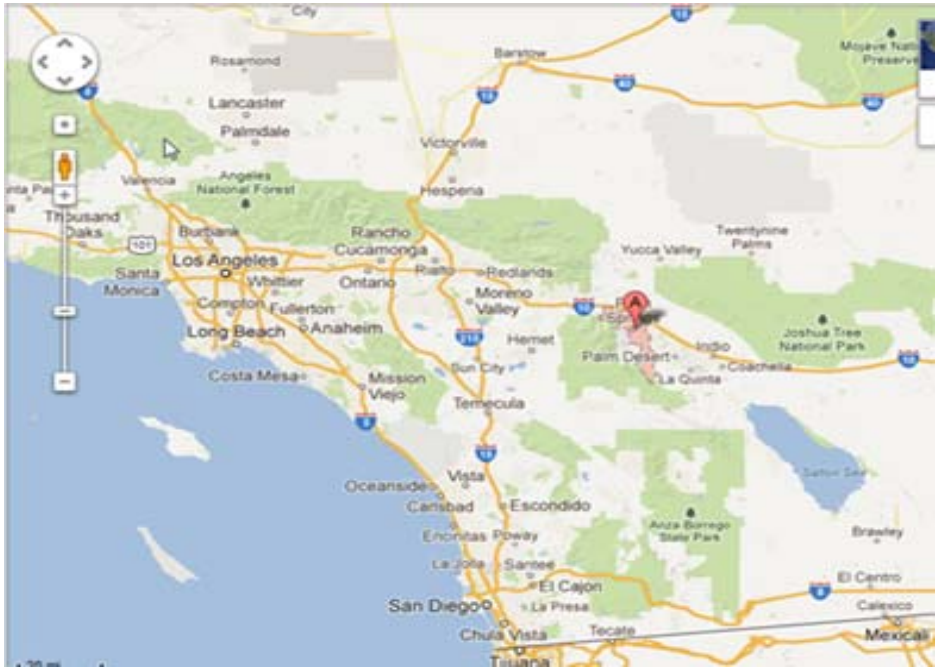
# Chapter 6. Wind Power Systems

- Wind Energy:
  - Clean, renewable energy Source
  - Intermittent Energy Source (operation time is about 75%)
- In the U.S., **Texas** and **California** have the most wind energy production → wind farm

