

## SUMMARY

Students use molecular model sets to become familiar with some simple chemical equations describing combustion, and to see how the burning of fossil fuels produces carbon dioxide.

## ESSENTIAL QUESTIONS

- What is combustion?
- What molecules does combustion produce?
- What are some of the benefits of combustion for humans?

## TIME NEEDED

This activity, including the warm-up and wrap-up, should take about 45 minutes.

North Carolina

## EARTH/ENVIRONMENTAL SCIENCE COURSE STUDY GOALS & OBJECTIVES

Objective 2.07

A project of the Environmental Education Fund.



## MAKING CONNECTIONS

Almost all air pollution is generated by the burning of organic materials, whether wood or fossil fuels such as natural gas, coal, or gasoline. The main reason humans burn these fuels is to produce energy to power our homes, industries, commercial buildings, cars, trains, and airplanes. The more combustion-based energy we use, the more air pollution we produce. In order to understand air pollution, we must understand the chemical process of combustion.

## BACKGROUND

This activity is appropriate for students who have not had a lot of experience with chemical equations. They are not expected to memorize or balance any of the equations. The main point is simply that burning a hydrocarbon in the presence of oxygen produces – at a minimum – carbon dioxide, water, heat, and light. Because fuel is hardly ever pure, and air is not just oxygen, real-life combustion can produce nitrogen oxides, sulfur oxides, soot (unburned carbon), and a variety of other pollutants. This activity focuses mainly on carbon dioxide; other pollutants will be looked at in later activities.

Of course, carbon dioxide is produced by natural processes as well, including forest fires and respiration of animals and plants. We'll look at the carbon cycle in more detail in later activities.

## CHEMICAL EQUATIONS

The law of conservation of mass states that matter cannot be created or destroyed in a chemical equation. Therefore, when you write a chemical equation, the number of atoms of each element to the left of the arrow must equal the number of atoms of each element to the right of the arrow. Often this means there will be different numbers of each molecule in order to make sure there are the same number of atoms of each element before and after the reaction.

Figuring out how many of each molecule are needed for the equation is called balancing the equation. Explain to your students that a large numeral in front of a molecular formula indicates how many of that molecule are involved in the equation. Small numerals written as subscripts refer to how many atoms of a particular element are needed in a molecule.

**NOTE:** For more advanced classes, you can have the students balance the combustion equations themselves rather than giving the equations to the students already balanced.

## COMBUSTION EQUATIONS

The following balanced equations represent the burning of various pure fuels in pure oxygen. Real life is more complicated, because most fuels are not pure and the air is not 100% oxygen. Air is 78% nitrogen, 21% oxygen and almost 1% argon.

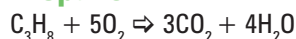
**Methane (natural gas is primarily methane)**



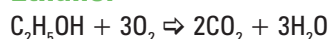
**Ethane**



**Propane**



**Ethanol**



Burning fossil fuels in air, as opposed to pure oxygen, results in the production of nitrogen oxides such as NO and NO<sub>2</sub> (often represented as NO<sub>x</sub>) in addition to carbon dioxide. Furthermore, real fuels usually have other compounds in them besides just carbon and hydrogen. Coal for example, can include carbon, hydrogen, oxygen, nitrogen, sulfur and even small amounts of lead and mercury. When we burn sulfur-containing coal, sulfur dioxide is one of the products. Sulfur dioxide is a factor in acid rain, and tiny drops of liquid sulfur dioxide are a kind of particulate-matter pollution.

While there are technologies such as power plant scrubbers and catalytic converters to reduce the amount of sulfur oxides or nitrogen oxides emitted, there is no way to get around the fact that burning fossil fuels and other organic matter produces carbon dioxide. The only way to reduce the amount of carbon dioxide emitted is to burn less fossil fuel (by conserving or using renewable energy) or to somehow store carbon dioxide to prevent it from entering the atmosphere. These concepts will be explored in later activities.

## MATERIALS

- Molecular model sets (enough for each group to have a complete set with all the atoms and bonds needed to complete each equation. One set equals: 4 carbon, 12 hydrogen, 14 oxygen, and 28 bonds).
- Less expensive options: construction paper, styrofoam balls or gumdrops in three different colors for atoms, and pipe cleaners or toothpicks for bonds.



