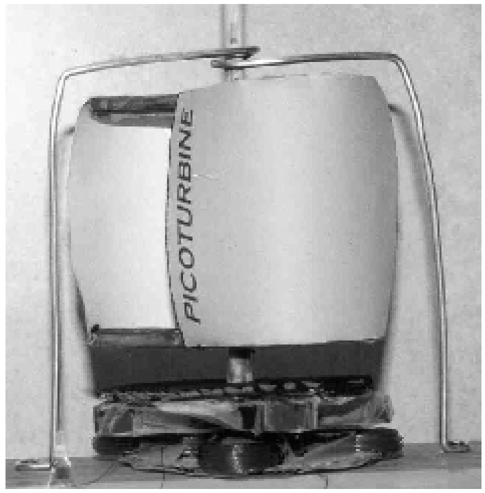
# PICOTURBINE WINDMILL KIT

## INSTRUCTIONS, TEACHER'S GUIDE, TECHNICAL NOTES

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www.PicoTurbineInternational.com

# PART 1: BUILDING PICOTURBINE

This document will show you how to build PicoTurbine—a fully functioning, electricity-producing scale model of a Savonius vertical axis wind turbine.

PicoTurbine can be built in less than one hour. Less time is needed if done as a group project. With some adult supervision PicoTurbine can be assembled by children as young as ten years old, making it an excellent project for renewable energy education.

PicoTurbine stands about eight inches tall--but don't let its size fool you. This version of PicoTurbine produces electricity using a direct-drive, single-phase, brushless permanent magnet alternator that you will build!

## *BEFORE YOU BUILD PICOTURBINE*

### Step 1: Check Your Materials

The following materials are supplied with your PicoTurbine kit. Please check to make sure you have all the parts:

- 2 feet of thick aluminum wire.
- 4 pre-wound coils of enamel coated copper wire.
- 4 ceramic grade-5 magnets
- 1 bicolor light emitting diode (LED) with 2 leads.
- 3 Phillips head (cross slot) screws.
- A wooden dowel sharpened on one end
- A piece of wood about 8” by 5” and ½” thick
- A piece of corrugated cardboard about 8” by 10”
- 3 retaining clips (small semi-circular metal e-clips, see picture)
- A strip of pre-cut double-sided tape pads
- A small piece of sandpaper for stripping copper wire
- This instruction manual and template sheet for the cardboard parts


An "e-clip"

You also need the following tools and materials that are commonly available:

- Scissors
- Phillips head screw driver
- Pliers
- Ruler
- Paste, or a glue-stick

It is also helpful to have the following tools, but not entirely necessary:

- A digital multimeter that can measure AC volts is useful for tuning and testing the alternator, and displaying the amount of electricity produced.

### Step 2: IMPORTANT: Review Safety Rules

PicoTurbine is not a dangerous project to build, but as with any project certain safety rules must be followed. Most of these rules are just plain common sense. Be sure to review these rules with children if you are building this project as part of an educational curriculum.

- **Adult supervision is required for this project.**
- **This project is not recommended for children under 10 years old.**
- **Children must be supervised when working with scissors and other sharp parts to avoid cutting injuries.**
- **Children under 4 years old should never work with wire or small parts like screws because they represent strangulation and choking hazards. Keep the kit parts out of the reach of small children.**

- **PicoTurbine generates low levels of electricity (2 volts at about 50 milliAmps) that is generally considered safe, and is of the same order as produced by batteries used in toys or radios. But, to avoid shock hazard never work with electricity of any level when your hands or feet are wet.**
- **Persons wearing pacemakers should not handle strong magnets.**
- **Do not allow magnets to "snap" together or fall together. They are brittle and may chip or break. They can also pinch fingers or send small chips flying through the air presenting an eye hazard if mishandled.**

## *BUILDING PICOTURBINE*

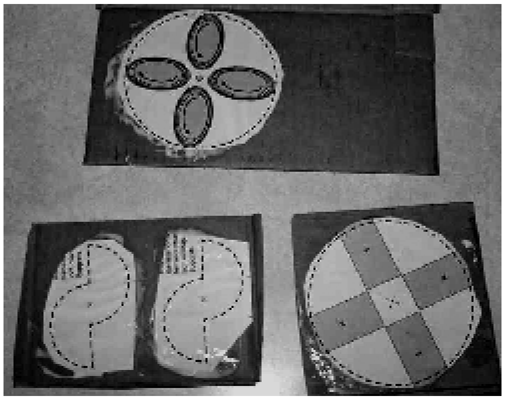

**Figure 1 - Templates glued to cardboard**.

### Step 1: Glue the Template Parts

Locate the templates marked "glue to cardboard". Cut these out and glue them (paste or glue-stick works best) to the piece of corrugated cardboard which is supplied with your kit. Set these glued parts aside to dry while you continue on to the next step. See Figure 1.

