Lesson Overview: Students explore the properties of wildland fuels through reading, a fuel scavenger hunt, and by designing and conducting experiments with fuels.

Lesson Goal: Increase students’ understanding of how fuel properties affect burning.

Objectives:
- Students can design experiments that test how fuels with contrasting properties burn.
- Students can apply observations from experiments to explain how wildland fuels with various properties burn.

Standards:

<table>
<thead>
<tr>
<th>CCSS</th>
<th>Reading: Informational Text</th>
<th>9th</th>
<th>10th</th>
<th>11th</th>
<th>12th</th>
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<td></td>
<td>Reading: Science and Technology</td>
<td>2,3,4,7,9,10</td>
<td>2,3,4,7,9,10</td>
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<tr>
<th>NGSS</th>
<th>Earth's Systems</th>
<th>9th</th>
<th>10th</th>
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| EEEGL             | Strand 1                    |     |      | A,C,D,E,F,G |

Teacher Background: See the Handout H05-1 “Fuel Properties: Pre-Lab Reading and Scavenger Hunt” for background information.

Materials and Preparation:
This activity requires that students do a technical reading and an outdoor search for various kinds of fuels before doing experiments in a laboratory. This preparation can be done as homework or as a mini-field trip the class period before the lab.

Student needs:
- Handout H05-1: Fuel Properties: Pre-Lab Reading and Scavenger Hunt, one for each student. Students should complete this handout before doing the lab.
- Handout H05-2: Fuel properties, one for each student, to be completed in lab.
Set up your lab. It should have heat-resistant work surfaces and good ventilation or a hood. You also need:
- 1 fire extinguisher
- 1 empty metal trash can without liner

Set up each student lab bench with:
- 8 sheets of newspaper (~57 x 63 cm)
- 2 Pie tins
- ~25 matches
- 1 pair safety goggles
- 1 ruler
- 1 water filled squirt bottle
- 1 digital scale
- 1 timer (phone, clock with second hand, stop watch)
- 1 metal tray (cookie sheet), if you would like the pie tins to sit on it

**Procedure:**

1. At least 1 day before the lab, distribute *Handout H05-1: Fuel Properties: Pre-Lab Reading and Scavenger Hunt*, 1 copy to each student. This handout requires students to read and also to go outside and find examples of different kinds of fuels. Have students complete the handout as homework or during a mini-field trip the class period before the lab.

2. Review Handout H05-1 as a class. Answer any questions that arise.

3. Distribute *Handout H05-2: Fuel Properties* to each student. Review the handout and stress:
   - There is a 1-page limit on how much newspaper students can burn in a single pie-tin treatment (except for experiment 3).
   - It is important to distinguish between experiment (investigating a variable) and treatment (the way that variable is altered within an experiment).
   - It is important to plan measurement methods before igniting a treatment. For example, who is going to time the burn? Who is going to measure flame height? Is it maximum flame height or typical or average? If the ruler is meltable, how will they get the measurement?
   - It is important to keep all variables constant except the one you’re investigating. For example, method of ignition should always be the same. Don’t use colored newspaper for one treatment and black-and-white for the other. Results for Experiments 1, 2, and 4 may be clearest if both treatments use about the same amount of fuel.

4. Have students get into groups and complete the experiments on Handout 05-2: Fuel Properties.
**Assessment:** Take students to an outdoor setting where they can collect fuels and safely build small campfires. Have them work in pairs to apply their knowledge of fuel properties. Each pair needs:

- 1 pie tin
- matches or lighter
- water bottle
- oven mitt
- 1 metal tray (cookie sheet), if you would like the pie tins to sit on it.

Have a fire extinguisher, charged hose, and/or bucket of water nearby and ready to use, if necessary.

Their goal is to collect fuel and make a mini-campfire that will **easily ignite, sustain burning, and consume the majority of their fuel**. They must fit all of their fuel within the pie tin—no overhanging fuel. For fun, consider distributing mini-marshmallows and kabab-skewers to roast over their mini-campfires!

