

## Chemistry and Environmental Sciences

### It's Time for a Change

**Subject/Topics:** Chemistry/Chemical Reactions and Energy

**Learning Objectives:** (adapted from the Secondary National Science Content Standards)

1. Chemical reactions may release or consume energy. Some reactions, such as burning fossil fuels, release large amounts of energy by losing heat and emitting light.
2. Light can initiate many chemical reactions such as the evolution of urban smog.
3. The total energy of the universe is constant. Energy can be transferred by collisions in chemical reactions. However, it can never be destroyed.
4. Everything becomes less orderly over time. In energy transfer the overall effect of the energy spreads out uniformly like the warming of our surroundings as we burn fossil fuels.

**Evidence of Understanding:**

- Students will be able to explain how automobiles contribute to air pollution.
- Students will be able to explain how a catalytic converter works and why it is important to air quality.
- Students will be able to compare the advantages and disadvantages of new types of fuels sources currently being used in automobiles.

**Instructional Procedures:**

- Engage: Brainstorm ways that the United States could reduce the amount of air pollution produced by automobiles. Ideas will be categorized into behavioral changes or technology changes.
- Explore: Students will read an article and complete a graphic organizer about how a catalytic converter works to give the class a more equal level of background knowledge.
- Explain: Students will use their knowledge of chemical equations to write thermochemical equations for the reactions occurring in a catalytic converter.
- Elaborate: Students will research and design a brochure analyzing an automobile that uses an alternative form of energy.
- Evaluate: Students will read brochures from other groups and create a chart that compares the advantages and disadvantages of each type of alternative fuel. They will then use the chart to write a reflection discussing which type of car they would buy to help reduce air pollution in the United States.

**Plan for Technology:**

- Students will use calculators for the Hess's Law calculations. They will use the internet to find information about alternative fuel sources for automobiles. They will use Microsoft Word to create their brochure on their alternative fuel automobile.

## **Curriculum Framing Questions:**

### *Essential Questions*

- How does science influence society in the past, present and future?
- Where does energy come from and where does it go?
- What determines a chemical reaction?

### *Unit Questions*

- How do chemical reactions cause heat changes?
- How do gases given off into the atmosphere effect the environment?
- How do you write chemical equations for real world processes?

### *Content Questions*

- How can you determine if a chemical reaction is endothermic or exothermic?
- How can chemical reactions be written to include heat changes?
- How can heat changes be calculated using standard heats of formation and combustion?

## Teacher's Notes

### **Engage:**

1. Divide class into small groups of 3-4 students. Give each group a poster board, chart paper or white board. Have them choose a recorder for the group.
2. Explain that the class will have about 10 minutes to brainstorm ways the US could reduce the amount of air pollution produced by automobiles each year. The recorder should write the ideas on their paper/board.
3. When groups are finished, all papers/boards should be collected and displayed in a place where all students can see them. Have students skim through the lists to see the ideas that were brainstormed.
4. Have each student take a piece of notebook paper and divide it in half. They should title it Changes to reduce air pollution from automobiles. One half should be labeled Behavioral Changes and the other half Technology Changes.
5. Students should write the brainstorming ideas onto their paper by placing the ideas under the appropriate heading. If there are any ideas they are not sure how to categorize, the group or class can discuss the idea aloud.
6. When each individual student has finished their categorizing they should compare and discuss their choices with a partner.

### **Explore:**

1. Distribute the articles discussing catalytic converters.
2. Have students read the articles to get the basic information about how a catalytic converter works.
3. Distribute the Frayer Model graphic organizer to students. Have them fill in information in each box using the article. (attached page)
4. Have a class discussion about the Frayer Model to make sure students have obtained the needed information.

**Explain:**

1. Complete the Chemical Reactions of the Catalytic Converter worksheet. (attached page)
2. Check and discuss answers to clear up misconceptions/difficulties.

**Elaborate**

1. Divide students into partners. Have them choose or assign each group an alternative fuel automobile to research: biomass (not ethanol), ethanol (E-85), hybrid, hydrogen, electric, compressed air (liquid nitrogen) and solar. There will be multiple groups on each topic.
2. Distribute and discuss the project sheet that explains the brochure that students will produce to teach others about their alternative fuel source. (attached page)

**Evaluate**

1. Students will bring their brochures to class and place them at a station for their alternative fuel type.
2. Distribute the comparison matrix to students and discuss the information they need to gather from the brochures.
3. Give students time to circulate through the stations and complete the matrix.
4. Students should then use their matrix to compose a reflection about the type of alternative fuel car they would be most likely to buy in the next five years. Students will share their reflection with their brochure partner.