- New Trend → Off-shore wind turbine installation

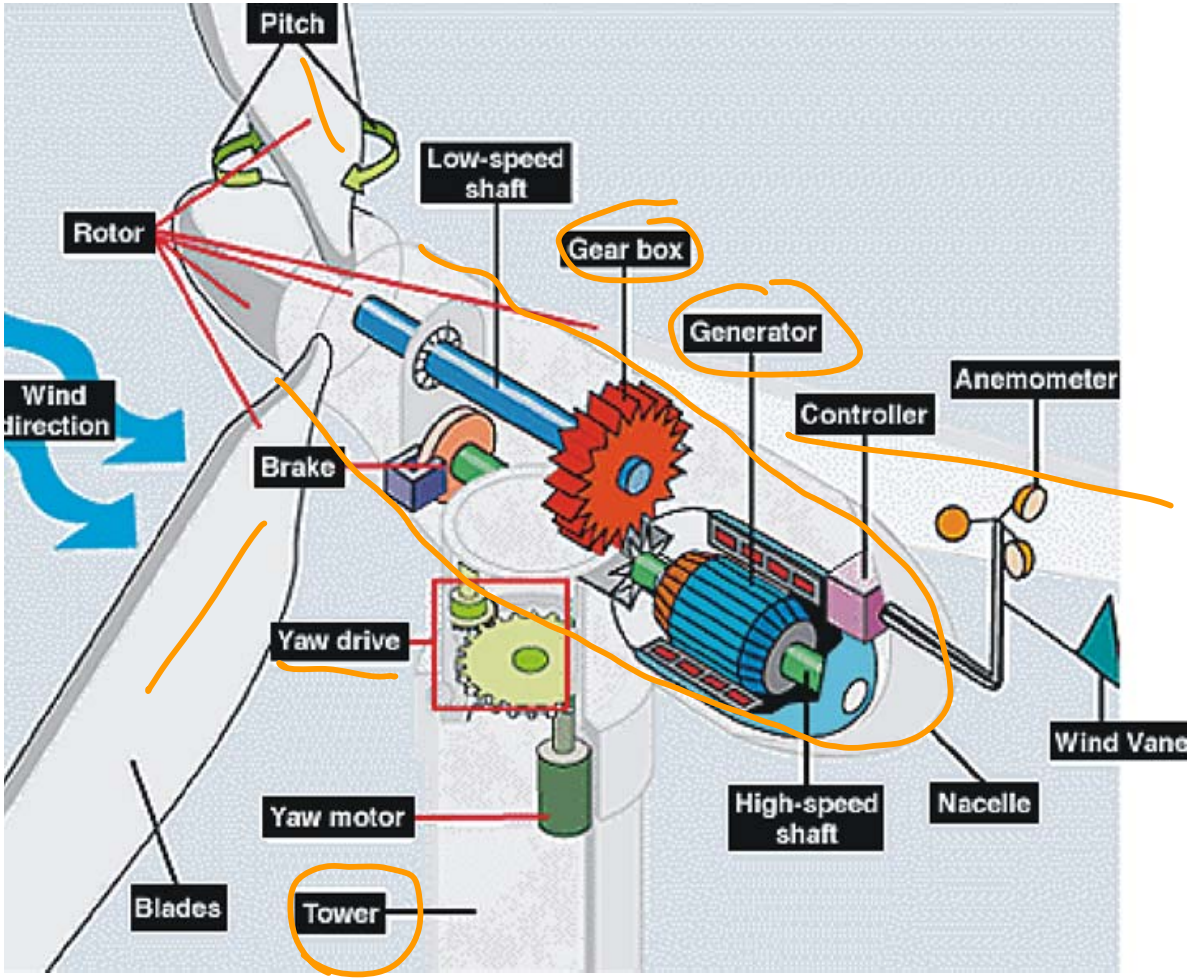
# A Wind Farm in California



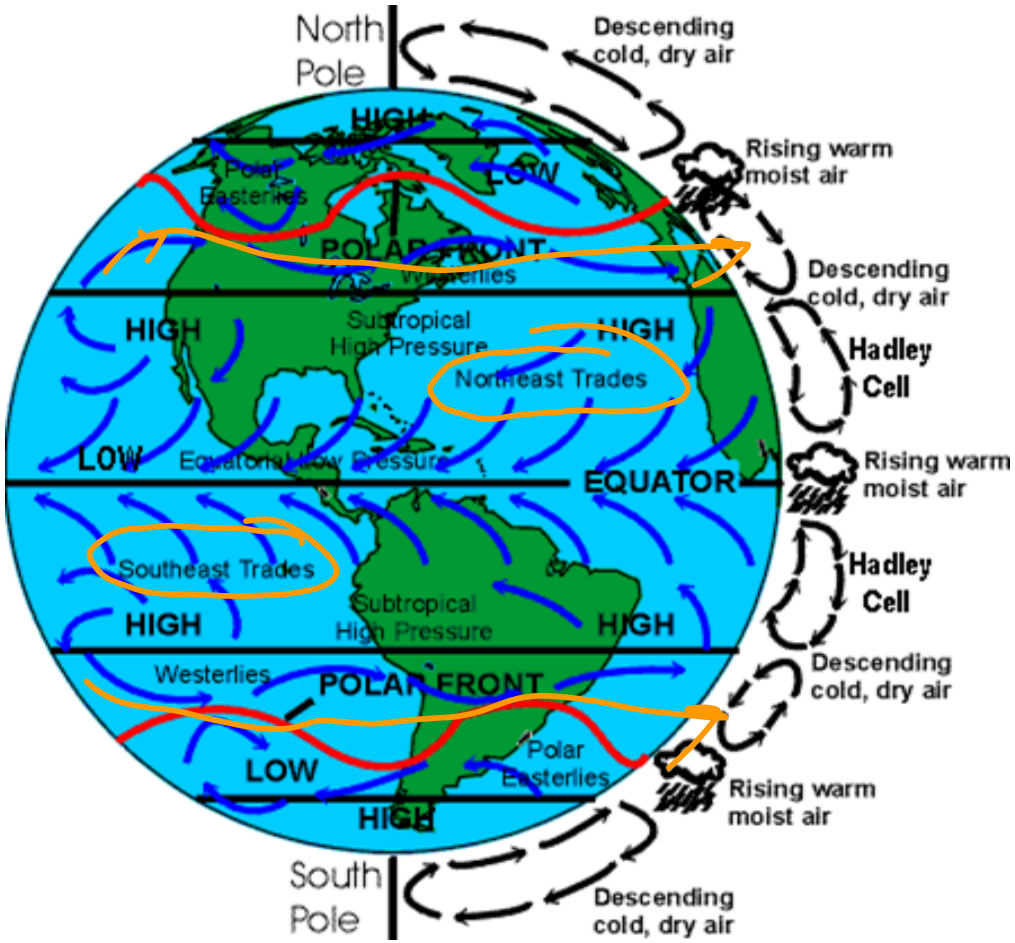

Location of San Gorgonio Pass Wind Farm

| | |
|---|---|
| Country | United States |
| Location | Riverside County, California |
| Coordinates | 33°54′N 116°35′W |
| Status | Operational |
| Construction began | 1980s |
| **Turbine information** | |
| Turbines | 3,218 |
| Hub height | 160 ft (49 m) (*max*) |
| **Power generation information** | |
| Installed capacity | 615 MW |

