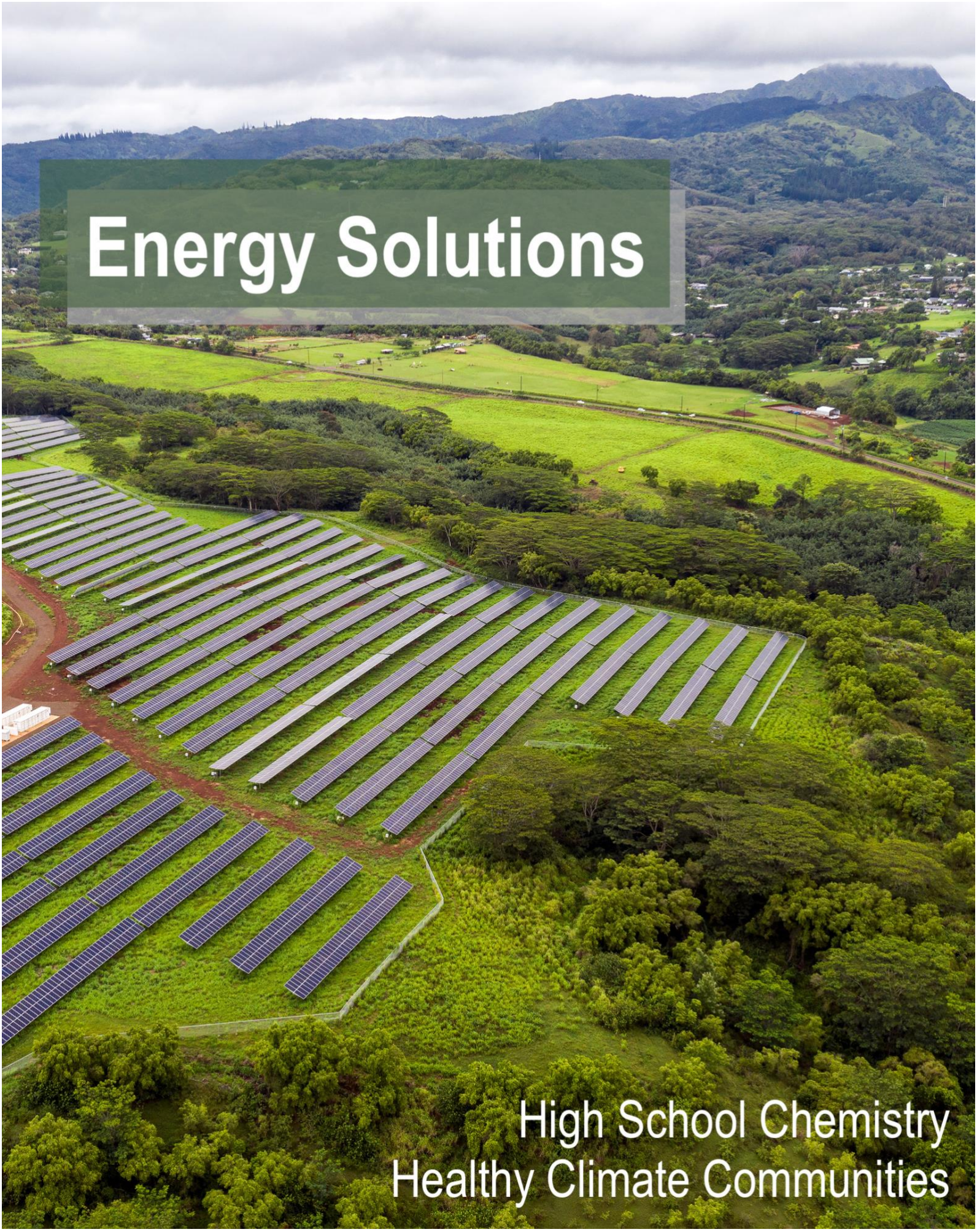
Energy Solutions
High School Chemistry
Healthy Climate Communities

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# SUPPORT AND MATERIALS

Healthy Climate Communities is committed to education and action in Hawaii to fight climate change.

This Hawaii place-based Next Generation Science Standards unit contains Hawai'i Department of Education grade-level standards for chemistry. Materials such as student worksheets and slide shows for use in class are available on our website www.healthyclimatecommunities.org. Please contact us for support or to provide feedback on the unit, or just to let us know you will use it. *healthyclimate@hawaii.rr.com*

# TABLE OF CONTENTS

Lesson 1. What Happens When You Burn Fossil Fuels?.....2

Lesson 2. How Does the Ocean React to Changes in $CO_2$ Concentration and Temperature? ……9

Lesson 3. How Can We Get Power Without Creating $CO_2$ Emissions?.....23

Lesson 4. Global Challenge: How Can Enough Renewable Energy be Made Available Where and When We Need It?.....30

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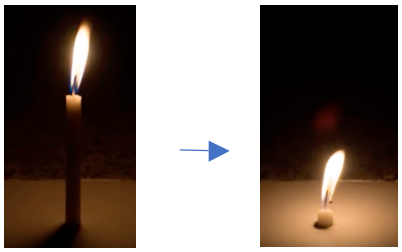
# LESSON 1. WHAT HAPPENS WHEN YOU BURN FOSSIL FUELS?

***HS-PS1-2:*** *Construct and revise an explanation for the outcome of a simple chemical reaction based on the outermost electron states of atoms, trends in the periodic table, and knowledge of the patterns of chemical properties*
***HS-PS1-7:*** *Use mathematical representations to support the claim that atoms, and therefore mass, are conserved during a chemical reaction*



**PHENOMENON: Wax disappears from burning candles.**

## QUESTIONS AND INVESTIGATIONS

### Candle Combustion Lab

Materials: tea light, timer, laboratory scale, 250 mL beaker or 1-cup container with loose lid such as a watch glass, 25 mL of vinegar, 1 tablespoon (15 g) of baking soda.

Procedure:

1) Weigh tea light with as much precision as your scale will allow (all the digits should be recorded).
2) Light candle and start 5-minute timer.
3) Record observations [wax melts, heat generated, smoke]
4) Make $CO_2$ by mixing the vinegar and baking soda in a container and closing with the lid to minimize the amount of air in the mixture. The $CO_2$ gas is heavier than air and will stay in the container.
5) When ready, "pour" the gas over the candle (gently, no liquid should be transferred). **https://www.youtube.com/watch?v=cmaaQYe96BU**
6) Record observations [wax melts, heat generated, smoke].
7) Once the tea light has cooled down, weigh it again in a similar way to step 1).
8) Record any difference in weight from measurement before burning.

1. What do you wonder about what happened?

| |
|---|
| Wax evaporated and became gas?<br>Was transformed to heat energy?<br>Why doesn't the wick burn up?<br>Why did it go out when we poured CO2 gas on it? |

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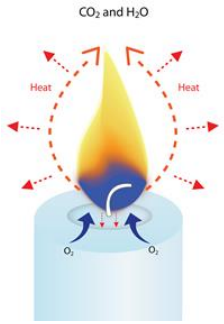
## Let's use chemistry to understand what we witnessed.

**HOW CANDLES BURN**




Wax is made from petroleum, so it is a fossil fuel like coal, oil and gas. All fossil fuels are hydrocarbons, which means they are largely composed of hydrogen (H) and carbon (C) atoms.

When you light a candle, the heat of the flame melts the wax near the wick. This liquid wax is then drawn up the wick by capillary action.

The heat of the flame vaporizes the liquid wax (turns it into a hot gas), and starts to break down the hydrocarbons into molecules of hydrogen and carbon. These vaporized molecules are drawn up into the flame, where they react with oxygen from the air to create heat, light, water vapor ($H_2O$) and carbon dioxide ($CO_2$).

Heat radiates from the flame in all directions. The heat melts more wax to keep the combustion process going until the fuel is used up or the heat is eliminated.

If the flame gets too little or too much air or fuel, it can flicker or flare and unburned carbon particles (soot) will escape from the flame before they can fully combust.

https://candles.org/candle-science/

For the candle to work, it needs a low melting point. The melting point of a molecule is determined by the type of bond between atoms. Use the **Electronegativity Trends in the Periodic Table** to figure out what type of bond wax has.

2. Define ionic and covalent bonds.

3. Using the electronegativity values, how do you determine if a bond is ionic or covalent?

look at pattern of electronegativity of metals vs nonmetals – the type of bond ionic/covalent is determined by the difference in electronegativity between two atoms. If the difference is greater than 1.7, the bond will have some ionic character; typically, difference of more than 2.0 is considered pure ionic

4. Assume the wax in the tea light is composed of $C_{31}H_{64}$. Calculate the electronegativity difference to determine if the wax in the candle contains ionic or covalent bonds.

0.4 – covalent

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Stronger bonds between molecules require more energy to break. Molecules with covalent bonds have very strong bonds between atoms, but the forces between the molecules are weak compared to ionic bonds.

5. Why do you think the type of bonds in wax make it work well for combustion in the form of a candle?

Covalent compounds are held together by weaker intermolecular forces so it lakes less energy to melt them than ionic substances. Since wax is covalent, it takes less energy or lower temperatures to break the weak interactions between molecules causing the wax to melt.

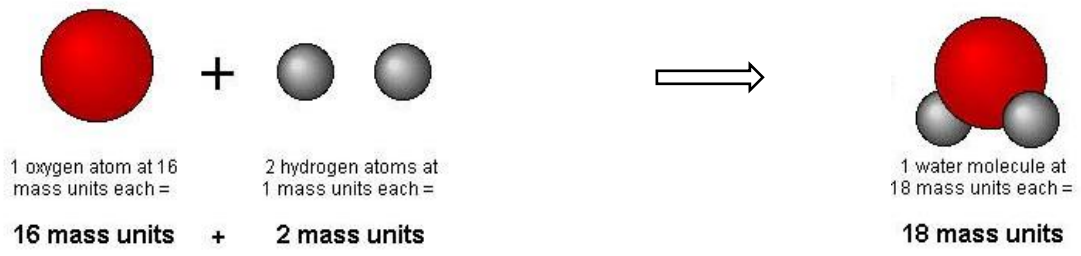
You measured to see if there was a change in mass after burning your candle. According to Lavoisier, all chemical reactions take place according to the **Law of Conservation of Mass**.

6. Write the law:

The total mass of the reactants in any chemical reaction is exactly equal to the total mass of the products.

The relationship (ratio) between the reactants and the products is called **stoichiometry**. When specific ratios of reactants combine, specific ratios of products are created, according to the law of conservation of mass.

7. Draw diagram to illustrate the Law of Conservation of Mass using the example of water. Draw colored single particles on reactant side, draw combined particles on product. Label each atom or molecule with its name and mass.
    - Oxygen = 16 atomic mass units
    - Hydrogen = 1 atomic mass unit




8. What were the reactants and products in the chemical reaction you witnessed when the candle burned?

Wax + oxygen → heat + light + carbon dioxide + water

$C_{31}H_{64} + O_2 \rightarrow CO_2 + H_2O$ + heat energy + light energy

9. Assume the wax is $C_{31}H_{64}$. Write a balanced chemical equation to evaluate how much product was generated during the burning of wax with oxygen to form carbon dioxide and water. Label each atom or molecule with its name and mass. Verify that the reactants and products are equal.
    - Oxygen = 16 atomic mass units
    - Hydrogen = 1 atomic mass unit
    - Carbon = 12 atomic mass units

$C_{31}H_{64} + 47\ O_2 \rightarrow 31\ CO_2 + 32\ H_2O$

436 AMU + 1504 AMU → 1364 AMU + 576 AMU

1940 AMU → 1940 AMU

10. You might have noticed smoke during the burning of the candle. In what situation did you observe the most smoke?

When the candle was first lit, or when the flame went out.

