Lesson Plan: Power, Energy, Dynamics- Wind Turbines

This is a lesson plan developed by the ARC Centre of Excellence for Climate Extremes (CLEX) and the Monash Climate Change Communication Research Hub (MCCCRH) with contributions by Troy Garrett (Winmalee High School); Dr Sanaa Hobeichi and Dr Ian Macadam (CLEX); Tahnee Burgess and Dr David Holmes (MCCCRH); and Dr. Roger Dargaville (Monash University). The lesson plan originated at the "Climate across the Curriculum: Educational Resources for Teachers" workshop at the Australian Meteorological and Oceanographic Society (AMOS) conference held in February 2020 in Fremantle, Western Australia. The workshop was supported by AMOS, CLEX, MCCCRH, the Schools Weather and Air Quality (SWAQ) Citizen Science project, TROP ICSU and the University of Western Australia. A version of the lesson plan tailored for use in Australian classrooms is available at https://www.monash.edu/mcccrh/projects/climate-classrooms.

As a **high school Physics** teacher, you can use this set of computer-based tools to help you in teaching about **power**, **energy,** and **dynamics** through the design and function of a wind turbine.

This lesson plan will help you teach various Physics concepts such as power, energy, and dynamics through the working of a wind turbine. In the context of 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. Thus, this lesson plan will enable the students to apply the concepts of energy, electrical energy, and power in a real-world scenario.

Thus, the use of this lesson plan allows you to integrate the teaching of a climate science topic with a core topic in **Physics**.

Curriculum Code (Australia):

- **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.

Cross Curriculum Priority (Australia): **Sustainability**

Presumed Knowledge (Australia):

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

Use this lesson plan to help your students find answers to:

- What is wind energy?
- How can wind power be harnessed for electricity using wind turbines?
- How can you compute the energy available due to wind?
- What are the advantages and challenges of producing electricity from a wind turbine?

About the Lesson Plan

Grade Level: High School

Discipline: Physics

Topic(s) in Discipline: Power, Energy, Work, Conservation of Energy, Electrical Energy, Dynamics, Transformers, Wind Turbine

Climate Topic: Energy, Economics and Climate Change; Climate Mitigation and Adaptation

Location: Global, Australia

Access: Online

Language(s): English

Approximate Time Required: 70 min

1 Contents

1. Teaching Module (20 min)

A teaching module to introduce or reacquaint students with concepts such as energy and power. It also includes a case study highlighting World's Energy Use and the need for renewable sources of energy.

This can be accessed at:

https://phys.libretexts.org/Bookshelves/University_Physics/Book%3A_Physics_(Boundless)/6%3A_Work_and_Energy/6.6%3A_Power

2. Video (~5.5 min)

A video to introduce wind turbines and how they harness wind energy (a renewable source) to generate electricity.

This can be accessed at:

https://www.youtube.com/watch?v=qSWm_nprfqE

3. Classroom Activity (2.5 min + 40 min)

A brief video to explain the physics of wind power followed by a solved word problem to compute the wind energy available for wind turbines to convert to electrical energy.

The video can be accessed at:

https://www.youtube.com/watch?v=o-Y3N7sNL4k

4. Suggested questions/assignments for learning evaluation

- What is wind energy?
- How can wind power be harnessed for electricity using wind turbines?
- How can you compute the energy available due to wind?
- What are the advantages and challenges of producing electricity from a wind turbine?

2 Step-by-step User Guide

Here is a step-by-step guide to using this lesson plan in the classroom/laboratory. We have suggested these steps as a possible plan of action. You may customize the lesson plan according to your preferences and requirements.

1. Topic introduction and discussion

Use the teaching module, '6.6: Power' by LibreTexts™ to bring together concepts we have learnt so far- energy, power, work, electrical energy, conservation of energy and transformers. Play the video tutorial within the text, to teach how numerical problems can be solved for computing values such as energy generated, and work done. Navigate to the next page (6.7), to read a case study on the World's Energy Use. Discuss how fossil fuel-based energy generation is undesirable in the context of climate change and the need to increase the use of renewable and cleaner sources of energy such as wind energy.

This can be accessed at:

https://phys.libretexts.org/Bookshelves/University_Physics/Book%3A_Physics_(Boundless)/6%3A_Work_and_Energy/6.6%3A_Power

2. Extend understanding

Explain to your students that they will now apply their understanding of the different concepts learnt in physics in a real-world situation by looking at how wind turbines work and identify the physics principles behind this form of renewable energy. Ask your students what they already know about wind turbines and about how they work. Allow the students to respond with their ideas and summarize their main points on the board.

Play the video, 'How do Wind Turbines Work' by Learn Engineering, to introduce the topic of using wind energy to generate electricity by wind turbines. Use this video to describe various aspects of wind turbines and the science involved in the electricity they produce.

This can be accessed at:

https://www.youtube.com/watch?v=qSWm_nprfqE

Allow some time for a classroom discussion following the video. Draw attention to Betz's Limit as a new idea.