**How Catalytic Converters Work**

by [Karim Nice](#) (How Stuff Works Website)

There are millions of cars on the road in the United States, and each one is potentially a source of air pollution. Especially in large cities, the amount of pollution that all the cars produce together can create big problems.

To solve those problems, cities, states and the federal government create clean-air laws, and many laws have been enacted that restrict the amount of pollution that cars can produce. To keep up with these laws, automakers have made many refinements to car [engines](#) and fuel systems. To help reduce the emissions further, they have developed an interesting device called a **catalytic converter**, which treats the exhaust before it leaves the car and removes a lot of the pollution.

In this article, you will learn which pollutants are produced by an engine and why, and how a catalytic converter deals with each of these pollutants. Catalytic converters are amazingly simple devices, so it is incredible to see how big an impact they have!

In order to reduce emissions, modern car engines carefully control the amount of fuel they burn. They try to keep the air-to-fuel ratio very close to the **stoichiometric** point, which is the calculated ideal ratio of air to fuel. Theoretically, at this ratio, all of the fuel will be burned using all of the oxygen in the air. For [gasoline](#), the stoichiometric ratio is about 14.7:1, meaning that for each pound of gasoline, 14.7 pounds of air will be burned.

The fuel mixture actually varies from the ideal ratio quite a bit during driving. Sometimes the mixture can be **lean** (an air-to-fuel ratio higher than 14.7), and other times the mixture can be **rich** (an air-to-fuel ratio lower than 14.7).

The main emissions of a car engine are:

- **Nitrogen gas** (N<sub>2</sub>) - Air is 78-percent nitrogen gas, and most of this passes right through the car engine.
- **Carbon dioxide** (CO<sub>2</sub>) - This is one product of combustion. The carbon in the fuel bonds with the oxygen in the air.
- **Water vapor** (H<sub>2</sub>O) - This is another product of combustion. The hydrogen in the fuel bonds with the oxygen in the air.

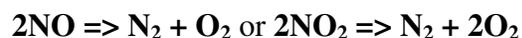
These emissions are mostly benign (although carbon dioxide emissions are believed to contribute to global warming). But because the combustion process is never perfect, some smaller amounts of more harmful emissions are also produced in car engines:

- **Carbon monoxide** (CO) - a poisonous gas that is colorless and odorless
- **Hydrocarbons** or **volatile organic compounds** (VOCs) - produced mostly from unburned fuel that evaporates. Sunlight breaks these down to form oxidants, which react with oxides of nitrogen to cause ground level ozone (O<sub>3</sub>), a major component of smog.
- **Nitrogen oxides** (NO and NO<sub>2</sub>, together called NO<sub>x</sub>) - contributes to smog and acid rain, and also causes irritation to human mucus membranes

These are the three main regulated emissions, and also the ones that catalytic converters are designed to reduce.

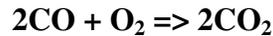
Most modern cars are equipped with **three-way catalytic converters**. "Three-way" refers to the three regulated emissions it helps to reduce -- carbon monoxide, VOCs and NO<sub>x</sub> molecules. The converter uses two different types of catalysts, a **reduction catalyst** and an **oxidation catalyst**. Both types consist of a ceramic structure coated with a metal catalyst, usually platinum, rhodium and/or palladium. The idea is to create a structure that exposes the maximum surface area of catalyst to the exhaust stream, while also minimizing the amount of catalyst required (they are very expensive).

The **reduction catalyst** is the first stage of the catalytic converter. It uses platinum and rhodium to help reduce the NO<sub>x</sub> emissions. When an NO or NO<sub>2</sub> molecule contacts the catalyst, the catalyst rips the nitrogen [atom](#) out of the molecule and holds on to it, freeing the oxygen in the form of O<sub>2</sub>. The nitrogen atoms bond with other nitrogen atoms that are also stuck to the catalyst, forming N<sub>2</sub>. For example:



The **oxidation catalyst** is the second stage of the catalytic converter. It reduces the unburned hydrocarbons and carbon monoxide by burning (oxidizing) them over a platinum and palladium catalyst.

This catalyst aids the reaction of the CO and hydrocarbons with the remaining oxygen in the exhaust gas. For example:



But where did this oxygen come from?

### The Control System

The third stage is a control system that monitors the exhaust stream, and uses this information to control the [fuel injection system](#). There is an [oxygen sensor](#) mounted upstream of the catalytic converter, meaning it is closer to the engine than the converter is. This sensor tells the engine computer how much oxygen is in the exhaust. The engine computer can increase or decrease the amount of oxygen in the exhaust by adjusting the air-to-fuel ratio. This control scheme allows the engine computer to make sure that the engine is running at close to the stoichiometric point, and also to make sure that there is enough oxygen in the exhaust to allow the oxidization catalyst to burn the unburned hydrocarbons and CO.

