The Winds of Change

Concept Statement: *Wind energy can be converted into a useful form, such as electricity, using wind turbines. The amount of energy that is available increases with wind speed.*
List of Materials Needed:

Each of the following is required per group:
- Anemometer (1)
- Wind Turbine (1)
- Digital Multimeter (1)
- Ruler (1)
- Fan (1)

Each of the following is required per student:
- Calculator (1)

Activity Time Frame:
This is a full-day activity, and shall take approximately six (6) hours to complete.

Environmental Settings:
This beginning of this activity shall be conducted indoors. The authentic assessment shall be conducted outdoors, at the top of a tall building.

PASS Standards:
Science Processes and Inquiry: Physical Science

Process Standard 1: Observe and Measure
1. Identify qualitative and quantitative changes given conditions (e.g., temperature, mass, volume, time, position, length) before, during, and after an event.
2. Use appropriate tools (e.g., metric ruler, graduated cylinder, thermometer, balances, spring scales, stopwatches) when measuring objects and/or events.
3. Use appropriate System International (SI) units (i.e., grams, meters, liters, degrees Celsius, and seconds); and SI prefixes (i.e., micro-, milli-, centi-, and kilo-) when measuring objects and/or events.

Process Standard 2: Classify
1. Using observable properties, place an object or event into a classification system.
2. Identify the properties by which a classification system is based.

Process Standard 3: Experiment
1. Evaluate the design of a physical science investigation.
2. Identify the independent variables, dependent variables, and controls in an experiment.
3. Use mathematics to show relationships within a given set of observations.
4. Identify a hypothesis for a given problem in physical science investigations.

Process Standard 4: Interpret and Communicate
1. Select appropriate predictions based on previously observed patterns of evidence.
2. Report data in an appropriate manner.
3. Interpret data tables, line, bar, trend, and/or circle graphs.
4. Accept or reject hypotheses when given results of a physical science investigation.
5. Evaluate experimental data to draw the most logical conclusion.
6. Communicate or defend scientific thinking that resulted in conclusions.
7. Identify and/or create an appropriate graph or chart from collected data, tables, or written descriptions.

Process Standard 5: Model
1. Interpret a model, which explains a given set of observations.
2. Compare a given model to the physical world.

Process Standard 6: Inquiry
1. Formulate a testable hypothesis and design an appropriate experiment relating to the physical world.
2. Design and conduct physical science investigations in which variables are identified and controlled.
3. Use a variety of technologies, such as hand tools, measuring instruments, and computers to collect, analyze, and display data.
4. Inquiries should lead to the formulation of explanations or models (physical, conceptual, and mathematical). In answering questions, students should engage in discussions (based on scientific knowledge, the use of logic, and evidence from the investigation) and arguments that encourage the revision of their explanations, leading to further inquiry.

**Content Standards: Physical Science**

**Standard 2: Motion and Forces**

1. Objects change their motion only when a net force is applied. Laws of motion are used to determine the effects of forces on the motion of objects.

**Standard 3: Interactions of Energy and Matter**

1. All energy can be considered to be either kinetic energy, which is the energy of motion; potential energy, which depends on relative position; or energy contained by a field, such as electromagnetic waves.
2. Waves, including sounds and seismic waves, waves on water, and light waves, have energy and can transfer energy when they interact with matter (such as used in telescopes, solar power, and telecommunication technology).

**Thai Science Standards**

**Junior High School Requirements**

- Question in terms of specifics and control variables, predict results, plan and check outcomes, analyze and evaluate relationship between raw data and knowledge.
- Communicate thought and knowledge of results analysis by speaking, writing, presentations and using IT.
- Show interest, determination, responsibility, care and honest attitude in searching for right tools and methods.
- Awareness of the importance of scientific knowledge and technology in daily life.
- Understand the importance of environmental issues on community level and the necessity to preserve natural resources.
- Work creatively in Teams, give opinions and accept the opinions of others.

**Upper High School Requirements**

- Understand geological processes and geological phenomenon and their effects on our lives and the environment.
- Understand the effect of scientific knowledge in developing technology and its effects on our lives and the environment.
- Identify problems, question in term of specifics and control variables, predict open answers, plan and check, analyze and evaluate relationships between raw data and knowledge.
- Plan for problem solving, analyze and connect relationships and variables by using mathematic equations or module from experimental data
- Communicate thought and knowledge from analysis by speaking, writing, presentations and using IT.
- Show interest, determination, responsibility, care and honest attitude in searching for right tools and methods.
- Awareness of the importance of scientific knowledge and technology in daily life.
- Show appreciation and care in using and preserving natural resources, look after local environment.
- Work creatively in teams, show opinion and accept others.
**Lesson Objectives:**
- Students will be able to measure wind speed using an anemometer
- Students will be able to convert wind power to electrical power using a wind turbine
- Students will be able to measure and compute electrical power output
- Students will be able to correlate wind speeds and available wind power
- Students will be able to correlate elevation and available wind power
- Students will be able to compute the efficiency of wind turbine
- Students will be able to determine the wind power class of a region.
- Students will be able to determine how many homes a wind turbine could power in a region.