<table>
<thead>
<tr>
<th>Evaluation</th>
<th>Full Credit</th>
<th>Partial Credit</th>
<th>No Credit</th>
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<tbody>
<tr>
<td>Students’ fire ignited easily and remained burning until the majority of the fuel was consumed.</td>
<td>Students’ fire was difficult to ignite but eventually ignited and consumed some fuel.</td>
<td>Students’ fire could not be ignited. No fuel was consumed.</td>
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Handout H05-1. Fuel Properties: Pre-Lab Reading and Scavenger Hunt

Name: _______________________

Read this information to learn about wildland fuels. This will help you design experiments to do in the lab. When you come to a “Scavenger Hunt assignment,” you will need to go outdoors and either sketch something or collect something to bring to class.

Fuel Properties: Properties of wildland fuels influence how they burn. Specifically, fuel properties determine how fires heat the fuels and how much oxygen is in contact with them, and thus how quickly they will ignite and how long they will burn. Anyone who has built a campfire knows that you have to choose your fuels wisely and arrange them carefully. Several fuel properties influence fire behavior, including:

- Size and shape
- Moisture content
- Amount
- Spatial arrangement

1. Particle Size and Shape: The size and shape of fuel particles affect how fuels heat up. One component of size and shape is the surface-area-to-volume ratio (SA/V). SA/V describes fuel particle fineness – that is, the amount of outer surface exposed to air and heat, relative to its volume. Surface-area-to-volume ratio is important because it affects the rate at which a fuel particle will change temperature as a result of heat transferred from its surroundings.

Imagine lighting the fuels in a campfire by holding a match beneath them. As you know, the match’s heat will rise, so the fuels will be heated by convection. Now ask: Which is easier to ignite - a thick, dead log or a dead pine needle? The pine needle is easier to ignite (if it is dry, of course), because the heat can penetrate the whole needle quickly, and the surface area exposed to oxygen is great relative to the needle’s volume. The log is harder to ignite because the heat that reaches the surface is transferred to the inside (so the log heats slowly), and because the surface area exposed to oxygen is small relative to the log’s volume.

a. Examples of fine (small) fuels: grasses, leaves, pine needles, and twigs. Because fine fuels are small, they burn up quickly – as long as they are dry.

Scavenger Hunt assignment: Find an example of a fine wildland fuel that is dry. Put the sample in a Ziploc bag and label it “fine fuel”.

b. Examples of coarse (large) fuels: logs, stumps, and thick branches. Coarse fuels tend to burn slowly. Think of a log as having many concentric layers of fuel. The outer layer has to burn away before the next layer is exposed to oxygen and heat and can burn away, exposing the next layer to oxygen and heat, etc., etc.

Scavenger Hunt assignment: Find an example of a coarse wildland fuel. Draw it below:

2. Moisture Content: How well fuels ignite and burn depends, to a large extent, on their moisture content. The drier the fuels, the less heat is needed to remove the water they contain.

a. Wet Fuels: Moisture makes fuels hard to ignite and also makes them burn slowly. This is because the moisture must be heated up and vaporized before a particle can be heated to ignition temperature.

b. Dry Fuels: The drier the fuels, the less heat needed to remove water, so the more easily they will ignite and the more completely they will burn. That’s why you don’t use wet wood to make a campfire!

Scavenger Hunt assignment: Find an example of a moist wildland fuel and an example of a dry wildland fuel. Put them into separate Ziploc bags and label them “wet fuels” and “dry fuels”.

3. Fuel Loading refers to the amount of fuel present. Fuel loading is measured in terms of weight per unit area (for example, tons per acre). The more fuel, the longer your fire can burn and the more heat it can produce.

