



3. The Fire Triangle, Combustion, and the Carbon Cycle

Lesson Overview: Students use an experiment, a PowerPoint presentation, and a technical article to explore how the Fire Triangle relates to the chemical equation (model) for combustion and the carbon cycle.

Lesson Goals: Increase students' understanding of combustion and the connections between combustion and the carbon cycle.

Objectives:

- Students can explain that combustion produces water, carbon dioxide, heat, and light.
- Students can explain how forests and wildland fire store and release carbon, and how this process is related to fire.

Subjects: Science, Mathematics, Speaking and Listening, Health and Safety 

Duration: one 90 minute session

Group size: Whole class/groups. 

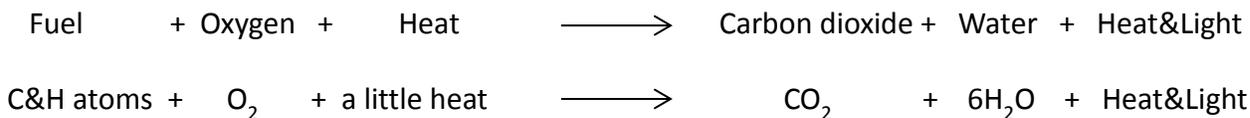
Setting: Classroom

New FireWorks vocabulary: *atom, carbon, carbon cycle, carbon dioxide, carbon sink, carbon source, cellular respiration, chemical equation, photosynthesis*

Standards:		9 th	10 th	11 th	12 th
Common Core ELA	Writing Standards		1,4		1,4
	Speaking and Listening		1,2,4		1,2,4
	Language Standards		1,2		1,2
	Science/Technical Subjects		9		9
NGSS	Chemical Reactions		PS1.A, PS1.B		
	Matter/Energy in Organisms/Ecosystems		LS1.C, LS2.B, PS.D		
EEGL	Strand 1		A,C,D,E,F,G		
	Strand 2.1		B, C		

Teacher Background: For a refresher on the chemistry of combustion and life, review the “Procedure” section below. Also download and review the presentation *H03_FireTriangle_CarbonCycle_Connection.pptx*. Here are some key concepts:

The three legs of the Fire Triangle actually represent the three inputs to the chemical equation for combustion, where H represents Hydrogen atoms, O represents Oxygen atoms, and C represents Carbon atoms:



The equation above does not give a specific formula for fuels, because they could be any mixture of millions of compounds. The point is that all fuels contain a lot of carbon and hydrogen. They usually contain oxygen and many other kinds of atoms as well. For example, the equation for combustion of glucose (the main component of cellulose, which is the component of wood that burns), with numbers of molecules balanced to show conservation of matter, is this:



The same equation represents cellular respiration, the process by which cells convert sugar into the energy that keeps living things – including us – alive. Furthermore, this equation is the reverse of the chemical formula for photosynthesis!



Thus the Fire Triangle can be used to introduce not only basic chemistry but also the basic principles of the biochemistry of life.

For additional information, see William Cottrell’s *The Book of Fire* (2004, available from <http://mountain-press.com/>) in the FireWorks trunk. This is a well-illustrated, easy-to-read description of the physical science of combustion and wildland fire.

Materials and preparation:

Read the technical reading assignment “Sink or Source: Fire and the Forest Carbon Cycle”. You can either read the entire article, which is online at www.firescience.gov/projects/briefs/03-1-1-06_FSBrief86.pdf, or only the excerpts on **Handout 03-2**.

Decide on your laboratory arrangement. This demonstration produces a flame about 1-3 cm long.

