Power In the Wind II

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Create It Lab!

Power In the Wind II

- A program jointly developed by *Williston Central School (Williston, Vermont)* and *Make It Science,* working in conjunction with the *IBM Technical Education Outreach* program.

Goal: **To enhance Middle School STEM education**

In such a way that

all students are motivated

So that

they are better prepared to manage

Design/Build challenges in high school…

…and in the real world

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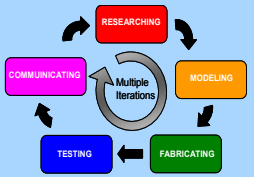
Power In the Wind II

Educational Design Components:

(1) Motivate with Hands-on Demos & Activities exploring Electricity & Magnetism

(2) Engage nearly all students by integrating the **A**rts into **STEM** => **STEAM**

(3) Introduce the Design Cycle as the form of the Scientific Method for Project-based Learning



(4) Coach students through Brainstorming and Design Focusing exercises

(5) Provide real-world application of Mathematics

$P = I * V$

Power In the Wind II

Educational Objectives

(1) To contribute to the WCS **STEM* curriculum**

(2) To provide a **STEAM* unit** which can be adapted for grades 6-12

(3) To Introduce students to the **science and technology of wind turbines**

(4) To transfer understanding of the interaction of **electricity & magnetism**

(5) To connect wind power to **energy concepts**

(6) To introduce the students to the **Design Cycle** as a form of the Scientific Method

(7) To coach the students through **brainstorming** and **design focus** exercises

(8) To **engage all the students**, not just those interested in math and science

Wind Turbine with milk-carton blades

*Science – Technology – Engineering - Arts – Mathematics

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Power In the Wind II

Scaffolding:

(1) Wind power history, artistry & issues
(2) Energy concepts & wind energy sources
(3) Exponents and metric prefixes
(4) Unit conversion using conversion factors
(5) Basic Electricity

Sessions

(1) E & M: Mag Slide, Ring Flinger, Coin Launcher
(2) E & M: Speakers & Ribbon Generator
(3) E & M: Motors, Generators & Muffin Fans
(4) Project: The Challenge & The Design Cycle
(5) Design: Brainstorming & Design Focusing
(6) Build: Turbine blade construction and testing
(7) Optimize: Blade optimization & Power Measurement
(8) Finalize: Prepare Presentations
(9) Presentations & Awards: Championship Team in each class

Wind Turbine with pinwheel blades

Power In the Wind II

Scaffolding

Chesterton Windmill shut due to repair work
http://www.bbc.co.uk/news/uk-england-coventry-warwickshire-14748757

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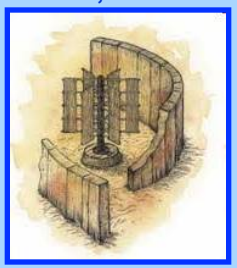
Power In the Wind II - History

EGYPT, 3500 BC

http://factsanddetails.com/world.php?itemid=1928&catid=56&subcatid=365

PERSIA, 600 AD



http://holytrinity.faithweb.com/p-on-Ecology/w01-aioliki.htm

VERMONT, 1941

http://www.yorkblog.com/yorktownsquare/2009/01/05/gordon-freierichs-windmill/

NASA, 1978

http://en.wikipedia.org/wiki/NASA_wind_turbines

BELGIUM

http://en.wikipedia.org/wiki/Wind_microturbine#Small_wind_turbines

BCE 3745	3500 BCE	First Sailboat, Egypt
BCE 865	200 BCE	Windmill Pumps, China
AD 575		Wind Grist mills,Persia
AD 1295		Windmills in Europe Hor. Axis Windmills
AD 1655		6 million Winmills in USA
AD 1835		1st Elec. Gen. Windmill
AD 1925		Windmill Turbines spread Vert. Axis Windmills 100kW Turbine in USSR 1250 kW Turbine in VT 3-Blade Turbine in DK
AD 1970		2M, 2-Blade Turbine
AD 2015		Wind Power=24.8 GW 1st Offshore Wind Farm Wind Power=159 GW

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Power In the Wind II - Art

Le Moulin De La Galette V
by Vincent Van Gogh

Le Moulin de Blute-Fin
by Vincent Van Gogh

Le Moulin De La Galette VII
by Vincent Van Gogh

Le Moulin de la Galette I
by Vincent Van Gogh

Field Of Tulips In Holland
by Claude Oscar Monet

A Windmill Near Zaandam
by Claude Oscar Monet

Windmill
by Pierre Auguste Renoir

http://www.1st-art-gallery.com/Architecture/Windmills-13.html

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Power In the Wind II

Power Generation Issues

Power Generation Issues		WIND	Nuclear	Oil	Coal	Natural Gas
Technology Challenges	Efficiency					
	Transmission					
	Infrastructure					
Ecological Factors	Pollution					
	Global Warming					
	Wildlife					
	Sound					
Landscape Impact	View					
	Tourism					

Power In the Wind II – Science

Energy Concepts

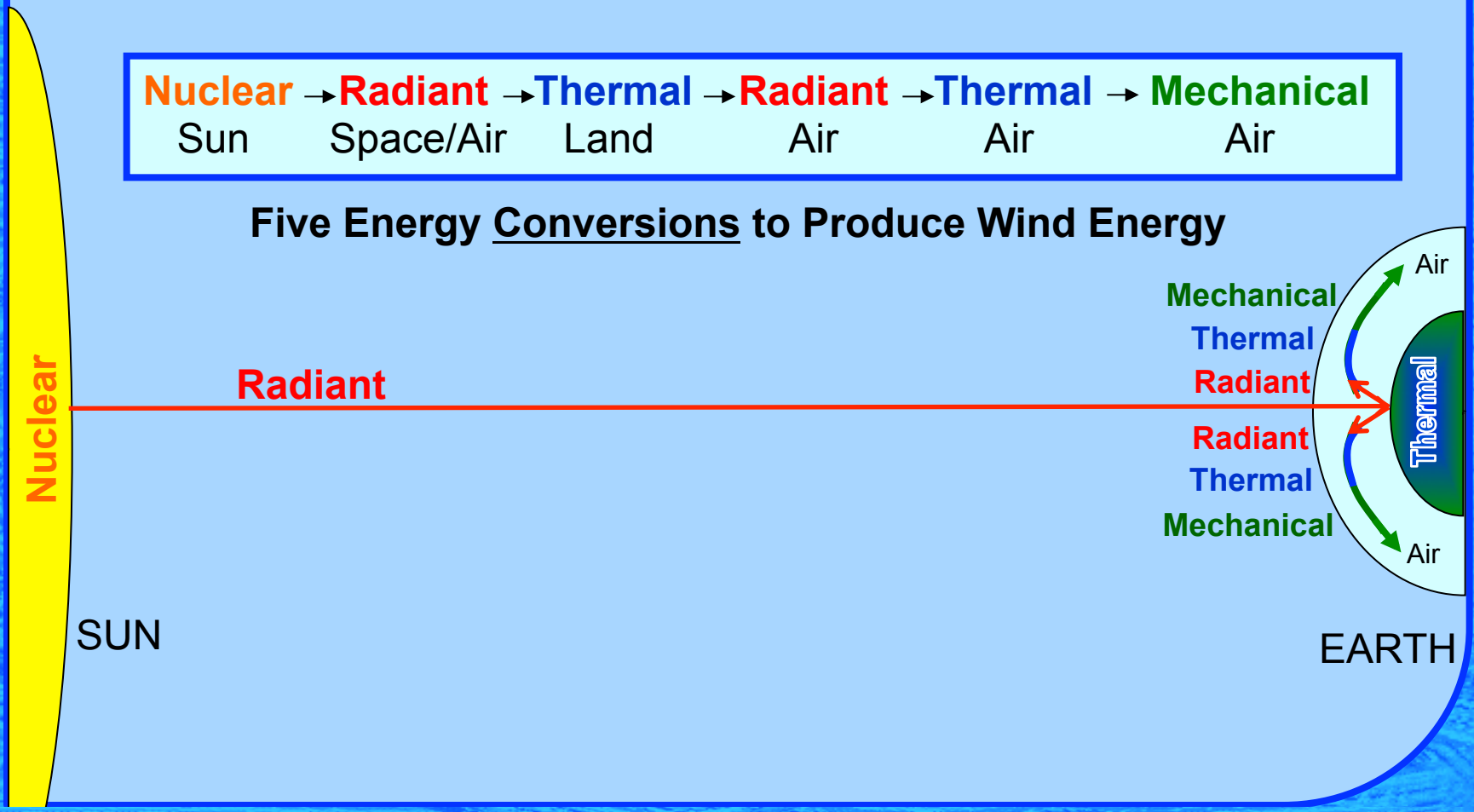
Kinetic Energy **Motion** of waves, electrons, atoms, molecules & substances	**Potential Energy** **Stored** energy and the energy of position
Radiant Energy Energy traveling in electromagnetic waves	**Chemical Energy** Energy stored in the bonds of atoms and molecules
Thermal Energy Heat: energy of vibration of atoms and molecules	**Nuclear Energy** Energy stored in the nucleus of an atom
Mechanical Energy Energy of substances in motion (e.g., wind energy)	**Stored Mechanical Energy** Energy stored in objects by application of a force (e.g., compressed springs)
Electrical Energy Energy of electrons in motion	**Static Electrical Energy** Energy difference due to position in an electric field
	Gravitational Energy Energy differences due to position in a gravitational field
	Magnetic Energy Energy differences due to position in a magnetic field