11. Smoke is the release of carbon that was not burned due to incomplete combustion. Write a balanced chemical equation for wax and oxygen forming carbon (C) and water.

$C_{31}H_{64} + 16\ O_2 \rightarrow 31\ C + 32\ H_2O$

12. How do the moles of oxygen for the reactions in number 9 and 11 compare?
    Why is the amount of oxygen important and how would this explain what you observed in the experiment?

Less oxygen used when carbon is generated for reaction 11 than for carbon dioxide in 9.

If enough oxygen is present, carbon dioxide is produced instead of C. When the flame did not have enough oxygen because we poured $CO_2$ on it, it smoked before it went out all the way. When it was first lit, it was not drawing in as much oxygen as it did once the heat from the flame created convection to introduce a sufficient amount of oxygen.

13. Another product that can be generated during incomplete combustion of candles is carbon monoxide. Carbon monoxide is invisible and it is poisonous if large amounts are inhaled. Balance the following equation.

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$$__C_{31}H_{64} + __ O_2 \rightarrow __ CO + __ H_2O$$

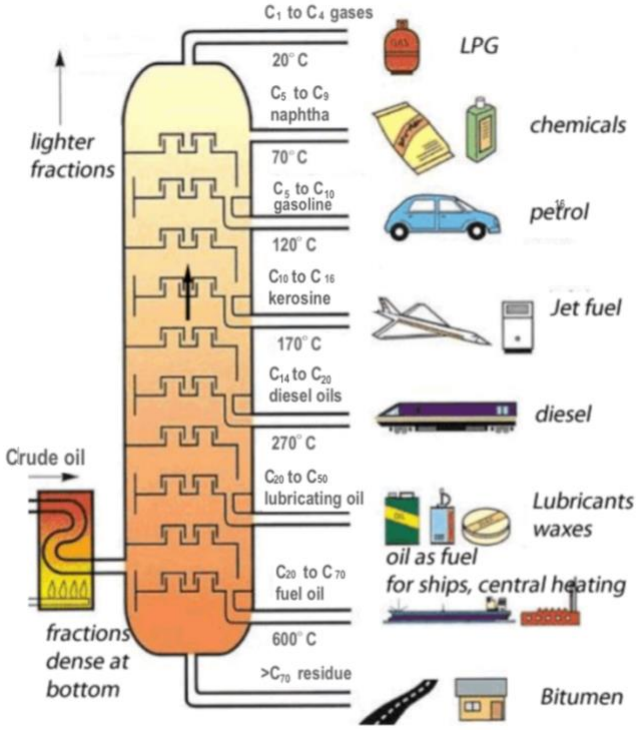
[$C_{31}H_{64} + 63/2\ O_2 \rightarrow 31\ CO + 32\ H_2O$ OR $2C_{31}H_{64} + 63\ O_2 \rightarrow 62\ CO + 64\ H_2O$]

14. Use the following link to discuss why it is important to have a functioning oxygen sensor in a fuel-operating vehicle.

    https://www.sundevilauto.com/what-you-need-to-know-about-the-oxygen-sensor/

## PRACTICE – CALCULATE CO2 EMISSIONS

Hydrogen and carbon atoms bond in different ratios to create hydrocarbons with different properties. Each is used to fuel different types of vehicles or make different products. Like the candle, all of them contain a lot of energy. That energy can be traced back to photosynthesis from the sun. Hydrocarbons such as coal, oil and gas were formed from the buried remains of plants, animals and bacteria. Also like the candle, all hydrocarbons release carbon dioxide during combustion. Principles from chemistry allow us to calculate how much $CO_2$ will be emitted by each hydrocarbon if we know the mass of the hydrocarbon and assume complete combustion.




15. In your candle experiment, what was the mass of wax ($C_{31}H_{64}$) lost in combustion? How many grams of $CO_2$ were generated?

    - Go back to #9 and get the balanced equation.
    - Use molar mass (MM) of $C_{31}H_{64}$ = 436.85 g/mol
    - Use molar mass (MM) of $CO_2$ = 44.01 g/mol

Grams of wax lost / 436.85 g/mol = moles of wax lost

Moles of wax lost x 31 moles $CO_2$/1 mole wax = moles of $CO_2$

Moles $CO_2$ x MM $CO_2$ = grams $CO_2$

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## Now let's discover how much $CO_2$ is released when we burn another commonly used hydrocarbon – gasoline.

16. What is the main component of gasoline? What is its molar mass (MM)?

    Octane MM = 114.23 g/mol

    * This is a simplification which we will use for our calculations. There are other components to gasoline, therefore there is some variation.

17. Write a balanced equation for combustion of octane with oxygen assuming complete reaction to generate water and carbon dioxide.

    $C_8H_{18} + 16\ O_2 \rightarrow 8\ CO_2 + 32\ H_2O$

18. Calculate how many grams of the main component of gasoline [*octane*] are contained in one gallon of gasoline – use the following conversion factors and use dimensional analysis to calculate.

- Density is 0.7489 g/cm3
- 1 gal = 3.78 L  1 L= 1000  mL = 1000 $cm^3$

    1 gallon x 3.78L/gal x 1000$cm_3$/1L x 0.7489 g/$cm_3$ = 2830 g

19. How many moles of [octane] in 1 gal gasoline? Use the MM found in # 16.

    2830 g/114 g/mol = 24.83 moles of octane

20. Using balanced equation for octane, how many molecules of CO2 are generated from combustion of 1 gallon of octane?

    24.83 moles of octane x 8 moles of $CO_2$/1 mole octane = 198.7 moles of $CO_2$

21. Hawaii combusted 1,797,600,000 gallons of petroleum products in 2017[i]. Is this information enough to calculate the total CO2 emissions from petroleum products in Hawaii in 2017?

    No, would need to know the breakdown of each type of petroleum product because they have different emissions per gallon depending on the number of carbons in each product.

22. CO2 emissions from energy in Hawaii was 18.5 million metric tons in 2016.[ii] The majority of this was from petroleum products, the remainder was from coal. Coal produced about 6% of energy and around 9% of emissions. That is 50% more emissions than energy, how can this be?

    Different fuels emit different amounts of carbon dioxide (CO2) in relation to the energy they produce when burned. Higher C content, yields higher emissions.
    Bituminous coal produces 205.7 lbs CO2 / million BTU
    Gasoline produces 157.2 lbs CO2 / million BTU[iii]

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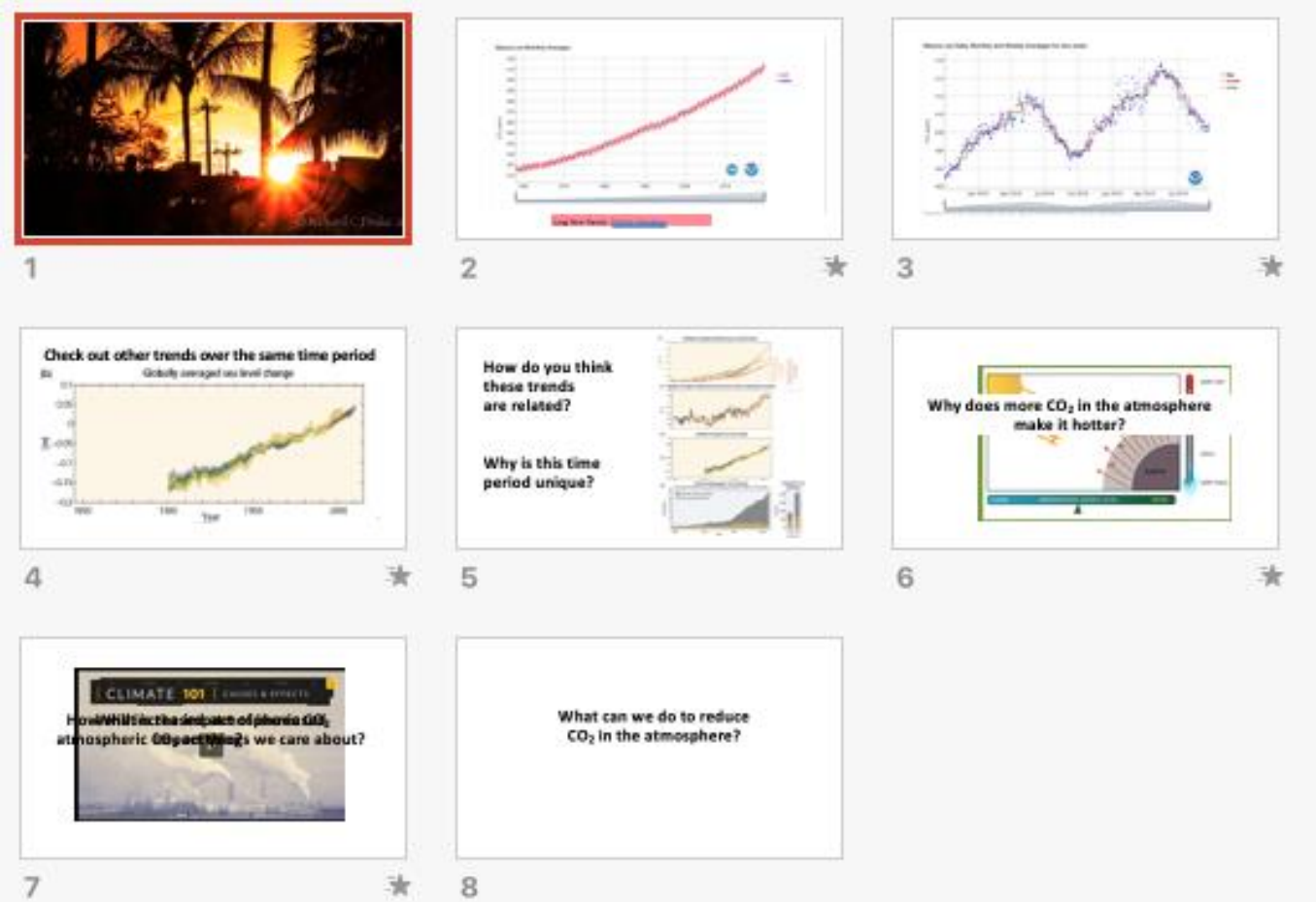
## BIG PICTURE ANALYSIS

**Brainstorm – 5 minutes** Pair share or form groups to list all the types of combustion reactions you can think of. Circle the ones that do not involve humans.