- Display the *FireWorks Safety* poster.
- Download *H03_FireTriangle_CarbonCycle_Connection.pptx*
- Make 1 copy of **Handout H03-1** and 1 copy of **Handout H03-2** (reading assignment) for each student (but if students will read the technical article online, you do not need to print Handout H03-2).
- Have a fully charged dry chemical fire extinguisher handy
- At your lab demonstration bench, you need the following items from the FireWorks trunk:
 - Two support stands
 - Two ~2.5” (~7 cm) diameter rings
 - Votive candle or other candle
 - Two fence-post caps (aluminum chain-link fence caps)
 - Oven mitt
 - Safety glasses
 - Spray bottle filled with water
- At your demonstration bench, you need the following that are NOT provided in the trunk:
 - Electric hot plate
 - Matches or lighter
 - Tissue (optional)
 - Flashlight (optional)



Preparation:

1. The day before you do this demonstration, fill the fence-post caps with water and freeze. (To keep them upright in the freezer, prop them in an empty egg carton, ice cube tray, muffin tin, etc.)
2. Set up the first support stand with the ring above the candle, so the bottom of the cap will be ~3 cm from the candle flame.
3. Set up the second support stand with the ring above the hot plate, so the bottom of the cap will be ~3 cm from the hot surface.



Setup for water-drop demonstration. Hot plate is heat source on the left; lighted candle is heat source on the right.

Procedure – Part 1. Developing a bigger, better model of combustion. (Use the PowerPoint presentation.)

1. **Explain:** Let's explore the model of the Fire Triangle a little more deeply so we can see how fire fits in with the functioning of life on Planet Earth. Use slides 1-5 in *H03_FireTriangle_CarbonCycle_Connection.pptx* to teach about the chemistry of combustion. STOP ON SLIDE 6.

Procedure – Part 2. Does combustion really produce water? (Lab demonstration – get the fence-post caps out of the freezer.)

2. **Hook:** Look again at the chemical equation for combustion. It says that combustion produces water! But that seems counter-intuitive, since we use water to PUT FIRES OUT. Let's treat that idea as our hypothesis and then try to verify experimentally that combustion does produce water.
3. Write on the board: **Hypothesis: Combustion produces water.**
4. **Ask and discuss:** Have you ever seen water dripping down the sides of a glass of ice water in the summer, when the weather is hot and perhaps humid? What is happening there?
(Water vapor in the air is touching the cold surface of the glass, where it is rapidly cooled from gas to liquid phase. It condenses on the surface of the glass, and eventually droplets come together and run down the sides.)
5. **Explain and discuss:** We can use the fact that water vapor condenses on cold surfaces to test our chemical equation, our model of combustion – to see if combustion actually does

produce water. We're going to melt the ice in the two post caps using heat from two different sources: a candle flame and an electrical hot plate.

- How is the heat transferred from these two heat sources? (The heat from the candle is transferred mainly by convection of hot gases produced by combustion. The heat from the hot plate is transferred mainly by radiation. There is no chemical change going on, and no hot gases are produced by the heating process.)
- What do you expect to happen? Write expectations on the board below "Hypotheses." (The ice will melt.)
- Based on your understanding of the combustion equation, do you expect any differences between the two procedures? (Water vapor produced by the burning candle will touch the cold surface of the cap, where it will rapidly cool and condense into droplets. No water vapor is being produced by the hot plate (combustion is not occurring), and its heat is vaporizing any water from the atmosphere that might otherwise condense on the outside of the post-cap, so the cap will remain dry.)

6. Place a post cap (with water frozen) in each ring.

7. Light the candle and turn on the hot plate.

8. Have the students go back and forth, observing each cap until the ice inside has melted to a 2-3 cm chunk. A flashlight may help them see what is happening more clearly. (The bottom of the post cap over the hot plate will be dry. The bottom of the post cap over flame will be covered with water droplets, and a large drop may collect right above the flame.)



9. **Discuss:** What differences did you observe? What caused the differences? Were any of our hypotheses verified? (The bottom of the post cap over the hot plate is dry because the heat source is not producing water vapor. The bottom of the post cap over the candle is moist because water produced by combustion is condensing on the cold surface of the cap.)

Results of water-drop demonstration. No water is visible on the electrically-heated post cap; water droplets have condensed on the combustion-heated post cap.

10. **Additional discussion points:** Smoke contains partly-burned particles of fuel. Water vapor condenses especially well on particle surfaces, so it condenses on the smoke particles. A wildland fire may produce so much water vapor that it eventually condenses in the cold upper atmosphere and creates rain that falls along the edges of the fire.