The catalytic converter does a great job at reducing the pollution, but it can still be improved substantially. One of its biggest shortcomings is that it only works at a fairly high temperature. When you start your car cold, the catalytic converter does almost nothing to reduce the pollution in your exhaust.

One simple solution to this problem is to move the catalytic converter closer to the engine. This means that hotter exhaust gases reach the converter and it heats up faster, but this may also reduce the life of the converter by exposing it to extremely high temperatures. Most carmakers position the converter under the front passenger seat, far enough from the engine to keep the temperature down to levels that will not harm it.

**Preheating** the catalytic converter is a good way to reduce emissions. The easiest way to preheat the converter is to use electric resistance heaters. Unfortunately, the 12-volt electrical systems on most cars don't provide enough energy or power to heat the catalytic converter fast enough. Most people would not wait several minutes for the catalytic converter to heat up before starting their car. [Hybrid cars](#) that have big, high-voltage battery packs can provide enough power to heat up the catalytic converter very quickly.

**Frayer Model Graphic Organizer**  
**Article:**

**Name:** \_\_\_\_\_

<p>Purpose:</p>	<p>Reactants and Catalysts:</p>
<p>Steps involved:</p>	<p>Products:</p>

## Catalytic Converter Chemical Reactions

Name:

### Part I: Demonstration

Nitrogen dioxide is a compound that contributes to photochemical smog.

Description of demonstration:

From the heat of formation chart, is the formation of nitrogen dioxide from nitrogen monoxide and molecular oxygen an endothermic or exothermic process? Explain.

If the equation is endothermic, where does the energy come from? If it's exothermic, where does the energy go? (Hint: re-read the first sentence on this page)

### Part II: Writing and Balancing Equations including states of matter, heat placement and possible catalysts.

Write the balanced equation that shows the decomposition of nitrogen dioxide.

Write the balance equation for the formation of carbon dioxide from carbon monoxide and molecular oxygen. (Hint: this is an exothermic reaction)

Write the balance equation for the combustion of octane ( $C_8H_{18}$ ).

How are these three equations related to catalytic converters?

### Part III. Heat Changes

Using the charts provided, find the heat change for the three equations listed in Part II. Be sure to include the units.

Using the three heat changes, calculate the total heat change by adding the numbers together. Does this number indicate an endothermic or exothermic reaction?

Using this information, explain why cars have a metal plate installed under the catalytic converter.

## Catalytic Converter Chemical Reactions

Name: Teacher's Guide

### Part I: Demonstration

Nitrogen dioxide is a compound that contributes to photochemical smog.

Description of demonstration:

*Before class create the nitrogen dioxide by dissolving copper(1-2g) in 0mL of 6 M nitric acid in a test tube under a fume hood (caution: test tube will be hot). Stopper test tube. Students will describe a brown gas filling the test tube.*

From the heat of formation chart, is the formation of nitrogen dioxide from nitrogen monoxide and molecular oxygen an endothermic or exothermic process?

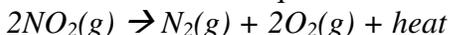
*Endothermic, because of the positive heat value, meaning as heat is added the reaction occurs.*

If the equation is endothermic, where does the energy come from? If it's exothermic, where does the energy go? (Hint: re-read the first sentence on this page)

*The term photochemical means light is the energy source, so the energy comes from the sun. This is why smog is worse on sunny days than cloudy days.*

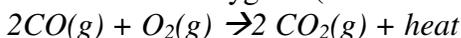
### Part II: Writing and Balancing Equations including states of matter, heat placement and possible catalysts.

Write the balanced equation that shows the decomposition of nitrogen dioxide.



*Catalysts: platinum or rhodium*

Write the balance equation for the formation of carbon dioxide from carbon monoxide and molecular oxygen. (Hint: This is an exothermic reaction)



*Catalysts: platinum, palladium, aluminum oxide*

Write the balance equation for the combustion of octane (C<sub>8</sub>H<sub>18</sub>).



*Catalysts: platinum, palladium, aluminum oxide*

How are these three equations related to catalytic converters?

*These are the three reactions catalytic converters use to take harmful pollutants out the car exhaust before it leaves the tailpipe.*

### Part III. Heat Changes

Using the charts provided, find the heat change for the three equations listed in Part II. Be sure to include the units.