**Vocabulary Terms:**

**Alternating Current (AC):** AC is an electrical current whose magnitude and direction vary cyclically. Electricity delivered to homes typically has a frequency of 60 Hz.

**Direct Current (DC):** DC is the constant flow of electric charge in one direction, typically from chemical cells found in batteries.

**Electric Current:** Electric current is the flow of electric charge. Current is measured in the units of Amperes, A. 1 A of current is equivalent to the flow of 1 C of charge past a point per second. Electric current can be either direct or alternating.

**Electric Power** - The amount of energy produced per second. Electric power is the power produced by an electric current. Power is given in Watts (1 W = 1 A x 1 V).

**Electricity** - A form of energy characterized by the presence and motion of elementary charged particles generated by friction, induction, or chemical change.

**Electricity Generation** - The process of producing electric energy or the amount of electric energy produced by transforming other forms of energy, commonly expressed in kilowatt hours (kWh) or megawatt hours (MWh).

**Energy** – The amount of work that can be done by a force. The SI unit of energy is Joules, J, which is equal to kg m/s².

**Energy Efficiency** - Refers to activities that are aimed at reducing the energy used by substituting technically more advanced equipment, typically without affecting the services provided. Examples include high-efficiency appliances, efficient lighting programs, high-efficiency heating, ventilating and air conditioning (HVAC) systems or control modifications, efficient building design, advanced electric motor drives, and heat recovery systems.

**Nonrenewable** - Fuels that cannot be easily made or "renewed." We can use up nonrenewable fuels. Oil, natural gas, and coal are nonrenewable fuels.

**Power** – The amount of energy transferred per unit time. The SI unit of energy is Watts, W, which is equal to kg m/s³.

**Resistance** – The opposition posed by a material or a device to the flow of current. The SI unit of resistance is the Ohm, Ω.

**Volt (V):** The volt is the International System of Units (SI) measure of electric potential or electromotive force. A potential of one volt appears across a resistance of one ohm when a current of one ampere flows through that resistance.

**Wind Power Density** - The wind power density, measured in watts per square meter, indicates how much energy is available at the site for conversion by a wind turbine.
**Wind Turbine** - A wind turbine is a rotating machine that converts the kinetic energy in wind into mechanical energy.

**Background Knowledge:**
Wind power converts wind into a useful energy form, such as electricity. Typically, wind turbines harness wind energy and transform it into electrical energy using electro-magnetic principles. At the end of 2007, worldwide capacity of wind-powered generators was 94.1 gigawatts. For some perspective, a typical light bulb in your home uses 60 watts of power. The total generator capacity is $94.1 \times 10^9$ watts, enough to power 35 million homes. Although wind currently produces just over 1% of worldwide electricity use, it accounts for approximately 19% of electricity production in Denmark, 9% in Spain and Portugal, and 6% in Germany and the Republic of Ireland (2007 data). Globally, wind power generation increased more than fivefold between 2000 and 2007. Wind power is produced in large-scale wind farms connected to electrical grids, as well as in individual turbines for providing electricity to isolated locations. Wind energy is plentiful, renewable, and widely distributed.

Wind power density is a useful way to evaluate the wind resource available at a potential site. The wind power density, measured in watts per square meter, indicates how much energy is available at the site for conversion by a wind turbine. Classes of wind power density are given for standard wind measurement heights. Wind speed generally increases with height above ground. In general, sites with a wind power class rating of 4 or higher are now preferred for large scale wind plants. Research conducted by industry and the U.S. government is expanding the applications of grid-connected wind technology to areas with more moderate wind speeds.

A wind turbine is a rotating machine that converts the kinetic energy in wind into mechanical energy. Wind machines were used for grinding grain in Persia as early as 200 B.C. The first windmill for electricity production was built in Cleveland, Ohio by Charles F. Brush in 1888. Around the time of World War I, American windmill makers were producing 100,000 farm windmills each year, most for water pumping. By the 1930s, windmills for electricity were common on farms, mostly in the United States where distribution systems had not yet been installed.

Small wind generation systems with capacities of 100 kW or less are usually used to power homes, farms, and small businesses. Isolated communities that otherwise rely on diesel generators may use wind turbines to displace diesel fuel consumption. Individuals purchase these systems to reduce or eliminate their electricity bills, or simply to generate their own clean power. Wind turbines have been used for household electricity generation in conjunction with battery storage over many decades in remote areas. Increasingly, U.S. consumers are choosing to purchase grid-connected turbines in the 1 to 10 kilowatt range to power their whole homes. Household generator units of more than 1 kW are now functioning in several countries, and in every state in the U.S. Grid-connected wind turbines may use grid energy storage, displacing purchased energy with local production when available. Off-grid system users either adapt to intermittent power or use batteries, photovoltaic or diesel systems to supplement the wind turbine. In urban locations, where it is difficult to obtain predictable or large amounts of wind energy, smaller systems may still be used to run low power equipment. Equipment such as parking meters or wireless internet gateways may be powered by a wind turbine that charges a small battery, replacing the need for a connection to the power grid.