Power In the Wind II - Science

The Source of Wind Energy

Nuclear →	Radiant →	Thermal →	Radiant →	Thermal →	Mechanical
Sun	Space/Air	Land	Air	Air	Air

Five Energy Conversions to Produce Wind Energy



Power In the Wind II - Science
The Source of Wind Energy

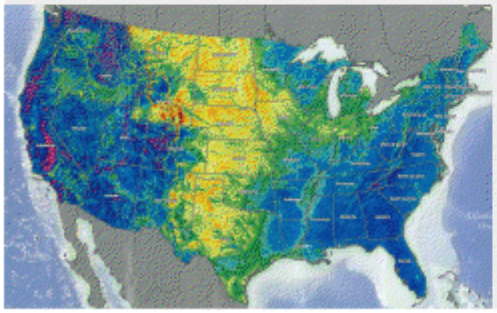
Related Topics

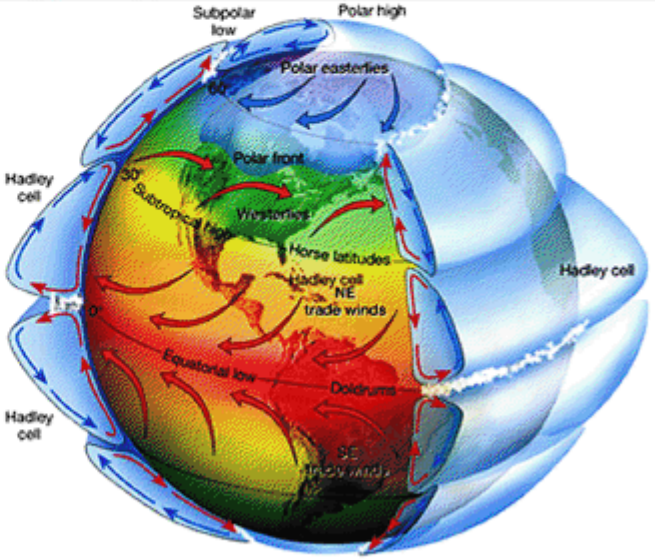
- Heat Conduction, Convection, Radiation
- Earth Axis Tilt & Differential Heating
- Air Pressure & Temperature
- Land & Sea Breezes

Power In the Wind II

Wind Overview

- **Wind Speed Varies with Time**
  - Probability Distribution
- **Wind Speed Varies with Height**
  - Hub Height is Interesting
- **Important Averages**
  - Annual
  - Extreme (3-second)





Northern Power Systems

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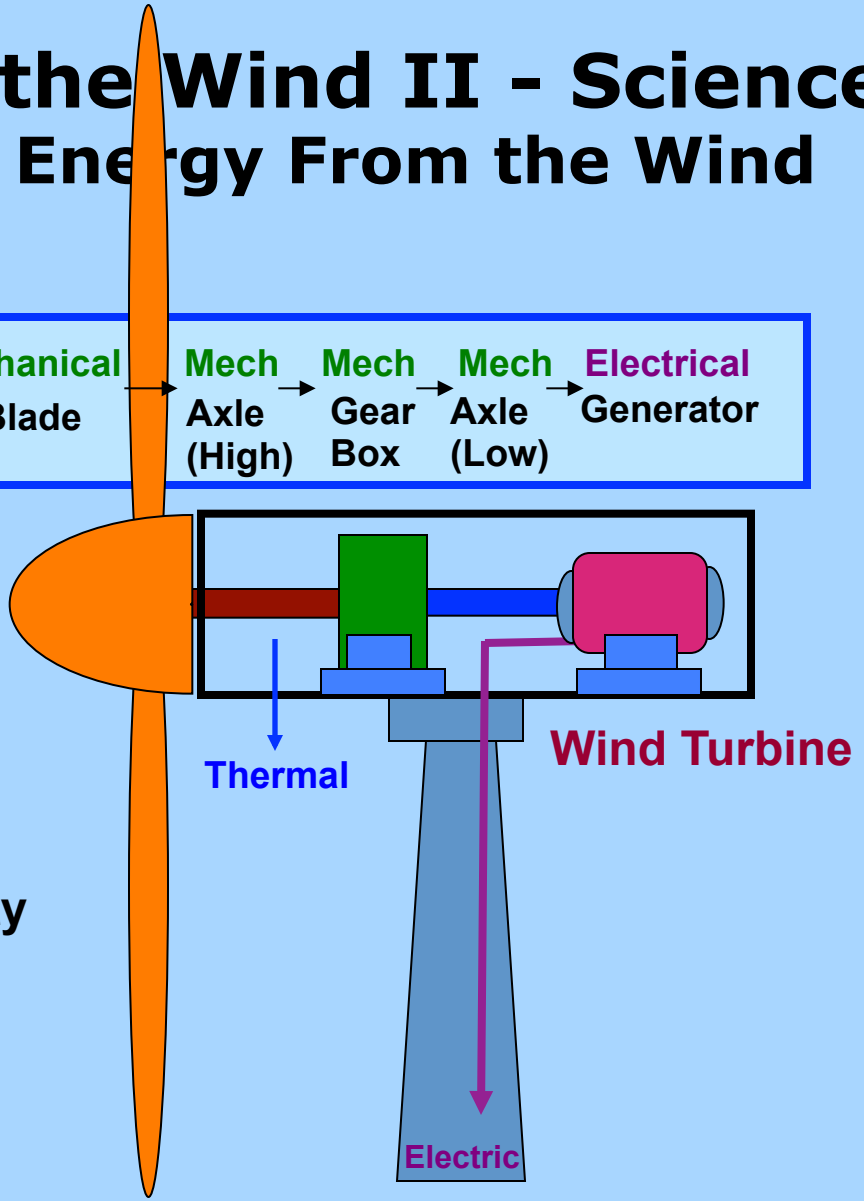
Power In the Wind II - Science
Electrical Energy From the Wind

