

**As the Rotor Turns: Wind Power & You (Student Handout)**  
*(An Investigation of Wind Power as an Energy Resource in Pennsylvania)*

**Part 1: How is wind created?**

## 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.

1. Use the scale above to make an observation about the wind conditions outside of your school today. Record your observations in the box below.

Date:	Time:
Beaufort number:	
Land Effects observed:	

2. Even if there is not much wind blowing today, think about a time when a gust blew your hat from your head or rustled leaves in a tree above you. How do you think wind is created?

## Part 2: Power in the Wind...A Simple Look<sup>1</sup>

If a large truck or a 250 lb. linebacker was moving towards you at a high rate of speed, you would move out of the way right?

Why do you move? You move because in your mind you know that this moving object has a great deal of ENERGY as a result of its **mass** and its **motion**. And you do not want to be on the receiving end of that energy.

Just as those large moving objects have energy so does the wind. Wind is the movement of air from one place on earth to another. That's the motion part.

What is air though? Air is a mixture of gas molecules. It turns out that if you get lots of them (and I mean lots of them) together in a gang and they start moving pretty fast they can definitely give you, a sailboat or a windmill a serious push. Just think about hurricanes, tornadoes or a very windy day!

Why aren't we scared of light winds while we stay inside during a hurricane or wind storm? The velocity of those gangs of gas molecules has a dramatic impact on whether or not we will be able to stay standing on our feet. In fact, in just a 30 mph gust you can feel those gas molecules pushing you around.

Humans have been taking advantage of the energy in the wind for ages. Sailboats, ancient wind mills and their newer cousins the electrical wind turbines have all captured the energy in the wind with varying degrees of effectiveness. What they all do is use a device such as a sail, blade or fabric to "catch" the wind. Sailboats use energy to propel them through the water. Wind mills use this energy to turn a rod or shaft. A simple equation for the **Power in the Wind** is described below. This is instantaneous and does not take time generating power into consideration.

$$P = \frac{1}{2} \rho \pi r^2 V^3$$

**$\rho$  = Density of the Air**  
 **$r$  = Radius of your swept area**  
 **$V$  = Wind Velocity**

From this formula you can see that the size of your turbine (radius of your turbine squared or  $r^2$ ) and the velocity of the wind ( $V^3$ ) are very strong factors when it comes to power production. If we increase the velocity of the wind or the area of our blades we increase power output. The density of the air has some impact as well. Cold air is more dense than warm air so you can produce more energy in colder climates (as long as the air is not too thin!).

You could calculate the peak power production of your wind turbine using this equation. It will be way off since it leaves out a number of variables that impact the actual power output of your turbine. This includes things like how well your blades transform the energy in the wind and the efficiency and type of generator that you are using. It might be fun to calculate the hypothetical and compare it to how much you are producing and generate some efficiency numbers. Be prepared to be shocked at how low your efficiency is.

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<sup>1</sup> Kidwind Project. "Building the Basic PVC Wind Turbine."  
<http://www.kidwind.org/pdffiles/basicinstv2.pdf>, accessed 17 July 2005.

# Engineers of the future...Step forth!

## Part 3: Build the Basic PVC Wind Turbine

### Student Handout



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## **Step 1: Collect Materials**

### **Materials You Need — PIPE IS 1" PVC Pipe!!**

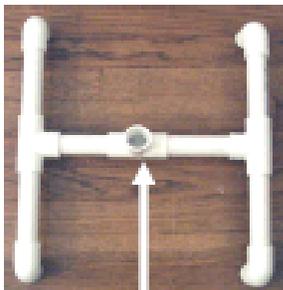
- (1) Some type of Hub
- (1) Some type of DC Motor
- (6) 6" long pieces PVC Pipe
- (1) 2" long pieces PVC Pipe
- (1) 24" long pieces PVC Pipe
- (5) 90° Pipe Fittings
- (3) T Pipe Fittings
- (1) Coupling Fitting

### **Tools & Materials NEEDED!!**

Saw or PVC Cutter, Wire Strippers, Wire, Solder, Duct Tape, Epoxy, Drill, Blade Materials, Hoy Glue, Hobby Knife or Scissors



2 Identical Base Sides



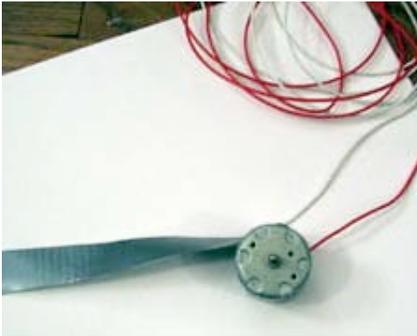
Sides joined together. Make sure to use the PVC tee with the hole so you can get the wires out!