# Typical Wind Turbine Schematic

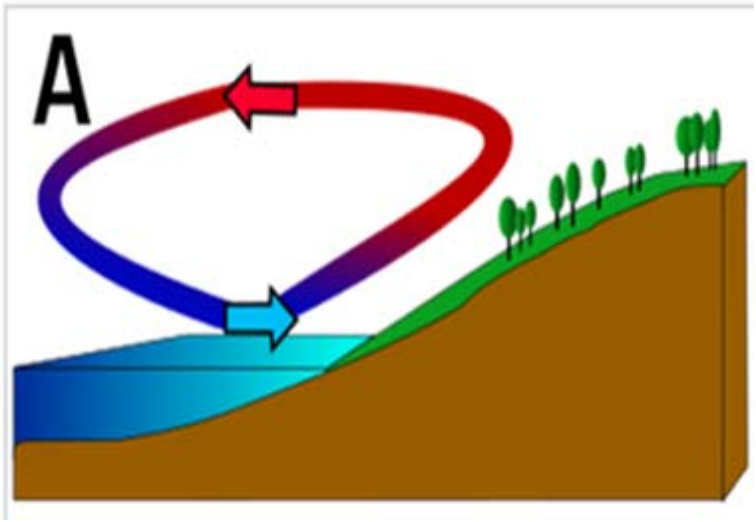


# Wind: General Circulation

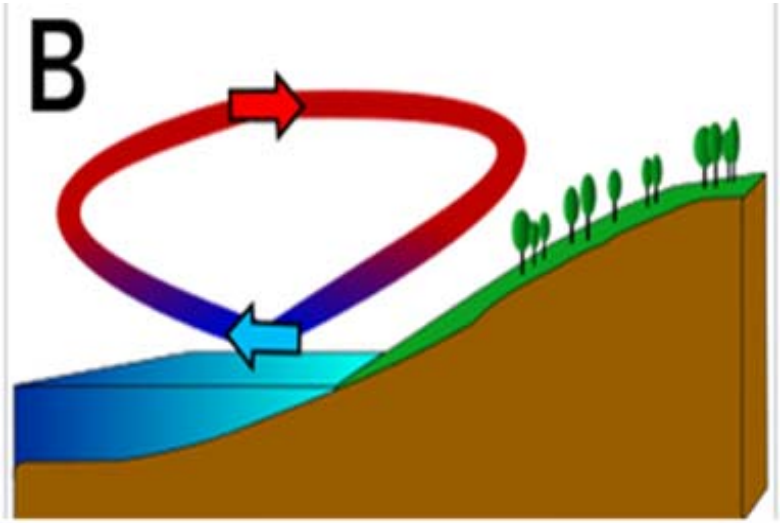



- Prevailing Winds
  - Westerlies
  - Trade Winds

# Sea and Land Breezes




⌘sea breeze: Daytime




⌘land breeze: Night time

# Wind Speed and Scale

## Beaufort Scale

| Beaufort number | Wind Speed (mph) | Seaman's term | | Effects on Land |
|---|---|---|---|---|
| 0 | Under 1 | Calm |  | Calm; smoke rises vertically. |
| 1 | 1-3 | Light Air |  | Smoke drift indicates wind direction; vanes do not move. |
| 2 | 4-7 | Light Breeze |  | Wind felt on face; leaves rustle; vanes begin to move. |
| 3 | 8-12 | Gentle Breeze |  | Leaves, small twigs in constant motion; light flags extended. |
| 4 | 13-18 | Moderate Breeze |  | Dust, leaves and loose paper raised up; small branches move. |
| 5 | 19-24 | Fresh Breeze |  | Small trees begin to sway. |
| 6 | 25-31 | Strong Breeze |  | Large branches of trees in motion; whistling heard in wires. |
| 7 | 32-38 | Moderate Gale |  | Whole trees in motion; resistance felt in walking against the wind. |
| 8 | 39-46 | Fresh Gale |  | Twigs and small branches broken off trees. |
| 9 | 47-54 | Strong Gale |  | Slight structural damage occurs; slate blown from roofs. |
| 10 | 55-63 | Whole Gale |  | Seldom experienced on land; trees broken; structural damage occurs. |
| 11 | 64-72 | Storm |  | Very rarely experienced on land; usually with widespread damage. |
| 12 | 73 or higher | Hurricane Force |  | Violence and destruction. |

- $V=0.836*B^{3/2}$ [m/s]
- 1 [mph] = 0.447 [m/s]
- 1 knot = 0.5144 [m/s]