### Step 2: The Axle and Yoke

A common axle is used by both the blade assembly and the alternator, made from a wooden dowel. The dowel is sharpened on one end. The dowel's point rests in the center groove of a Phillips head screw, and the blunt end is held by a wire loop. See Figure 2.

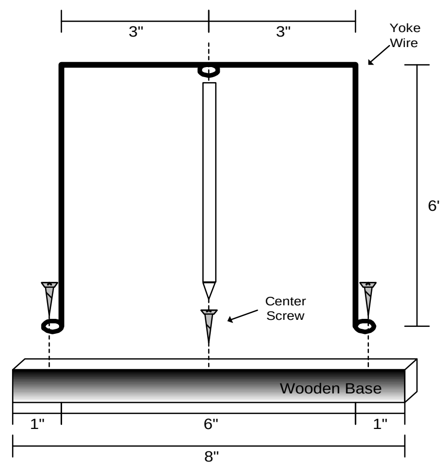


**Figure 2 – The wire yoke assembly.** The sharpened wooden dowel's point will rest on a screw in the center of the wooden base. The top of the dowel will turn within a loop of aluminum wire formed within the yoke wire.

To make the base and yoke assembly, start with the thick, 2-foot piece of aluminum wire. Using pliers, bend a small loop on one end. Bend the loop so it forms a 90-degree angle with the rest of the wire. Measure 6 inches up from the loop and make a 90-degree bend in the wire. Measure 3 inches from this bend and form another loop, slightly larger than the diameter of the dowel. You may do this easily by actually wrapping the wire around the dowel loosely. Measure 3 inches from the center of this loop and make another 90-degree bend, forming a large, square, U-shape with the wire. Measure 6 inches from this bend, and form another small loop. Clip off any excess wire. The U-shaped piece of wire will be called the "yoke". See Figure 2.

Using a screw driver, attach one screw in the exact center of the wooden base. Do not screw it all the way down or it may pierce through the wood, make sure it does not show through on the bottom of the wooden base. Then, fasten the yoke to the wooden base using two screws, such that the central loop of the yoke is directly above the screw in the center of the base. See Figure 2. The legs of the wire yoke should be centered on the wide face of the wood as shown. Insert the dowel in the center hole of the yoke and rest the point in the center screw's groove. The dowel should stand as near vertical as possible. Adjust the yoke by bending the wire if necessary to make the dowel vertical both side-to-side and front-to-back. Make sure the dowel turns freely in the yoke's center loop. If you wish, you can put a drop of any type of oil in the center screw's groove to make the dowel turn more freely.

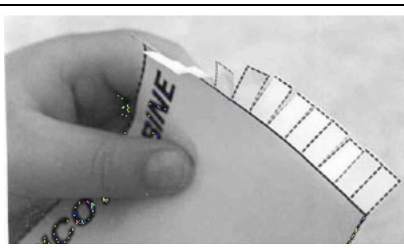

**Figure 3 - Feathered Edges.** Cutting carefully on the dotted lines will create a feathered edge that is more easily assembled.

### Step 3: Cut Out Parts

Cut out the Blade Coverings from the templates. The blade may be colored or decorated using crayons or markers at this time. If you are constructing this in a mixed age group then this is a good task for younger children. The ends of the blade coverings should be carefully cut into a "feathered" edge. See the Figure 3. If the previously glued templates are dry enough carefully cut them out. The complete set of cardboard and paper parts you need for further assembly is shown in Figure 4.

## Step 4: The Alternator

An alternator is little more than magnets moving relative to wire loops. The magnetic flux density changes as the magnets (or wire) move around, inducing an electric current in the wire. In PicoTurbine, the magnets will spin on an assembly called the rotor, while the wires will remain motionless on a part called the stator.

The alternator is the most challenging part of PicoTurbine to build. If you build it carefully, you can achieve about 1.5 to 2 volts of electricity—enough to light up the bicolor LED provided in the kit.

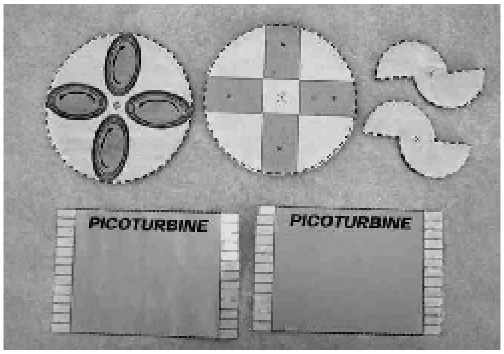


**Figure 4 - Paper and Cardboard parts**. The items on the top row are glued to cardboard and carefully cut out. The two blade coverings on the bottom are not glued to cardboard.