PVC Tee with Hole

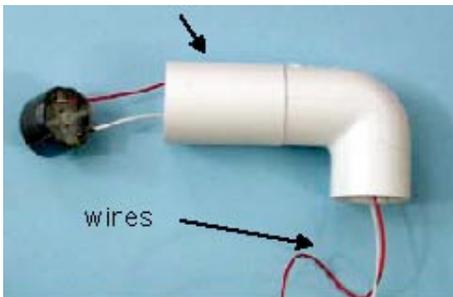
### **Building the PVC Tower Base**

1. Using (4) 90° PVC fittings, (2) PVC tees and (4) 6" PVC pipe sections construct the two sides of the PVC turbine base. Make sure in this step to use the PVC tees that **DO NOT** have a hole drilled in them.
2. Fit the parts together without using glue (PVC glue is really nasty stuff). To make them fit snugly you can tap them together with a hammer, or bang them on the floor once assembled.
3. Next you need to connect the two sides. Use the PVC Tee with the hole to do this. You need the hole to snake the wires from the DC motor out.

## Step 2: Building the Rotor and Hub



Arrange the pieces like the image to the right. Then push them together to make a solid piece. It is called the **nacelle** and it holds the DC motor, blades and other equipment.

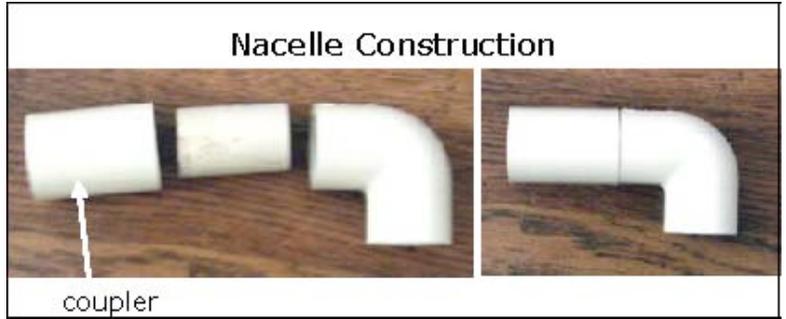


Make sure the wires come out the bottom!



Nacelle complete with rotor hub.

1. For this step you need (1) PVC 90 fitting, (1) PVC coupler, (1) 3" piece of PVC pipe and a DC motor that is around 1.1" in diameter.
2. Wrap a piece of duct tape around the outside of the motor. This will help the motor fit securely into the PVC coupler. To make it really solid you can epoxy it in.

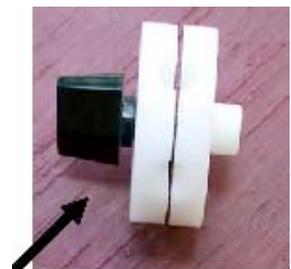


3. Insert the wires attached to the DC motor through the nacelle. They should come out of the 90° PVC fitting. Your motor will rest in the coupler.
4. Insert the motor into the coupler. It should fit very snugly. If it is loose you should wrap some more duct tape around the outside. As you are frequently pushing on the motor you need to make sure this is tight!



Notice the motor is straight and not pushed all the way in!

5. When you insert the motor you also should make sure that it is straight and not too far in. If it looks cockeyed you should straighten it out as it will cause your hub and blades to wobble while spinning.
6. After you have secured the motor attach your hub. Press the hub onto drive shaft. It should fit very snug. Do not press it on so hard that the adapter rubs on the motor body. This would slow your drive shaft.



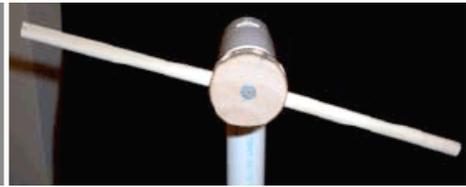
Crimping hub with driveshaft adapter. This makes life easy!

### **Step 3: Attaching the Tower to the Base**

1. Snake the motor wires through down the tower and through the hole that is drilled in the PVC tee at the base of the wind turbine.
2. Attach the nacelle to the top of the tower.
3. Insert the bottom of the PVC tower into the tee at the center of the turbine base.
4. It should look just like the wind turbine to the right!
5. Make sure the PVC pipe has seated well into the fittings by tapping together with a hammer, or by banging on the floor.
6. Make sure that you didn't use any glue! (Because once you are done you can take it apart and then store it away for next year.)
7. To make your life easier you should attach alligator clips to the wires coming out of the turbine. This will make it easy for you to hook your turbine up to a multimeter!