Procedure – Part 3. The Carbon Cycle (use the rest of the PowerPoint)

11. Return to *H03_FireTriangle_CarbonCycle_Connection.pptx* at slide 6, and finish the presentation. Use the final slide to introduce the assessment.

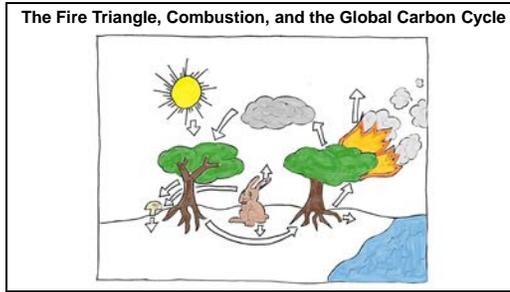
Assessment:

- Give each student a copy of **Handout H03-1**.
- Have them answer items 1 and 2 based on the demonstration and the presentation.
- Have them do the reading assignment and then complete item 3. Reading assignment: Have students read **EITHER** the full article entitled *Sink or source? Fire and the forest carbon cycle* available at www.firescience.gov/projects/briefs/03-1-1-06_FSBrief86.pdf **OR** the excerpts on **Handout H03-2**.

Evaluation: Use the answer key to Handout H03-1 to evaluate student responses.

Slides and Narrative for *H03_FireTriangle_CarbonCycle_Connection.pptx*

Slide 1

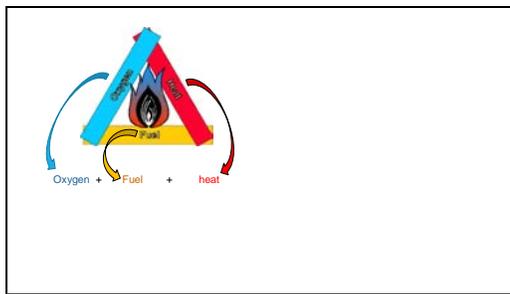


Procedure Part 1.

Explain: We've been studying the Fire Triangle and the process of combustion.

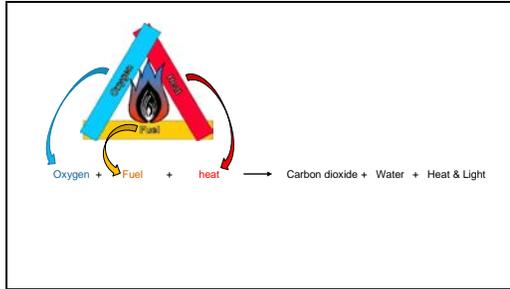
Let's explore combustion a little more deeply and then fit it in with the basic life processes on Earth, as described in the Global Carbon Cycle.

Slide 2



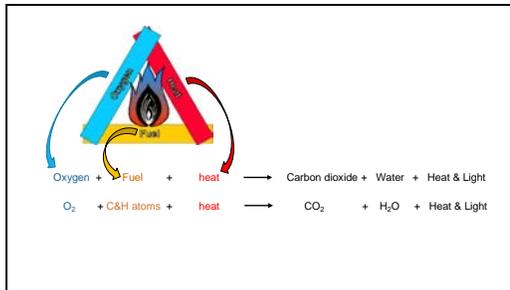
We'll start with the Fire Triangle: oxygen, fuel, and heat. If you break it apart and line up the "ingredients," you have an arithmetic expression for what makes fires "go" – what makes combustion happen.

Slide 3



Now let's list the products of combustion. They are carbon dioxide, water, heat, and light.

Slide 4

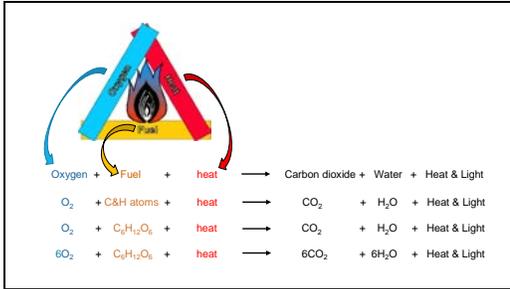


We can use chemical symbols for both the ingredients and the products of combustion.