Scavenger Hunt assignment: Find a landscape with heavy fuel loading and find a landscape with light fuel loading. Sketch and label them in the boxes below.
4. **Spatial Arrangement** means how fuels are arranged in space, both horizontally and vertically. Fuel continuity describes the arrangement of fuels.

   a. **Continuous Fuels**: fuels that are in contact with each other with no substantial gaps between them. Continuous fuels provide an uninterrupted path for fire spread, either horizontally or vertically.

   **Scavenger Hunt assignment**: Find a landscape with continuous fuels (either horizontal or vertical) and sketch it in the box.

   ![Continuous Fuels](image)

   b. **Discontinuous Fuels**: describes fuels that have gaps between them. Fuels are interrupted by bare ground, rock outcroppings, water, and/or vegetation that is highly resistant to ignition. Discontinuous fuels along the ground surface are also called “patchy fuels.”

   **Scavenger Hunt assignment**: Find a landscape with discontinuous fuels and draw it in the box.

   ![Discontinuous Fuels](image)
c. Fuel particles can be so tightly packed that heat and oxygen cannot easily reach their surfaces. This makes it hard to ignite them, and they burn slowly. (For example, think of a thick pile of newspapers or deep duff on the forest floor.)

**Scavenger Hunt assignment:** Find a small area with tightly packed fuels and draw it in the box.

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d. Fuels may look continuous but be so loosely packed that fire cannot spread easily from one particle to the next. (For example, think of a thin layer of sparse grasses.)

**Scavenger Hunt assignment:** Find a landscape with loosely packed fuels and draw it in the box.

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**Sources:**
Introduction to Wildland Fire Behavior, S-190 Wildfire Coordination Group’s (NWCG), Wildland and Prescribed Fire Curriculum.
[http://learningcenter.firewise.org/Firefighter-Safety/1-5.php](http://learningcenter.firewise.org/Firefighter-Safety/1-5.php)
Handout H05-2: Fuel Properties

Name______________________________

Materials for each team:
- 8 sheets of newspaper (~57 x 63 cm)
- 2 aluminum pie tins
- ~25 matches
- 1 spray bottle filled with water
- 1 pair safety glasses
- 1 oven mitt
- 1 ruler
- 1 timer (phone, clock with second hand, stop watch)
- 1 digital scale

There is a 1-page limit on how much newspaper you can burn in a single pie-tin treatment (except for experiment 3). For each experiment, ignite the fuels in one pie tin at a time and record data in the table. Hint: To get the correct fuel weight, either “tare” the pie tin or subtract the weight of the tin from the weights of the fuels.

Plan your measurement methods before igniting a treatment. For example, who is going to time the burn? Who is going to measure flame height? Is it maximum flame height or typical or average? If the ruler is meltable, how will they get the measurement?

Be careful to keep all variables constant except the one you’re investigating. For example, method of ignition should always be the same. Don’t use colored newspaper for one treatment and black-and-white for the other.

Experiment 1 - particle size. Manipulate a sheet of newspaper (by cutting, rolling, folding, wrinkling, twisting, arranging, etc.), so one pie tin contains newspaper representing fine fuels and one pie tin contains newspaper representing coarse fuels.

Experiment 2 - moisture. Manipulate a sheet of newspaper so one pie tin contains moist newspaper and one pie tin contains dry newspaper.

Experiment 3 - loading. Manipulate one or more sheets of newspaper so one pie tin contains more newspaper and one pie tin contains less.

Experiment 4 – spatial arrangement. Manipulate a sheet of newspaper so one pie tin contains loosely packed newspaper and one pie tin contains tightly packed newspaper.
<table>
<thead>
<tr>
<th>Experiment</th>
<th>Treatments</th>
<th>Preburn weight (g)</th>
<th>Postburn weight (g)</th>
<th>Amount combusted (g)</th>
<th>Percent combusted (%)</th>
<th>Burn time (sec)</th>
<th>Flame height (cm)</th>
<th>Describe how you manipulated the fuels</th>
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<tbody>
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