## Step 4A – The Permanent Magnet Rotor

Tape the four magnets onto the rotor template as shown in Figure 5 by using pieces of double-sided tape. Affix the sticky side to the magnet, then peel off the backing using your fingernails, then affix the magnet to the proper place on the rotor template. Note that the magnets are magnetized on their faces, and you must alternate poles going around the diameter. Magnets distributed with your kit are marked with a dot on one pole. So, you should alternate: dot, no dot, dot, no dot going around as shown in Figure 5.

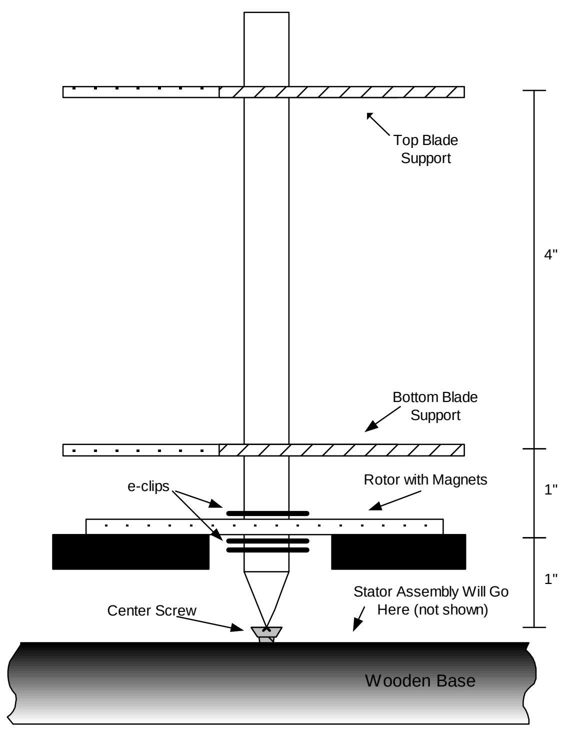


**Figure 6 – Rotor with magnet disk and blade supports**. The black rectangles on the bottom represent the magnets, they are attached to a double-thickness cardboard disk.

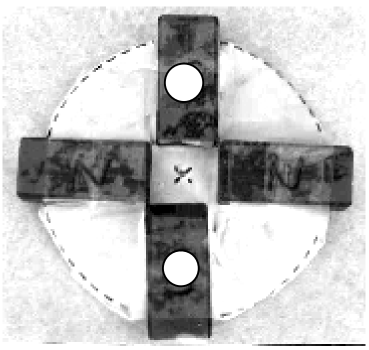

**Figure 5 – Magnets attached to rotor disk**. Note that dot sides are up for upper and lower magnets and down for left and right sides.

Carefully poke the dowel through the rotor's center as shown in Figure 6, being careful not to break the point and always keeping your hand out of the path of the point so you don't stab yourself. Work it down slowly so as not to stretch the hole bigger than needed, it must remain tight. Slip two retaining clips (small semi-circular metal "e-clips") over the point and push up against the cardboard so it does not slip down easily. Push another retaining clip from the top of the dowel down to the top side of the cardboard rotor. The rotor is now sandwiched between one e-clip on top and two on the bottom, helping keep it stable.

Thread the top of the dowel up from the bottom into the yoke loop, pull it through, and lower the point into the center screw. Spin the rotor by twisting the blunt end between thumb and forefinger. It should spin freely and vertically. Adjust the wire yoke if necessary to keep it level. Watch the rotor as it spins. It should spin evenly, with as little wobble as possible. If you give it a good spin, the rotor should turn on its own for quite a long time, 30 to 60 seconds or more. The yoke loop should not be too tight around the dowel, which would restrict free spinning, but must also not be so loose that it allows excessive wobble. Adjust as needed.

## Step 4B: Constructing the Stator

Strip the ends of the wires coming out of the coils using sandpaper. Make sure the stripped wire is shiny copper, with no red enamel remaining. Affix the coils to the stator template as shown on the coil template by using the doubled-sided tape provided with your kit. Note that the loops should alternate between clockwise and counter-clockwise rotation going around the disk. A simple way to ensure this is to notice that both wire leads for a given coil come out of the black tape that secures them on the same side. Notice on the stator template that the direction of the wires exiting the black tape alternates going around the disk: one coil's leads point out toward the perimeter, the next going clockwise points toward the center of the disk, the next out to the edge again, and the last back toward the center. Follow the template picture carefully and place the coils exactly the same way as shown.

Attach the coils to the stator  disk using pieces of double-sided tape. The coils should lie very flat, press them down with your fingers. Carefully poke a hole in the center of the stator cardboard. Tightly twist together the stripped wires from one coil to the next as shown on the template, leaving the final two wires (the first and last) unattached. Do not cross the wires coming out of a coil. The rightmost wire lead of one coil should attach to the leftmost lead of the coil next to it in the clockwise direction, etc., exactly as shown on the template.