Mechanical Wind → Mechanical Blade → Mech Axle (High) → Mech Gear Box → Mech Axle (Low) → Electrical Generator



Many Mechanical Energy Transfers And at Least One Energy Conversion to Produce Electricity

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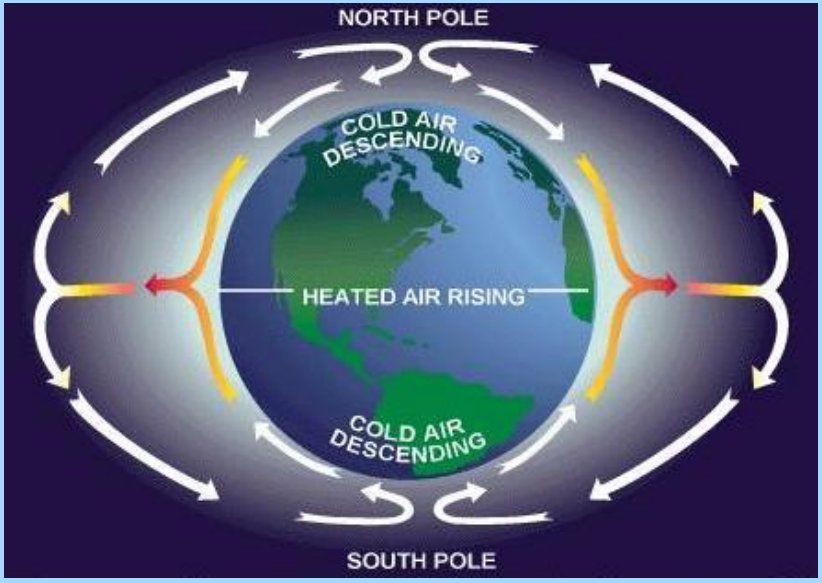
Power In the Wind II - Science
The Source of Wind

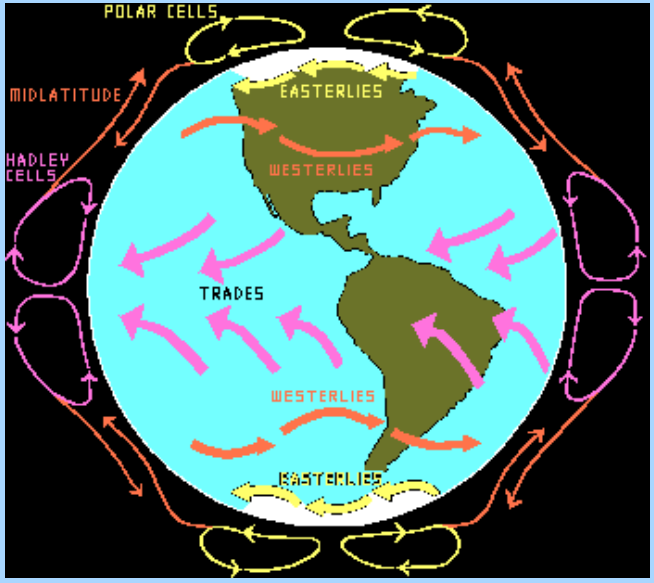
Non-Rotating Earth



If the Earth did not rotate, solar heating at the Equator would cause the air to circulate uniformly

http://avstop.com/AC/5-3.html

Rotating Earth



The rotation of the Earth breaks the air flow into three zones: Equatorial, Polar and Temperate Zones

http://www.noao.edu/education/gsmt/weather

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Power In the Wind II - Science

Max Wind Power Efficiency - Betz's Law

"**Betz's law means that wind turbines are limited to 59.3% efficiency.** …if all of the energy coming from wind movement into the turbine were extracted as useful energy then the wind speed afterwards would drop to zero. If the wind stopped moving at the exit of the turbine, then no more fresh wind could get in - it would be blocked. In order to keep the wind moving through the turbine there has to be some wind movement, however small, on the other side with a wind speed greater than zero".

"Practical utility-scale wind turbines achieve at peak 75% to 80% of the Betz limit".

http://en.wikipedia.org/wiki/Betz'_law

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Power In the Wind II - Math

Metric Prefixes

Symbol	Prefix	Multiplication Factor	
E	exa	10^{18}	1,000,000,000,000,000,000
P	peta	10^{15}	1,000,000,000,000,000
T	tera	10^{12}	1,000,000,000,000
G	giga	10^{9}	1,000,000,000
M	mega	10^{6}	1,000,000
k	kilo	10^{3}	1,000
h	hecto	10^{2}	100
da	deka	10^{1}	10
d	deci	10^{-1}	0.1
c	centi	10^{-2}	0.01
m	milli	10^{-3}	0.001
μ	micro	10^{-6}	0.000,001
n	nano	10^{-9}	0.000,000,001
p	pico	10^{-12}	0.000,000,000,001
f	femto	10^{-15}	0.000,000,000,000,001
a	atto	10^{-18}	0.000,000,000,000,000,001

Most Used

"Intro to Chemistry", Antrannik, 04/26/12, http://antranik.org/intro-to-chemistry/

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Power In the Wind II - Math
Conversion Factors

QUESTION:

What is the simplest way to convert the units of a quantity and be sure you get the correct answer?

ANSWER: Multiply by Unity Fractions!!!

EXAMPLE:

If light travels about 299700000 meters per second in air (2.997×10^8 m/s), how many feet does it travel in 1 nanosecond (1 ns = 10^{-9} s)?

ANSWER: Multiply the speed by unity factors that convert the units to ft/ns:

$$\text{Speed of Light in Air} = \left[\frac{2.997 \times 10^8 \text{ m}}{1 \text{ s}}\right]\left[\frac{39.37 \text{ in}}{1 \text{ m}}\right]\left[\frac{1 \text{ ft}}{12 \text{ in}}\right]\left[\frac{10^{-9} \text{ s}}{1 \text{ ns}}\right] = \left[\frac{0.98326 \text{ ft}}{1 \text{ ns}}\right]$$

Speed

Unity Fractions

btw… this means light travels about 1 foot per nanosecond!