$$B2V(b) := 0.836 \cdot b^{\frac{3}{2}}$$

$$B2V(5) = 9.346764 \quad m/s$$

$$B2V(5) \cdot \frac{1}{0.447} = 20.909987 \quad mph$$

$$B2V(11) = 30.499682 \quad m/s$$

$$B2V(11) \cdot \frac{1}{0.447} = 68.23195 \quad mph$$

# Wind Speed/Scale and Wind Turbine

## Beaufort Scale

| Beaufort number | Wind Speed (mph) | Seaman's term | |
|---|---|---|---|
| 0 | Under 1 | Calm |  |
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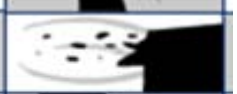
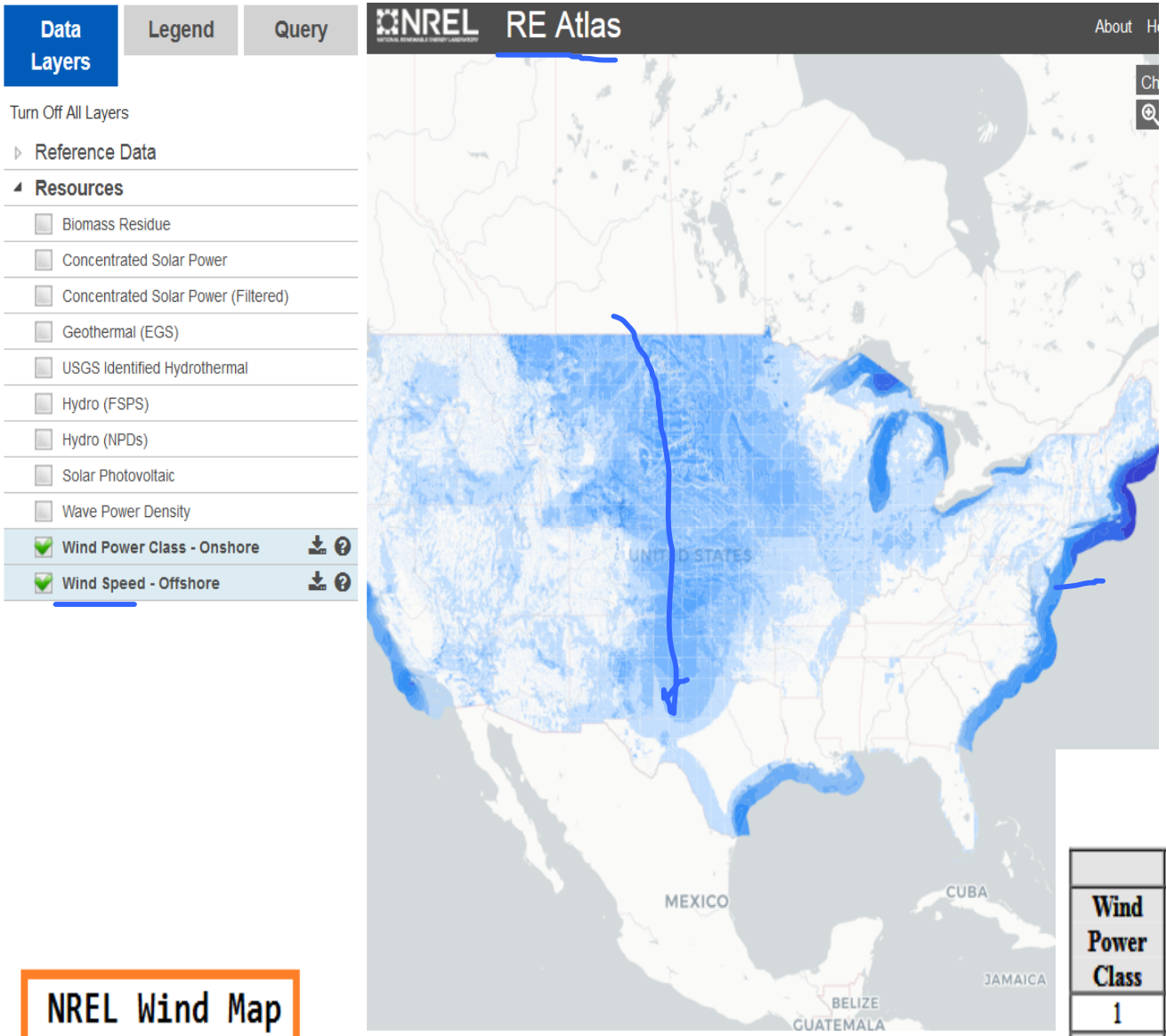
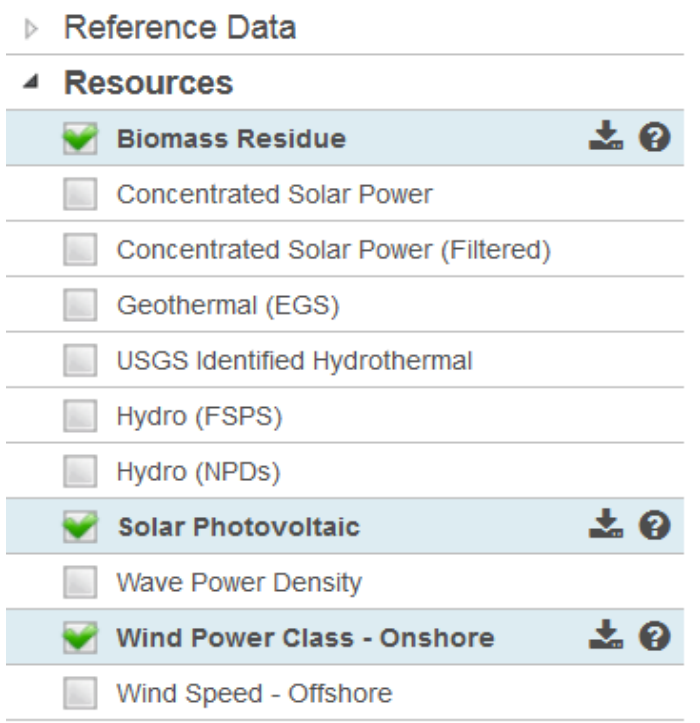
| 6 | 25-31 | Strong Breeze |  |
| 7 | 32-38 | Moderate Gale |  |
| 8 | 39-46 | Fresh Gale |  |
| 9 | 47-54 | Strong Gale |  |
| 10 | 55-63 | Whole Gale |  |
| 11 | 64-72 | Storm |  |
| 12 | 73 or higher | Hurricane Force |  |