Remove the rotor/axle assembly by pulling up on the blunt end of the dowel, separating the point from the center screw, then angling the rotor assembly out and down. Put the stator assembly's hole over the center screw, and press it down firmly so the central screw protrudes through the stator hole. Put the rotor/axle back on by angling it back through the yoke. There should be as little gap between the coils and magnets as possible, but not so little that there is any chance of the magnets crashing into the coils when you spin them. About ¼ inch gap will work well (about twice the thickness of the corrugated cardboard), but a gap of more than 3/8 inches may prevent the LED from lighting because the magnetic field will be too weak. If the magnets are too low and crash into the coils, push up from the bottom on the e-clips to raise them. If too high, push down from the top e-clip carefully. You may also fine-tune by adjusting the center screw using a screw-driver.

If you have a multimeter, set it to AC volts mode and hook the two remaining wire leads to your multimeter. Give the rotor a hard spin. If you spin fast, and everything is aligned well, you should get between 1.5 to 2.0 volts AC (or more if you've built very well).

## Step 5 – The Blade Assembly

You're almost finished! Cut the two blade supports out, and carefully poke a hole in each of their centers, keeping your fingers out of the way. Slide them onto the dowel from the blunt side. They should be aligned with each other, don't turn one upside down accidentally. Looking from the top they should look the same, in the same alignment. Space them about four inches apart.

Paste (or glue-stick) each paper blade covering on the circular side of the blade support, both top and bottom. Use the feathered edges to negotiate around the circular support. The final effect is as if you took a cylinder, cut it lengthwise, and offset the two halves half-way horizontally before fastening them back together.

## Step 6 – Testing

Carefully insert the blade/rotor/axle assembly back into the yoke. Blow into the blades from any direction, and they should start up very easily. Short, puffing blows are best. If you have a multimeter, hook up the leads to it again and puff into the blades. If you have very good lungs you'll get a couple of hundred millivolts--real wind will do much better than you!

For classroom demonstrations a small fan or hair blow dryer can provide the "wind". Finally, if it's a windy day give it a real test using Mother Nature.  Attach the LED to the leads and carefully twist them tight. In a wind of about 10 to 15 miles per hour the LED will flicker weakly, in a 15 to 20 mile per hour wind it will flicker quite brightly.

This is a bicolor LED. When current flows in one direction, it will glow green. In the other direction, it will glow red. Because PicoTurbine creates alternating current, it will go from green to red and back again many times per second. PicoTurbine needs to produce a minimum of about 1.5 volts to light the LED. To produce this much power, it must turn about 6 to 10 cycles per second, which should not be difficult if you've built properly. A good spin with your fingers will produce this rate of turning, or a hair dryer positioned close to the blades, or a wind of about 10 to 15 miles per hour.

## Trouble Shooting

This section discusses some common problems and provides advice on how to fix them. Look through this section and try out everything suggested. If you still cannot get the kit to work, send electronic mail to **support@PicoTurbinesite.com** and we'll give you a hand. This section discusses the most common problems.

### Problem: Blades Do Not Spin, or Only Spin Slowly

1. **Yoke Too Tight.** Make sure the top of the wire yoke loop is loose enough. The dowel should be able to move slightly left and right, and should be able to turn freely. If not, use pliers to form a larger loop.
2. **Rotor/Stator Collision**. Make sure the magnets are not hitting the coils or a stray piece of tape or wire lead. If a piece of tape has come loose, clip it off or use more tape to hold it down. If the magnets are hitting the coils, move them slightly farther away and affix tightly with tape. If the magnets tend to sag to one side, then you may have to add another cardboard disk glued to the top of the rotor to reinforce it.
3. **Bad Point**. Make sure the dowel point is sharp. If it is not, use a pencil sharpener to sharpen it.

### Problem: LED Does Not Light Up

If the LED will not light up, then you may not have enough voltage. The LED requires about 1.5 volts to light up. The most likely causes of a failure to light are:

- The magnets are too far away from the coils to produce enough voltage, or
- There is friction that is causing the PicoTurbine to spin too slowly, or
- The coil connections are not tight enough are and causing too much resistance in the circuit.

If you have a digital multimeter you can check the voltage directly by putting it in AC volts mode and spinning the turbine by hand or using a fan or blow dryer.

