5. Fuel Properties: The Campfire Challenge

Lesson Overview: In this activity, students explore how different properties of fuels affect fire behavior – especially how hard it is to ignite fuels and how long they are likely to burn. Students consider various combinations of fuels ("fuel recipes"), predict how they will burn, then test their hypotheses.

Lesson Goal: Increase students' understanding of fuel properties and how they affect fire spread and fire duration.

Subjects: Science, Reading, Writing, Speaking and Listening, Health and Safety

Duration: One half-hour session

Group size: Teams of 3-4

Setting: Outdoors or laboratory with good ventilation

New FireWorks vocabulary: *fuel moisture, ladder fuels*

Objectives:

- Students can select and arrange fuels to build a small campfire that will be easy to ignite and burn a relatively long time.
- Students can explain how fuel properties affect fire spread and fire duration.

Standards:		1st	2nd	3rd	4th	5th
CCSS	Reading: Informational Texts	10	10	10	10	10
	Reading: Foundational Skills	4	4	4	4	4
	Writing	1,8	1,8	1,8,10	1,8,10	1,8,10
	Speaking and Listening	2,3,6	2,3,4,6	3,4,6	3,4,6	3,4,6
	Language	1,2	1,2,3	1,2,3	1,2,3	1,2,3
NGSS	Structures and Property of Matter		PS1.B		ETS1.B	ETS1.A,B,C
EEEGL	Strand 1	A,B,C,D				A,B,C,D

Teacher Background: Anyone who has built a campfire knows that you have to choose your fuels wisely and arrange them carefully. Four fuel properties influence fire behavior: amount, size, moisture content, and spatial arrangement. These properties determine how flames 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:

- All other conditions being equal, larger amounts of fuel will produce the most heat. Whether they burn quickly or slowly, however, depends on their moisture, size and arrangement.
- Small particles tend to ignite more easily than large particles because they have more surface area (per volume) exposed to heat and oxygen. (Interesting exceptions to this guideline are explored in the High School curriculum, Activity H07.) Large fuels, once ignited, usually burn longer than small ones.

- It is more difficult to ignite moist fuels than dry ones; they also burn more slowly, make more smoke, and tend to burn less completely.
- Spatial arrangement of fuels is complex: If they are packed so tightly that oxygen isn't available, they won't ignite; if they are so far apart that heat from one particle can't reach the next, they won't ignite.

In this activity, students are assigned specific recipes for the fuels for a campfire. Some of the recipes will be very hard to ignite, some easier; some have the potential to burn for a long time; some will burn out quickly. They also get 7 matches, which can be put into the fuel mixture if they wish – but they must keep at least 1 for lighting the campfire. The students will make hypotheses about how their fuel recipes will burn. Then they will arrange the fuels to burn as well as they can, and then they will test their fuel arrangements – and thus their hypotheses.

Materials and preparation:
This activity is best done outdoors because it can be messy and smoky. However, do not do it outdoors on a windy day. Select a place far from dry grass, bark chips, and other fuels. Have a bucket of water and a hose available, with the water turned on. The student teams will be using matches, although your or another adult will actually light the fires. For safety's sake, ask a parent or other volunteer(s) to help.

If you do this activity indoors, use a laboratory with good ventilation.

- At least two days ahead of time, obtain enough of these dead fuels to do the activity—that is, about a dozen "handfuls" of each:
  - dead conifer needles
  - small twigs (less than 0.5 centimeter in diameter)
  - large sticks (about 2-3 centimeters in diameter)

  Spread them out in a dry place so they are uniformly dry by the time you use them.
- The day before you do the activity, remind students to dress appropriately for burning. Post and refer to the FireWorks Safety poster.

FireWorks Safety

When you do experiments with fire…

1. **Wear cotton clothing. No synthetic pants, soccer shorts, etc.**
2. **Wear closed-toed shoes. No sandals or flipflops.**
3. **Tie back loose sleeves.**
4. **Tie back loose hair.**
5. **Make sure a fire extinguisher is close. Make sure it is charged. Know how to use it.**
6. **Make sure spray bottles are close and filled with water.**
7. **Wear safety goggles when burning.**
8. ***Never* lean over a fire.**
9. **Extinguish burned materials with water before putting them in the trash. *Fire is not out if there is any smoke or heat coming from the fuels.***
10. **If a fire starts on you, stop, drop, and roll.**

Use fire ONLY if a responsible adult is working with you.

- The day before you do the activity, collect enough green conifer needles to do the activity.

- Copy the ingredients for the fuel recipes onto the board (or a poster, if you plan to do the activity outdoors).