# Solar and Wind Energy - Resources

https://maps.nrel.gov/re-atlas



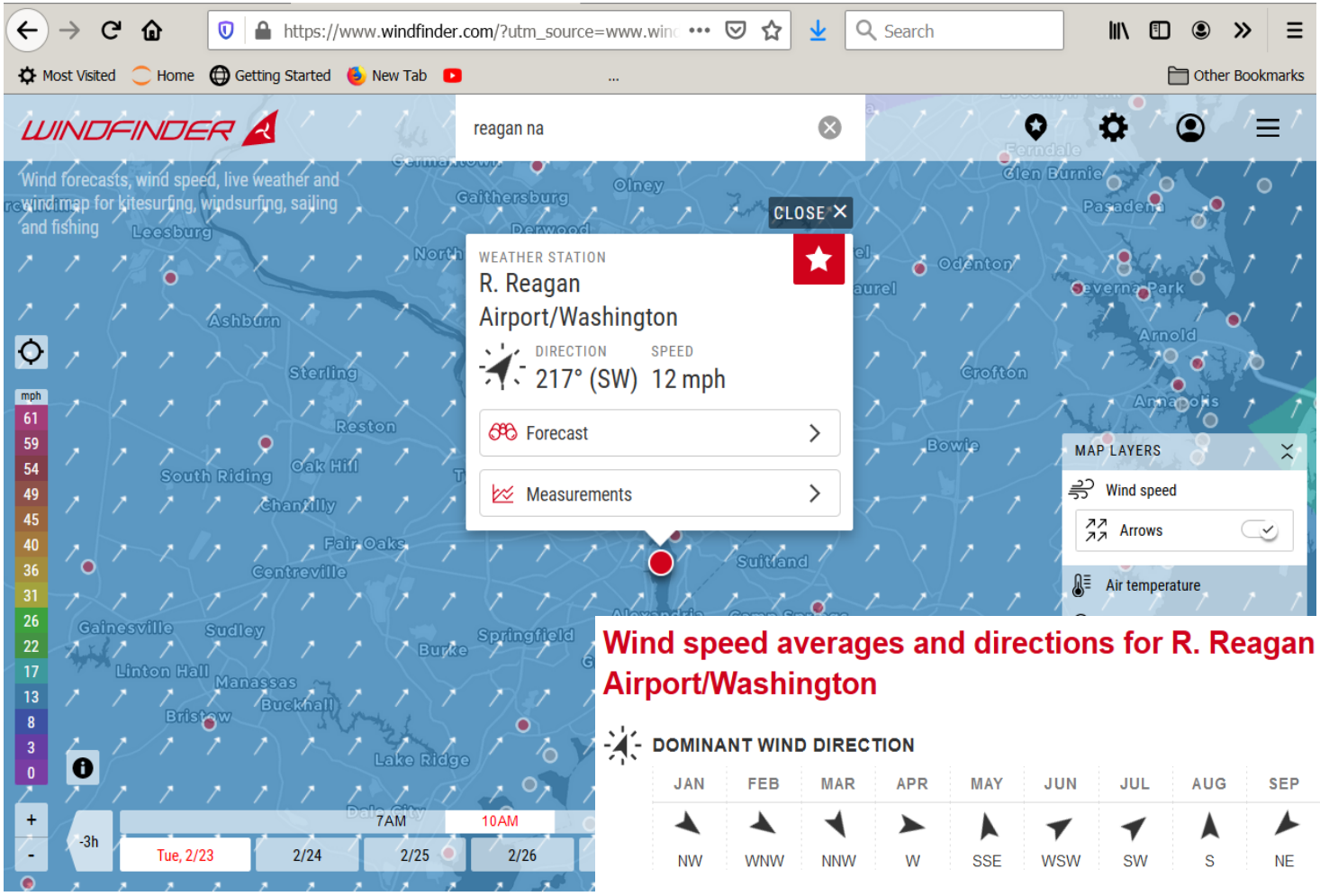




NREL Wind Map

https://www.nrel.gov/gis/wind.html/

**Table 3.1**
**Classes of Wind Power Density**

| | 30 m (98 ft) | | 50 m (164 ft) | |
|---|---|---|---|---|
| Wind Power Class | Wind Power Density (W/m²) | Wind Speed m/s (mph) | Wind Power Density (W/m²) | Wind Speed m/s (mph) |
| 1 | ≤160 | ≤5.1 (11.4) | ≤200 | ≤5.6 (12.5) |
| 2 | ≤240 | ≤5.9 (13.2) | ≤300 | ≤6.4 (14.3) |
| 3 | ≤320 | ≤6.5 (14.6) | ≤400 | ≤7.0 (15.7) |
| 4 | ≤400 | ≤7.0 (15.7) | ≤500 | ≤7.5 (16.8) |
| 5 | ≤480 | ≤7.4 (16.6) | ≤600 | ≤8.0 (17.9) |
| 6 | ≤640 | ≤8.2 (18.3) | ≤800 | ≤8.8 (19.7) |
| 7 | ≤1600 | ≤11.0 (24.7) | ≤2000 | ≤11.9 (26.6) |



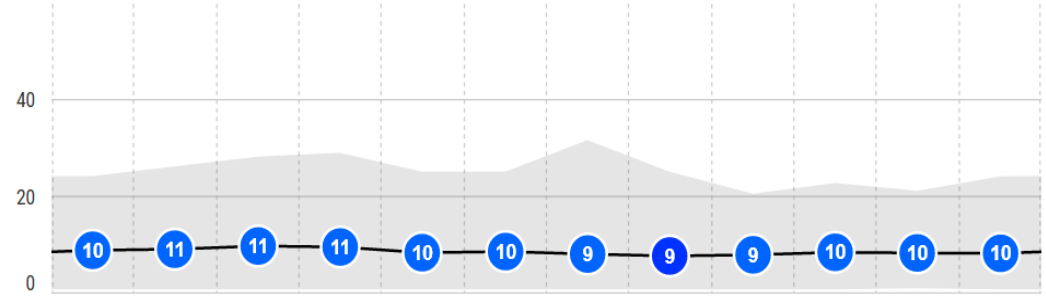

## Wind speed averages and directions for R. Reagan Airport/Washington

### DOMINANT WIND DIRECTION

| JAN | FEB | MAR | APR | MAY | JUN | JUL | AUG | SEP | OCT | NOV | DEC |
|---|---|---|---|---|---|---|---|---|---|---|---|
| NW | WNW | NNW | W | SSE | WSW | SW | S | NE | NW | NW | WNW |