Never make blades using metal or any sharp edged material as these could cause injury during testing. Blades tend to spin very fast and they can easily cut people if they have sharp edges.



#### **Step 4: Blade Design and Power Output**



*Sand one end of the dowel until it fits snugly in the tinker toy hub. You can also cut a slit, but this can be challenging. You can also use Tinkertoys, but they are rather pricey.*

1. Attach blades to the hub using the short dowels included if you are using a Basic PVC Turbine Kit from Kidwind.
2. The 3/8" dowels are purposely a tiny bit too big to fit into the Tinkertoy holes. To make them fit you must sand some wood away at one end. Don't sand too much because you do not want the dowels to be loose. If they are too loose, they can fly out during testing.
3. To make blades, carve or cut different shapes and sizes out of a variety of material (wood, cardboard, felt, fabric) and hot glue or tape them to the dowel. We have seen students make blades out of **styrofoam bowls, pie pans, paper and plastic cups**. Basically, anything you can find around your house or classroom!
4. Before testing make sure that the blades are securely attached to the dowel or Tinkertoy rod. If you do not secure them properly, they may detach as you begin to test your turbine.



#### **Observations and Other Ideas**

- If you do not want to sand dowels we recommend getting a can of **Tinkertoys** and use the rods to attach your blades. These work great! We would add them in the kit but they are pricey as one small can is around \$20.
- You can add up to eight (8) blades and set them at any angle on the Tinkertoy hub. The one problem with the Tinkertoy hub is that you can only use even numbers of blades.
- If you want to use odd numbers of blades check out our six (6) hole hubs for sale at the KidWind shop. While these are a little expensive, they allow you to use 3 and 6 blades in an even distribution.
- Be careful that your blades are not too big. They might hit the tower or the ground as they spin around.
- Blades need to be balanced to work properly. If they are not balanced, the entire turbine will vibrate while spinning which can cause problems.



## **Step 5: Safety & Blade Testing**

- It is important to wear safety goggles when constructing blades with hot glue or sharp knives.
- You should always stand **in back of** or **in front of** the wind turbine during testing. If you stand in the PLANE of ROTATION you could be hit if your blade flies off during testing.
- Never make blades using metal or any sharp edged material as these could cause injury while spinning fast during testing.
- The voltage and current made by your turbine is not enough to cause injury. But it is always a good idea to treat electricity with care and caution.

### **SETUP FOR TESTING:**

Safely set up your testing area like the picture below. It is important to clear this area of debris and materials.



→ Make sure that the center of the fan matches up with the center of the wind turbine. You may need to raise your fan with some books or a container.



While you can use your wind turbine outside, you must make sure that you face it into the wind. This is because your wind turbine cannot YAW (or rotate) to face the wind. If the wind shifts, and the turbine cannot rotate, it may cause the driveshaft to be blown out of the hole.

## Step 6: Measuring Your Wind Turbine's Power Output

### **How do we use the multimeter with our wind turbine?**

Small DC motors do not produce much power when we spin them slowly. As this turbine does not have any gearing our electrical output will be limited and a great set of blades in high winds might be able to light an LED. To accurately measure our production you should use a multimeter.

**Power = Voltage (V) X Current (A) ←-Watch Your Units**

Make sure you are recording volts and amps (not milli or microvolts unless you want to!)

#### **a. Voltage**



1. Attach the wires from the generator to the multimeter.
2. To check the voltage select DC Volt (V) and choose a the whole number setting say up to at least 5 volts.
3. Place your turbine out in the wind or in front of a fan and let it run up to speed. It is normal for the readings to fluctuate. Power output is not

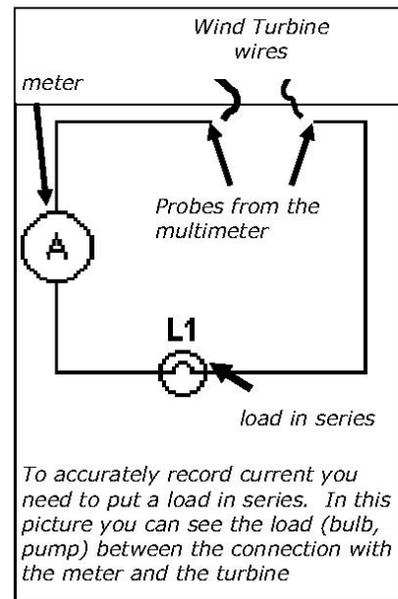
steady because the wind is not steady.