Other possible problems include:

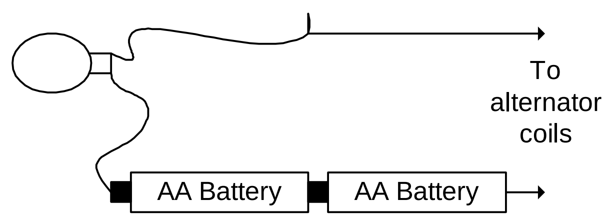

**Figure 7 – Simple way to test coil continuity without a multimeter.**

1. **Coils Lack Continuity**. Make sure the coils are connected well. If you have a multimeter that can test continuity or has an Ohms test, then hook one end of each alternator lead to the multimeter. A continuity check should pass. A resistance check should show approximately 24 to 32 ohms for the four coils, or about 6 to 8 ohms for a single coil. If the resistance check shows more than 40 ohms, or shows infinite resistance, then your coils are not properly connected. If you do not have a multimeter, check continuity by using the supplied LED and two 1.5 volt AA batteries. Connect the coil leads to the batteries and LED in series as shown in Figure 7. The LED should light (assuming the LED is good as shown in (1) above and the batteries are known to be good).

   The most common cause of coil problems is that the wire leads are not properly stripped. Strip each lead using sandpaper, or carefully use the edge of a knife or scissors edge. Strip about 1 inch. The stripped part should look like shiny copper with no red enamel coating at all. Tightly twist together the leads from the coils and check continuity again using a multimeter or the LED with an AA batteries. If you still cannot get a positive continuity check using multimeter or LED, then there is a possibility that a coil is broken or kinked. To test this, disconnect all the coils from each other and test continuity on each one individually. If you find that one coil is bad, then double check that the ends are properly stripped. Inspect the coil visually and look for damage such as kinks or breaks in the wire. If you locate a break, then strip the ends of the two broken pieces and tightly twist them together, then put a little tape around the twisted pieces.

2. **Coils Not Placed Properly**. Double-check that the coils are properly aligned. The coils must alternate direction, otherwise they will cancel each other out. Look carefully at the stator template diagram, and make sure the leads coming out of the taped portions alternate between pointing toward the center and pointing toward the radius, and make sure the wires are connected as shown and do not cross. For your convenience, a smaller version of the diagram

- Germany is currently the number one producer of wind powered electricity in the world. As of 1999, Germany had 4,000 megawatts of installed wind capacity, as much as two large nuclear power plants. The United States has about 2,500 megawatts of installed wind capacity. Most "wind farms" in the USA are located in California, and they may have dozens, and in some cases thousands of windmills. The Netherlands and Denmark also have aggressive plans to increase wind power in their countries.
- Commercial sized wind electric generators can produce between 100,000 and 2 million watts of power, as compared with little PicoTurbine which produces only a fraction of a watt.
- Wind power has been used for thousands of years. Early designs were used in Mesopotamia to grind wheat. Grinding and pumping water were the two biggest uses of windmills before the $20^{th}$ century. Even today, thousands of water pumping windmills are used in the central and western portions of the USA, saving millions of tons of pollution and providing water in remote areas.
- There is enough wind in two states (Texas and Oklahoma) to produce all the electricity used in the entire USA if it were fully developed.
- Wind power and hydro-electric power are currently the only alternative energy sources that are clearly competitive in cost with fossil fuel electricity generation. Solar electricity is still more expensive than fossil fuel power generation. However, fossil fuels cause pollution, so renewable energy proponents argue there is a hidden cost that will be paid by future generations for burning fossil fuel, and this hidden cost makes renewable energy more economical in the long run.
- Currently, hydro-electric generation produces about 10% of all power in the USA, however there are few remaining sites that can be developed for major amounts of power. For this reason, wind power has more potential for future clean energy production in the USA than hydro.
- Wind and Solar power are very complementary renewable electricity sources, and are often used in combination for power in remote areas. For example, the sun is less intense in the winter, but wind is usually stronger in the winter (cold air is denser, leaves that block wind are not on trees in winter, etc.). The sun doesn't shine during rainstorms, but the wind is usually higher during storms.
- The United States has a goal to produce at least 2% of all electric power using Solar and Wind within 10 years. Some states have goals of 5%.
- Wind generators do not produce any chemical pollution, but they do produce some "noise pollution." For this reason, large commercial wind farms are usually placed away from heavily populated areas. Scientists are working to reduce the noise levels of the whirling blades (great strides have been made in the last 10 years).
- Some environmentalists have worried in the past that wind power may be dangerous to birds (which may be killed when flying into the whirling blades.) However, studies have shown that the severity of this problem has been overstated. Wind power produces no air pollution and has minimal impact on the environment compared to most other forms of power generation.

## *Classroom Experiments and Activities*

Here are some experiments and classroom ideas you can perform with PicoTurbine.

### Lung Power

If you have a multimeter that displays AC millivolts, you can have a lung power contest. Allow each child to puff on PicoTurbine from a distance of several inches for up to 10 seconds. The teacher watches the multimeter, and whatever the highest reading was during the 10 seconds is the score for that child. Best lung-power wins!