Recipe	Ingredients
1	Small twigs Big sticks
2	Big sticks Green conifer needles
3	Dead, dry conifer needles Big sticks
4	Dead, dry conifer needles Small twigs

- Set up your teacher area with:
  - The Fuel Recipe box. Be sure to select the recipes labeled "E" for Elementary students.
  - 4 grocery bags or boxes containing fuels (dead, dry conifer needles; small twigs (<0.5 cm); big sticks (2-3 cm); green needles). Label the bags. You can use the tie-on labels in the trunk. If there's a label for "duff," ignore it.
  - Fire extinguisher
  - 2 spray bottles, filled with water
  - Other water (bucket, charged hose, etc.) to ensure you can easily put a fire out
- Set up student work stations. Four work stations work well (1 station/recipe), but you can have more stations and repeat recipes. Each station needs:
  - One 9" diameter aluminum pie tin with tilted edges
  - 1 metal tray (i.e., cookie sheet) can be used beneath the pie tin, if desired
  - 1 match box with **7 matches** (not in trunk)
  - 1 ashtray
  - 1 pair of safety goggles
  - 1 oven mitt
- Have a *metal* trash can *without a plastic liner* available.
  - Decide whether you will project *E05_ Photos_FuelProperties.pptx* for the assessment or provide a copy for each student. Make copies if necessary.

Procedures:

1. Explain: Students will work in teams to build small "campfires," but they don't get to choose their own fuels. They will use specific combinations of fuels. The experimental questions are:

   - What kinds of fuels are easiest to start on fire ("ignite")?
   - What kinds of fuels burn longest?

2. Using the recipes listed on the board, ask students to "vote" on:

   - which will be easiest to start on fire
   - which will be hardest to start on fire

3. Then have them vote on:

   - which will burn out in the shortest time
   - which will burn longest

   Record their votes on the board. Explain: These are their hypotheses.

4. Do a **safety checkup** with students using the *FireWorks Safety* poster. Remind students of the item on the poster that says they should never lean over a burning fire.

5. Group students into teams (4 teams works well).

6. Explain the procedure. The whole team is responsible for safety. If any student is hurt, the team must alert the teacher and use water to put out their campfire immediately. Each team will:

   a. Draw a recipe from the Recipe Box.

   b. Collect the two ingredients on their recipe from the labeled ingredient bags. Fuels are "measured" by the "handful," which is subjective, but the point is to use about the same amount of each fuel in a campfire.

   c. Discuss and work together to arrange the fuels. The goal is to make the fuels ignite as easily as possible and burn as completely as possible. The fuels must fit inside the pie tin; they may not spill over the sides. The 7 matches may be used within the fuels or to ignite them. Obviously, at least 1 match will be needed for ignition.

   d. Have a teacher or other adult verify that they have met the requirements. Answer any questions. Explain that, after ignition, the team may not rearrange the fuels, but they may blow on the fire.

7. Have yourself or another adult light the match(es) for each team. If you have 1 adult per team, all teams can ignite at the same time. If not, ignite the fires one at a time so you can supervise. After ignition, monitor progress and watch for safe practices. Dispose of burned matches in the ashtray or on the metal tray.

8. After all teams have either burned all their fuels or used all their matches, have each team explain to the class their strategy for arranging fuels and how they might do it differently the next time. Note that some campfires may still be burning.

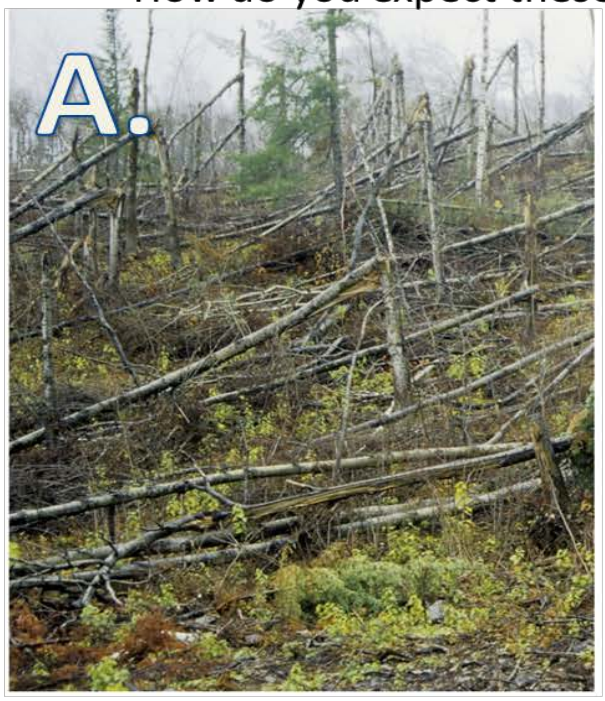
9. Discuss the four hypotheses with the class. Which ones were verified by the experimental campfires? Include these concepts in the discussion: heat transfer, the Fire Triangle, and the four fuel properties that influence fire behavior (amount, size, moisture content, and spatial arrangement).