> Wood fires, forest fires, volcanic eruptions burning materials in their paths, propane BBQ, charcoal BBQ, cars, planes, motor boats, diesel generators, electric power plants, gas stoves, hot water heaters, candles, matches, fireworks, bombs

Teacher will choose pairs / groups and ask for one type of combustion that has not been shared already.
Ask: Which types existed before humans? (Forest fires, materials burned by hot lava)
Ask: Which types existed here in Hawaii before European contact? (wood fires)

**Let's take a look at the effects of this recent increase in combustion by looking at some images and a short video together.** **See Lesson 1 Slide Show.**

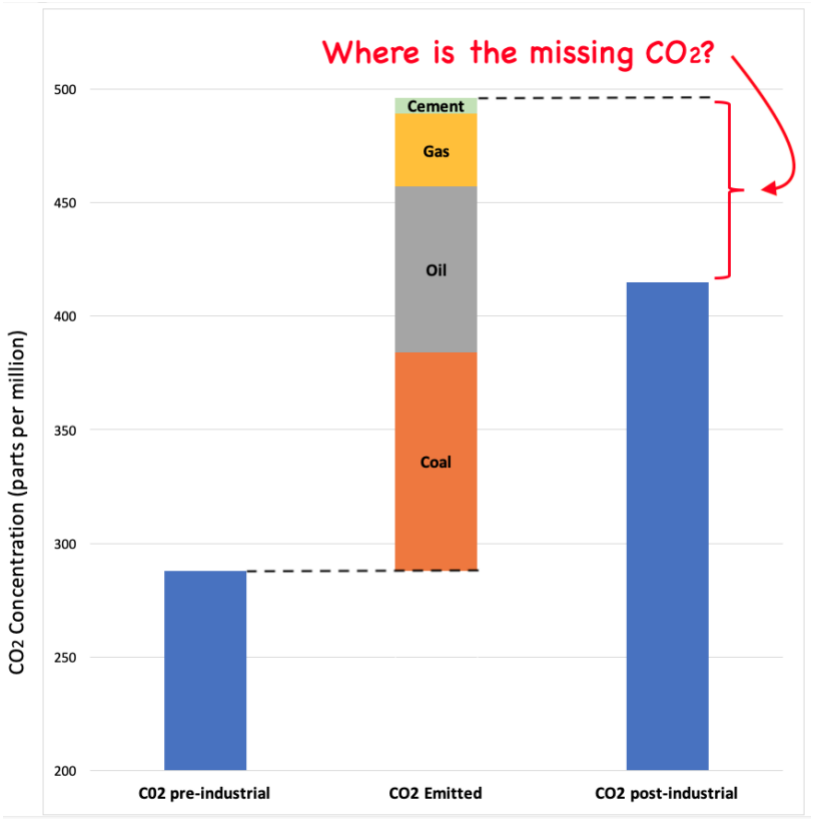


# LESSON 2. HOW DOES THE OCEAN REACT TO CHANGES IN $CO_2$ CONCENTRATION AND TEMPERATURE?

*HS-PS1-5: Apply scientific principles and evidence to provide an explanation about the effects of changing the temperature or concentration of the reacting particles on the rate at which a reaction occurs.*

*HS-PS1-6: Refine the design of a chemical system by specifying a change in conditions that would produce increased amounts of products at equilibrium.*

**PHENOMENON: Where is the missing $CO_2$? Since the industrial revolution, humans have emitted more CO2 than the increase measured in the atmosphere. See graph.**




Source: https://qz.com/1149925/climate-change-would-be-way-worse-if-oceans-didnt-absorb-carbon-dioxide/

**What do you wonder about this phenomenon?**

**QUESTIONS AND INVESTIGATIONS**

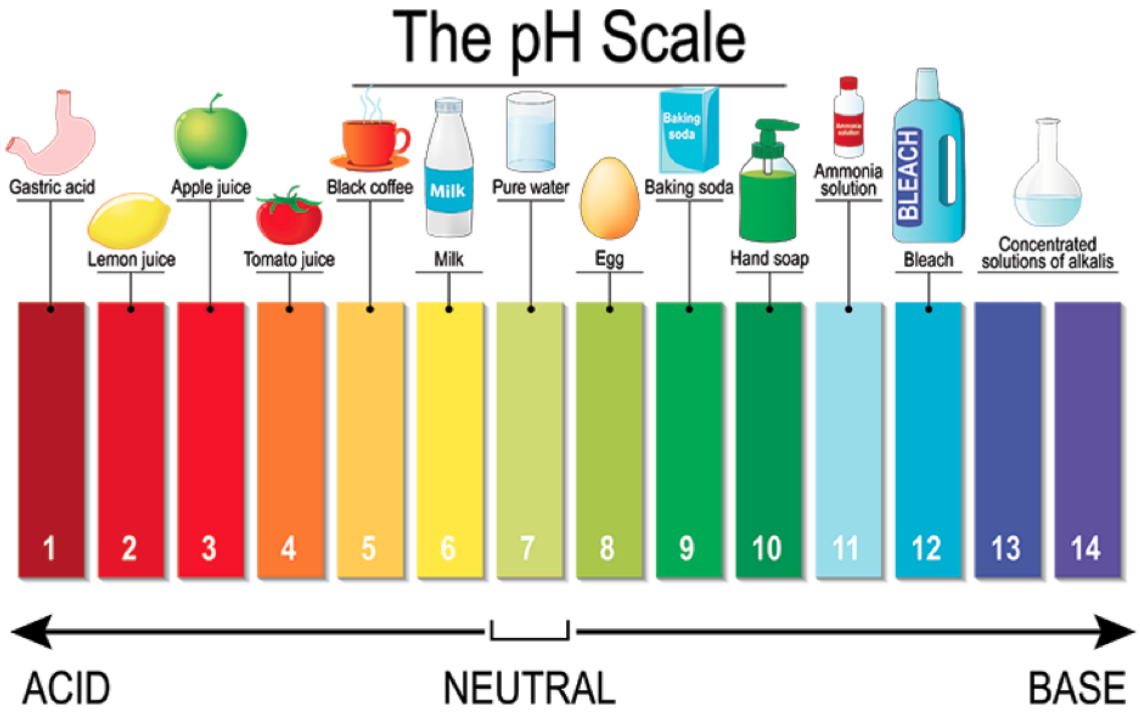
## What happens to the pH of water when $CO_2$ is introduced? How is the reaction affected by concentration and temperature?

Provide students with materials, water acidification lab procedures, and a data table and graph to complete.

**Water Acidification Lab Procedures**

**How acidic or alkaline is a solution?**

Universal indicators measure the concentration of hydrogen ions ($H^+$) in a solution, called pH (potential of Hydrogen). They change color depending on the concentration of $H^+$ and indicate whether a solution is acidic or alkaline (or basic). An acid is a substance that releases $H^+$. Use this graphic as a reference to record a value on the Lab Sheet based on the color you observe.




https://www.sciencenewsforstudents.org/blog/scientists-say/scientists-say-ph

For this lab, carbon dioxide will be added to water using three different methods. First, air will be blown through a straw (exhaled air is about 5% carbon dioxide). For the second method, carbon dioxide will be made from mixing baking soda and vinegar and the gas will be "poured" into the

beaker. Finally, carbonated soda will be added to the beaker for the last variation (this has the highest concentration of carbon).

*Materials: water, universal indicator and pH color chart or pH meter, 5 clear plastic cups or beakers, straws, carbonated water, baking soda and vinegar, graduated cylinder, and timer.*

*Note: smaller straws will introduce smaller amounts of air (and $CO_2$) in the solution and it will take longer to see the color change whereas larger straws will cause a more dramatic color change*

Procedure:

1. Using a graduated cylinder, pour 100 mL of distilled water each of four beakers (or plastic cups).
2. Label each cup as follows: control, straw, $CO_2$ pour, carbonated soda.
3. Add approximately one milliliter of universal indicator to each cup and observe and note the color. If using pH meter, measure the pH of the control. Set the control aside for future comparisons.
4. Method 1: One student monitors the timer and the other student uses the straw to blow air in the beaker labeled straw. If you have a pH meter, set it up in the container then start blowing air into the water. The monitor will note the color and pH at 5, 10, 15, 20, and 30 seconds and will enter the values in the table provided. Compare the color with the control.
5. Method 2: Use a beaker or plastic cup to prepare the $CO_2$ gas. You must work quickly and start measuring pH as soon as the vinegar and baking soda are combined and the $CO_2$ is "poured". Mix 50 mL of vinegar with one tablespoon of baking soda then stir (you should observe a lot of bubbling). If you have a pH meter, set it up in the container labeled $CO_2$ pour, start the timer and quickly pour the gas into the container. Monitor the pH or color change at 5, 10, 15, 20, and 30 seconds and enter the data in the table provided. Compare the color with the control.
6. Method 3: If you have a the pH meter, set it up in the container labeled carbonated soda then start the timer and pour 50 mL or carbonated soda in the container. Monitor the pH or color change at 5, 10, 15, 20, and 30 seconds and enter the values in the table provided. Compare the color with the control.
7. Repeat Method 1 with hot water.

## Lab 2 Worksheet

**Group _____**

**Our predictions:**

**When $CO_2$ is introduced to water, the pH will _____.**

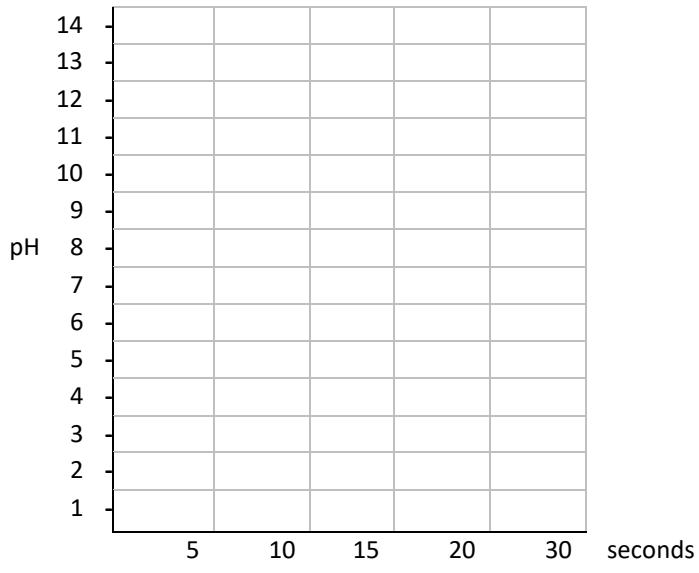
**The higher the concentration of $CO_2$, the pH will _____.**

**The greater the temperature of the water, the pH will _____.**

| pH value based on meter OR color chart | | | | | |
|---|---|---|---|---|---|
| **$CO_2$ source** | **5 seconds** | **10 seconds** | **15 seconds** | **20 seconds** | **30 seconds** |
| Air blown through straw | | | | | |
| $CO_2$ gas pour | | | | | |
| Carbonated water | | | | | |
| **HOT WATER (at least 75○C)** | | | | | |
| Air blown through straw | | | | | |

Graph the measured or estimated pH values from the table. Label a line for each method:

- Exhaled air (cold water)
- $CO_2$ gas pour
- Carbonated water
- Exhaled air (hot water)

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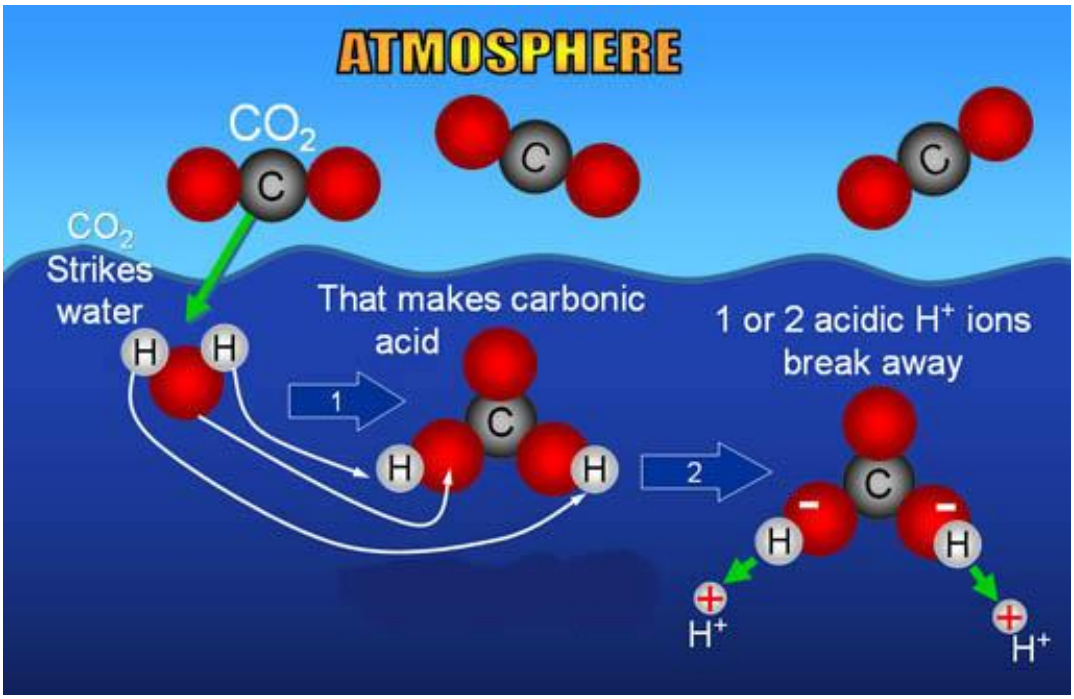
# Lesson 2 Worksheet: Chemical reactions under changing conditions

## What was the reaction when you introduced $CO_2$ sources to the water?

1. In the lab, what happened to pH of the water when $CO_2$ was added?

| |
|---|
| The pH went down indicating the water became more acidic. |

At the molecular level, this is what was happening: Carbon dioxide ($CO_2$) diffused into water combined with the water ($H_2O$) to form a weak acid called carbonic acid ($H_2CO_3$). Carbon dioxide gas becomes liquid once it forms carbonic acid. Almost immediately, the carbonic acid then separated into hydrogen ions ($H^+$) and bicarbonate ions ($HCO_3^-$). See illustration below.