It's a little tricky to give a specific formula for fuels, because they could be any mixture of millions of compounds. But all fuels contain carbon and hydrogen, and they usually contain oxygen and other kinds of atoms as well. Let's plug in the formula for glucose, $C_6H_{12}O_6$, since the main component of woody fuels is cellulose - a very long chain of glucose molecules.

Now we have a brand-new model – the chemical formula (“equation”) for combustion.

Slide 5

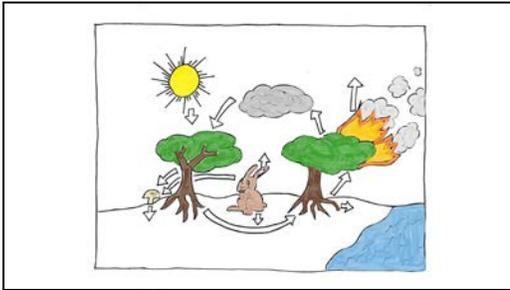


Finally, let's make sure the equation shows that the number of atoms going into the combustion process is the same as the number that are produced. This is called "balancing" the equation.

Our new model is more complicated than the Fire Triangle, but it is also more powerful. It helps us keep track of the atoms that are moved around in this chemical change, and it lets us predict how much of each "ingredient" ("reactant") is needed to produce a specific amount of products.

Part 1 ends here.

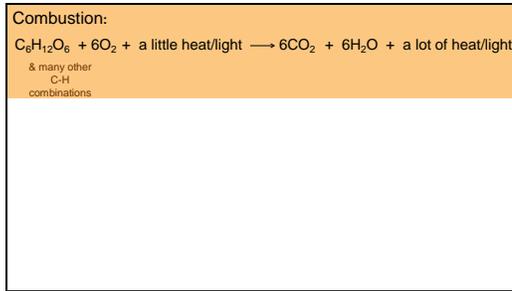
Slide 6



Procedure Part 3.

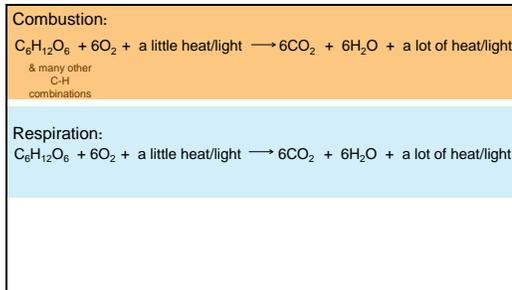
Now let's see how the process of combustion fits into the life processes on Planet Earth.

Slide 7



Here's our model of combustion.

Slide 8



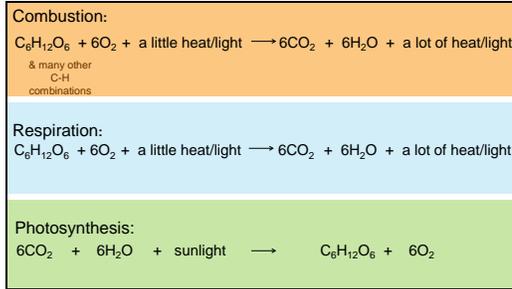
Here's another chemical equation. It describes the process that living things use to obtain energy – a process called **respiration**:

What do you notice about these two equations?

Explain: Fire isn't the only process that takes energy from carbohydrates and releases CO₂ and water into the air. Respiration is just a fancy word for breathing; breathing is how we get oxygen to our cells so they can produce energy, a process called *cellular respiration*. Animals aren't the only living things that use respiration to get energy. Nearly EVERY living thing does – animals, plants, algae... even the tiniest microorganisms use respiration. But if plants and animals just kept on doing respiration, all the carbohydrates and oxygen would be converted to CO₂. We wouldn't last very long.

Ask: How do carbohydrates and oxygen get replenished—how do we reverse the process?

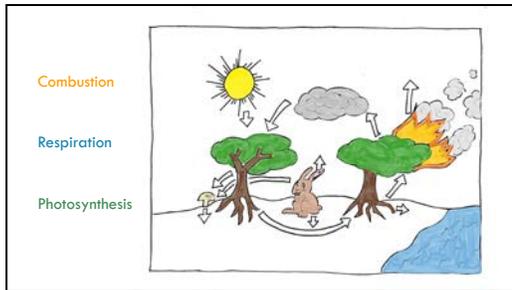
Slide 9



Explain: Lucky for us, plants are able to reverse the process of combustion and respiration by grabbing the energy from sunlight and storing it in the high-energy bonds of carbohydrates. This is called photosynthesis. And the chemical equation for photosynthesis is the mirror image of the equation for combustion of glucose and respiration.