Wind turbines can be separated into two types based by the axis in which the turbine rotates. Turbines that rotate around a horizontal axis are more common. Vertical-axis turbines are less frequently used.

Horizontal-axis wind turbines (HAWT) have the main rotor shaft and electrical generator at the top of a tower, and must be pointed into the wind. A simple wind vane points small turbines, while large turbines generally use a wind sensor coupled with a servomotor. Most have a gearbox, which turns the slow rotation of the blades into a quicker rotation that is more suitable to drive a generator. Since a tower produces turbulence behind it, the turbine is usually pointed upwind of the tower. Turbine blades are made stiff to prevent the blades from being pushed into the tower by high winds. Additionally, the blades are placed a considerable distance in front of the tower and are sometimes tilted up a small amount.
Downwind machines have been built, despite the problem of turbulence, because they do not need an additional mechanism for keeping them in line with the wind, and because in high winds, the blades can be allowed to bend which reduces their swept area and thus their wind resistance. Since turbulence leads to fatigue failures, and reliability is so important, most HAWTs are upwind machines.

Vertical-axis wind turbines (or VAWTs) have the main rotor shaft arranged vertically. Key advantages of this arrangement are that the turbine does not need to be pointed into the wind to be effective. This is an advantage on sites where the wind direction is highly variable. VAWTs can utilize winds from varying directions. With a vertical axis, the generator and gearbox can be placed near the ground, so the tower does not need to support it, and it is more accessible for maintenance. Drawbacks are that some designs produce pulsating torque. Drag may be created when the blade rotates into the wind. Air flow near the ground and other objects can create turbulent flow, which can introduce issues of vibration, including noise and bearing wear, which may increase the maintenance or shorten the service life. However, when a turbine is mounted on a rooftop, the building generally redirects wind over the roof and this often doubles the wind speed at the turbine. If the height of the rooftop mounted turbine tower is approximately 50% of the building height, this is near the optimum for maximum wind energy and minimum wind turbulence.

Wind energy, like solar energy is already used on land. Wind turbines, and wind farms can only be placed where the wind constantly blows. Along the coast of much of the US, conditions are well suited to use wind energy. There are people who are opposed to putting turbines just offshore. People think the turbines will spoil the view of the ocean. Right now, there is a plan to build an offshore wind plant off the coast of Cape Cod, MA. Wind is a renewable energy source that does not pollute so some people see it as a good alternative to fossil fuels.

Wind turbines are designed to exploit the wind energy that exists at a location. Aerodynamic modeling is used to determine the optimum tower height, control systems, number of blades, and blade shape.

Virtually all modern wind turbines convert wind energy to electricity for energy distribution. The turbine can be divided into three components. The rotor component, which is approximately 20% of the wind turbine cost, includes the blades for converting wind energy to low-speed rotational energy. The generator component, which is approximately 34% of the wind turbine cost, includes the electrical generator, the control electronics, and most likely a gearbox component for converting the low speed incoming rotation to high-speed rotation suitable for generating electricity. The structural support component, which is approximately 15% of the wind turbine cost, includes the tower and rotor pointing mechanism.

Betz’ law reflects a theory for flow machines, developed by Albert Betz. It shows the maximum possible energy that may be derived by means of an infinitely thin rotor from a fluid flowing at a certain speed. In order to calculate the maximum theoretical efficiency of a thin rotor (of, for example, a wind mill) one imagines it to be replaced by a disc that withdraws energy from the fluid passing through it. At a certain distance behind this disc, the fluid, that has passed through flows with a reduced velocity. The coefficient of performance ($C_p$) applying Betz’ law can be calculated to be 16/27 (59.3%). Rotor losses are the most significant energy losses in, for example, a windmill. Modern rotors achieve values for $C_p$ in the range of 0.4 to 0.5, which is 70 to 80% of the theoretically possible.
References:

Activity Procedures:
- Students will watch three short videos pertaining demonstrating wind power. The videos contain hurricane and tornado footage.
- Students will measure and calculate basic physical parameters of a wind turbine
- Students will use wind turbine to generate electricity
- Students will measure and calculate wind velocity
- Students will compute available wind power
- Students will determine the effects of wind velocity and elevation of available wind power
- Students will compute electrical power
- Students will compute the efficiency of the wind turbine
- Students will watch a short video pertaining to large-scale wind turbines
- Students will determine the wind power class of a region, and determine how many homes a wind turbine can power
- Students will take a field trip to the top of a large building and harvest wind energy
- Students will develop the concept statements

Technology Component:
Students will use electronic equipment to measure electrical power. If the resources are available, students will use wind turbines to harness energy from a wind tunnel.

Engineering Application:
Certain regions of the earth are endowed with abundant available wind power. In these regions, wind power can be harvested in a clean, inexpensive and renewable manner using wind turbines. Luckily, the Oklahoma is one such place where wind harvesting is ideal. In this lesson, students determine how much power a wind turbine would generate for their own home.

Assessment Tools:
The students will be graded in accordance with the Authentic Assessment rubric.