Source: http://www.chemistryland.com/CHM107Lab/Exp05_CO2/Lab/CO2intoOcean.jpg

2. Why would the chemical reaction create the changes in pH you observed?

| |
|---|
| Carbonic acid releases hydrogen ions and creates a higher concentration of them in the water which is what pH measures. |

3. Where might this chemical reaction be taking place naturally on a large scale?

| |
|---|
| Carbonic acid is found in nature wherever carbon dioxide and water combine, such as rain water and bodies of water like the ocean. |

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4. How would this impact the concentration of $CO_2$ in the atmosphere? Does this shed light on any questions you had about the phenomenon of the "missing $CO_2$" in the atmosphere from combustion of fossil fuels?

$CO_2$ diffuses into the ocean from the atmosphere and then turns into carbonic acid. This keeps it in the ocean and out of the atmosphere which accounts for the $CO_2$ "missing" from the atmosphere.

## What was the effect of temperature on the water acidification reaction rate?

5. What happened to the speed of pH change when you changed the temperature of the water before blowing through a straw?

The hot water reaches the final pH value (equilibrium) faster.

**Temperature, kinetic energy and reaction rates**

Temperature is a way to measure the kinetic energy (movement) of molecules. Higher temperatures mean molecules have greater levels of kinetic energy. When there is more movement of molecules the likelihood of effective collisions between atoms is higher. More effective collisions provide a better chance for chemical reactions to take place. Therefore, at higher temperatures chemical reactions typically occur faster.

Higher temperature → more kinetic energy → faster reaction

The effect of temperature on reaction rate impacts our everyday life. It takes hours or days to pull the soluble chemicals from the coffee grounds when coffee is brewed in cold water, so we use very hot water to get the same chemical reaction in minutes. Our refrigerators and freezers maintain low temperatures to slow the chemical reactions that decompose fresh foods.

## What was the effect of concentration on the water acidification reaction rate?

6. In the reactions you observed, what was the impact of concentration of $CO_2$ on the speed of pH change?

Note: Of the sources tested, carbonated water has the highest concentration of $CO_2$ (more molecules) and exhaled air has the lowest concentration of $CO_2$ (fewer molecules).

pH went down most rapidly when carbonated water was added. Carbonated water has the highest $CO_2$ concentration so we can deduce that reaction rate (speed) can be increased by increasing concentration of reactants.

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# Changing Concentrations – M&M Lab

This model uses M&Ms (or other small objects like pennies) to represent chemical compounds undergoing a reaction. In pairs, draw a line down the middle of a sheet of paper. Label the left side of the paper "R" for reactants and the right side "P" for products.

You will be performing all of your reactions according to the following equation: R ↔ P. To represent molecules that are reactants, you will put M&Ms on the reactant side of the paper; products will be M&Ms on the product side of the paper. Reactions will be represented by moving an M&M from one side of the paper to the other. The % represents the reaction rate. Equilibrium will be achieved once the number of reactants and products no longer changes (they may not necessarily be equal).

Materials: 45 M&Ms, calculator, paper, pencil

Procedure:

**Part I**

For this part, one person should take care of moving M&Ms from the reactant side and the other should take care of the product side of the paper.

1. Start with 30 M&Ms on the reactant side of the paper.
2. Each round, you will be exchanging M&Ms between R and P.
3. For each round, R should move 20% of his/her M&Ms to the P side. P should move 10% of his/hers to the R side. When you end up with a decimal of any size for the number to exchange, you should round up. Hint: Keeping M&Ms in groups of 10 will save time counting.
4. Fill in Table 1 as you go.
5. Stop once the number of reactants and products remains unchanged for two consecutive rows or after 10 rounds, whichever comes first.

**Part II**

6. Part two is the exact same as part one except for the starting amounts of reactants and products. Start with 15 reactants and 15 products.
7. Start exchanging the M&Ms by following the same rules from step 3 in part one. Keep track of the number of candies on each side after each transaction in another table.
8. Fill in Table 2 as you go.
9. After 6 rounds, introduce a stress to the system by changing the concentration on the reactant side. Add 15 M&Ms to the Reactant side of the sheet.
10. Stop once the number of reactants and products remains unchanged for two consecutive rows or after 15 rounds, whichever comes first.

**Part III**

11. Follow the same instructions as part one. Start again with 40 reactants and no products.
12. Start exchanging the M&Ms by following the same rules from step 3 in part one, but exchanging 50% of the reactants and 25% of the products.
13. Fill in Table 3 as you go.
14. Stop once the number of reactants and products remains unchanged for two consecutive rows or after 5 rounds, whichever comes first.

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| Part I | R 20% | P 10% | |
|---|---|---|---|
| Round # | Reactants | Products | |
| 0 | 30 | 0 | |
| 1 | 24 | 6 | |
| 2 | 20 | 10 | |
| 3 | 17 | 13 | |
| 4 | 15 | 15 | |
| 5 | 14 | 16 | |
| 6 | 13 | 17 | |
| 7 | 12 | 18 | |
| 8 | 11 | 19 | |
| 9 | 10 | 20 | Ratio R/P |
| 10 | 10 | 20 | 0.5 |
| Part II | R 20% | P 10% | |
| Round # | Reactants | Products | |
| 0 | 15 | 15 | |
| 1 | 14 | 16 | |
| 2 | 13 | 17 | |
| 3 | 12 | 18 | |
| 4 | 11 | 19 | |
| 5 | 10 | 20 | Ratio R/P |
| 6 | 10 | 20 | 0.5 |
| Change in conditions | +15 = 25 | same = 20 | |
| 7 | 22 | 23 | |
| 8 | 20 | 25 | |
| 9 | 19 | 26 | |
| 10 | 18 | 27 | |
| 11 | 17 | 28 | |
| 12 | 16 | 29 | |
| 13 | 15 | 30 | |
| 14 | 15 | 30 | Ratio R/P |
| 15 | 15 | 30 | 0.5 |
| Part III | R 50% | P 25% | |
| Round # | Reactants | Products | |
| 0 | 30 | 0 | |
| 1 | 15 | 15 | |
| 2 | 11 | 19 | |
| 3 | 10 | 20 | |
| 4 | 10 | 20 | Ratio R/P |
| 5 | 10 | 20 | 0.5 |

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## How does concentration impact reaction rate?

7. Compare the change in the number of reactants and products in the first 3 rounds of Part I and of Part II. What was the impact on reaction rate of different starting concentrations? What can you compare this to from the Lab?

In the first 3 rounds of Part I there was a change of 13 units. In the first 3 rounds of Part II there was a change of 3 units. The greater concentration had a faster rate of change. This was like having treatments in the lab with higher and lower concentrations of $CO_2$.

8. Part III and Part I had the same concentrations of reactants, but had different rates of exchange. How did the different rates of exchange in affect the reaction rate? What can you compare this to from the Lab?

Equilibrium was reached much more quickly with the greater rate of exchange in Part III vs. Part I: 3 rounds vs. 9 rounds. In the lab, this was like when we increased the temperature of the water.

## How does concentration impact equilibrium?

9. Based on your data for Part I, were the numbers of reactants and products ever the same? If so, was that equilibrium? Why or why not?

Yes, both reactants and products had the same number in round 4, but it is not equilibrium when numbers are the same on each side. Equilibrium is when the same number of products and reactants going back and forth are the same and the total numbers of products and reactants on each side stop changing.

10. Part I started with a greater concentration of reactants (30) than Part II (15), but the total number of M&Ms in the system was the same. What was the impact on the equilibrium of different starting concentrations?

The equilibrium was the same for both (R=10, P=20). It took more rounds to reach equilibrium when starting with the higher concentration of reactants.

11. How did the ratios you calculated compare to each other for the three Parts which had different starting points, concentrations, and rates of exchange? How do the ratios help us understand the equilibrium?

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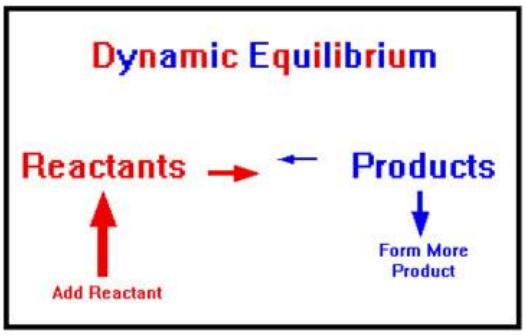
Starting point, concentration and rates of exchange do not change the ratio, they were all the same. The ratio tells us the equilibrium of the reaction is reached when there is twice as much product as reactant since the ratio was 0.5 for all of the calculations. This is because the rates of exchange all had twice as much going from reactant to product as from product to reactant. The equilibrium ratio is the same for all three parts but the rate at which it reaches equilibrium is what changes.

12. A change in conditions was introduced in Part II when 15 M&Ms were added to the system on the reactant side, thereby increasing the concentration of reactants. How did that change in conditions affect the concentrations of both reactants and products at equilibrium? What can you compare this to from the Lab?

After changing conditions by adding more M&Ms to the system, the new equilibrium had 5 more reactants and 10 more products than the equilibrium for the previous conditions – greater concentrations of each. However, at equilibrium, the ratio between reactants and products ended up the same. In the lab when we introduced more $CO_2$ to the system, the pH of the water changed, indicating that the equilibrium of the chemicals in the water had shifted to one that had more carbonic acid.

**Le Chatelier Principle**

Henry Louis Le Chatelier was a scientist who discovered that if a system in **chemical** equilibrium is subjected to a disturbance it tends to change in a way that opposes this disturbance (Le Chatelier's Principle).




Many reactions start with reactants and move in one direction to generate products. Other reactions also undergo a similar process but under certain conditions, the products may reverse the process and form reactants. In an equilibrium reaction, both processes occur simultaneously and a small change in conditions is sufficient to affect the amount of substance of both the reactants and product side.