    - *How much fuel is there*? The more fuel, the longer your fire can burn and the more heat it can produce… if you can get the fuels to ignite.
    - *Fuel particle size. Fine fuels* – that is, small pieces – are usually easiest to ignite (if they are dry, of course), because even a small heat plume can surround them and heat them up fast. But because they are small, they burn up quickly. *Large fuels* tend to burn slowly because it takes time for the outside surface to burn away, exposing new layers to oxygen and heat.
    - *Moisture* makes fuels hard to ignite and also makes them burn slowly. This is because the moisture must be removed before a particle can be heated to ignition temperature.
    - *Spatial arrangement*
        - The *fluffiness* of fuels determines how easily heat and oxygen can reach the fuels. An important skill in building a campfire is to get the spatial arrangement of fuels "just right" so lots of heat and oxygen are available to the unburned fuels. Fuels have to be sort of near each other for fire to spread from one piece to another. For example, if you crumple up 20 pieces of newspaper and scatter them across a large room, a fire cannot spread from one piece to another. But the pieces can also be too tightly packed for heat and oxygen to disperse among them. For example, a tightly piled stack of newspapers will be hard to start on fire. (Once started, however, that pile of newspapers could smolder for a long time.)
        - *Vertical arrangement:* A clever campfire builder takes advantage of heat's tendency to rise by putting easily-ignitable fuels beneath those that are hard to ignite. That is, we place small ("fine") fuels, which we call kindling, near the bottom of the fuel bed and then place layers of large ("coarse") fuels directly above. This principle also applies in forests: If the gaps between surface fuels and tree crowns are large, a fire cannot get from the surface fuels into the tree crowns. If the gaps are small – if the surface litter and grass are connected with shrubs and saplings, and these are connected with the lowest branches of the trees – then fire can climb up these *ladder fuels* and reach the crowns.

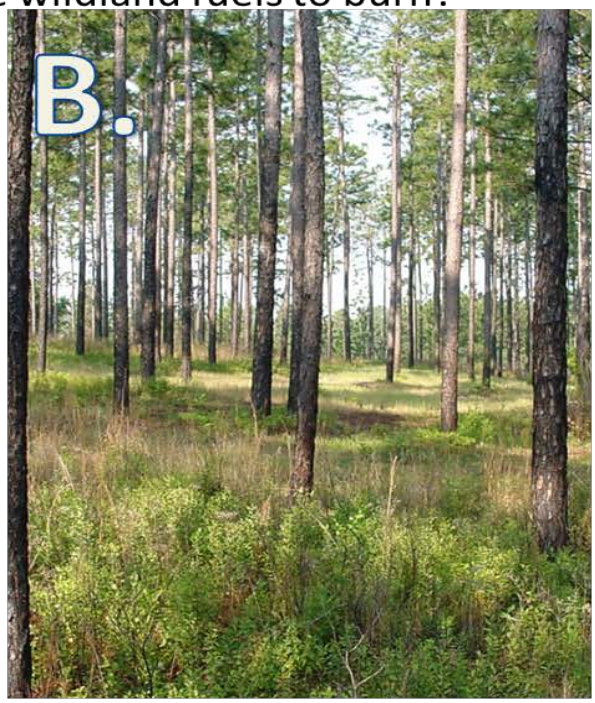
10. **Clean up:** Make sure all burned materials and matches are out before you dispose of them – that is, there is no smoke and no heat being released. Use oven mitts if the pie tins are still hot. Use an empty metal trash can without a plastic liner. If in doubt, dump fuels into a bucket of water before putting them in the trash.