## WARMUP

If necessary, before showing the video, review some basic vocabulary with your class, such as atoms, molecules, and bonds. The molecule oxygen consists of two atoms of oxygen, connected with a double bond, which gives it extra stability. Also, review the way molecules are written. For example, carbon dioxide is written  $\text{CO}_2$ , which means one carbon atom and two oxygen atoms.  $3\text{CO}_2$  means three carbon dioxide molecules.

Show the Combustion Video to the class. Afterwards, remind your students about the law of conservation of mass: Matter cannot be created or destroyed in a chemical equation. Then light a candle. Ask the students to describe what is happening. The candle is burning, but what does burning mean? What is needed to produce a flame? (Fuel, oxygen, spark.) Why does the candle get shorter the longer it burns? Where does the mass that was in the candle go? What does combustion produce? Students should be able to say combustion produces heat and light. Some may be able to say combustion produces carbon dioxide and water, but if not, that's okay. This will become clear in this activity.

Now blow the candle out. Point out the smoke rising from the wick and ask the students what is in the smoke. Smoke can contain a wide variety of different solids, liquids, and gases, depending on the fuel and on the amount of oxygen available. The visible particles are often soot – tiny unburned particles of carbon.

Put a match in the smoke chain, near but not touching the wick. Ask the students to explain what happens – the candle relights. The smoke contains enough unburned fuel that it will burn and relight the wick. The implication is that not all of the fuel is being used up in the combustion process.

Discuss the meaning of the word combustion as a chemical reaction. Combustion requires fuel (usually hydrocarbons), oxygen, and a spark. In addition to producing carbon dioxide and water, the combustion of hydrocarbons produces heat and light.

Brainstorm a list of ways students use combustion in their everyday lives and point out that most of these are related to energy use: internal combustion engines such as cars and lawnmowers; electricity, which is usually generated by burning fossil fuels; furnaces and water heaters powered by fossil fuels; cooking and heating water; fire in the fireplace; grilling; candles; smoking cigarettes; burning trash (which is illegal).

## COMBUSTION VIDEO

### THE VIDEO:

- Introduces to the concept of combustion as a chemical reaction;
- Reminds students of the Law of Conservation of Mass;
- Illustrates how combustion of a simple hydrocarbon (methane) in pure oxygen causes the rearrangement of atoms from one set of molecules to another set of molecules, creating carbon dioxide and water vapor;
- Shows how air pollution can result when other gases in our atmosphere and other substances in fuel are added into the combustion mix;
- Presents a live demonstration of how some fuels burn cleaner than others. Introduces the concept...

**Key elements:** video footage, animation, demonstration.

## Teacher Tips

**Set-up Time:** 15 Mins. **Activity Time:** 45 Mins.

For this activity, I separate the students into the smallest groups the materials will allow – groups of two are ideal – and have the students stop and show me their work after each equation is put together. This helps maintain time-on-task by not allowing the more motivated students to get too far ahead, and will allow you to reinforce understanding by providing the students with relevant examples of where each of these products can be found after each equation is modeled.

When handing out the molecule sets, I recommend giving students only the exact number and type of atoms they will need for the activity. Otherwise, they can't resist wasting time building fun shapes out of the spheres and rods.

If appropriate for your class, you may want to ask students to do only the methane equation. You can model the other equations as a class demonstration.

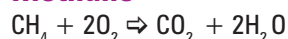
For extra fun, you can have each student represent a single atom and act out the reactions with the whole class – for the combustion of methane, you need nine atoms (i.e., nine students); for the combustion of ethane, you need 30 atoms (i.e., 30 students).



### THE ACTIVITY

1. Use the molecular model set to build models of a few simple molecules that you know, such as water ( $\text{H}_2\text{O}$ ) and oxygen ( $\text{O}_2$ ).
2. Identify the methane molecule on the first worksheet. Make a model of methane, which is  $\text{CH}_4$  (one carbon atom and four hydrogen atoms). Natural gas is mostly methane.
3. Shown below is the chemical equation for pure methane burning in pure oxygen. Make models of the three molecules on the left side of the arrow – one methane and two oxygen molecules – which are the reactants of the equation. Then take them apart and use the exact same atoms to make the three molecules on the right side of the arrow – one carbon dioxide and two water molecules – which are the products of the equation.

#### Methane

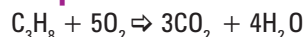


4. Build models of the following combustion equations for ethane, propane, and ethanol. Identify the hydrocarbon molecules on the first worksheet as you go.