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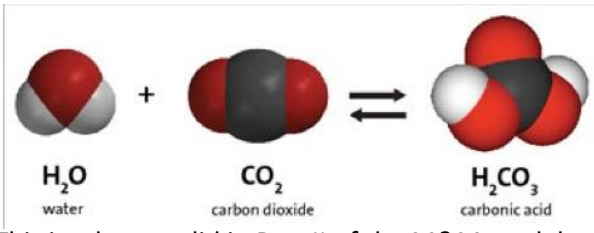
Some of the disturbances that can affect a system include change of temperature, change of concentration and change of pressure. We have focused on what happens to the equilibrium when concentrations of reactants or products are changed. In the picture, if reactants ($CO_2$) are added to water, the equilibrium will be temporarily disturbed to create more products (carbonic acid) until equilibrium is re-established. This is what we did in Part II of the M&M model when we introduced a stress. If instead it is products (carbonic acid) that are added to the system, the equilibrium would shift to the left to form more reactants until the equilibrium is achieved.

**Carbon dioxide Dissolution Reaction**




13. Using Le Chatelier's Principle, predict how the concentration of carbonic acid will change in a solution when:

Carbon dioxide is added? It will increase

Carbon dioxide is removed? It will decrease

Water is removed? It will decrease

14. What happens with the concentration of carbon dioxide if carbonic acid is removed? Why?

It will decrease because the equilibrium will shift to replace the removed carbonic acid until both reactants and products are at equilibrium.

15. Based on your observations in the Lab, your analysis of the model and what you learned about the Le Chatelier Principle, explain what the effects of changing the concentration of reacting particles is on the rate at which a reaction occurs and why.

A greater concentration of reactants will result in faster reaction rates and equilibrium will be achieved more quickly because more reactions will be going on at the same time.

**Teacher options: Do the remaining sections as a class discussion using the PowerPoint slideshow, or finish as a worksheet.**

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## Why pH Matters

**A small change in pH is a big change in acidity**

Source: https://www.pmel.noaa.gov

pH is logarithmic, so one unit of pH (going from 8.2 to 7.2) means the acidity has increased by 10 times. A 0.1 unit of pH corresponds to an increase of 26% in acidity. The way the impact of the concentration of hydrogen ions on pH is calculated, is with the following formula:

$pH = -\log [H^+]$

**Living things are sensitive to changes in acidity**

Many organisms are very sensitive to seemingly small changes in pH. For example, in humans, arterial blood pH normally falls within the range 7.35–7.45. A drop of 0.1 pH units in human blood pH can result in profound health consequences, including seizures, heart arrhythmia, or even a coma.

Similarly, many marine organisms are very sensitive to either direct or indirect effects of the change in acidity (or $H^+$ concentration) in the marine environment. The general pH of ocean water was approximately 8.2, but as a result of this change in carbonate-bicarbonate equilibrium in recent years, the pH has dropped to 8.1. This may not seem like much but remember that it corresponds to a 26% increase in hydrogen ions which can significantly impact marine life.

## Impact on the Marine Life

Materials from weathered rocks wash into the ocean water and are used by coral and other marine creatures to build their shells and skeletons in a process called calcification. The sea creatures take calcium ions ($Ca^{2+}$) and carbonate ions ($CO_3^{2-}$) from the sea water to form the calcium carbonate they need ($CaCO_3$) and generate an extra $CO_2$ and extra water molecule as follows:

$$Ca^{2+} + CO_3^{2-} \Leftrightarrow CaCO_3 + CO_2 + H_2O$$

As we saw when we learned the equilibrium reaction for the formation of carbonic acid, introducing carbon dioxide in the water creates an increase in ocean acidity which means that there is a greater concentration of free $H^+$ ions floating around in the ocean.

$$CO_2 + H_2O \Leftrightarrow HCO_3^- + H^+$$

Carbonate ions in the ocean also react with $H^+$ ions to form a bicarbonate ion as follows:

$$H^+ + CO_3^{2-} \Leftrightarrow HCO_3^-$$

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16. As ocean acidification occurs (more $H^+$), does the concentration of bicarbonate ion ($HCO_3^-$) increase or decrease? In which direction will the equilibrium shift?

> As ocean acidification occurs the concentration of bicarbonate will increase. The equilibrium will shift left.

17. If increased concentrations of $H^+$ react with the unchanged concentrations of carbonate ions ($CO_3^{2-}$) to produce increased amounts of bicarbonate ($HCO_3^-$) at equilibrium, how will this changed equilibrium impact calcification by sea creatures?

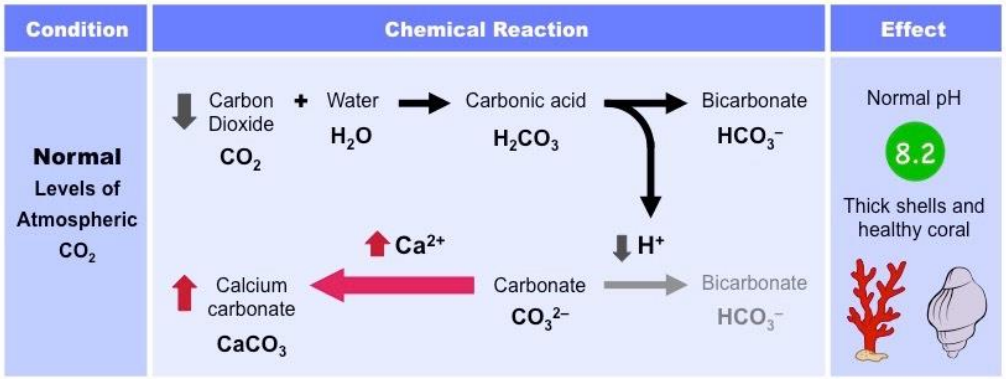
> Less carbonate will be available for marine creatures to form calcium carbonate that they need to build shells and skeletons.

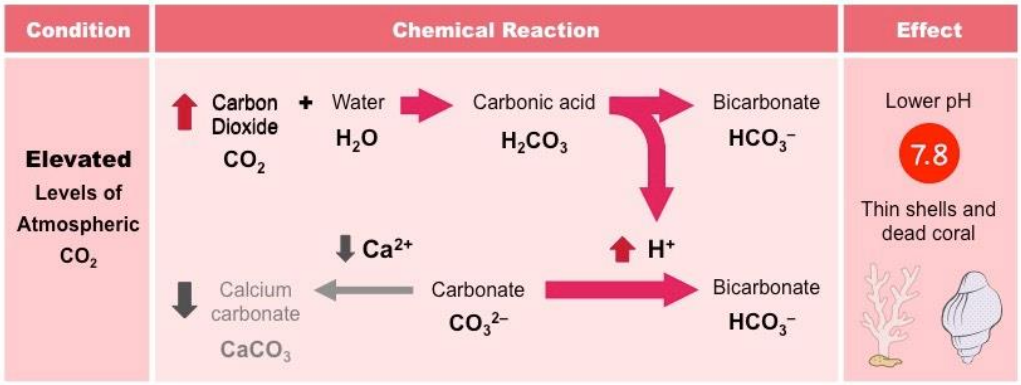
18. Two $H^+$ ions can also react with calcium carbonate to release a calcium ion and form carbonic acid. How might an increase in the concentration of free H+ ions impact marine creatures in an additional way?

$$CaCO_3 + 2\ H^+ \Leftrightarrow Ca^{2+} + H_2CO_3$$

> A higher concentration of $H^+$ might actually dissolve shells or coral skeletons that have already been formed by breaking apart the calcium carbonate.

The graphics below depict the changes in ocean chemistry when there is an increase in atmospheric $CO_2$.

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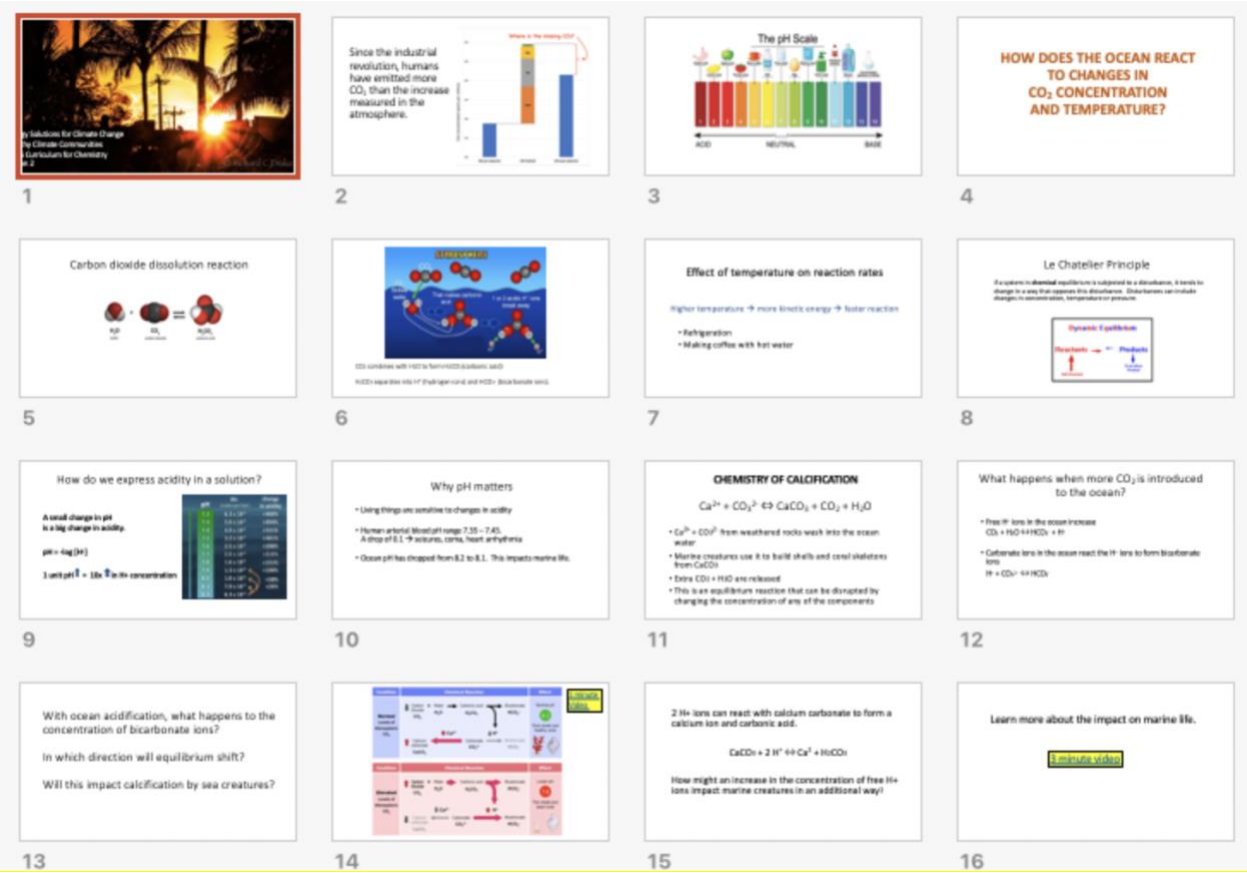
Source: https://ib.bioninja.com.au/standard-level/topic-4-ecology/43-carbon-cycling/ocean-acidification.html

VIDEOS

Review the chemistry (1 minute):
https://www.youtube.com/watch?time_continue=20&v=ObiJIuRYr3g

Learn more about impacts on living things (3 minutes):
https://www.youtube.com/watch?time_continue=166&v=Wo-bHt1bOsw&feature=emb_logo



# LESSON 3. HOW CAN WE GET POWER WITHOUT CREATING $CO_2$ EMISSIONS?

***HS-PS3-3:*** *Design, build, and refine a device that works within given constraints to convert one form of energy into another form of energy*

**The amount of energy from the sun that strikes the Earth in one hour is more than the entire world consumes in a year.**

What do you wonder about this phenomenon?