3. Classroom Activity

- Ask your students: How can we determine the kinetic energy of a mass of air of density ρ that is moving at the speed v through a turbine of radius r?

Form groups and encourage your 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 ($KE = \frac{1}{2}\pi r^2 \rho v^3$).

- Play the video, 'The Physics of Wind Power: how does a wind turbine work?' by the European Energy Centre (EEC) to elucidate how the kinetic energy of a mass of air moving through a wind turbine can be determined.

This can be accessed at:

https://www.youtube.com/watch?v=o-Y3N7sNL4k

- Solve a word problem with guidance:

Consider a wind turbine with a span of 100 m is situated at a site, subjected to a constant 8ms^{-1} wind. If air density is 1.25 kgm^{-3}, how much kinetic energy passes through the plane of the blades every second?

Solution: We can directly substitute in the formula $\mathrm{KE} = \frac{1}{2}\pi r^2 \rho v^3$, 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

$A = \pi r^2$

$A = \pi . 50^2$

$A = 7854 m^2$

At $8 m s^{-1}$, volume through plane

$V = Av$

$V = 7854 m^2 \times 8 m s^{-1}$

$V = 62{,}832 m^3 s^{-1}$

With density of $\rho = 1.25 kg m^{-3}$

$m = \rho V$

$m = 1.25 kg m^{-3} \times 62{,}832 m^3 s^{-1}$

$m = 78{,}540 kg s^{-1}$

Kinetic energy every second

$KE = \frac{1}{2} m v^2$

$KE = \frac{1}{2} (78{,}540\ kg\ s^{-1}) \times 8^2\ m^2 s^{-2}$

$KE_{/s} = 2.513 \times 10^6 J s^{-1}$

$P = 2.513 \times 10^6 W = 2513\ kW$

- Give a word problem for independent practice

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.

Solution:

Kinetic Energy every second

$$KE_{/s} = \frac{1}{2}\,\pi r^2 \rho\, v^3$$

$$KE_{/s} = \tfrac{1}{2}\,\pi(50^2)(1.23)\,(12^3)\,(m^2)(\tfrac{kg}{m^3})(\tfrac{m}{s})^3$$

$$KE_{/s} = 8{,}340{,}000\; m^2\; kg\; s^{-3}$$

$$KE_{/s} = 8.34 \times 10^6\; J\; s^{-1}$$

$$P = 8.34 \times 10^6\; W\; = 8{,}340\; kW$$

- Wrap up the session with a discussion on ways other than wind energy to generate sustainable energy. Discuss their benefits and caveats in the context of climate change.

Learning Extensions:

- Electricity in Households

Draw attention to 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. Determine how much 1kWh is in terms of joules.

Solution:

$$P = \frac{E}{t}$$

$$E = Pt$$

$$E = 1000\ Js^{-1} \times 3600\ s$$

$$E = 3.6 \times 10^{6}\ J$$

- Cost of Electrical Energy

Students to research the cost of electrical energy by visiting power-company websites to get rates. Typical rates in Australia are $0.15 - 0.30\ AUD/kWh$. Students to then determine the revenue generated by this wind turbine per day (by multiplying $\mathrm{Energy}_{\mathrm{electrical}}$ with the rate they find).

4. Questions/Assignments

Use the tools and the concepts learned so far to discuss and determine answers to the following questions:

- What is wind energy?
- How can wind power be harnessed for electricity using wind turbines?
- How can you compute the energy available due to wind?
- What are the advantages and challenges of producing electricity from a wind turbine?

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.
- explain the advantages and challenges of producing electricity from a wind turbine.
- learn the physics of wind power.
- compute the energy available from wind as a renewable and clean source of energy.
- solve real-world problems in the context of climate change.

4 Additional Resources

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

1. Visualization; 'Electricity generation by source, World, 2018'

An interactive visualization by Our World in Data to show the relative contributions of global renewable and non-renewable sources of energy for electricity generation.

This can be accessed at:

https://ourworldindata.org/grapher/electricity-generation-by-source

2. Video micro-lecture; 'Wind turbine terminology and components'

A video micro-lecture provided on Coursera by the Technical University of Denmark, to explain various aspects of wind turbine technology.

This can be accessed at:

https://www.coursera.org/lecture/wind-energy/wind-turbine-terminology-and-components-XYfkc

3. Classroom/Laboratory Activities; 'Off the Grid'

A series of activities for students by University of Boulder Colorado, to learn about various aspects of renewable energies and how to make homes free from the electricity grid.

This can be accessed at:

https://www.teachengineering.org/lessons/view/cub_housing_lesson04

5 Credits/Copyrights

1. Teaching Module; '6.6: Power'

By LibreTexts™

2. Video; 'How do Wind Turbines Work'

By Learn Engineering

3. Video; 'The Physics of Wind Power: how does a wind turbine work?'

By the European Energy Centre (EEC)

4. Additional Resources

Our World in Data

Coursera

TeachEngineering, University of Colorado Boulder.