Power In the Wind II

Sessions: Demos & PBL

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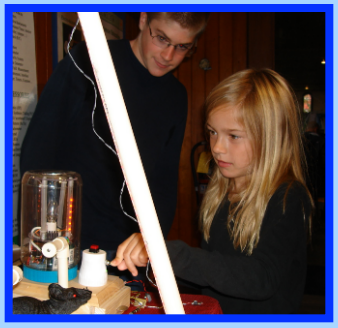
Power In the Wind II

Hands-on Demos:

- Electricity
- Speaker Thing
- Ring Flinger
- Coin Launcher
- Mag Slides
- Motors & Generators



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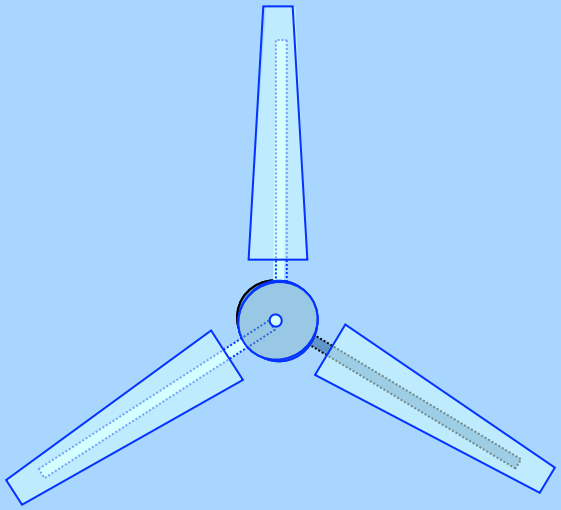
Power In the Wind 2

THE CHALLENGE !



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Power In the Wind II
The Challenge

Design & Build:

- A turbine blade for maximum power output
- Constructed of recycled or low-cost materials (not metal)*
- Aesthetically pleasing appearance
- The design can not be a pinwheel

Test: Measure & record windspeed and output power for optimum designs

Communicate: Document your project in a 10 minute presentation

- Document the design goals & the design & build process used for your turbine blades
- Describe the blades you designed, including the artistic design elements & dimensioned diagrams
- Discuss the energy transfers & conversions for your turbine (air flow to electricity)
- Include data tables, plots and photos
- Discuss the effect of varying 1 variable (# blades, blade length, width, curvature, etc.)
- Make conclusions regarding the output power, efficiency & aesthetics of your designs

* Sample Materials:

Milk Cartons	Nuts & Bolts	Film Canisters
BIC pens	Paper Towel Rolls	Paper or Foam Plates
Cardboard	Brass Fasteners	Popsicle Sticks
Card Stock	Paper & Binder Clips	Chop Sticks

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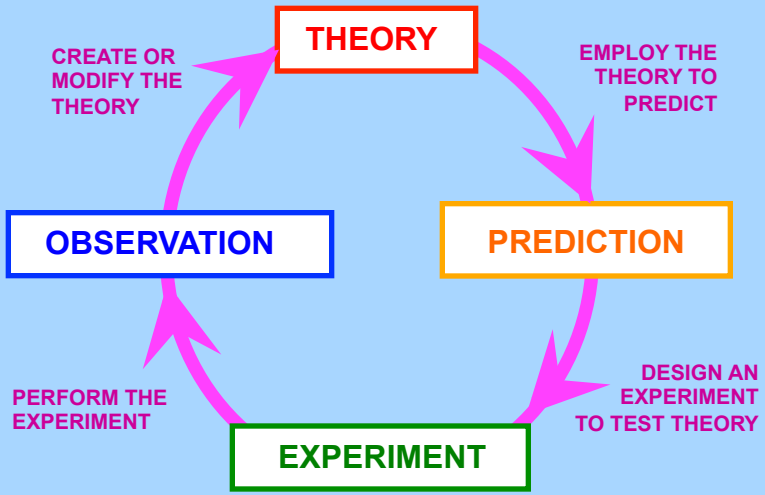
Power In the Wind II

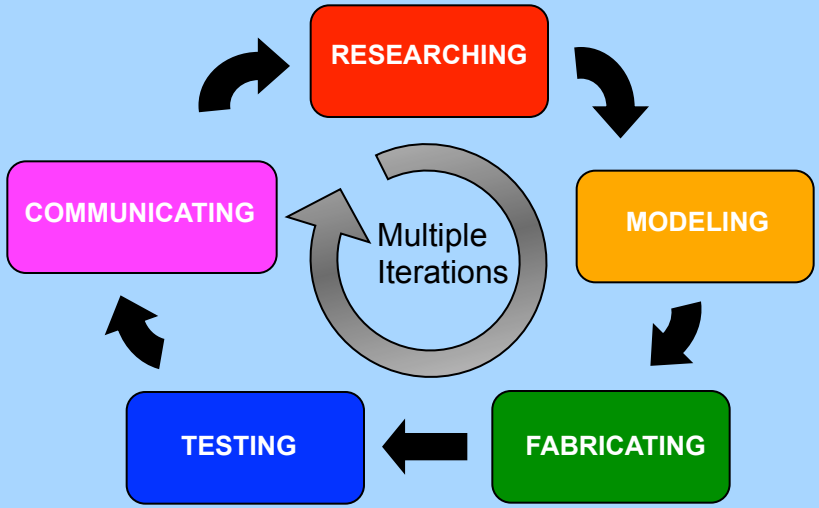
Design Cycle !

Scientific Method(1)



(1) http://www.tomatosphere.org/teacher-resources/teachers-guide/principal-investigation/scientific-method

Design Cycle(2)



(2) Product Design Funda!, Importance of Research in Engineering Design, 4/23/12, http://www.productdesignfunda.com/technology/importance-of-research-in-engineering-design

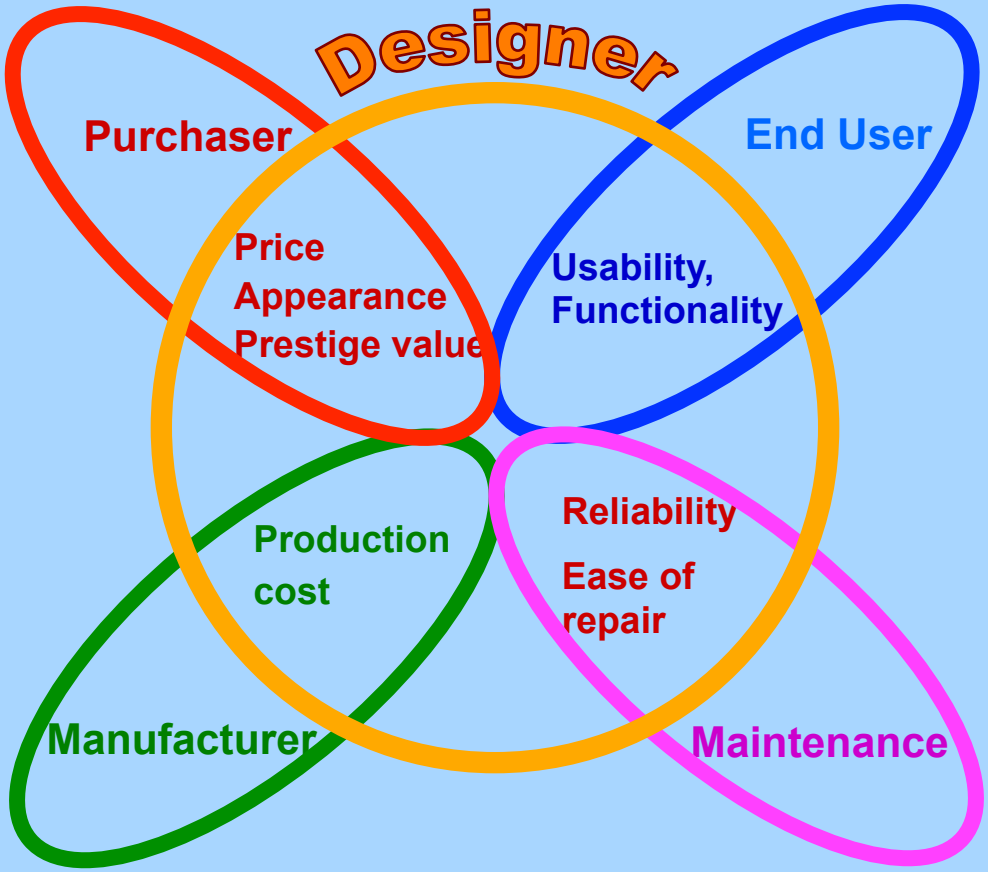
- **The Design Cycle is a natural fit for Project-based Learning**