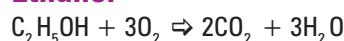
#### Ethane



#### Propane



#### Ethanol



### WRAP UP AND ACTION

Discuss with the class that the combustion equations in this activity are pretty simple. In practice, however, many of the fuels we use (wood, gasoline, coal) contain other atoms besides just carbon and hydrogen. And air is not pure oxygen – it's 78% nitrogen, 21% oxygen, and almost 1% argon. Furthermore, the conditions of combustion are not always perfect, in terms of the amount of fuel available, the amount of oxygen available, and the temperatures achieved.

Combustion in air usually produces nitrogen oxides such as  $\text{NO}$  and  $\text{NO}_2$ . Combustion of coal, some of which contains sulfur, often produces sulfur oxides such as  $\text{SO}$  and  $\text{SO}_2$ . And if the conditions of combustion are not ideal some of the carbon atoms in the fuel combine with just one oxygen atom to produce carbon monoxide ( $\text{CO}$ ) and some of the carbon doesn't burn at all, producing soot (tiny carbon particles). This process is called incomplete combustion; candles and campfires are good examples of incomplete combustion.

Also remind students that combustion produces two qualities that are not molecules: heat and light. These qualities are beneficial to humans; that's why humans tamed fire in the first place. Today we use the combustion of gasoline to power our cars; the combustion of coal, oil, and natural gas and to produce electricity; and the combustion of natural gas or oil to heat our homes, to heat water, and to cook.

Ask the students the following questions in class, or have them write the answers on the student worksheet.

1. What two atoms are present in fuels such as natural gas (methane), propane, and ethanol? [Answer: hydrogen and carbon]
2. Name two molecules that are products of combustion of those fuels. [Answer: carbon dioxide and water.]
3. What two qualities does combustion produce that are not molecules? [Answer: light, heat]
4. Name some of the ways that humans use and benefit from combustion. [Answer: to produce heat and light directly, to cook, to produce electricity for many uses, to power cars and other vehicles, to provide enjoyment and beauty from campfires and candles]
5. Remember that air is not pure oxygen. It is 78% nitrogen, 21% oxygen, and almost 1% argon. What other molecules, besides the two listed in question 2 might be produced when burning fuels made of hydrogen and carbon in air? [Answer: nitrogen oxides – molecules made of nitrogen and oxygen.]
6. Most coal contains sulfur and nitrogen as well as carbon, hydrogen, and oxygen. What other molecules besides carbon dioxide and water might be produced when burning coal in air? [Answer: molecules made of nitrogen and oxygen; molecules made of sulfur and oxygen.]
7. Almost all of our energy use is based on combustion. What are some energy sources that are not based on combustion? [Answer: nuclear power, hydropower, solar power, wind power]



## ASSESSMENT

### HAVE STUDENTS:

- Write a paragraph naming and explaining the chemical products of burning fuels made of carbon and hydrogen in pure oxygen and in air.
- Write an essay about what your life would be like if you could not make use of combustion for one full day.

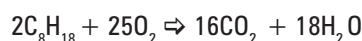
## EXTENSIONS

### OPTIONAL ACTIVITY

#### How Much Carbon Dioxide Does Burning One Gallon of Gas Produce?

For every gallon of gas burned in a car, about 20 pounds of carbon dioxide is emitted. As a class discussion or individually, ask students to explain how burning a gallon of gas (which weighs about 6.3 pounds) can produce more than its weight in carbon dioxide? Go through the calculations as a class, or if your students are advanced, have them perform the calculations themselves as homework.

Here's an equation describing the reaction of octane gas with oxygen:



Carbon has an atomic weight of 12 and carbon dioxide has a molecular weight of 44 (1 carbon atom at 12 and 2 oxygen atoms at 16 each). If you assume that each carbon atom in the gasoline combines with two oxygen atoms in the air then you know for every 12 parts mass of carbon you will end up with 44 parts mass of carbon dioxide. If you want to know how much carbon dioxide you will end up with for every ONE part of carbon, simplify the ratio by dividing 44 by 12 and you will get 3.7 parts carbon dioxide for every 1 part carbon.