### Best Turbine

If several different PicoTurbine units have been built by a class, then you can have contests and award prizes. Some ideas are:

- Most electricity. Using a hair dryer and a multimeter, see whose model produces the most electricity under the same conditions. Make sure the dryer or fan is at the same distance for each contestant. If you don't have a multimeter, judge which machine lights the LED the brightest.
- Smoothest motion. The teacher judges whose model has the smoothest operation and least wobble when spinning.
- Lowest start-up speed. See whose model will start up in the lowest wind speed. This is judged by using a hair dryer set at different distances from the PicoTurbine. The PicoTurbine that spins with the dryer the farthest away is the winner (the wind speeds drops quickly with distance from the dryer).
- Best construction. The teacher judges whose machine is the neatest looking and most finely crafted.

- Best Blade Coloring. The teacher judges whose machine has the nicest blade coloring design. Clever designs might look interesting when turning, for example a “barber pole” stripe design. This contest is good for younger children in mixed age level settings.

### *Alternative Designs for PicoTurbine*

This section provides some design alternatives for PicoTurbine for experimenters and perhaps science fair projects.

#### Weatherproof PicoTurbine

PicoTurbine, as described in the main plans, is not weatherproof. The tape, glue, paper, and cardboard will quickly disintegrate in rain. Here are some ideas to produce a weatherproof PicoTurbine that can be left outdoors. It will be harder to build, but worth the effort. Adult supervision will be more necessary for this version of the project, especially if hot glue is used.

- Instead of tape and glue, use hot glue, or weatherproof tape. These can be purchased at hardware stores. Hot glue should only be used by adults.
- Instead of cardboard, use an old plastic CD for the rotor. You will need to build up the dowel using duct tape, a cork, or some other method because the hole in a CD is larger than the ¼ inch dowel thickness.
- Instead of paper, use a plastic soda bottle for the blades. Carefully cut the top and bottom off the bottle using scissors, leaving a four inch long cylinder with open top and bottom. Then cut this cylinder in half length-wise, resulting in two half-cylinders. Use hot glue to affix these blades to the top of the CD used as the rotor. A second CD hot glued on top of the blade set will provide further stability.

#### High Power PicoTurbine

To make a higher power version of PicoTurbine, follow these instructions:

- Make the Blade coverings 8 inches tall instead of 4 inches, perhaps using the cut-soda bottle idea above.
- Use a 1 foot long ¼ inch threaded rod instead of a wooden dowel. Obtain 6 nuts and 6 large washers to use to attach the rotor and blade supports.
- Use 6 magnets instead of 4. Equally space the magnets and remember to alternate north and south poles.
- Attach the magnets to a 1 gallon paint can lid. This provides a metal backing to the magnets and increases the magnetic field strength somewhat. Use hot glue to affix the magnets. Only adults should use hot glue! Carefully poke a center hole by using a ten penny nail and hammer over a piece of scrap wood. Be careful of jagged edges in the hole when attaching to the threaded rod.
- Use 6 coils instead of 4.
- This version produces about 4 times as much power. Warning: the LED can’t handle the voltage that will be produced. Obtain a 3-volt flashlight lamp. To use the LED, you must put a small resistor in series with the LED to limit the current, otherwise you will burn it out as well. Use about a 200 to 500 ohm resistor.

Additional parts for this project may be obtained locally or at the www.PicoTurbineInternational.com web site.

#### Alternative Blade Designs

As shown in this document, PicoTurbine uses a traditional “barrel offset” Savonius blade design. But, blades can be offset more or less. Also, the curved portion can be a shallower or deeper curve. Play around with the shape of the blade support parts and test these to see which is more efficient. This would make an excellent science fair project. It would even be possible for an advanced student to look up patented designs for Savonius wind turbines (that’s the kind PicoTurbine is) and do a study of which one is best. To do this, go to the website: http://www.uspto.gov (the US Patent and Trademark Office) and search for “Savonius”. You will get quite a few patents back. Look at the blade design described in the 1996 patent by Benesh. It claims to be much more efficient than the blade design used in PicoTurbine. Put it to the test!

## PART 3: Technical Notes

### *Introduction*

These technical notes may be useful for science fairs or for adult hobbyists and experimenters. Science background equivalent to high school level physics would be useful for some sections, but most don’t even require that.