Power In the Wind II

Design Considerations

Tesla Roadster

- Prestige
- Appearance
- Functionality
- Usability
- Reliability
- Ease of Repair
- Production cost
- Price



2007 Ford E-450

- Functionality
- Usability
- Reliability
- Ease of Repair
- Appearance
- Production cost
- Prestige
- Price

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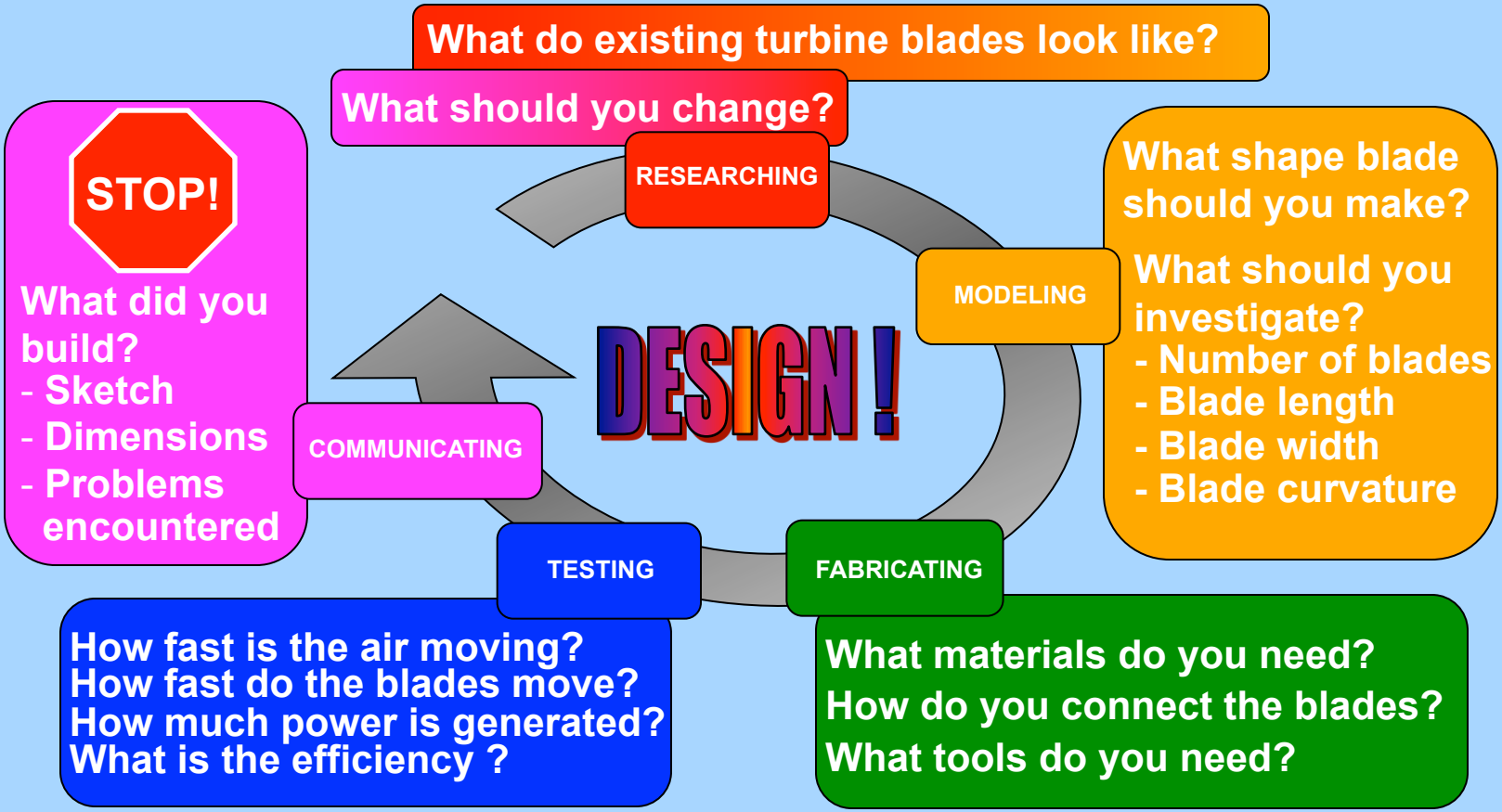
Power In the Wind II
Turbine Blade Design



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Power In the Wind II

Brainstorming !

Question: What features would make your turbine blade the best?

Materials & Connector Considerations:

- **Weight**
- **Strength**
- **Shape**
- **Size**
- **Appearance**
- **Cost**

What would make the best turbine blade?

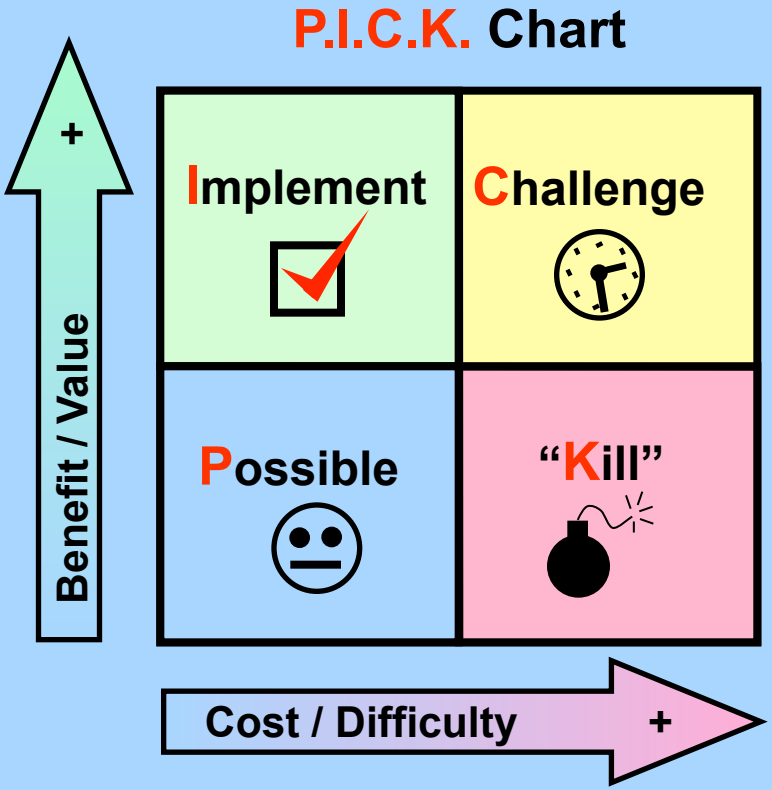
- Functionality (Does it work?)
- Ease of Use (Is it easy to use?)
- Quality (Does it work well?)
- Reliability (Will it last?)
- Artistry (Is it aesthetically pleasing?)
- Safety (Can it cause injuries?)
- Portability (Can it be easily moved?)
- Features (Does it do what you want?)
- Maintainability (Is it easy to maintain?)
- Cost (How expensive is it?)

