INTRODUCTION

Hello! We're so glad you're interested in making your very own Dye Sensitized Solar Cells in your classroom.

This lesson covers the following Next Generation Science Standards (NGSS) for middle school:

- **MS-PS3-2**: Develop a model to describe that when the arrangement of objects interacting at a distance changes, different amounts of potential energy are stored in the system.
- **MS-PS3-5**: Construct, use, and present arguments to support the claim that when the kinetic energy of an object changes, energy is transferred to or from the object.
- **MS-ETS1-1**: Define the criteria and constraints of a design problem with sufficient precision to ensure a successful solution, taking into account relevant scientific principles and potential impacts on people and the natural environment that may limit possible solutions.

However, it can also be adapted for ages 8–100+! We taught this lesson in the Netherlands in 2019, during *Cycle for Science: Materials*, to students ages 8–17.
After this lesson, students should be able to:

1. Give one or more examples of renewable energy, and explain why it is important
2. Explain how a solar panel works (briefly)
3. Explain how to measure the performance of a solar panel

**Key Concepts**

- **Solar panels** are a type of **renewable energy**
- Solar panels are composed of “**solar cells**”, and solar cells are composed of different layers, each with a unique function
- We need better solar cells, so scientists like Rachel are researching brand new materials to use as layers in solar cells to make them more efficient. You can become a scientist and do this too!
- You can make your own solar cell out of simple ingredients like blackberries! This is called a “**dye sensitized solar cell**”
- You can figure out how well a solar cell works by measuring its **current** and **voltage** using a **multimeter**

**Vocabulary**

- Renewable energy
- Materials science
- Solar panel
- Solar cell
- Absorber
- Contact
- Electron catcher
- Electron refiller
- Dye sensitized solar cell (DSSC)
- Titanium dioxide (TiO2)
- Graphite
- Transparent conducting material (TCO)
- Electricity
- Energy conversion
- Electrons
- Current
- Voltage
- Power
- Multimeter
- Circuit
- Energy storage
1. Solar cell “kit” (can be purchased online, or sourced individually)
   a. 8 indium tin oxide (ITO)-coated glass slides
   b. 8 ITO and titanium dioxide (TiO2) coated glass slides (alternate: toothpaste)
   c. 8 blackberries (alternate: blueberries) (option: scavenge them!)
   d. Iodine electrolyte solution
   e. 8 soft-tip graphite pencils
   f. 8 binder clips
2. Tools for assembly
   a. 8 cups or tins for blackberry smashing
   b. 8 q-tips
   c. 8 paper towels or small trays
   d. A pair of gloves for each student
   e. “+” and “−” stickers to label glass slides on side without coating (optional)
3. Measurement
   a. 8 miniature multimeters
   b. 16 wires with alligator clips
   c. Bike light or solar simulator
   d. Red LEDs
4. Add-ons
   a. “Booster” silicon solar module
   b. Miniature speaker
   c. Miniature motor
   d. Other electronics to power
Lesson

This lesson is flexible, and can be run in multiple ways. Here is a sample of how we would run a lesson, with some suggestions for other activities or topics that are interchangeable.

Preparation

Before class

- Forage for blackberries, if the season and location allows
- Label the ITO-coated glass slides with “-” and TiO2-coated glass slides with “+”

Note: can be done before class enters, or during the introduction

- Set a paper towel or tray down on each of the 8 workspaces
- On each workspace, place the ITO-coated glass slide, TiO2-coated glass slide, a blackberry inside of a cup or tin, a q-tip, a graphite pencil, a mini multimeter, and a binder clip
- Have teacher arrange students in 8 groups (3–5 students) at the start of class
- Make it clear students can not touch the items until instructed to do so

Introduction to Us

1. Who are we?
2. How did we get interested in STEM?
3. What do we do now, as scientists?
4. Why do we do it?
1. Introduce energy and renewable energy
   - Class brainstorm: what are the different types of renewable energy? What are different types of dirty energy? Write the responses on the board in columns labeled “renewable” and “non-renewable”
   - Connect to location: in this country (e.g. The Netherlands), what percentage of our energy comes from renewables? How about solar? Less that one percent solar!!

2. Hold up the “booster” silicon solar module
   - Do any of the students know what it is?
   - Today we’re going to make our own solar cells! But first, we need to learn a little more about how they work

3. How does a solar panel work?
   - What is an electron?
   - What is a photon?
   - Draw a schematic on the board → Sun emits photons, photons transmit energy to electrons, electrons get excited and move through the surface of the panel, down the red wire and into the light bulb, which steals the photon/energy, and the electron returns to its nucleus to repeat the pathway
4. **[optional activity, if time allows and students are on the younger side]** Ask for four volunteers – (1) a sun, an atom of the solar panel represented by (2) an electron (someone who wants to run around!) and (3) a nucleus, and (4) a lightbulb.

