Power, Energy, Dynamics - Wind Turbines

Physics - Year 11-12

Renewable energy power from wind turbines

1. About the lesson plan

Grade Level	Year 11-12
Discipline	Physics
Topic(s) in Discipline	Power, Energy, Dynamics
Australian Curriculum Code	ACSPH037: Electrical circuits enable electrical energy to be transferred efficiently over large distances and transformed into a range of other useful forms of energy including thermal and kinetic energy, and light. ACSPH039: Energy is conserved in the energy transfers and transformations that occur in an electrical circuit. ACSPH042: Power is the rate at which energy is transformed by a circuit component; power enables quantitative analysis of energy transformations in the circuit. ACSPH065: Energy is conserved in isolated systems and is transferred from one object to another when a force is applied over a distance; this causes work to be done and changes to kinetic and/or potential energy of objects
Climate Topic	Renewable energy power from wind turbines
Cross Curriculum Priority	Sustainability
Lesson Length	70 min

2. Brief Introduction to the Lesson Plan

This lesson plan helps teachers to show how the various concepts of power, electrical energy and kinetic energy taught across the Australian Physics curriculum can be brought together. It demonstrates the interconnectedness of these concepts in the context of renewable energy through the working of wind turbine. To reduce global warming due to carbon emissions, wind power is a renewable and clean source of energy that can be harnessed as electricity by wind turbines. This lesson allows students the opportunity to mathematically apply the concepts of problem-solving strategies in real-world scenarios.

3. Learning Outcomes

The tools in this lesson plan will enable students to:

- Apply the concepts of conservation of energy, electrical energy and power together in a meaningful way.
- Solve real-world problems in context.

4. Introduced Climate Science Concepts

The tools in this lesson plan will expose students to:

- The advantages and challenges of producing electricity from a wind turbine.
- Computing the energy available from wind.

5. Presumed Knowledge

- Kinetic energy (ACSPH065).
- Conservation of energy (ACSPH039).
- Electrical energy and power (ACSPH037).
- Rate of energy and power (ACSPH042).

6. Teaching Resources

Type of Tool	Name and web link to the Teaching Resources	Brief Description	Credits
Video	How do Wind Turbines work?	A short video on the various aspects of wind turbines and the science behind the electricity they produce.	Learn Engineering https://www.patreon.com/LearnEngineering

7. Step-by-Step Lesson Plan activities

Teacher activities and student tasks	Timing
Class discussion **Starter Task:** Bringing together learnt concepts: Energy, Work, Electricity, Transformers. *"Ok, so we're going to now look at how a number of different concepts we've learnt in physics all come together in a real-world situation. We're going to look at how wind turbines work and the physics principles behind this form of renewable energy."* *"What do we know already about wind turbines and how they work?"* Students to respond with their ideas while teacher continues discussion and/or summarises main points on board.	5 min
Students watch the YouTube video: How Do Wind Turbines Work? *'Was there anything in that video that you didn't know already?'* Students might refer to Betz's Limit as a new idea.	10 min
Group activity **Kinetic Energy of a Mass of Air** *"So how can we determine the kinetic energy of a mass of air of density ρ that's moving at a speed v through a turbine of radius r?"* In groups, students to determine the general formula for calculating the kinetic energy of a mass of moving air. Students will need to combine density ($\rho = \frac{m}{V}$) with the volume of air flow ($V = Av$), the area of a circle ($A = \pi r^2$) with the kinetic energy formula ($\frac{1}{2}mv^2$) to define the kinetic energy of a mass of air as ($KE = \frac{1}{2}\pi r^2 \rho v^3$) .	5 min

Group activity **Electricity in Households** *"Now let's look at how this energy can be used in homes.* *We wish to sell this energy to households, and we need a unit of measure that makes sense to the average person. The unit used is called a kilowatt-hour* (kWh) *and is defined as the energy delivered to a* $1000\ W$ *appliance over 1 hour. In groups, try to determine how much* $1\ kWh$ *is in terms of joules."* *Solution:* $P = \frac{E}{t}$ $E = Pt$ $E = 1000Js^{-1}\ \times 3600s$ $E = 3.6 \times 10^6 J$	5 min
Group activity **Problem:** Consider a wind turbine with a span of $100\ m$ is situated at a site, subjected to a constant $8\ ms^{-1}$ wind. If air density is $1.25\ kgm^{-3}$, how much kinetic energy passes through the plane of the blades every second? *Solution:* *"While we can directly substitute in the formula* $KE = \frac{1}{2}\pi r^2 \rho v^3$*, but instead we will use a different strategy"* Strategy • Determine area of plane • Determine volume of air passing through plane every second • Determine mass of air passing through plane every second • Calculate kinetic energy of the mass of air passing through the plane every second	15 min

$A = \pi r^2$ $A = \pi . 50^2$ $A = 7{,}854 m^2$ At $8ms^{-1}$, volume through plane $V = Av$ $V = 7854 m^2 \times 8 ms^{-1}$ $V = 62{,}832 m^3 s^{-1}$ With density of $\rho = 1.25 kgm^{-3}$ $m = \rho V$ $m = 1.25\ kgm^{-3} \times 62{,}832\ m^3 s^{-1}$ $m = 78{,}540\ kgs^{-1}$ Kinetic Energy every second $KE = \frac{1}{2} mv^2$ $KE_{/s} = \frac{1}{2}(78{,}540\ kg\ s^{-1}) \times 8^2\ m^2 s^{-2}$ $KE_{/s} = 2.513 \times 10^6 Js^{-1}$ $P = 2.513 \times 10^6 W = 2513\ kW$	
Think, pair, share **Kinetic Energy of a Mass of Air** Students to research the cost of electrical energy by visiting power-company websites to get rates. Typical rates are $0.15 - 0.30\ AUD/kWh$. Students to then determine the revenue generated by this wind turbine per day (by multiplying $Energy_{electrical}$ with the rate they find).	10 min
Independent practice **Problem:** Consider a wind turbine with a span of $50\ m$ is situated at a site, subjected to a constant $12\ ms^{-1}$ wind. If air density is $1.23\ kgm^{-3}$, how much kinetic energy passes through the plane of the blades every second? Round your answer to $3\ s.f$.	10 min

Solution: Kinetic Energy every second $KE_{/s} = \frac{1}{2}\, \pi r^2 \rho\, v^3$ $KE_{/s} = \frac{1}{2}\, \pi (50^2)(1.23)\ (12^3)\ (m^2)(\frac{kg}{m^3})(\frac{m}{s})^3$ $KE_{/s} = 8{,}340{,}000\ m^2\ kg\ s^{-3}$ $KE_{/s} = 8.34 \times 10^6\ J\ s^{-1}$ $P = 8.34 \times 10^6\ W\ \ = 8{,}340\ kW$	
Wrap Up Students can discuss other ways to generate sustainable energy, besides wind. Discuss benefits and caveats.	5 min

8. Additional Resources:

If you or your students would like to explore the topic further (e.g. homework), these additional resources will be useful.

Type of Tool	Name and web link to the Additional Teaching Tool	Brief Description	Credits
Activities	[Off The Grid: Activities for Teaching Renewable Energies]()	A series of activities for students to learn various aspects of making homes free from electricity grid.	Tyler Maline, Lauren Cooper, Malinda Schaefer Zarske, Denise W. Carlson (Regents of the University of Colorado). [TeachEngineering]()

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