Power In the Wind II

Design Focus

Question: What is the value and the difficulty for each idea?

Difficulty Considerations:
- Methods (how)
- Machines (equipment)
- People (personpower)
- Materials
- Cost Adder
- Environment



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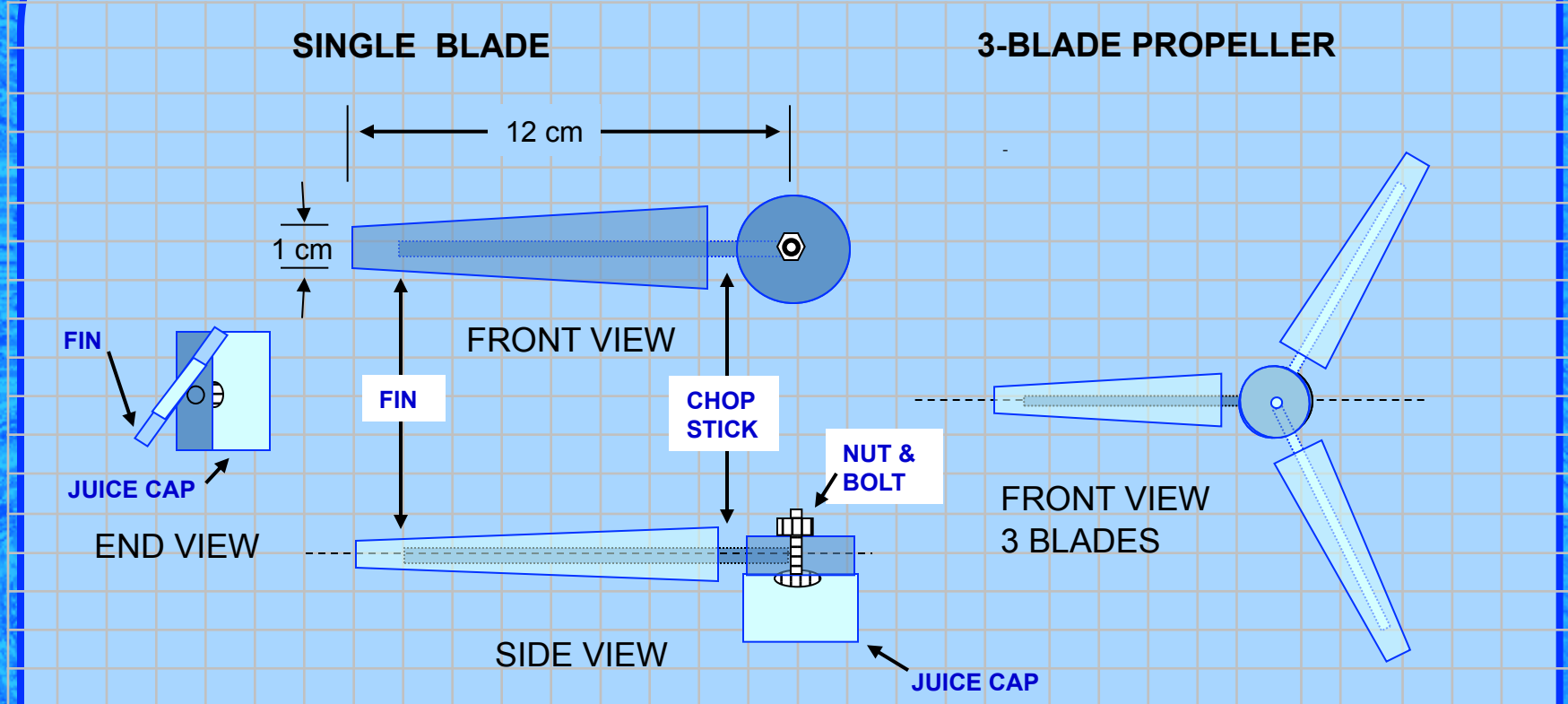
Power In the Wind II - Diagram



Design Name: Chinook
Team The Tempestuous Typhoons

Design Version: 2
Date: 5/4/12

Power In the Wind II
Fabrication Skills

Sawing Wood

Drilling Holes

Safely Teaching Fabrication Skills

Tool	Student	Volunteer
Utility knife ?	Yes?	YES
Scissors & tape	YES	YES
Drill Stand	**Heavily supervised**	
Screwdriver & nutdriver	YES	YES
Hot Glue	**Heavily supervised**	

Collaboration with Music & Art Departments may be desirable

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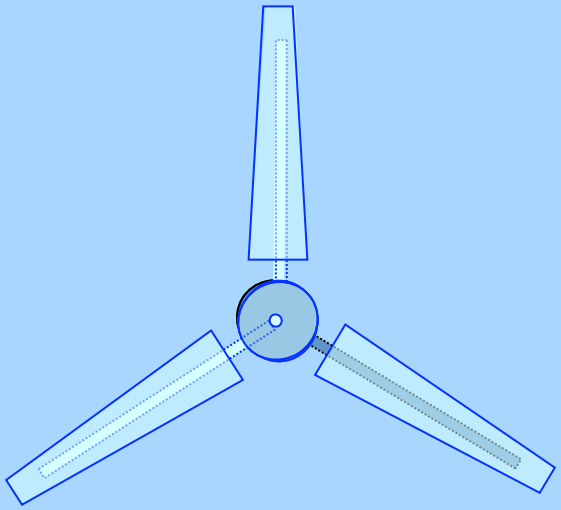
Power In the Wind 2

EQUIPMENT & MEASUREMENTS !



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Power In the Wind II - Equipment

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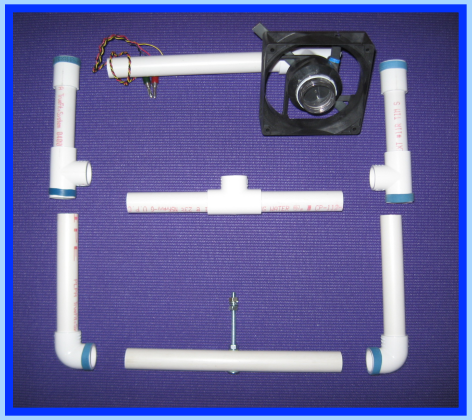
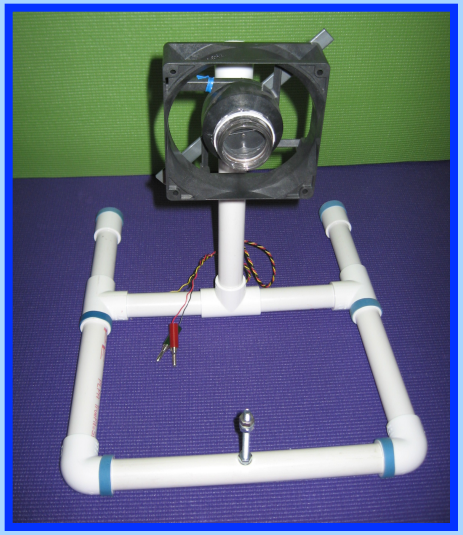
Power In the Wind II – Turbine Assembly