## *Types of Wind Turbine*

There are four main types of wind turbine:

- Horizontal Axis Wind Turbine (HAWT) – Drag based
  This is the old “water pumper” wind turbine. It uses a many-bladed design to produce high torque for water pumping and typically uses flat blades. This is what most people picture in their minds as a “windmill”.
- Horizontal Axis Wind Turbine (HAWT) – Lift based
  This design uses lift, like an airplane wing, to produce torque. Most commercial designs have 2 or 3 blades. This type of turbine is far more efficient than the drag based HAWT.
- Vertical Axis Wind Turbine (VAWT) – Drag based
  This design is used in the PicoTurbine project. Specifically, the design is called the Savonius turbine, after its inventor, S. I. Savonius. It was invented in the 1920’s. It uses drag, like a cup anemometer, to produce torque. Because it is horizontal there is no need to have a mechanism to keep it turned into the wind.
- Vertical Axis Wind Turbine (VAWT) – Lift based
  This design uses lift, but is vertical in design. Examples include the Darrius “egg beater”. These designs are in commercial use, but no longer in widespread commercial production. There are several hundred still in use for commercial power generation in California and elsewhere. Again, because it is lift based, it is more efficient than the drag based VAWT. Darrius VAWTs are about as efficient as lift based HAWT designs.

## *Advantages and Disadvantages of Various Designs*

The table below lists advantages and disadvantages of these major types of wind turbine.

| Design | Advantages | Disadvantages |
|---|---|---|
| Drag based HAWT | • Simple blade structure<br>• High torque, good for applications like water pumping | • Low efficiency, not good for electricity production |
| Lift based HAWT | • Most commercial wind electric generators use this design because it is well understood.<br>• High efficiency: about 40% efficient, not too far from the theoretical limit of 59%.<br>• Relatively low material costs because blades are few (2 or 3 usually) and thin. | • Complexity is increased because the blades must be turned into the wind by a “yaw” mechanism.<br>• Alternator must be atop a tall tower, thus is hard to access for maintenance. |
| Drag based VAWT (Savonius) | • Easy to build (PicoTurbine is a Savonius VAWT)<br>• Few moving parts, no “yaw” mechanism needed<br>• Slow speed of rotation means parts don’t wear out as fast.<br>• Alternator is near ground level. | • Lower efficiency. Estimates range from 10% to 24% efficient as compared to 40% for lift based designs.<br>• More material needed to build, because the blades are totally covered. |
| Lift based VAWT (Darrius) | • Few moving parts, no “yaw” mechanism needed.<br>• High efficiency, about 40% efficient like lift based HAWT.<br>• Alternator is near ground level, so easy to service. | • Blades travel at near sonic speeds (500 to 600 miles per hour) and thus are under a lot of stress. Catastrophic failures have occurred.<br>• Design is less well understood.<br>• Not self-starting, requires starting mechanism. |

## *Notes on Wind Physics*

This section is for high school students and adult experimenters. Some parts require knowledge of high school level mathematics. Students building this kit for grade school level projects might want to skip this section.

### Power Available in the Wind

The power that is available in the wind depends on the wind speed, the density of the wind (which varies with altitude and temperature), and the amount of turbulence (swirling) in the wind. Turbulence is difficult to quantify, but in general it detracts from our ability to extract mechanical energy from the wind. For this reason, wind turbines are typically installed as far above ground level obstacles as possible, since trees and buildings both add to turbulence and detract from wind speed.

The power available at a given wind speed can be approximated by using the following formula:

$$P = \frac{1}{2} \rho v^3$$

Where:

- P is power in Watts per square meter of wind. Imagine a "window" one meter square through which the wind passes, P measures the power available sweeping through that window.
- ρ (Greek letter rho) is the density of air in Kilograms per cubic Meter.
- v is the velocity of the wind in meters per second. There are about 2.2 miles per hour in each meter per second.

The density of air at sea level and room temperature is approximately 1.3 kilograms per cubic meter. This is more than most people would guess. It means a cube of air a little more than one yard in each dimension would weigh just under 3 pounds.

Note that the power depends on the cube of the velocity. This means each time you double the wind speed you increase the available power by a factor of 8. The following table gives approximate power available for some common wind speeds (all values are rounded for ease of reading):

| Wind Speed (MPH) | Wind Speed (Meters/Second) | Wind Description | Power Available (Watts) |
|---|---|---|---|
| 2 | 1 | Very light, flags do not raise | Less than 1 |
| 5 | 2 | Small branches on trees move slightly | 5 |
| 10 | 4.5 | Leaves or papers are lifted off ground | 60 |
| 15 | 6.5 | Large branches move, flags flap vigorously | 175 |
| 20 | 9 | Trees sway | 475 |

As you can see, there is very little available power below 10 MPH, but as wind speed increases the power becomes very significant.

## How Much Power Can We Extract?

We cannot necessarily get at all the power in the wind. In the early 1900's a German researcher named Albert Betz reasoned that if you extracted all the energy from the wind then the air would stop moving near the wind turbine, and thus air coming in downstream would be blocked. Using an elegant argument based on conservation of momentum and conservation of energy, he derived that the most you can possibly extract is 59.25% of the available power. This is called the Betz limit. So, even though there are about 60 watts of power available per square meter in a 10 MPH wind, the best you can do is to extract about 35 watts.