## QUESTIONS AND INVESTIGATIONS

**How do we convert the sun's energy into a form we can use?**

Light trapping pigments in the leaves of plants absorb solar energy which causes the electrons to boost out of the orbit around the nuclei of their atoms. The movement of the electrons allow the set of chemical reactions called photosynthesis that plants use to make food.

Solar cells of different types also use the sun's energy to enable electrons in the materials they are made of to move from orbits close to the nuclei of their atoms to higher orbits where they set off chemical reactions that create electric currents. The most common type of solar cells is Photovoltaic. Photovoltaic (PV) simply means something that converts sunlight (photo) into electricity (volt).

In the case of PV panels, solar energy causes "extra" electrons in the negative layer of the panel to be released forming an electric current as they are drawn towards the positive layer of the panel which has holes in need of the extra electrons. The electrons traveling along a pathway between the positive and negative layers create an electric current and if an electric device is inserted along the pathway it receives power from the current.

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**Learn more about solar energy**

Short, general video on use of solar panels: **"**Solar Energy," National Geographic (1:30 min)
https://www.nationalgeographic.com/environment/global-warming/solar-power/

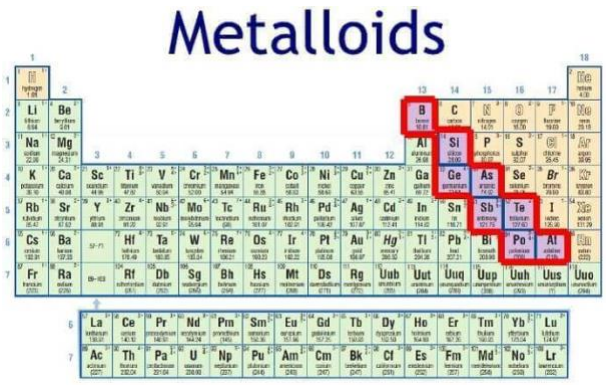
**Learn more about PV cells**

Video includes models of chemical reactions.
"Electricity from [PV] Solar Cells," MIT (5:22 min)
**https://www.youtube.com/watch?v=go0aotVeXoE**

### PV panels are made of:

- Silicon
- Copper Indium Gallium Selenide
- Cadmium Telluride
- Gallium Arsenide

### Look at the periodic table – in what group can you find those materials?




Semi-metals aka metalloids

Semiconductors are made by taking a pure material, like silicon, that does not conduct electricity because the electrons are stable, and adding impurities (also known as doping). To one layer of the silicon, a small amount of an impurity is mixed in that will provide one too many electrons which will be free to move around creating an electric current. Another layer has a small amount of a different impurity mixed in that will make it have one too few electrons so there will be a "hole". Holes can conduct current by accepting an electron from the other layer.

**In the video, what was mixed with silicon to form the corresponding layers? Which one was positive and which was negative?**

| | **Extra electron** | **Hole** |
|---|---|---|
| **Element** | P | B |
| **Positive or Negative?** | N | P |

**What is the role of the electrical field created by the junction where N and P layer come together in a semiconductor?**

The electrical field acts like a wall that keeps the electrons and holes from combining with each other unless they go through the external circuit first.

Another promising type of solar cell is the Dye Sensitized Solar Cell (DSSC) which uses pigment from plants, similar to what happens when chlorophyll undergoes photosynthesis, to capture the sun's energy and start a chemical reaction that creates an electric current. Advantages of DSSC include the fact that the materials are more abundant than those used for PV panels, and there are no toxic substances to dispose of when the panels are no longer in use.

Generally, a modern **DSSC** is composed of a porous layer of titanium dioxide nanoparticles, covered with a molecular dye that absorbs sunlight. The photogenerated electrons from the light absorbing dye are passed on to the n-type titanium dioxide and the holes are absorbed by an electrolyte on the other side of the dye. The circuit is completed by a redox reaction in the electrolyte.

We can build DSSCs that will power a device with sunlight.

Watch these to understand how DSSC work.

Simple (3.5 mins)
https://www.youtube.com/watch?v=7Au3Yc0bhCg

more advanced but very good (5 mins)
https://www.youtube.com/watch?v=g1TfQ9rypHI

**Explain the difference between the materials necessary to build Photovoltaic (PV) vs dye-sensitized solar cell (DSSC)**

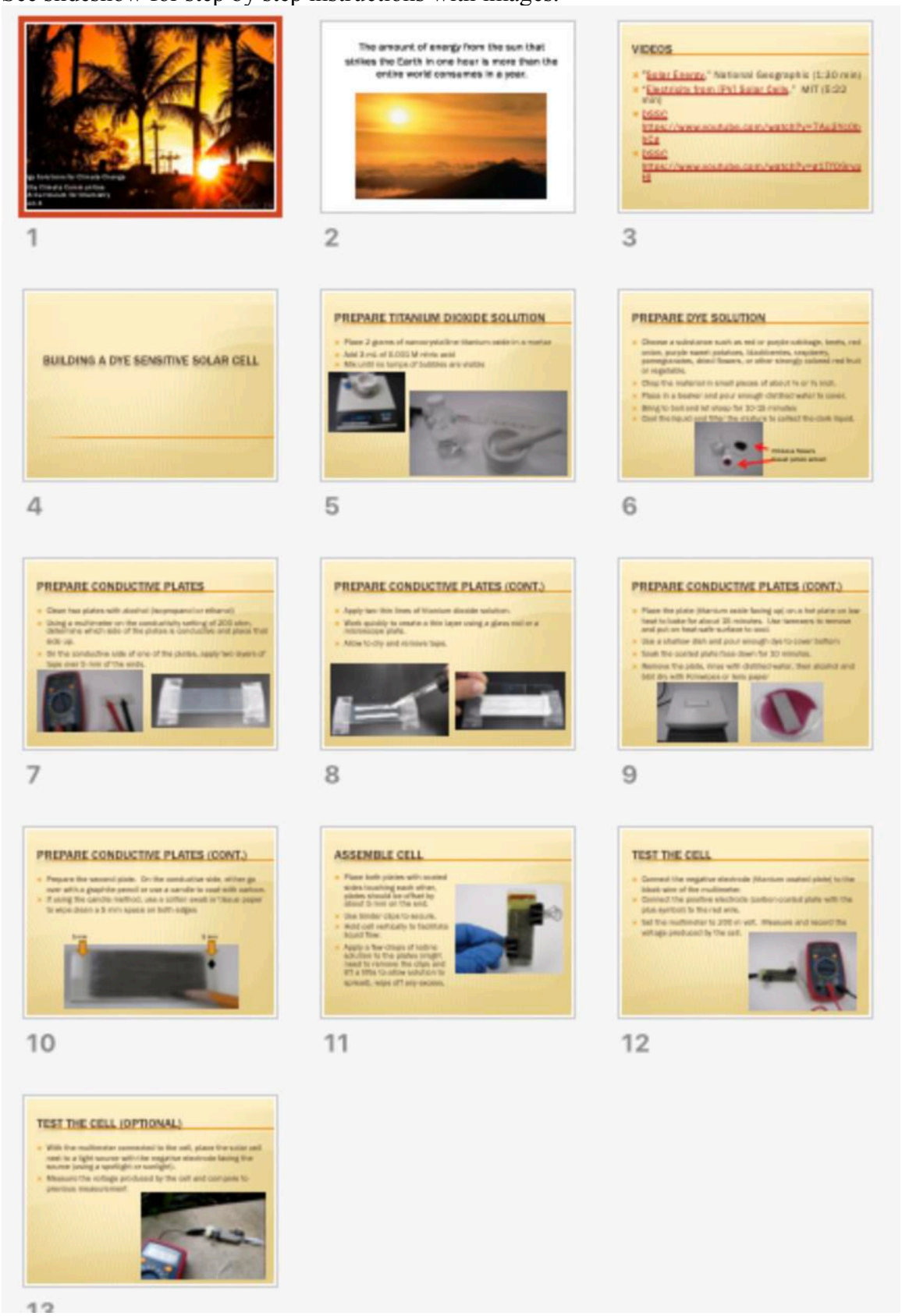
A Dye sensitized solar cell is a hybrid technology as it involves organic and inorganic materials in the active layer. Organic PV is made of pure organic materials (either small molecules or polymers).

## Experiment: build a DSSC using natural dyes from food

You will build a DSSC using basic materials then measure the voltage output of your cell.

The general steps are: 1) prepare a concentrated dye solution, 2) coat plates with the semi-conductive substances and the dye, 3) assemble the cell, then expose to the sun and measure the voltage.

See slideshow for step by step instructions with images.



Materials:

5 mL of ethyl or isopropyl alcohol
1 mL of iodine/potassium iodide solution
25 mL of nitric acid 0.001M
2 g of nanocrystalline titanium dioxide
Distilled water
2 binder clips
Tea light candle or pencil
Two 1" x 3" conductive glass plates (microscope slides)
Red or purple fruit, flower or vegetable for dye
250 mL beakers
Petri dish or other shallow dish large enough to fit plate
Tweezers
Hot plate
Funnel and filter paper
Glass rod
Kimwipes or lens paper
Multimeter with alligator clips
Transparent tape
Gloves
*NOTE: The teacher may elect to prepare the dye solution and the titanium dioxide solutions ahead of time.*

**Prepare dye solution**

Extract dye from red or purple cabbage, beets, red onion, purple sweet potatoes, blackberries, pomegranates, raspberry, or other strongly colored red fruit or vegetable. Teacher may elect to have everyone use the same dye or study different dyes.

1. Chop material in small pieces about ¼ to ½ inch.
2. Place in a beaker and pour enough distilled water to cover.
3. Bring to boil and let steep for 10 to 15 minutes (the liquid will be a dark color).
4. Cool the liquid and filter the mixture to collect the liquid dye.

Optional: use phone color app picker to measure and compare color between different extracts (need details for app if we decide to include this option)

**Optional question: What processing method yields the most dye?**

Article on dyes (good reference but may be too complex for students)
https://www.hindawi.com/journals/jnm/2019/1867271/

## Prepare titanium dioxide solution

1. Place 2 grams of nanocrystalline titanium oxide in a mortar, add 3 mL of 0.001 M nitric acid and mix until no lumps or bubbles are visible.

## Prepare plates

1. Clean two glass plates with alcohol.
2. Use multimeter to determine which plate side is conductive (and keep track of that side). Set the multimeter to 200 ohm, you should get a reading around 25-35.
3. On the conductive side of one plate, apply two layers of tape over about 5 mm of the ends of the plates.
4. Apply two thin lines of titanium dioxide solution on the plate, roll a glass rod or another microscope plate over to create a thin layer. Must work quickly before the solution dries out.
5. Allow to dry for a few minutes then remove the tape.
6. Place the plate (with titanium oxide facing up) on a hot plate on low heat to bake for about 15 minutes. Use tweezers to remove the plate and put on a ceramic plate or other heat-safe surface to cool.
7. Use a shallow dish (petri dish) and place enough dye to cover the bottom.
8. Soak the coated plate in dye face down for 10 minutes.
9. While the first plate soaks, coat the conductive side of the other plate by either going over with a pencil, applying graphite lubricant, or using a candle to cover with carbon (leaving a 5mm clean edge on each end – cotton swab can be used to wipe the edges clean) –mark one corner of the plate with a plus symbol.
10. Remove the plate and rinse with deionized water then alcohol. Blot dry with Kimwipes or lens paper.