(1) Layout base

(2) Connect short pipes

(3) Complete base



(4) Add turbine tower

(5) Place multimeters

(6) Plug LED into meters

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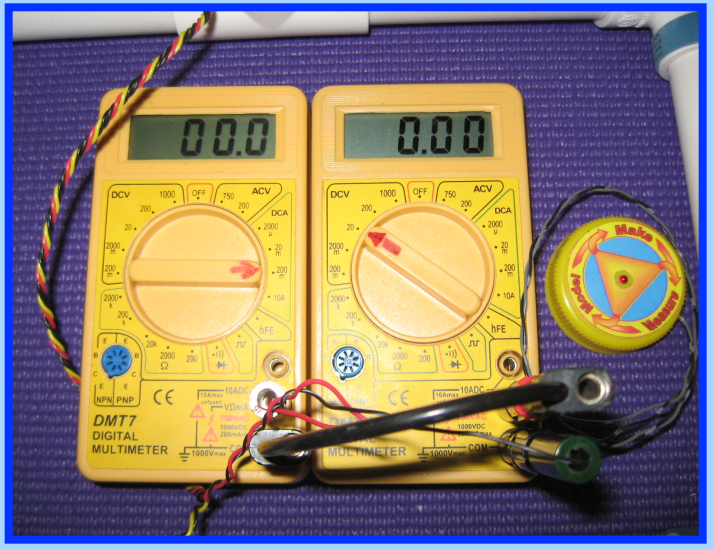
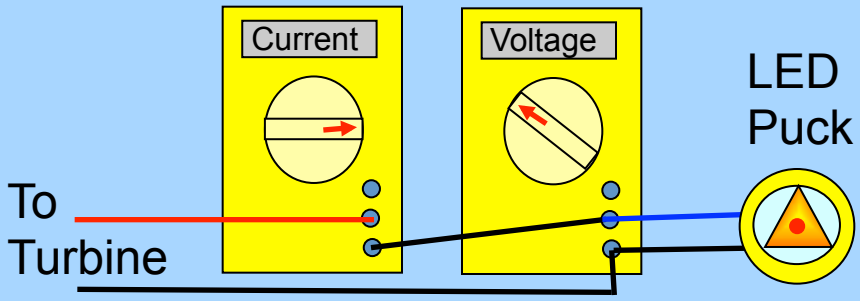
Power In the Wind II – Measurements

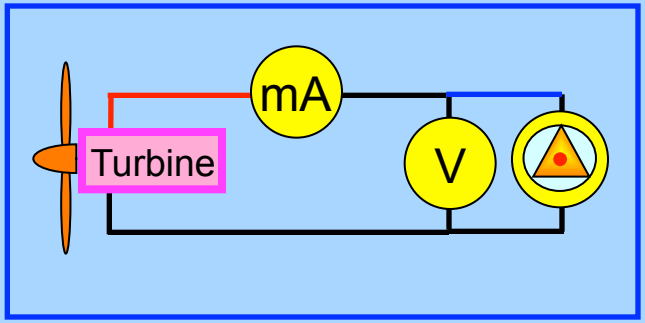
(7) Insert connector wire

(8) Plug in turbine



(9) Set left multimeter to 200 mA
Set right mutlimeter to 20 V





Power = Current x Voltage

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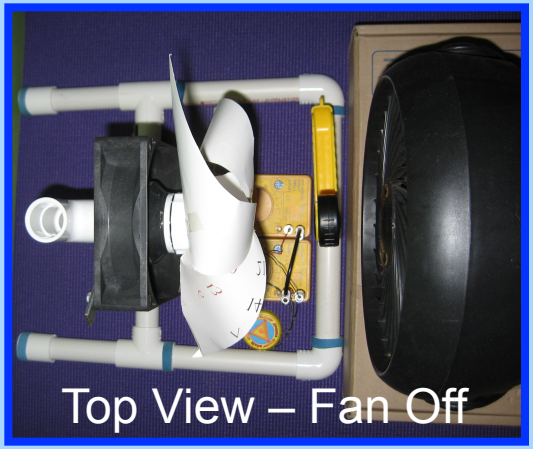
Power In the Wind II – Turbine Assembly

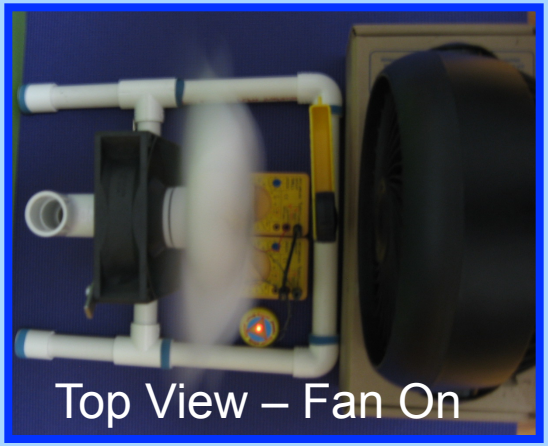
(10) Add anemometer,

(11) Add blade,

(12) Add fan stage and

(13) Add fan





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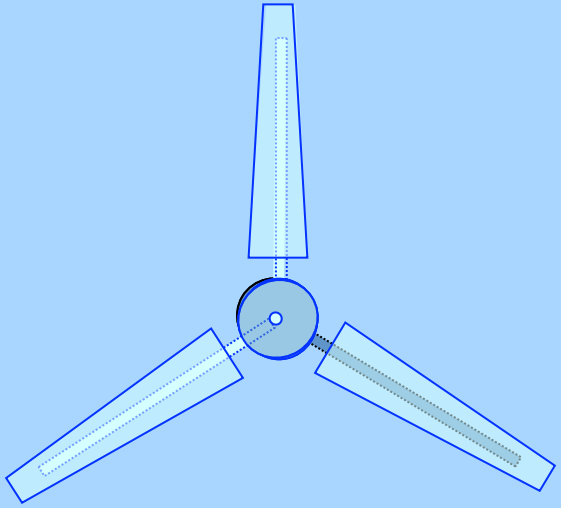
Power In the Wind 2

DATA & CALCULATIONS



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Power In the Wind II
Initial Data Sheet - Example

Blade # 1: Wind Whisperer						
Trial #	**Air Speed (m/s)**	**Voltage (V)**	**Current**		**Power (W)**	**Comments (Modifications, Problems, etc.)**
			(mA)	**(A)**		
1	5					
2	5					
3	5					
4	5					
5	5					
6	5					
7	5					
8	5					
9	5					
10	5					

Power in Watts = Current in Amps X Voltage in Volts

Current = ____ milliAmp x $\left[\frac{1\ A}{\_\_\_\_\ mA}\right]$ = ____ Amps

Power In the Wind II - Math

Efficiency: Sample Calculation

$$\text{Efficiency} = \frac{\text{Electric Power Out}}{\text{Air Power In}} = \frac{\text{Voltage x Current}}{\text{Air Density} \times \text{Blade Diameter}^2 \times \text{Air Speed}^3 \times \frac{\pi}{4}}$$

Air Density = 1.29 kilograms / meter^3
Blade Diameter = ____meters
Air Speed = ____ meters/second
Voltage = ____V

Unity Fraction

Current = ____milliAmp X $\left[\frac{1\ A}{\quad mA}\right]$ = ____ Amps

Efficiency = _____ = _____ = _____ %
_____

Theoretical maximum = 59 %

Power In the Wind II - Math

Efficiency: Sample Calculation

$$\text{Efficiency} = \frac{\text{Electric Power Out}}{\text{Air Power In}} = \frac{\text{Voltage x Current}}{\text{Air Density} \times \text{Blade Diameter}^2 \times \text{Air Speed}^3 \times \frac{\pi}{4}}$$

Air Density = 1.29 kilograms / meter^3
Blade Diameter = 0.25 meters
Air Speed = 5 meters/second
Voltage = 1.5 V

Unity Fraction

$$\text{Current} = 30 \text{ milliAmp} \times \left[\frac{1 \text{ A}}{1000 \text{ mA}}\right] = 0.03 \text{ Amps}$$

$$\text{Efficiency} = \frac{1.5 \times 0.030}{1.29 \times 0.25^2 \times 5^3 \times 3.14159 / 4} = 0.0057 = 0.57\ \%$$

Theoretical maximum = 59 %

Turbine improvements needed!