Assessment: Project *E05_ Photos_FuelProperties.pptx* or provide a copy to each student:

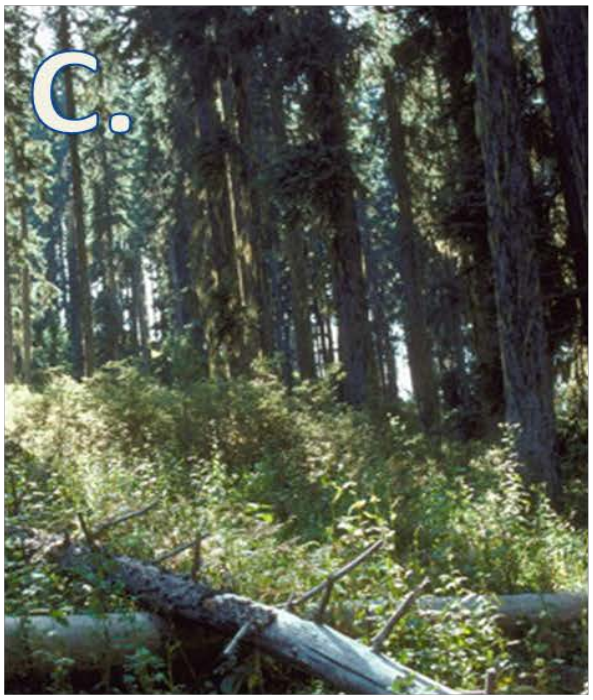
How do you expect these wildland fuels to burn?



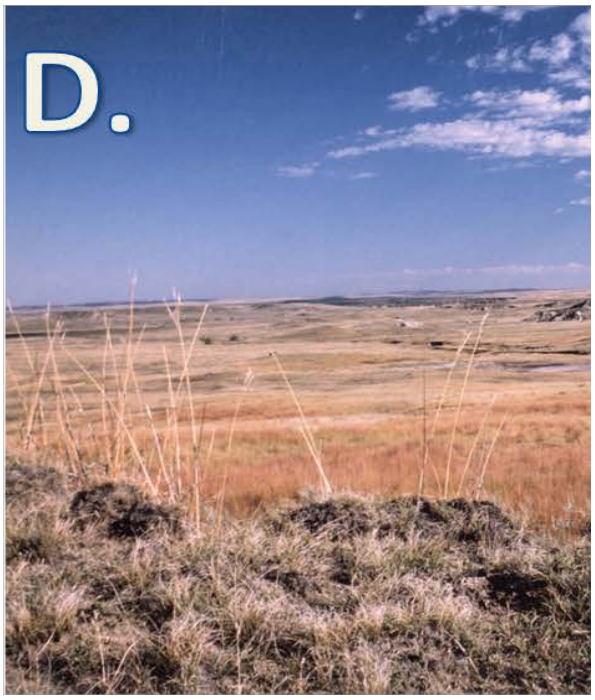
Fallen trees after a wind storm, Superior National Forest, MN. USDA Forest Service photo by Joseph O'Brien, Bugwood.org.



Longleaf pine forest, Georgia. Photo by Chuck Bargeron, University of Georgia, Bugwood.org.



Forest of grand fir and other species, Idaho. USDA Forest Service photo by Dave Powell, Bugwood.org.



Medora Landscape, Dakota Prairie Grasslands. USDA Forest Service photo.

Explain: Each of these wildland sites has different kinds of fuels (amount, moisture, size, and fluffiness). Discuss the questions below as a class. Then have students either answer the questions in writing or answer/explain together in pairs:

1. Which place will start on fire most easily? Use at least one fuel property to explain why.
2. If the weather has been hot and dry for a long time, which place will burn longest? Use at least one fuel property to explain why.
3. **Optional challenge question**: If it gets dry enough for a surface fire to spread under the trees in photos B and C, which site is most likely to have a crown fire?

Evaluation:	**Full Credit**	**Partial Credit**	**Less than Partial Credit**
Question #1	”D” will ignite most easily because it has a lot of fine fuels. It is also the only site that has a lot of dry fuels.	”D” will ignite most easily. Explanation addresses only one fuel property.	“D” is not mentioned. Response does not indicate student understands how fuel properties affect ignition.
Question #2	”A” or “C” will burn longest. (Either answer is valid.) Both of these have a lot of large fuels. Fuel moisture does not apply to this question because it states “If the weather has been hot and dry for a long time…”	”A” or “C” will burn longest. Explanation addresses the amount or size of fuels.	Neither “A” nor “C” is mentioned. Response does not indicate student understands how fuel properties affect fire duration.
Question #3. Optional challenge question	“C” is more likely to have crown fire because the surface fuels are more continuous from ground to crowns – that is, there are more ladder fuels.	“C” is more likely to have crown fire, but continuous vertical fuels/ladder fuels are not mentioned.	“C” is not mentioned. Response does not indicate student understands how fuel properties affect potential for crown fire.

Extension: Ask each student to write down his or her favorite three ingredients for a successful campfire. In another class period, have students select a handful of each of their favorite ingredients and build a campfire that ignites easily and burns long.