



## 6. Pyrolysis

**Lesson Overview:** Students learn the steps of *combustion* and *pyrolysis* through videos, class discussions, and an optional activity.

**Lesson Goal:** Increase students' understanding of the combustion process.

**Objectives:**

- Students can explain the steps necessary for fuels to combust.
- Students can explain that gaseous, pyrolyzed molecules (pyrolysates) are the source of the flames from combustion.

**Subjects:** Science, Reading, Writing, Speaking and Listening, Arts

**Duration:** 40 minutes

**Group size:** Whole class

**Setting:** Indoors

**New FireWorks vocabulary:** *ash, cellulose, pyrolysis, charcoal, pyrolysates*

\*Fire activity is optional




Standards:		9th	10th	11th	12th
CCSS	Writing Standards	1,4,10		1,4,10	
	Speaking and Listening	1,4,6		1,4,6	
	Language	1,6		1,6	
	Writing: Science and Technical Subjects	1,4,7,10		1,4,7,10	
NGSS	Matter and Its Interactions	PS1.B			
EEEEGL	Strand 1	A,C,D,E,F,G			

**Teacher Background:** In order for wildland fuels to burn, several things have to occur:

1. Temperature of moisture must rise to the boiling point (~100° C (212° F))
2. Moisture must be changed from liquid phase to gas phase (stays at 100° C (212° F))
3. Temperature of fuels must rise to the point where carbohydrates *pyrolyze*—that is, break down into small molecules (200°-300° C (400°-600° F)) in the gas phase
4. The small, gaseous carbohydrate molecules must combine with oxygen. This is combustion! See Figure H06-1 on Handout H06-1 for a diagram of the process – the Stair Step Guide to Combustion. This guide is referred to throughout the activity.

This activity examines these 4 steps in the processes of combustion, in particular combustion of wood. Watch the video in Step 3 below for further, detailed background.

The assessment for this activity can be done either through watching a video or through setting up a laboratory investigation of pyrolysis in a burning candle. This investigation is the “optional activity” referred to above.

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### Materials and Preparation:

- Access to internet. Make sure you can play the videos referred to in Steps 1 and 3.
- Make 1 copy of **Handout H06-1: Combustion and Pyrolysis** for each student

### Procedure:

1. Ask: When you light something on fire, what exactly is burning? What is making the flames?
2. Show this 1.5-minute video: <https://www.youtube.com/watch?v=Ky5AvnXGqC0>. Ask:
  - a. Just before you see the first flame coming off the wood, what do you see occurring?
  - b. Why does the lighter fail to ignite the wood the first three times it comes near?
  - c. Once the lighter does ignite the wood, what is actually creating the flames?

Explain: We'll learn about some subtle aspects of combustion in this activity.

3. Give a copy of **Handout H06-1: Combustion and Pyrolysis** to each student. Explain: Look at the figure at the top of the handout, **Figure H06-1: Stair Step Guide to Combustion**. Let's look at the video again (<https://www.youtube.com/watch?v=Ky5AvnXGqC0>.) and use the stair step guide to explain what is happening.
  - a. Just before you see the first flame coming off the wood, what do you see occurring? **Water is being driven off. We're seeing some of it (condensed into tiny droplets) as it leaves the hot wood. We're seeing Steps 1-2 in the stair step guide.** Explain: There may be tars and other volatile substances in the vapors too.
  - b. Why does the lighter fail to ignite the wood the first three times it comes near? **Two things may be going on: First, the water may still be heated and vaporized from the wood, absorbing the heat from the lighter (steps 1-2 in the stair step guide). Second, the heat from the lighter has not yet gotten the cellulose (fuel) hot enough to break down – that is, to pyrolyze (step 3) - into particles small enough to combine with oxygen molecules and burn (step 4). As we learned in Activity H03, cellulose is just a very, very long chain of glucose molecules strung together. It is the formula for glucose (C<sub>6</sub>H<sub>12</sub>O<sub>6</sub>) that we used in the chemical equation (model) for combustion.**
  - c. Once the lighter does ignite the wood, what is actually burning? **Carbohydrates that have been pyrolyzed – that is, broken down into flammable gases (pyrolysates).**
4. Explain: Now we will watch a 13-minute video that explains the pyrolysis and combustion of wood in detail. We'll pause the video several times so you can answer the questions on Handout H06-1. Use the stair step guide as you answer the questions.

5. Start the video: <https://www.youtube.com/watch?v=15ah91txQAE>
  - Pause at 3:35. Have students answer Question 1 - “What is the white stuff in the cylinder?” - or discuss the answer as a class. **For an explanation, see the answer key.** Press play.
  - Pause at 4:10. Have students answer Question 2 - “What is the yellow smoke filling up the cylinder?” – or discuss. **See the answer key.** Press play.
  - Pause at 6:10. ... Question 3 – “What is burning to create the flames?” ...
  - Pause at 9:05. ... Question 4 – “What has left the wood?” ...
  - Pause at 9:26. ... Question 5 – “What is left after all of the cellulose has been pyrolyzed?” ...
  - Pause at 11:05. ... Question 6 – “Why does wood burn with a flame, while charcoal smolders without a flame?” ...
  - Pause at 12:00. ... Question 7 – “What is ash, why doesn’t it burn, and why is it good for the soil?” ...
  - Press play and watch until the end.