Power In the Wind II

Final Data Sheet - Example

Blade # 5: Air Foil of Power				Blade Diameter: _____		
Trial #	**Air Speed (m/s)**	**Voltage (V)**	**Current**		**Power (W)**	**Efficiency (%)**
			(mA)	**(A)**		
1						
2						
3						
4						
5						
				Average:		
				Maximum:		

$$\text{Efficiency} = \frac{\text{Electric Power Out}}{\text{Air Power In}} = \frac{\text{Voltage x Current}}{\text{Air Density} \times \text{Blade Diameter}^2 \times \text{Air Speed}^3 \times \frac{\pi}{4}}$$

Air Density = 1.29 kilograms / meter^3

Create It Lab!

Power In the Wind II

How Many Mini Turbines Are Needed To Provide Energy for a House For 1 Day?

The POWER produced by a mini turbine in kilowatts (kW) is given by :

$$\left[\frac{\#\ kW}{1\ Turbine}\right] = \left[\frac{\_\_\_\_\ W}{1\ Turbine}\right] \times \left[\frac{1\ kW}{1000\ W}\right] = \frac{\_\_\_\_\_\ kW}{Turbine}$$

The daily ENERGY from a mini turbine in kiloWatt-hours (kW-h) :

[ENERGY Produced] = [POWER Produced] x [Run TIME]

$$\left[\frac{\#\ kW\text{-}h}{1\ Turbine}\right] = \left[\frac{\_\_\_\_\ kW}{1\ Turbine}\right] \times [\ 24\ hours\ ] = \frac{\_\_\_\_\_\ kW\text{-}h}{turbine}$$

The number of mini turbines required for a typical US house :

Note : The daily ENERGY consumption for a typical US house is about $\frac{32\ kW\text{-}h}{1\ House}$

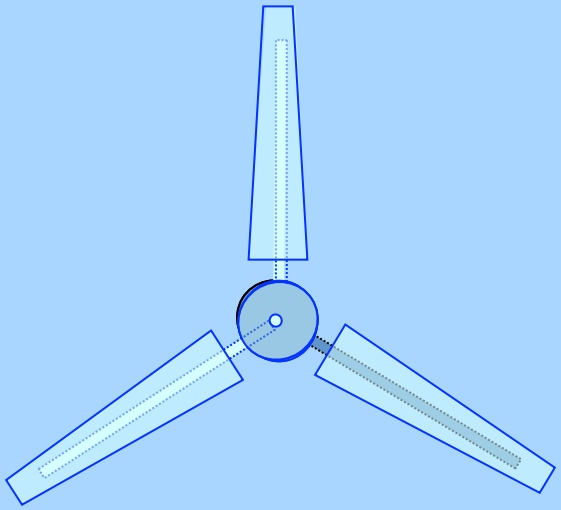
$$\left[\frac{\#\ Turbines}{1\ House}\right] = \left[\frac{1\ Turbine}{\_\_\_\_\ kW\text{-}h}\right] \times \left[\frac{32\ kW\text{-}h}{1\ House}\right] = \frac{\_\_\_\_\_}{Turbines\ House}$$

ANSWER: _____ Mini Turbines

Create It Lab!

Power In the Wind 2

PRESENTATION !



Make It Science and IBM Systems & Technology,
Williston Central School, Williston, VT

Power In the Wind II

Presentation !

Document your project in a 10 minute presentation to a panel of judges. In your presentation you should:

- Document the design goals and the design & build process used for your turbine blades
- Describe the blades you designed, including the artistic design elements and dimensioned diagrams
- Discuss the energy transfers & conversions for your turbine (from air flow to electricity generation)
- Include data tables, plots and photos
- Discuss the effect of varying at least 1 variable (Number of blades, blade length, width, curvature, etc.)
- Make conclusions regarding the output power, efficiency and aesthetic appeal of your designs

Create It Lab!

Power In the Wind II

Assessment Rubric

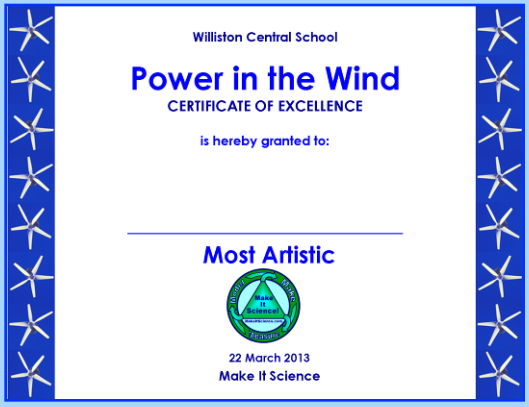
Content	4	3	2	1
Energy Concepts	Design illustrates thorough understanding of energy conversion and transfer.	Design illustrates accurate understanding of most concepts.	Design illustrates a limited understanding of concepts.	Design illustrates inaccurate understanding of concepts.
Design Inquiry	Develops & conducts Investigations.	Follows procedures accurately, begins to design investigations.	Does not conduct an inquiry completely.	Needs significant support to conduct an inquiry.
Data	Comprehensive data collected & thorough observations made. Diagrams, tables & graphs are used appropriately	Necessary data is collected. Diagrams, tables & graphs are used appropriately most of the time.	Some data is collected, but design depends more on observation.	Data and/or observations are missing or inaccurate.
Design Originality	Design shows much original thought. Features are creative and inventive.	Design shows some original thought and insights.	Design provides required functionality, but little evidence of original thinking.	Design provides required functionality, but no original thought.
Design Aesthetics	Aesthetics were planned as an integral part of the design. Color and space were used effectively.	Color and space were used effectively, but aesthetics was not an integral part of the design.	Artwork was applied to the design, but there is little evidence of planning.	No attempt was made to improve the aesthetics of the design.
Presentation Content	Clearly stated design goal and description of design. Conclusion is supported by evidence.	Design goal and description of design is provided. Conclusion is supported by some evidence.	Design goal and/or design description unclear. Conclusion stated but not supported.	Design goal, design description or conclusion Missing.
Presentation Organization	Content is very well organized and presented in a logical Sequence.	Content is logically presented.	Content is logically organized with a few confusing sections.	There is no clear organizational structure, just a compilation of facts
Teamwork	The workload is divided and shared equally by all members of the group.	The workload is divided and shared fairly equally by all group members.	The workload is divided, but one person is viewed as not doing a fair share.	The workload is not divided, or several members did not do a Fair share of the work.

Create It Lab!

Power In the Wind II Awards!

Team “We in Da Nuc”

Team “Ventus”



Sample Certificate

Award Certificates

Class Champions
Most Artistic
Best Engineering
Most Entertaining
Best Teamwork
Most Creative
Greatest Perseverance

Chocolate Windmills!