Animals ensure there is abundant CO_2 in the atmosphere, which means plants can grow well, which means there's plenty of food for animals (including us!) to eat. It also means fuels are abundant, which means there's plenty of fuel for fires to burn.

Slide 10

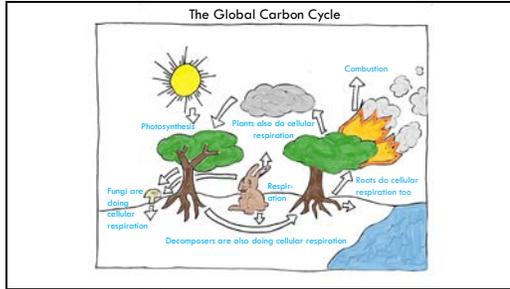


Ask: Where are combustion, respiration, and photosynthesis occurring in the image?

Answer: Photosynthesis occurs where sunlight & oxygen are going into the tree. Combustion is occurring where the tree is releasing carbon dioxide, water, and smoke into the air. All the other processes – growth, uptake of water and minerals by plants, decay, and defecation - are powered by cellular respiration.

Explain: All of these processes, put together, are called the Carbon Cycle. It is a cycle because you can trace carbon as it moves through one process after another, from one kind of molecule to another. Throughout the process, carbon is reused at every step.

Slide 11



Explain: See the labels on the picture. We often talk about “burning” calories or carbs. “Burning” is a short way of saying we use cellular respiration to get the energy we need to rearrange food molecules (carbs) into the molecules we need to live (proteins, DNA, etc. – which make muscle, eyeballs, babies, poop, etc.)

Ask: How do forests store carbon? When do forests release carbon? Overall, do forests function as *sources of carbon* or storage – reservoirs – of carbon (also called *carbon sinks*)?

Slide 12



Explain: Read the article “Sink or Source? Fire and the Forest Carbon Cycle”. Based upon the information in the article, do forests function as storage for carbon or sources of carbon? This is the answer to question number three on your handout.

Terminology:

When carbon accumulates and is being stored for an indefinite period, it is considered to be a **carbon sink**. The process by which carbon sinks remove carbon dioxide (CO₂) from the atmosphere is known as carbon sequestration.

When carbon is being released to the atmosphere, it is called a **carbon source**.

H03-2: Reading: Excerpts from “Sink or Source: Fire and the Forest Carbon Cycle”*

Forests have a life cycle: trees die after disturbance, such as a stand-replacing fire, setting the stage for new growth to begin. If a forest fully replaces itself, there will be no net carbon change over that life cycle. The fire consumes only about 10 to 20 percent of the carbon and immediately emits it back into the atmosphere. It kills trees but doesn't consume them. So, new trees grow (storing carbon), old trees decompose (emitting carbon), and the organic layer of the soil accumulates (storing carbon). This balance between simultaneous production and decomposition determines whether the forest is a net source or sink. The net ecosystem carbon balance, also known as net ecosystem production (NEP), specifically quantifies the annual net change in carbon stored in the ecosystem. And that's the “magic number,” so to speak, needed to gauge whether a forest is a carbon source (negative NEP) or sink (positive NEP) at any given point in time. NEP is often quantified on an annual basis and for a single forest stand. But to determine whether an entire landscape (which is composed of many stands of different ages) is a carbon source or sink over a longer time frame, annual NEP must be assessed over both space and time.