### AVERAGE WIND SPEEDS (MPH)

Show: Average, min, max | Wind gusts



# Types of Wind Turbines

## Horizontal Axis Wind Turbines (HAWT)

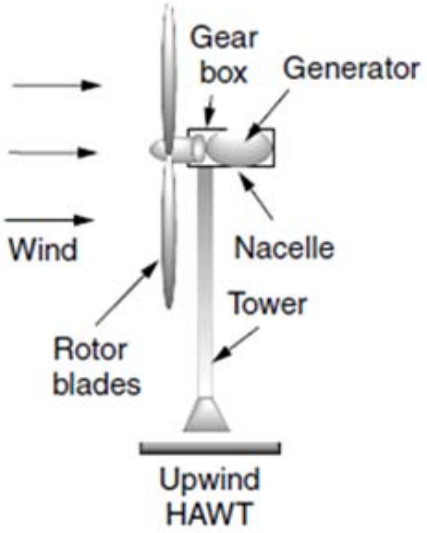
- Upwind Machine
- Downwind Machine

## Vertical Axis Wind Turbines (VAWT)

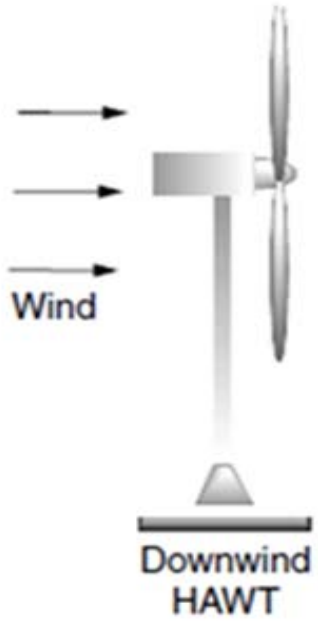
- Accept wind from any direction

# Horizontal Axis Wind Turbines (HAWT)

## Upwind Machine:



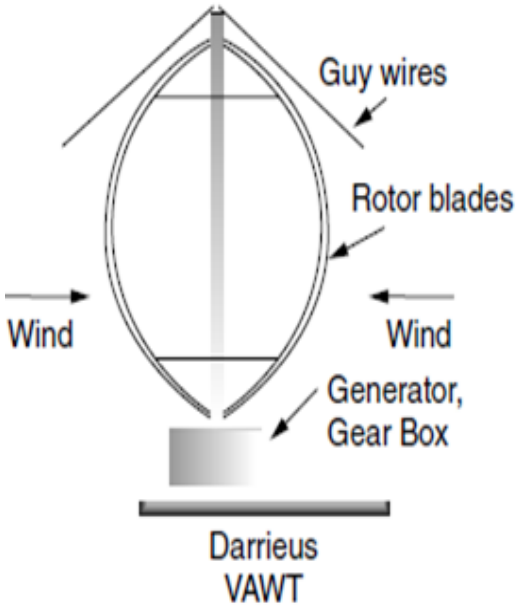

## Downwind Machine:



# Vertical Axis Wind Turbines (VAWT)

- Accept wind from any direction
- **Advantages:**

- **Disadvantage:**



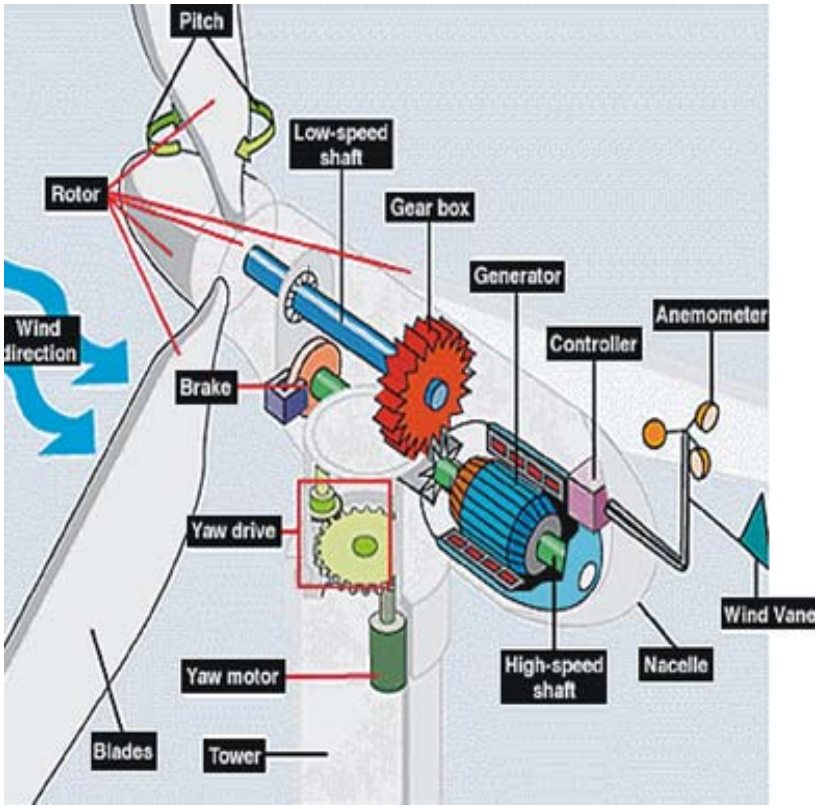
# Blades of Wind Turbines

- 3-blade turbines:

- 2-blade turbines:

Two-Bladed Wind Turbines Make a Comeback

# Wind Turbine Generators



# Wind Turbine Speed Control

machinedesign.com/energy/green-technology-inside-advanced-wind-turbine