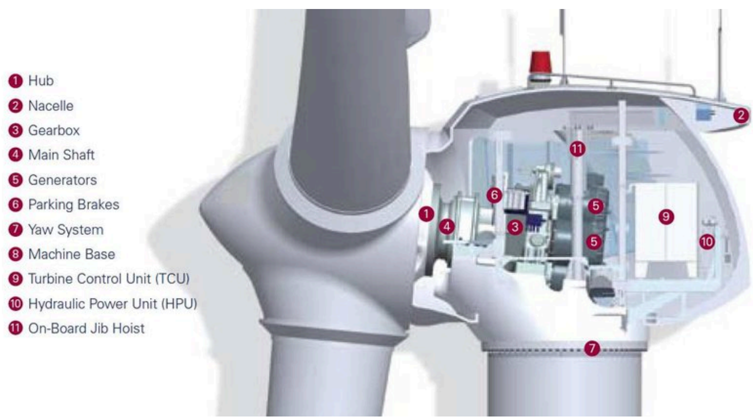
Yaw Drive + Motor

- The towers are 80 meters high in a standard Liberty 2.5MW turbine system.





Main Components
1 Rotor blades
2 Hub
3 Control system monitoring
4 Rotor bearing
5 Gearbox
6 Disk brake
7 Generator coupling
8 Cooling radiator
9 Wind measuring system
10 Generator
11 Yaw drive
12 Hydraulic system
13 Yaw bearing
14 Tower



1 Hub
2 Nacelle
3 Gearbox
4 Main Shaft
5 Generators
6 Parking Brakes
7 Yaw System
8 Machine Base
9 Turbine Control Unit (TCU)
10 Hydraulic Power Unit (HPU)
11 On-Board Jib Hoist

This is where you can add appendices or other back matter.