*Decomposition of nitrogen dioxide is -33.85 kJ/mol (opposite of heat of formation)*

*Formation of carbon dioxide is -566 kJ/mol*

*Combustion of octane is -5471 kJ/mol*

Using the three heat changes, calculate the total heat change by adding the numbers together. Does this number indicate an endothermic or exothermic reaction?

*The total heat change is -6070.85 kJ/mol. This indicates an exothermic reaction.*

Using this information, explain why cars have a metal plate installed under the catalytic converter.

*This is a great deal of heat being given off so the car could start a fire if parked over grass or wood surfaces.*

**E.P.A. Says Catalytic Converter Is  
Growing Cause of Global Warming**

**By Matthew L. Wald**

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**May 29, 1998**

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WASHINGTON -- The catalytic converter, an invention that has sharply reduced smog from cars, has now become a significant and growing cause of global warming, according to the Environmental Protection Agency.

Hailed as a miracle by Detroit automakers even today, catalytic converters have been reducing smog for 20 years. The converters break down compounds of nitrogen and oxygen from car exhaust that can combine with hydrocarbons, also from cars, and be cooked by sunlight into smog.

But researchers have suspected for years that the converters sometimes rearrange the nitrogen-oxygen compounds to form nitrous oxide, known as laughing gas. And nitrous oxide is a potent greenhouse gas, more than 300 times more potent than carbon dioxide, the most common of the gases, that is warming the atmosphere, according to experts.

This spring, the EPA published a study estimating that nitrous oxide now comprises about 7.2 percent of the gases that cause global warming. Cars and trucks, most fitted with catalytic converters, produce nearly half of that nitrous oxide, the study said. (Other sources of nitrous oxide include everything from nitrogen-based fertilizer to manure from farm animals.)

The EPA study also showed that nitrous oxide is one of a few gases for which emissions are increasing rapidly. Collectively known as greenhouse gases, they trap heat in the earth's atmosphere.

The increase in nitrous oxide, the study notes, stems from the growth in the number of miles traveled by cars that have catalytic converters. And the problem has worsened as improvements in catalytic converters, changes that have eliminated more of the nitrogen-oxygen compounds that cause smog, have conversely produced more nitrous oxide.

Wylie J. Barbour, an EPA official who worked on the recently published inventory, said that the problem created by the converter is classic. "You've got people trying to solve one problem, and as is not uncommon, they've created another."

Nitrous oxide, or N<sub>2</sub>O, is not regulated because the Clean Air Act was written in 1970 to control smog, not global warming. And no regulations exist to control gases that are believed to cause global warming.

The United States and the other industrialized nations agreed in Kyoto, Japan, last December to lower emissions of greenhouse gases to 5 percent below 1990 levels, over the next 10 to 15 years, but the agreement has not been approved by the Senate, and no implementing rules have been written.

"This hadn't really been on people's radar screen until climate change started becoming an issue," said one EPA official involved in reducing pollution from cars, who asked not to be identified by name.

The EPA has not proposed a solution at this point, and is seeking public comment on its study. Auto industry experts say they could solve the problem by tinkering with the catalytic converter, but some environmentalists suggest that the growing production of nitrous oxide is yet another reason to move away from gasoline-powered cars. The EPA's study estimated that nitrous oxide may represent about one-sixth of the global warming effect that results from gasoline use.

"It's like, clean is not green," said Sheila Lynch, executive director of the Northeast Alternative Vehicle Coalition, a public-private partnership that encourages non-traditional power sources.

Another expert, Christopher S. Weaver, an engineering consultant who wrote a study on the subject for the environmental agency, said, "We haven't cared enough to establish standards."

Precisely how much nitrous oxide the converters produce remains an issue. A report used by the EPA in preparing its greenhouse gas study, calculated that a car with a fuel economy of about 19 miles a gallon would produce .27 grams of nitrous oxide per mile. That represents an amount that is about one-third the limit of emissions for nitrogen oxide, the chemicals causing smog.

Steven H. Cadle, a research scientist at General Motors, said, "it's a huge number." In contrast, an older car without a catalytic converter produces much larger amounts of nitrogen oxides, but only about a tenth as much nitrous oxide, the greenhouse gas.

The EPA calculated that production of nitrous oxide from vehicles rose by nearly 50 percent between 1990 and 1996 as older cars without converters have neared extinction. Using a standard unit of measure for global warming gases, millions of metric tons of carbon equivalent, nitrous oxide emissions rose to 54.7 million tons from 36.7 million during those years, the study said.

