Energy Values

Overview: A demonstration of how different fuels have different energy densities.

Keywords: Isobutanol, Ethanol, Energy Density

Age / Grade Range: 5th-6th Grade students

Background: This demonstration was created to explore how fuels have different energy densities and are not created equally.

The misconception is that there is no difference between ethanol and isobutanol. Molecularly these alcohols are different from each other in the fact that ethanol is a two carbon chain while isobutanol is a four carbon chain. If comparing these fuels energy density, isobutanol provides 25% more energy released than ethanol. As additives to gasoline, the limit on ethanol is 10% by volume while isobutanol is limited to 16%[1].

Isobutanol that is created from processing woody biomass is converted into jet fuel. Isobutanol can be created from non-woody biomass such as corn, however this demonstration is intended to build upon Value of a Tree lesson. Ethanol can be processed into jet fuel, however to create one gallon of jet fuel more ethanol is needed compared to the amount of isobutanol. The other consideration about biofuels is what source, or feedstock, is used to create these fuels[2].

Ethanol is primarily processed from corn and soybeans, crops which can also be used as food for people and animals. This ethanol feedstock (A feedstock is the term used to describe the source of the fuel) is called a first generation biofuel since it relies on food crops[3].

Isobutanol used in the Northwest Advanced Renewables Alliance (NARA) project is processed from limbs and leftovers from logging operations called slash piles. These slash piles are normally left to burn. While burning slash piles stops a hormone being released by the limbs that may attract bark beetles burning also releases greenhouse gases and other particulates into the air which can be harmful to human and animal health. The isobutanol

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[1] http://www.aiche.org/chenected/2011/11/search-environmentally-friendly-energy-ethanol-vs-butanol, http://biofuel.org.uk/bioalcohols.html
[2] http://nararenewables.org/news/features/jetfuel, http://www.epa.gov/ncer/sbir/success/pdf/gevo010711.pdf
[3] http://www.aiche.org/chenected/2011/11/search-environmentally-friendly-energy-ethanol-vs-butanol

feedstock is called a second generation biofuel because the sources are not food related[4].

Burning bio-jet fuel does release greenhouse gases, however the carbon dioxide being emitted from burning the fuel was captured by the plant the bio-jet fuel was processed from. It releases the same amount of carbon dioxide being burned as was gathered by the plant when it was growing. This is referred to as a carbon neutral process[5].

Energy density refers to the amount of energy that is stored in "fuel." Fuel depends on the situation. For example, in cars fuel is gasoline and for people fuel is food. Different fuels have different energy densities based on their molecular formula.

This concept of unequal energy density is a common theme in nature. Certain food sources provide more energy than others. There are examples of animals that do not survive the winter season because of the fuel that is available to them. Deer have been found with full stomachs of bark that have starved because of the energy density of the bark was less than what was needed to survive.

Next Generation Science Standards

5-ESS3-1: Obtain and combine information about ways individual communities use science ideas to protect the Earth's resources and environment.

MS-PS1-1: Develop models to describe the atomic composition of simple molecules and extended structures.

MS-PS1-2: Analyze and interpret data on the properties of substances before and after the substances interact to determine if a chemical reaction has occurred.

MS-PS1-3: Gather and make sense of information to describe that synthetic materials come from natural resources and impact society**.**

Common Core:

WHST.6-8.7: Conduct short research projects to answer a question, drawing on several sources and generating additional related, focused questions that allow for multiple avenues of exploration.

MP.2: Reason abstractly and quantitatively.

[4] http://www.gevo.com/assets/pdfs/GEVO-wp-iso-ftf.pdf
[5] http://www.afdc.energy.gov/fuels/emerging_biobutanol.html

Goals: Students will create a hypothesis about which fuel source will raise the temperature of the water faster and record data during the experiment.

Are all energy sources equal to each other?
How could we tell that fuels have different energy outputs?