4. A set of very well designed blades may make around 1 volt. Typical blades will be in the 0.2 - 0.5 volt range.
5. When you are measuring voltage you are measuring how fast the DC generator is spinning. The faster it spins the higher the voltage. As there is no load on the generator it has very little resistance so it can spin very fast. If you look closely when you add a load the RPM may drop as will your voltage.

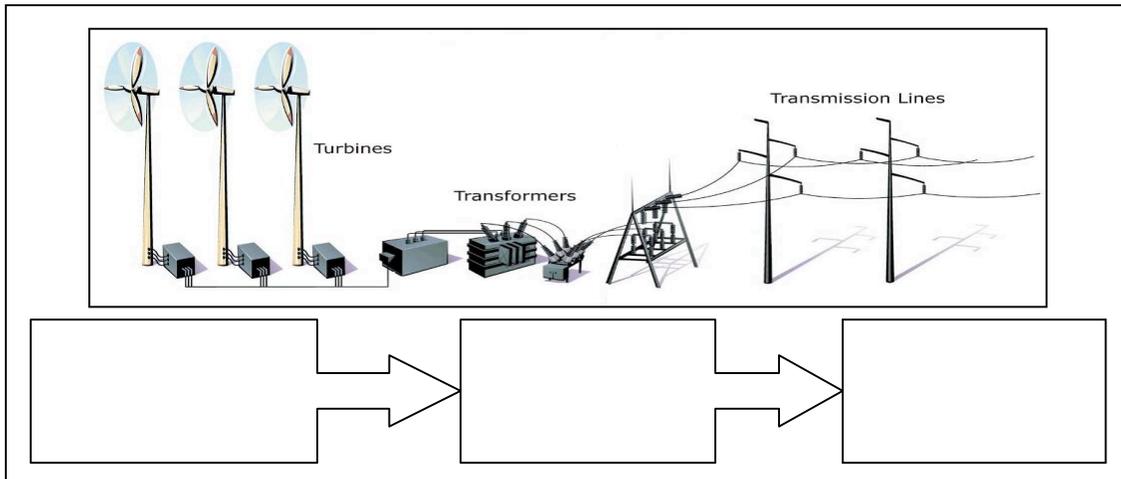


#### **b. Amperage**

1. To get a more accurate picture of the power output of your turbine you should measure amperage as well. To accurately measure the amperage you need to hook up your multimeter differently.
2. You need to place a load (or a resistive object - small bulb, resistor, pump etc.) in series with the meter so that the generator is "loaded" and has to do work.
3. A set of very well designed blades will make around 0.1 amps (100 milliamps) with this motor. Typical blades will be in the .02-.05 amp (20 -30 milliamp) range. This will vary based on your resistive load.
4. When you are measuring amperage you are measuring how many electrons your turbine can push. This relates to how much torque your blades are generating.



a) Before you move ahead to the next step, stop and write down your thoughts about how the energy of the wind is being transformed to electricity. Record the energy transformations in the boxes below.



**Step 7. What Kinds of Things Can We Test with the Wind Turbine?**

Some Factors that Affect Power Output

Now that you have a wind turbine, it is time to explore the factors that affect how much power your turbine produces by designing your own experiment. (You will need to use additional sheets of paper to describe your experimental and results ☺).

Here are a few ideas to get you thinking about your hypothesis and the factors you would like to test:

- *Wind Speed*
- *Generator Type*
- *Blades*

**Option 1:** *If you want to explore the affects of wind speed, look at questions a and b below and design an experiment to test your ideas.*

a) How do changes in wind speed cause the power output change?

b) Why does it change? Make a graph and discuss with your team. (Think about this in relationship to the Power in the Wind equation.)

**Option 2:** If you want to explore how **blade design** affects power output, check out the information below and design an experiment to test your ideas.

The blades on modern turbines "capture" the wind and use it to rotate the shaft of a generator. The spinning shaft of the generator spins magnets near wires and generates electricity. How well you design and orient your blades can greatly impact how much power your turbine produces.

Some variables you can test about blades include:

- *Blade Length*
- *Blade Shape*
- *Blade Number*
- *Blade Materials*
- *Blade Pitch*
- *Blade Weight*

a) How do changes in blade design cause the power output change?

b) Why does it change? Make a graph and discuss with your team. (Think about this in relationship to the Power in the Wind equation.)