## Assemble cell and measure output

1. Place both plates with coated sides touching each other, plates should be offset by about 5 mm.
2. Use binder clips to secure.
3. Apply a few drops of iodine solution at the junction of the plates (might need to remove the clips and lift a little to allow solution to spread), wipe off any excess. It's also easier to work with cell held vertical, the solution will flow between the cell using gravity. The solution is made from Lugol's Iodine – take 1 mL of 5% Lugol solution and dilute to 10 mL with distilled water.
4. Connect the negative electrode (titanium coated plate) to the black wire of the multimeter.
5. Connect the positive electrode (carbon coated plate with the plus symbol) to the red wire.
6. Set the multimeter to 200m volt and measure and record the voltage produced by the cell.
7. Place the solar cell next to a light source with the negative electrode facing the source (using a spotlight or sunlight).
8. Measure and record the voltage produced by the cell and compare to previous measurement.

Reference: https://www.wikihow.com/Make-Solar-Cells

**Optional question: If different dyes were used, were the voltages different?**

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## Optional question: What could be done to increase output?

If time allows, implement that change and measure again.

Reference: https://pdfs.semanticscholar.org/1b66/e6150a0b3ef3f2316a2143c1511d27204a0f.pdf

What form of energy conversion was done by our DSSC cells?

| |
|---|
| Photons from sun (solar) convert to chemical energy (chemical reaction) which converts to electricity. |

**Go to the following simulation and see how the other types of energies can be converted to power equipment, then fill out the table with the appropriate type of energy according to its source.**

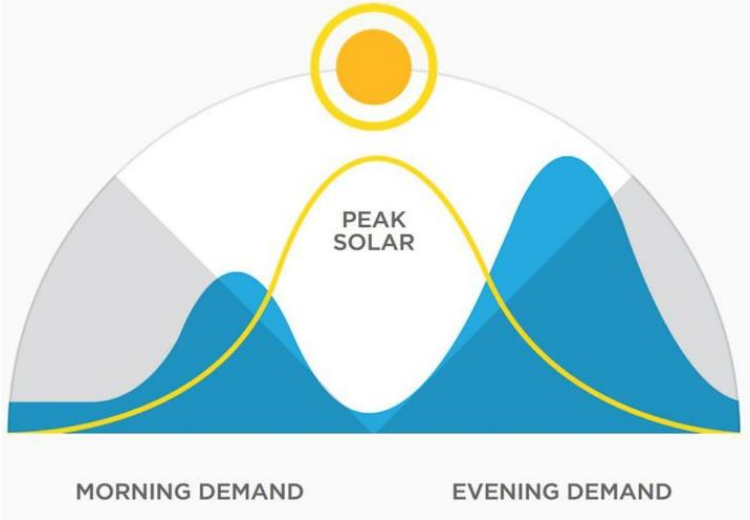
- https://phet.colorado.edu/sims/html/energy-forms-and-changes/latest/energy-forms-and-changes_en.html

| ***Steam: thermal*** | ***Wheel: Mechanical*** | ***Cable: Electrical*** | ***Lightbulb: light and thermal*** |
|---|---|---|---|
| **Water spout:** | **Wheel:** | **Cable:** | **Fluorescent light:** |
| **Sun:** | **PV panel:** | **Cable:** | **Windmill:** |
| **Bicycle:** | **Wheel:** | **Cable:** | **Water:** |
| **What happens to the cyclist after a few seconds?** | | **What kind of energy is needed to continue the work?** | |

# LESSON 4. GLOBAL CHALLENGE: HOW CAN ENOUGH RENEWABLE ENERGY BE MADE AVAILABLE WHERE AND WHEN WE NEED IT?

**PHENOMENON: The timing of electricity production from solar panels (yellow line) is out of synch with typical demand for electricity (blue area).**

**What issues does this raise?**




Source: Tesla

**HS-PS1-2:** *Construct and revise an explanation for the outcome of a simple chemical reaction based on the outermost electron states of atoms, trends in the periodic table, and knowledge of the patterns of chemical properties.*

Teachers:
If you are unable to do the Lesson 3 Lab, this Lab may be substituted and expanded with the optional components suggested here in order to meet standard HS-PS3-3.

***HS-PS3-3**: Design, build, and refine a device that works within given constraints to convert one form of energy into another form of energy*

## Experiment: Transforming energy from plants

You will need: fruit/vegetable, 2" galvanized nails, penny (before 1983 works best as they contain more copper) or copper wire, multimeter, LED lights.

*Best choice is lemon, then potatoes, maybe apples, limes or other water-containing produce can be tested. Typical voltage just under 1 V for lemon, about 0.1 for potato and about 0.03 or less for other items.*

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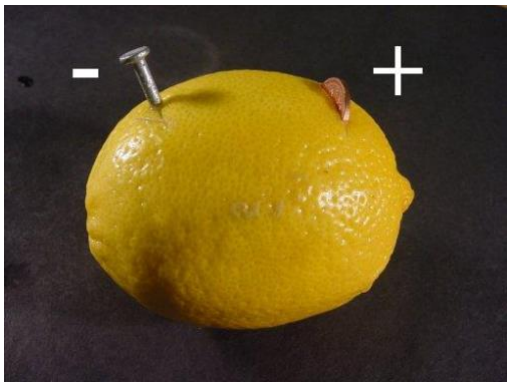
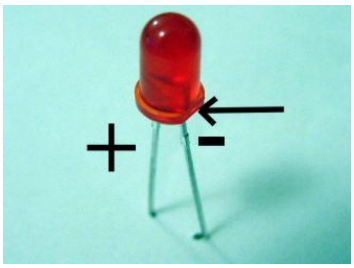
Method:

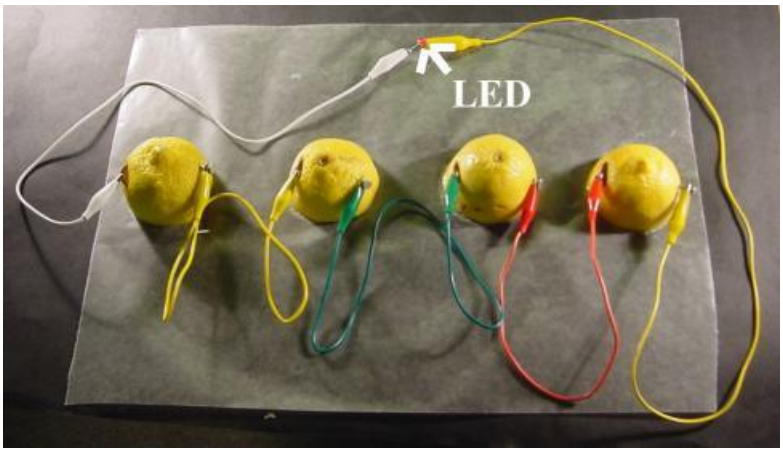



1) Cut a slit on one side of the select food and insert the penny OR insert the copper wire (positive end of the battery).
2) Push the galvanized nail into the other side ensuring the metals don't touch (negative end of the battery).
3) Connect the red clip of the voltmeter to the penny and the black one to the nail.
4) Measure the voltage generated

**Optional:**
This is not sufficient to power anything but if 3 lemons are connected in series, the voltage will add up and will generate enough power to light an LED.




To connect the lemons, get alligator clip wires and connect the negative end of one lemon to the positive end of the other. Do the same thing for all three lemons. Finally, connect the zinc end of the last lemon to the positive end of the LED (that is the side with a flat spot – see picture) and the copper end of the first lemon to the negative end of the LED.




If the LED doesn't light up, maybe one or more additional lemons need to be added.

**Optional:** Other types of produce can be tested to compare the voltage.

---

1. **When and what type of energy did the lemon acquire? When and what type of energy did we tap into? What kind of energy did we convert it to? How does the lemon experiment relate to the phenomenon about the mismatched timing between solar production and electricity use?**

The solar energy was stored in the lemon during sunny days when it was growing. It stored that energy in its juice as chemical energy. We tapped into that chemical energy at the exact time we wanted the energy and we converted it to electric energy. The lemon is a natural battery. It relates to the phenomenon because we can use batteries to fix the problem of mismatched timing between solar production and electricity use.

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2. **Where did the lemon acquire its energy? Where did we access that energy? Does the lemon experiment provide any ideas for solutions to using the sun's energy to power electric vehicles that cannot be attached directly to solar panels while moving?**

The lemon got energy from the sun where it was planted on the tree. We tapped into that energy in our classroom, away from the tree. The stored energy is portable. In the same way, batteries can provide energy to vehicles wherever they are.

Lemons accumulate energy from the sun and store it as chemical energy that can be accessed later. They act like a battery with the skin acting like a battery case holding the lemon juice (citric acid) which acts as the electrolyte. The copper **p**enny is the **p**ositive electrode and the zinc galvanized coating on the **n**ail is the **n**egative electrode. Electrons travel from the negative to the positive electrode.

**Could our lemon battery power equipment such as an electric car or a mobile phone?**

Although we measure the voltage of the lemon battery, what is needed to run equipment are watts (that is the power to run things). The relationship between Voltage and Watts is as follows.

Voltage x Current (Amps) = Watts

Watts are usually connected to the amount of time they are used which is why the electric bill will charge in kilowatt hours (how much power was used per hour). Imagine the voltage is the amount of water contained in a dam and the current is the diameter of the pipe. If you have a lot of water (volt) but a small pipe (amp), not a lot of power will come out but the power will be available for a relatively long time until the dam is empty. If you have the same amount of water but a large pipe, the power will be depleted quickly.

In theory, 3.6 volts are sufficient to charge a battery but we need a large output to get our devices charged up quickly. An average mobile phone needs about 5.45 watt hours to work which is a lot more than your typical lemon that only produces about 0.000216 watts. Although there are enough volts in a lemon, it would take a very long time to charge your cell phone!

We are going to learn more about battery technology to understand how they can help us solve our Global Challenge.

Teachers:
There are 3 videos to choose from, depending on the right level for your students.

The following video explains the concepts on which battery technology is based, starting from the beginning.

*Galvanic Cells, Tyler Dewitt (23 minutes)*
*https://www.youtube.com/watch?v=7b34XYgADlM*

If the students are already familiar with REDOX equations, then you could choose between these 2 shorter videos instead.

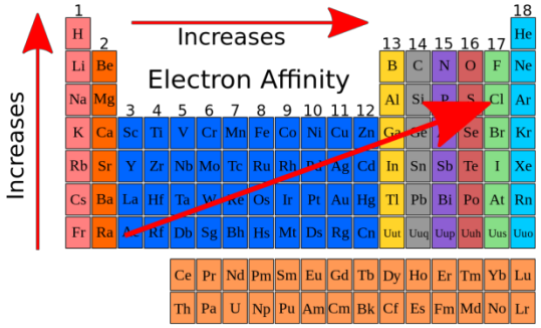
*Electrochemistry, bozemanscience.com (8:40 minutes)*
*https://www.youtube.com/watch?v=Rt7-VrmZuds*

*Electrochemistry, Professor Dave Explains (6:20 minutes)*
*https://www.youtube.com/watch?v=2VT5rl8P84M*

Galvanic cells described in the video and other early batteries get depleted over time and can no longer be used. Newer options use the same general principals as galvanic cells, but use other materials and can be recharged. They have reversible cell reactions so that once the electrons finish naturally discharging, an external power source can be used to force electrons back along the wire the other direction. This can be repeated over and over again.