Objectives: Students will understand that not all energy sources are equal
Using the scientific process can answer complex questions

Materials: 95% Alcohol, check to make sure this contains no benzene, methanol, propanol, or other harmful additives. Regardless of additives make sure to run this experiment in a ventilated area.
40% Vodka
75.5% Grain alcohol
Isobutanol
Fuel container
Wire mesh
Water container
Hot pads
IR thermometer/labquest with stainless steel temperature probe
1 oz measuring cup for measuring fuel and water
Long Matches / Lighter
Glass burning containers
Plastic tubing
Air pump (optional)

Set up: Clearly setup a space before running this experiment as it will involve fire.
Check to see if there are smoke detectors nearby when lighting matches.
Do this activity in a well ventilated space
Trivets (hot pads)

To charge a glass bottle you will need to take the plastic tubing and place it into bottle above the alcohol. If you have a air pump you can hook it up to the tubing, if not you'll need to blow air into the bottle via the tubing. Without the pump you will need to do this for one minute, with the pump it should take 30 seconds. When adding air to the bottle use a free hand and "cap" the opening of the bottle so that your hand will divert the air away from your face. You do not want to inhale these vapors. Once you are finished adding the air seal the bottle with the cap and vigorously shake the bottle for 20 seconds. This will aerosolize the alcohol and create a fuel-air mixture ready to be ignited. Repeat this process for all three bottles before and after use to ensure the activity runs smoothly.

HAZARDOUS WARNING: DO NOT RUN THIS ACTIVTY IN A SEALED ROOM.

DO NOT INGEST ANY ALCOHOL.

Classroom Time: 15-25 minutes

Overview

1. Gather materials
    a. Make sure the glass bottles are charged.
2. Prompt students about energy sources and outputs
    a. If they look the same do they give off the same amount of energy when used?
3. Add two ounces of water to each water container
    a. Measure and record temperature
4. Add one ounce of each type of fuel to the fuel container
    a. One ounce burns approximately 10-14 minutes
5. Light fuels on fire, set wire mesh over burning fuel then set water containers over the flames
    a. Light Isobutanol first since it is hardest to ignite
    b. Make sure you are in a ventilated area
6. While fuel burns set out three glass burning containers
    a. Each should be labeled.
    b. 'Ethanol' container contains 95% alcohol by volume
    c. '75.5%' container contains 75.5% alcohol by volume
    d. '80 Proof' container contains 40% alcohol by volume
    e. Each container should have a small amount of alcohol at the bottom measuring about 1/4 of an inch
    f. Prompt students to observe and hear differences as each one is lit
    g. Lighting the bottles works best in a darkened environment to see the flames.
7. Light the jugs
    a. Light the '75.5%' first, then the 'Ethanol' second and you can let a student light the '80 Proof'
    b. The '80 Proof' bottle will not ignite. If it does it will be very faint and weak.
8. Compare the results from the jugs
    a. Review with students what each label and measurement means
    b. How would they apply the results to the fuel burning
9. Record final water temperature when fuel burns out
10. Debrief
    a. Final results of the fuel
    b. Flame color
    c. Expansion of ideas to relate to ecology
    d. What may have influenced the fuel during the activity
    e. What could influence the output of the fuels

Introduction (Engage): **Note: Text in "quotations" signifies suggested dialogue to engage students in and is not intended to be a script. Use your best judgment**

when delivering these lessons.

"This next activity has to do with energy. I have here two energy sources. One is called Ethanol the other is called Isobutanol. They look the same (show students both are clear) They smell the same (you can pretend to smell, do not let students smell) Do they release equal amounts of energy when used? What do you think? (Field answers) Lets find out!"