The contradictory impact of the converter has not been lost on environmental officials or industry experts, who continue to debate not only the extent of the growing problem as well as how to reduce the emissions in future years.

Ned Sullivan, the head of the Maine Department of Environmental Protection, said the converter problem requires a "comprehensive" response. "This specific issue fits into a broader context that our regulatory system has tended to deal with pollutants on an individual, rather than a comprehensive, basis," he said.

He and others favor moving away from today's typical car design, a big gasoline engine driving the wheels, to electric cars. Maine would like electric cars. Another solution is hybrid cars, which use small, efficient engines running on gasoline to help turn the wheels and to charge batteries for electric motors that also run the wheels. Those have much higher fuel economy, and thus lower greenhouse gas emissions.

Car industry experts, however, favor less drastic changes. They propose cutting nitrous oxide production by adjusting catalytic converters in future models. They suspect that the gas is produced when the converter is warming up, and believe the converters could be redesigned to reach optimum temperature faster. That would also help them destroy other pollutants better.

Weaver said that measurements on more kinds of cars and light trucks would be needed to be certain about the size of the problem. But Weaver said, "It is quite clear that you produce nitrous oxide in a catalyst, in some circumstances."

At the Union of Concerned Scientists, an environmental group, an expert on transportation pollution, Roland Hwang, said, "We can't be pushing forward trying to reduce smog while making the global warming problem worse; we can't have programs that undercut each other." He said this was evidence that the transportation system would have to use something besides gasoline.

Cadle, of General Motors would not go that far. But, he said, "You have to be holistic and try and look at everything, which is obviously difficult."

## Alternative Fuel for Automobile Project

Due date:

Name:

Assigned Fuel:

### The Mission:

You are an employee of the Environmental Protection Agency's Air Quality Division. Knowing that changes in our society must be made to protect our air, our nation will not be able to depend on traditional gasoline for much longer. You and a partner have been asked to create a brochure that looks at a new alternative fuel source for automobiles in an unbiased way. Consumers need accurate information to make educated decisions about what kind of car in which to invest their money. It is your job to compile that information and present it in a way that is understandable for the average vehicle buyer.

### The Brochure:

Partners will be assigned one of seven different types of alternative fuels to research. The brochure must include information useful to consumers like a description of how the fuel works, advantages and disadvantages of its use. The brochure must be a professional-looking tri-fold with pictures, diagrams or text on six panels. All sources must be cited and the brochure will be submitted to Turnitin.com so be careful to use your own words.

### Grading: 40 points possible

Each partner will receive the same grade unless I am informed of a lack of participation by one person. In that case, we will discuss a fair deduction based on the work done.

	10 points	5 points	1 point
Content	Information is thorough and unbiased. It is accurate and easy to understand.	Information is unbiased and accurate. It is fairly easy to understand.	Information is biased or incomplete or unclear.
Professionalism	Brochure is well-organized and neatly done. There are no errors in grammar or spelling.	Brochure is mostly well-organized and neatly done. There are few errors in grammar and spelling.	Brochure is not organized or not neatly done. There are many grammar and spelling errors.
Sources	Students cited at least three different sources of information	Students cited at least two different sources of information	Students cited one or no source of information
Effort	Brochure shows extra effort and attention to detail. Students made good use of class time.	Brochure shows a good deal of effort. Student mostly made good use of the given class time.	Brochure shows little effort. Students made little use of the given class time.

**Alternative Fuels Comparison Matrix****Name:**

Fuel Type	Description (How it works)	Advantages	Disadvantages
Biomass (nonethanol)			
Ethanol			
Hybrid			
Hydrogen			
Compressed Air (Liquid Nitrogen)			
Electric			
Solar			

**Comparison Matrix/Reflection Rubric**  
10 points

**Name:**

**Reflection Instructions**

You are now the consumer. After reading the different brochures and compare the types of fuel you need to make a decision about which type of vehicle you will purchase. State your decision in clear terms and give supporting details as to how you came to that decision. In paragraph form, thoroughly explain your thoughts and justify your decision.

	5 points	3 points	1 point
Comparison Matrix	Matrix is completely filled in with accurate and valuable information.	Matrix is mostly filled in and information is accurate. Most of the information is valuable.	Matrix is incomplete and missing many key pieces of valuable information.
Reflection	Reflection is more than three paragraphs and shows a great deal of insightfulness and thoughtfulness. A detailed explanation of the decision and the reasons for it is included.	Reflection is at least three paragraphs. It shows some thoughtfulness. The decision and the reasons for it are discussed.	Reflection is less than three paragraphs. It shows little thought and does not discuss the reasons for the decision or the decision itself.