Lithium ion (Li-Ion) batteries are the most effective type of rechargeable battery available today. The reaction that occurs during discharge follows the same rules as the galvanic cell.

Half reaction: $C_6Li \rightarrow Li^+ + e^- + 6\ C$
Half reaction: $Li_{1-x}CoO_2 + xLi^+ + xe^- \rightarrow LiCoO_2$
Overall reaction: $6\ C + Li_{1-x}CoO_2 \leftrightarrow C_6Li + LiCoO_2$




3. What chemical properties make Li and C effective? How are these properties represented in the periodic table? Draw arrows on the periodic table to illustrate.

The periodic table indicates the electron affinity for the elements. It shows that Li has a low electron affinity (releases electrons) and C has a high one (attracts electrons). This difference generates the natural flow of electrons during discharge.

4. Explain what is happening to the electrons in this chemical reaction. Identify which element is the anode, which is the cathode, which is oxidizing and which is reducing and why.

The first half reaction is the anode where lithium is oxidized. Electrons are released and travel through the wire to the cathode where they are reduced, or absorbed by the carbon. If they flow through an electrical device as they travel between the anode and the cathode, they can power it. The lithium is the anode because it has a lower electron affinity and electrons are attracted to the carbon (cathode) because it has a higher electron affinity.

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# Design a Solution to the Global Challenge: How can enough renewable energy be made available where and when we need it?

**HS-ETS1-1**: *Analyze a major global challenge to specify qualitative and quantitative criteria and constraints for solutions that account for societal needs and wants.*

| Observable features of the student performance by the end of the course: | | |
|---|---|---|
| 1 | | Identifying the problem to be solved |
| | a | Students analyze a major global problem. In their analysis, students: |
| | | i. Describe* the challenge with a rationale for why it is a major global challenge; |
| | | ii. Describe*, qualitatively and quantitatively, the extent and depth of the problem and its major consequences to society and/or the natural world on both global and local scales if it remains unsolved; and |
| | | iii. Document background research on the problem from two or more sources, including research journals. |
| 2 | | Defining the process or system boundaries, and the components of the process or system |
| | a | In their analysis, students identify the physical system in which the problem is embedded, including the major elements and relationships in the system and boundaries so as to clarify what is and is not part of the problem. |
| | b | In their analysis, students describe* societal needs and wants that are relative to the problem (e.g., for controlling $CO_2$ emissions, societal needs include the need for cheap energy). |
| 3 | | Defining the criteria and constraints |
| | a | Students specify qualitative and quantitative criteria and constraints for acceptable solutions to the problem. |

## ANALYZE THE CHALLENGE; SPECIFY CRITERIA AND CONSTRAINTS

5. **Why is making renewable energy available where and when we need it a major global challenge (what about it is challenging)? What are the consequences if we can't solve this problem?**

The most commonly available forms of renewable energy on all islands in Hawaii and elsewhere are wind and solar, but they are not available all the time. Solar is never available at night when we need it most for electricity. We also need energy that is portable so we can use it in transportation that doesn't run on electric tracks or wires. Other types of renewable energy that are available all the time like hydro and geothermal are not available in every place, or at the scale needed. If we can't meet these needs, we will keep using fossil fuels. If we keep using fossil fuels, climate change will worsen.

## What do we mean by criteria and constraints?

**If we were inventing a new energy technology, these are examples we might consider.**

| Criteria: | Constraints: |
|---|---|
| **Must be…**<br>**1. Safe**<br>**2. Reliable**<br>**3. Cost competitive**<br>**4. Aesthetic**<br>**5. Socially acceptable**<br>**6. Low environmental Impact** | **1. Uses toxic chemicals, high voltage?**<br>**2. Operates 24 hours? weather dependent? Supply of raw materials?**<br>**3. Cost of the technology and management of any waste?**<br>**4. Large bulky contraption visible in homes or on view planes?**<br>**5. Do resources impact social/cultural locations?**<br>**6. Necessary materials impacting our land when extracted/acquired, do they cause pollution, generate waste, or harm wildlife?** |

**7. What are the <u>criteria,</u> or standards that must be met, in order to meet our needs through renewable energy? Be as specific as you can. Rank what you consider to be highest to lowest priority on your list.**

1. Must be available in sufficient quantities
2. Must be available regardless of time of day or current weather,
3. Must be portable for some types of transport,
4. Must be affordable to all users,
5. Must not cause major environmental or social problems.

**8. List <u>constraints</u> that must be overcome. These may be technological, environmental, social, economic, and political.**

1. Cost of infrastructure to capture and transport that energy;
2. There can be long periods with no sun, or with no wind;
3. Every night there is no sun;
4. Vehicles with combustion engines can take their fuel with them anywhere, but vehicles drawing electricity must stick to fixed lines;
5. Populations may disagree with method (e.g. wind farms on North Shore, thermal energy on Big Island, perception that nuclear energy is dangerous in other parts or the country);
6. Poor people cannot afford big upfront costs for their own solar panels;
7. Politics of replacing carbon-based fuel with other sources of energy.

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**HS-ETS1-2**: *Design a solution to a complex real-world problem by breaking it down into smaller, more manageable problems that can be solved through engineering.*

| Observable features of the student performance by the end of the course: | | |
|---|---|---|
| 1 | | Using scientific knowledge to generate the design solution |
| | a | Students restate the original complex problem into a finite set of two or more sub-problems (in writing or as a diagram or flow chart). |
| | b | For at least one of the sub-problems, students propose two or more solutions that are based on student-generated data and/or scientific information from other sources. |
| | c | Students describe* how solutions to the sub-problems are interconnected to solve all or part of the larger problem. |
| 2 | | Describing criteria and constraints, including quantification when appropriate |
| | a | Students describe* criteria and constraints for the selected sub-problem. |
| | b | Students describe* the rationale for the sequence of how sub-problems are to be solved, and which criteria should be given highest priority if tradeoffs must be made. |

## BREAK DOWN THE PROBLEM AND DESIGN A SOLUTION

A Global Challenge as large as meeting our needs through renewable energy requires multiple solutions to address different parts of the problem. Rechargeable batteries are one solution for one part of the problem, but there are other solutions that may be used in combination with or instead of batteries.

Pick 2 articles to read that describe parts of the challenge and potential solutions. Fill out one table for each article.

Teachers:
Students may choose freely, or you may assign different articles to different students or groups so they can share what they learned with their peers.

**Lithium Batteries Finally Get their Due with Nobel Prize Win** *[Describes uses of the lithium battery.]*
https://blog.ucsusa.org/mike-jacobs/lithium-batteries-nobel-prize-win

**Besides Buying Renewables, How Can Companies and Cities Create a Greener Grid?**
*[Describes strategies to balance electricity demand with production.]*
https://www.wri.org/blog/2019/06/besides-buying-renewables-how-can-companies-and-cities-create-greener-grid

**4 Emerging Ways to Pair Electric Vehicles and Renewable Energy** *[Describes strategies to ensure the sources used to generate electricity for EVs are renewable.]*
https://www.wri.org/blog/2019/11/4-emerging-ways-pair-electric-vehicles-and-renewable-energy

**Comparing Electric Vehicles: Hybrid vs. BEV vs. PHEV vs. FCEV** *[Describes different types of electric vehicles and their relative benefits.]*
https://blog.ucsusa.org/josh-goldman/comparing-electric-vehicles-hybrid-vs-bev-vs-phev-vs-fcev-411

**What Is Grid Modernization—and What's the Role of Electric Vehicles?** *[Describes strategies and technology to balance supply of energy with demand on electric grids.]*
https://blog.ucsusa.org/peter-oconnor/grid-modernization-and-smart-charging

**More Charging Infrastructure Coming for Electric Trucks and Buses in California**
*[Describes policy to support electric buses and heavy vehicles in San Diego.]*
https://blog.ucsusa.org/jimmy-odea/more-charging-infrastructure-coming-for-electric-trucks-and-buses-in-california

**The Transportation and Climate Initiative, Explained** *[Describes cap and trade system to get funds from fossil fuel companies to invest in alternative transport systems.]*
https://blog.ucsusa.org/daniel-gatti/the-transportation-and-climate-initiative-explained

**Table 1**

| | |
|---|---|
| **Reference 1** | |
| **Relevant challenges / constraints cited in the article** | |
| **Relevant solutions cited in the article** | |

| | |
|---|---|
| **Reference 2** | |
| **Relevant challenges / constraints cited in the article** | |
| **Relevant solutions cited in the article** | |

Share out as a group or have teachers select a few to share as a class. Use what you learned from the articles, and what you learned from your classmates, to pick just one concrete part of the problem, or a sub-problem. Think though and list the criteria and potential constraints specific to this sub-problem. Propose 2 different possible solutions the sub-problem that you learned about or thought of. The solutions might involve investing to deploy a technology, creating a regulation, or creating a financial incentive. The solutions could be alternatives to each other, or strategies that complement each other.

Table 2

| |
|---|
| Sub-problem: |
| Criteria: |
| Constraints: |
| Proposed Solution 1: |
| Proposed Solution 2: |

How do these solutions to the sub-problem connect to solving our global challenge?

| |
|---|
| |

## EVALUATE

**HS-ETS1-3**: *Evaluate a solution to a complex real-world problem based on prioritized criteria and trade-offs that account for a range of constraints, including cost, safety, reliability, and aesthetics, as well as possible social, cultural, and environmental impacts.*

| Observable features of the student performance by the end of the course: | | |
|---|---|---|
| | Evaluating potential solutions | |
| 1 | a | In their evaluation of a complex real-world problem, students: |
| | | i. Generate a list of three or more realistic criteria and two or more constraints, including such relevant factors as cost, safety, reliability, and aesthetics that specifies an acceptable solution to a complex real-world problem; |
| | | ii. Assign priorities for each criterion and constraint that allows for a logical and systematic evaluation of alternative solution proposals; |
| | | iii. Analyze (quantitatively where appropriate) and describe* the strengths and weaknesses of the solution with respect to each criterion and constraint, as well as social and cultural acceptability and environmental impacts; |
| | | iv. Describe* possible barriers to implementing each solution, such as cultural, economic, or other sources of resistance to potential solutions; and |
| | | v. Provide an evidence-based decision of which solution is optimum, based on prioritized criteria, analysis of the strengths and weaknesses (costs and benefits) of each solution, and barriers to be overcome. |
| | Refining and/or optimizing the design solution | |
| 2 | a | In their evaluation, students describe* which parts of the complex real-world problem may remain even if the proposed solution is implemented. |

Select your top 4 criteria and constraints from Table 2 and put them in order of priority in the first column of Table 3 below. Then analyze how well each solution meets each criterion and each constraint. Finally, consider possible sources of resistance to implementation.

**Table 3**

| | Met by Solution 1? | Met by Solution 2? |
|---|---|---|
| Criteria<br>1. | | |
| 2. | | |
| 3. | | |
| 4. | | |
| Constraint<br>1. | | |
| 2. | | |
| 3. | | |
| 4. | | |

| | | |
|---|---|---|
| Sources of cultural, environmental or economic resistance? | | |

**Based on your analysis in Table 3, which of the 2 solutions is better choice? Cite evidence from your table to back up your choice. If there is expected resistance to implementation, how would you overcome it?**

| |
|---|
| |

**If you were to implement one or both solutions, what parts of the global challenge would still remain?**

| |
|---|
| |

[i] https://www.eia.gov/state/seds/data.php?incfile=/state/seds/sep_fuel/html/fuel_use_pa.html&sid=US

[ii] https://www.eia.gov/environment/emissions/state/

[iii] https://www.eia.gov/tools/faqs/faq.php?id=73&t=11