Activity (Explore): (After fielding answers show students how each alcohol behaves in water. Each vial has equal parts colored water and each type of fuel)
"Using the information I told you, create a hypothesis about which one will release the greater amount of energy, ethanol or isobutanol? Why? How could we test these fuels to see the amount of energy each fuel gives off when used? (give students time to create a hypothesis. You can review each students hypothesis before moving on)

(Set the trivets down on the table and place each fuel container on the trivet to prevent the table from being exposed to high heat. Add 1 oz of each fuel type to a container. **SAFETY ISSUE: DO NOT LET STUDENTS TOUCH THE ALCOHOL. ONLY BURN OUTSIDE OR IN A WELL VENTIALTED ROOM.** Add 2 oz water to each holding container and have the wire meshes on standby)

"We have the fuel placed in, don't touch the fuel because it is dangerous if it goes into your eyes. If you smell it, that is ok just move upwind or stand by a window. We'll measure the temperature of the water before we place them on the flames and afterwards. So let's record the temperature at the beginning (record temperature)"

(Light each fuel container on fire and place the wire mesh on top followed by the water container) "Ok now we'll wait and see what happens" (This can be a variable amount of time, at least five minutes or until the fuel is burned off which can take between 10 and 15)

(While the fuel is heating the water gather the three glass bottles labeled 'Ethanol','75.5%',and '80 Proof.' Make sure all bottles have been charged)

"While we wait to see the results, here is an another example of the difference between fuels. I have three bottles with three different concentrations of the same fuel. You need to use your eyes and ears to determine the difference between them. Stand back as I will be igniting the contents in the bottles."

(Light the '75.5%' bottle first, 'Ethanol' second, and '80 Proof' last. Dim the lights and close curtains if possible. The first bottle should have a slow moving blue flame and moderate sound. The second bottle will be the most reactive with a fast blue flame and a very loud sound. The third bottle should not ignite at all, if it does it would be a very faint flame and no sound. The third bottle you can 'let' a student try to ignite. Use the matches or lighter at the very top of the bottle. If the flame needs to go into the neck of the bottle it was not properly charged)

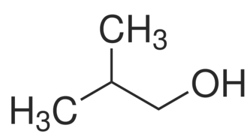
"What changes did you hear or see? I said that these were of different concentrations of fuel. Which one do you think had the most concentration? The least? Why?" (field answers)

"The first bottle is ethanol at 75.5% concentration. The second bottle was 95.5% concentration. The last bottle was 40% concentration. The more refined the fuel is, in this case ethanol, the better it burns. Let's see how our other experiment is doing."

(After time has elapsed record the final temperature) "Ok we're done gathering data, lets analyze the results." (Review which was higher and ask students to see if their hypothesis was supported. If their hypothesis was not supported have students write down reasons that may have affected the experiments and their results)

Explanation

"Isobutanol is classified as an alcohol. Its molecular formula is $(CH_3)_2CHCH_2OH$ and it looks like:



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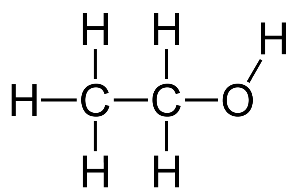
Ethanol looks like:



and its molecular formula is CH_3CH_2OH. Which one raised the water temperature the highest? What do you think may affect the energy amount in the fuels? (Field answers) Not all energy sources are the same."

"Each molecule is different from each other. This difference accounts for each fuel type's energy density. Also remember how each fuel behaved with water. The molecular makeup of each fuel type also affects how they interact with other molecules. Energy density can also depend on the concentration of the fuel as well."

"Eating celery compared to eating bacon will provide your body with very different energy amounts. The same is true with combustion fuels. Ethanol will provide a different amount of energy than isobutanol. This is a theme echoed throughout nature. Not only does it apply to animals it applies to fuel that we use to power our vehicles. Not all fuels are created equal."

Elaboration/Content Tie-In: This content ties into ecology topics used all year, Energy Explorations, and What's a Watt Worth

Ecology Topics:
Different food sources have different energy content. Human food for animals could cause animals to not store enough for the day.
During winter chickadee birds must eat enough food to survive through the night. If the food is not energy dense the birds may die in the night.

Energy Explorations and **What's a Watt Worth**
Different energy sources produce different amounts of electricity when used.
Carbon dioxide can be generated at any point along

Evaluation: Have students think-pair-share to create a list of reasons why understanding the concept of energy density is important for their lives.

Additional resources:

See Appendix E for materials