Immediately after a fire, carbon is lost to the atmosphere through combustion. Stand-replacing fires kill living biomass in forests and reduce carbon gains to near zero. The strongest effect of fire on carbon cycling, however, occurs in the changing balance between carbon lost through subsequent decomposition and simultaneous carbon gains through growth of new vegetation. In fact, the decomposition of dead biomass that lasts for several decades post-fire can release up to three times as much carbon as that lost in the initial combustion. And during this period, carbon lost through decomposition exceeds the carbon accumulating in regrowth. Then, as the forest continues to reestablish and decomposition tapers off, carbon storage in trees eventually “catches up,” and the carbon balance of loss and gains approaches an NEP of zero. According to Dr. Ryan [interviewed for this article], “In 30 to 40 years or so of regeneration, you cross the positive line because growth and accumulation is outpacing the decomposition of the dead matter. And then in approximately 80 to 100 years, the ecosystem has recovered completely to pre-fire carbon levels.” So in the short-term, over the time frame of the first century post-fire, stand replacing fires convert the landscape into a carbon source and then back into a carbon sink. Long-term effects of fire (over centuries) on the carbon balance depend on post-fire regeneration and fire frequency. We see a large difference in the ability to recover pre-fire carbon storage levels between stands having low initial regeneration and those that replace biomass quickly. The take-home message here is that the replacement of biomass for a given stand over multiple fire intervals plays the critical role in the relationship between fire and the carbon balance. If, as a result of crown fire, a forest converts to grassland or meadow rather than regenerating, much carbon can be lost from the ecosystem. Dr. Ryan emphasizes the point: “Regeneration is absolutely critical to carbon. If you don't get regeneration, the ecosystem loses about half of its carbon.” But if the forest does regenerate—and exists on the landscape long enough before the next stand-replacing fire—it will recover the carbon lost over the fire cycle.

*Frame, Christine. 2010. Sink or source? Fire and the forest carbon cycle. Fire Science Brief. Joint Fire Science Program. Issue 86. 6 p. Available: www.firescience.gov/projects/briefs/03-1-1-06_FSBrief86.pdf.

Handout H03-1: Answer Key/Evaluation

Water, Combustion, and the Global Carbon Cycle

1. Write one paragraph that explains what is going on in the white columns of smoke in this photo. Use what you know about where heat goes and what chemicals are produced by combustion.

Answer: The smoke is rising because heat usually does rise, as we observed in an earlier experiment. The model says that combustion produces water vapor, and we saw that in the demonstration that the water condenses into droplets when it cools. Water vapor produced by the fire must be cooling and condensing as it rises. The model also says that combustion produces carbon dioxide, so that must be in the plume too – even though we can't see it.

Optional details: Smoke contains partly-burned particles of fuel. Water vapor condenses especially well on surfaces, so it condenses on the smoke particles. A wildland fire may produce so much water vapor that it eventually condenses in the cold upper atmosphere and creates rain that falls along the edges of the fire.

2. Write a few sentences that explain how the chemical processes of combustion, cellular respiration, and photosynthesis are related.

The chemical reactions of combustion are basically the same as those in cellular respiration. The chemical process of photosynthesis is the reverse of combustion and cellular respiration.

3. Read the article on **Handout H03-2** (or the full article online). Then write 1-2 paragraphs that answer these questions. Use specific evidence and quotes from the article to support your answers.
 - a) Based upon the information in the article, how does stand-replacing fire affect whether forests are a source or sink for carbon?
 - b) Does a forest change over time from source to sink, or from sink to source?
 - c) What is the most important variable that makes an ecosystem gain or lose carbon after fire?

Answer: Forests are usually a carbon sink. Stand-replacing fires convert forests into a carbon source for about 30 to 40 years, and then – if trees regenerate successfully - the forest gradually changes back into a carbon sink after about 80 to 100 years. During a severe wildfire, a lot of carbon is released, and then even more carbon is released through decomposition that follows the fire. That is why, during this time, the forest is a carbon source. As the forest grows back, it manufactures and stores a lot of carbohydrates. Eventually, the pace of storing new carbohydrates surpasses the pace of decomposition. That means the forest has become a carbon sink again.

The most important variable that determines whether the ecosystem gains or loses carbon after fire is tree regeneration. If trees grow back successfully after a stand-replacing fire, forests usually become carbon sinks again in about 80 to 100 years. If trees do not regenerate and the forest becomes a grassland or shrubland, it may remain a carbon sink for many centuries. It may not ever store as much carbon as before the fire.