   - The sun is given a starburst – this is a photon! A tiny packet of energy.
   - Position the four students in a line. The sun at one end of the space, the electron, walking slowly, sleepily, around the nucleus about 5-10 feet away, and the lightbulb stands inert at the far end. If desired, lay down red and black tape/paper beforehand to represent the wires.
   - Set up the scenario, narrating: at night, the electron is sleepy and has no energy to move away from its nucleus, so the student who has volunteered to be the electron rotates around the nucleus.
     - The sun rises and wakes up and tosses the starburst/photon to the electron.
     - The electron now has lots of energy. The student runs around the room, then down the red wire to the lightbulb.
     - The lightbulb is hungry – it's breakfast time in lightbulb-land – and steals the starburst from the electron and starts shining (throw hands up in the air! You shine!).
     - The electron returns, exhausted, to the nucleus (its “parent”) and slowly rotates again.

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**[15–20 min] Solar Cell Making Activity**

1. Students get in groups of 3–5 (8 total, helps if already arranged in groups)
2. **[optional]** Distribute gloves, ask each student to wear gloves
3. Using q-tip, have students smash the blackberry into a fine paste

4. Have students apply a light layer of blackberry paste onto the white side of the TiO2-coated glass (labeled “-”), such that it is completely covered and turns dark pink but is not clumpy or thick so that it won’t dry.
   - Set aside and wait for it to dry.
5. Have students take the ITO-coated glass and flip it so the label is down and the coating is up
   - [optional] Use a multimeter to test whether the correct conductive side is up
   - With the graphite pencil, have students draw a thick layer of graphite onto the ITO-coated glass so that it is completely covered
   - This is the “negative electrode”
6. When these two steps are completed, apply one small drop of iodine electrolyte solution to the positive electrode, and wait for it to spread across the glass with surface tension.

![Diagram of electrode setup]

7. Place the negative electrode onto the positive electrode, such that the graphite side comes in contact with the iodine solution.
   - Offset the two pieces of glass such that there are edges hanging (see photo)
   - Use binder clip to hold together
   - Note: we’ve found it’s easier if we do this step, rather than the students. Also adding a second binder clip or paper clip helps to stabilize the cell
8. This is your dye sensitized solar cell! You just made a solar cell!

(5–10 min) Solar Cell Testing

1. Testing in ambient light: With a multimeter, place the red lead on the positive electrode and the black lead on the negative electrode
   - What is the current? It’s probably really low
   - What is the voltage?
   - [Optional] Can you calculate the power from this? Remember, Power = Current x Voltage
2. Testing with sunlight, a solar simulator, or a bike-light
   ○ How does the performance change under sunlight?
   ○ What happens when the light is covered up? By doing this, are you convinced the solar cell is working?

1. Have everyone gather together
2. Using the wires and alligator clips, connect all 8 solar cells from the group in series (note: this needs to be done rather quickly or else the class gets bored here)
   ○ How do you expect the current and voltage to change?
   ○ Have a volunteer measure the current and voltage — how does it actually change?
   ○ How does it change under constant light? (ideally outside, bike lights or phone lights may work too)
3. Is this enough to power a lightbulb? Or a tiny motor?
   ○ Hook up a lightbulb to the “power plant”
   ○ If necessary, can add “booster” silicon solar cells
1. Recap: What did you learn from activities? (How does solar work?) What were you surprised by?
2. These solar cells are great to demonstrate the principle, but are really inefficient — why?
   o [optional] discuss light absorption and solar cell contacts
   o [optional] discuss new solar cell materials, connect to our research
3. [optional, could discuss earlier] Why is renewable energy important? What is climate change?
   o The natural patterns and geologic ages of the earth are changing because of the pollution we emit into the atmosphere, and put into the ocean and the ground
     ● Oil and gas release greenhouse gasses when they are burned
     ● This traps heat in the atmosphere, and/or has torn a hole in our atmosphere, which means more radiation can reach the earth
   o Animals and other species going extinct ... healthy biodiversity = healthy humans
4. Solar and the future
   o So, how do we incorporate more solar energy into the electricity grid?
   o How can we use solar energy when it’s raining, or at night? Discuss the need for energy storage and batteries
5. Any last questions for us? Ask a scientist anything!