Next you have to know how much of the weight of a gallon of gas consists of carbon as opposed to hydrogen. Assume octane gas ( $\text{C}_8\text{H}_{18}$ ). The molecular weight of that molecule is 114 (the atomic weight of carbon is 12 and the atomic weight of hydrogen is 1). Carbon's portion, 96, divided by 114 is 84.2%. So octane gas is about 84% carbon.

A gallon of gas weighs about 6.3 pounds. So the amount of carbon in one gallon of gas is 84% of 6.3 pounds, or 5.3

pounds. Because we know that every 1 part carbon burned will result in 3.7 parts of carbon dioxide, multiply 5.3 by 3.7 and you get 19.6 pounds of carbon dioxide.

How can burning 6.3 pounds of gasoline produce more than its weight in carbon dioxide? It's because the "ingredients" in the carbon dioxide come from both the gasoline and the air.

## RESOURCES

This website has a very concise explanation of how burning a gallon of gas produces 20 pounds of carbon dioxide:

<http://www.fueleconomy.gov/Feg/co2.shtml>

The Carbon Dioxide Information Analysis Center has an excellent FAQ about carbon dioxide. Some of the questions are: "What percentage of the  $\text{CO}_2$  in the atmosphere has been produced by human beings through the burning of fossil fuels?" "How much  $\text{CO}_2$  is emitted as a result of my using specific electrical appliances?" "Why do some estimates of  $\text{CO}_2$  emissions seem to be about 3.5 times as large as others?"

<http://cdiac.ornl.gov/pns/faq.html>

Another excellent CDIAC website with data on the concentrations of greenhouse gases now and pre-1750s and giving the estimated life-time of those gases in the atmosphere, all heavily annotated. It says that carbon dioxide stays around for about 100 years.

[http://cdiac.ornl.gov/pns/current\\_ghg.html](http://cdiac.ornl.gov/pns/current_ghg.html)

## SUPPORTERS

*It's Our Air* is a project of the Environmental Education Fund [www.eefund.org](http://www.eefund.org).

### LEAD SUPPORTERS

Progress Energy  
GlaxoSmithKline  
NC Department of Environment and Natural Resources,  
Division of Air Quality

### MAJOR SUPPORTERS

Duke Energy Foundation  
NC Touchstone Energy Cooperatives  
US Environmental Protection Agency  
NC Department of Public Instruction





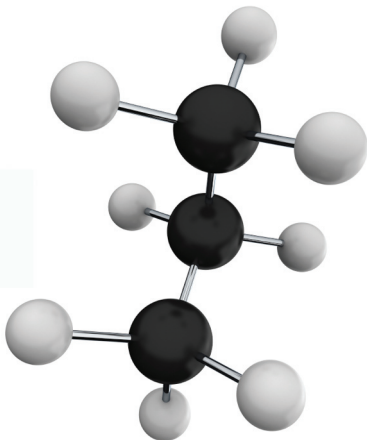
# Combustion Equations

Student Page  
#1

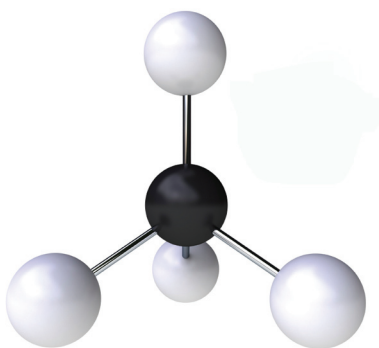
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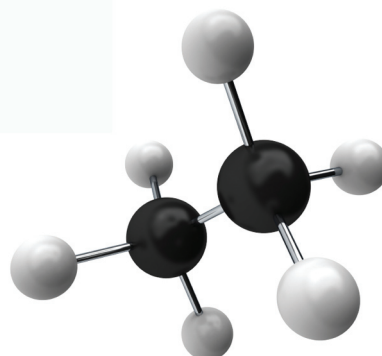
### Methane



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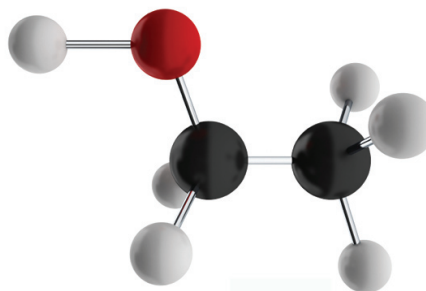
### Ethane



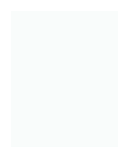
### Propane



### Ethanol



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## WORKSHEET

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