In practice, no wind turbine has ever achieved the Betz limit. Most commercial turbines are about 40% efficient at converting wind to mechanical energy. Then, there are additional losses converting that mechanical energy to electrical power. The best alternators are about 90% efficient, there are also frictional losses in the drive train and bearings, and power conditioning losses. Overall, commercial machines end up being between 25% and 30% efficient.

Commercial wind turbines used for power production on a large scale sweep huge areas of wind. Sometimes the turbine blades are over 100 feet in diameter. In addition, they are placed in very windy places. Typically the average wind speed suitable for a "wind farm" would be at least 15 miles per hour. Small wind turbines used at homes and farms can operate successfully in places with average wind speeds as low as 9 miles per hour and typically have blades that are between 5 and 20 feet in diameter. About half of the continental USA has wind speeds high enough for successful small home or farm systems.

## *Notes on Alternator Physics*

This section is for high school students and adult experimenters. It requires some knowledge of high school level physics concepts.

## Voltage Produced by an Alternator

A permanent magnet alternator is simply a set of magnets moving relative to wires. Electric current is induced in the wires in a phenomenon that has been know since the days of Faraday. The voltage produced is alternating current (hence “alternator”) and follows a classic sine wave pattern. The level of maximum (peak) voltage produced is approximated by the following equation:

$$V_{max} = NARPB$$

Where:

- N is the number of loops of wire.
- A is the area enclosed by a loop of wire, in square meters.
- R is the rotational velocity of the magnets, in cycles per second.
- P is the number of magnet poles per cycle.
- B is the strength of the magnetic field of each pole, in Tesla.

The magnets used in PicoTurbine have an intrinsic strength of about 0.39 Tesla at the surface of a pole. However, there is an air gap between the magnets and the wire loops. The magnetic field intensity drops off very quickly in an air gap. If the air gap is around a quarter inch, then the field would be approximately 0.10 Tesla at the center of the coil. The area enclosed by a loop of wire in PicoTurbine is about 1.5 centimeters by 4 centimeters, or about $6.0 \times 10^{-4}$ square meters. PicoTurbine has 4 magnetic pole changes per cycle. It has 1,200 loops of wire.

Let’s say PicoTurbine spins at 9 cycles per second. Then, an estimate of the peak voltage would be:

$$\begin{aligned} V_{max} &= (1200 \text{ loops})*( 6.0\text{x}10^{-4} \text{ square meters})(9 \text{ cycles/sec})(4 \text{ magnet poles})(0.10 \text{ Tesla}) \\ &= 2.592 \text{ volts} \end{aligned}$$

However, this is the peak voltage. A digital multimeter in AC volts mode will display the root mean square (RMS) voltage. For a sine wave, this will be the peak voltage divided by the square root of 2 (about 1.41). So, a multimeter will read out about 2.6/1.41 or about 1.84 volts in this case. In practice, you will see somewhere between 1.5 and 2.2 volts depending on how well you have built PicoTurbine and precisely how fast its maximum speed is. Most critical is how small the air gap is, and how little “wobble” there is. A larger air gap will rob the magnetic field of strength, and wobble will make the conversion efficiency of the wind to mechanical energy lower.

## Amps and Power

The wire coils in PicoTurbine have a total resistance of about 30 ohms. Amperage is voltage divided by resistance. So, if we get 2.0 volts RMS, then we expect about 2.0/30 = about 66 milliAmps.

Power is voltage times amps. So, power would be about 2.0 * 0.066 = 132 milliwatts, or about a sixth of a Watt. However, this is the power with no load. The maximum power that can be output by an alternator occurs when the load resistance is equal to the internal resistance. So, if we put a 30 ohm load on PicoTurbine, it would actually only deliver about 1/12 Watt overall, and only half of that would actually make it out to the load. The rest would dissipate as heat in the PicoTurbine coils.

## Rectification to DC

PicoTurbine produces AC power. AC power is fine for things like lights or heating elements, but DC is needed for most electronic devices. PicoTurbine can be made to produce DC by feeding its output through a diode. Because diodes cause a further voltage drop, and we are already dealing with small amounts of voltage, we must choose a diode with very little drop. A proper choice would be either a germanium diode or a Schotky diode, each of which have drops below a half volt. The output must further be smoothed out using a capacitor because it follows a sine wave and we need a steadier current. In fact, several capacitors and diodes would be used in a real rectifier circuit.

To do experiments with DC power, you can obtain the PicoTurbine-DC kit at http://www.PicoTurbineInternational.com. That kit includes diodes, capacitors, and a solderless breadboard along with other items to help you perform DC and AC experiments using PicoTurbine’s power, with easy to understand explanations of the concepts.