**Assessment:** Show this video of a candle being lit – several times, if necessary <https://www.youtube.com/watch?v=EJpVd6pcYOA> **OR** rather than showing the video, have your students DO the video. This is the OPTIONAL ACTIVITY.

Have students answer this question orally or in writing: **When the candle is lit for the second time, what is igniting and creating the flame? Explain what is happening using the stair step guide.**

After viewing the video, especially in slow motion (or doing the activity), students should notice that the match does not come in contact with the wick when the candle is ignited for the second time. How does it ignite? **The pyrolysates (flammable gases) that were produced from the candle wax during the first flame had not all burned before the flame was extinguished. Because they were trapped by the cup-shaped extinguisher, they had not dispersed before the second match reached them, so they were ignited by the second match. Combustion of these pyrolysates re-ignites the candle.**

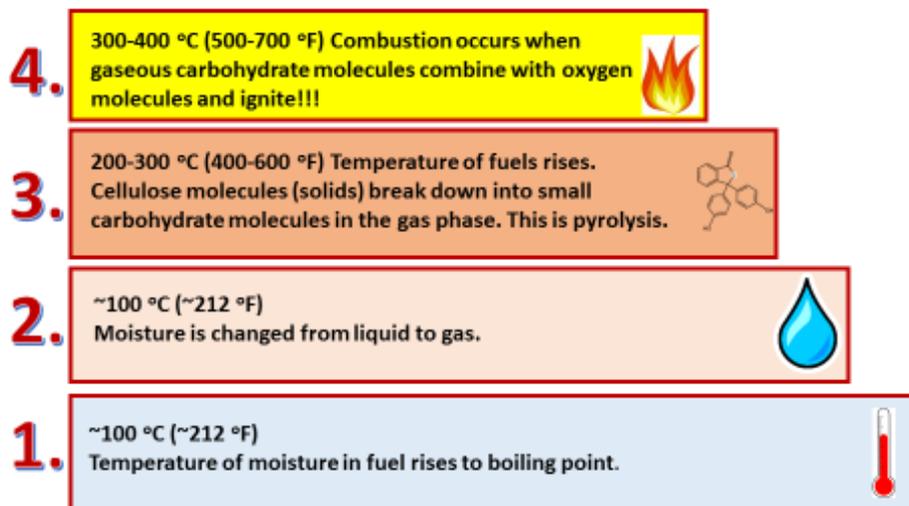
**Evaluation:**

Fully successful	Moderately successful	Not successful
-Student explained that pyrolysates from the first ignition remained and were ignited before the wick ignited. -Student referred to Steps 3-4 of the stair step guide.	-Student’s explanation referred to either pyrolysis or the stair step guide, but not both – or interpreted one of them incorrectly.	-Student did not refer to either pyrolysis or the stair step guide – or interpreted them incorrectly.

# Handout H06-1: Combustion and Pyrolysis

Name \_\_\_\_\_

Figure H06-1: Stair Step Guide to Combustion.



1. What is the white stuff in the cylinder? Use the stair step guide to answer.
2. What is the yellow smoke filling up the cylinder? Use the stair step guide to answer.
3. What is burning to create the flames? Use the stair step guide to answer.
4. What has left the wood?

5. What is left after all of the cellulose has been pyrolyzed?
  
6. Why does wood burn with a flame, while charcoal smolders without a flame?
  
7. What is ash, why doesn't it burn, and why is it good for the soil?

## Answer Key: H06-1: Combustion and Pyrolysis

1. What is the white stuff in the cylinder? Use the stair step guide to answer. Water that has been driven off from the fuels. In the stair step guide, we are moving through Steps 1 (blue) and 2 (pink).
2. What is the yellow smoke filling up the cylinder? Use the stair step guide to answer. Products of pyrolysis, also called *pyrolysates*. The heat is breaking carbohydrates (long chains of *cellulose* and related molecules) into smaller molecules – small enough that they stay in the gas phase. This is *pyrolysis*, Step 3 (orange) in the stair step guide.
3. What is burning to create the flames? Use the stair step guide to answer. The small, gaseous carbohydrate molecules that were created by pyrolysis. This is *combustion*, Step 4 (yellow) in the stair step guide.
4. What has left the wood? Water and pyrolysates have left.
5. What is left after all of the cellulose has been pyrolyzed? *Charcoal*, which the presenter calls “coal” and refers to as elemental carbon, “C” in the periodic table.
6. Why does wood burn with a flame, while charcoal smolders without a flame? Flame is a sign that fuel has pyrolyzed and is burning, but also that the fuel is burning with less than 100% efficiency and produced soot. Flames are glowing particles of soot, which is elemental C. Since charcoal has already lost all of the cellulose that could be pyrolyzed, it does not burn with a flame. Watch this 7-minute video “What is a Flame?”: <https://www.youtube.com/watch?v=5ymAXKXhvHI>
7. What is ash, why doesn't it burn, and why is it good for the soil? Ash consists of minerals, which do not burn. Some of these are essential nutrients for plants; they may enrich the soil for a few years after wildland fires.