

**February/March 2017 Teacher's Guide for**

**The Drive for Cleaner Emissions**

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# About the Guide

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Articles from past issues of *ChemMatters* and related Teacher’s Guides can be accessed from a DVD that is available from the American Chemical Society for $42. The DVD contains the entire 30-year publication of *ChemMatters* issues, from February 1983 to April 2013, along with all the related Teacher’s Guides since they were first created with the February 1990 issue of *ChemMatters*.

The DVD also includes Article, Title, and Keyword Indexes that cover all issues from February 1983 to April 2013. A search function (similar to a Google search of keywords) is also available on the DVD.

The *ChemMatters* DVD can be purchased by calling 1-800-227-5558. Purchase information can also be found online at: <https://www.acs.org/content/acs/en/education/resources/highschool/chemmatters/products.html>.

# Student Questions

**The Drive for Cleaner emissions**

* 1. Why did Volkswagen tamper with the software in some models of its diesel automobiles?
	2. What are the three fundamental properties that car manufactures need to balance, in order to reduce car emissions?
	3. What are the reactants and products of the most common type of combustion reaction?
	4. What are the two gases that are found in large amounts in air?
	5. Under what condition will a gasoline engine produce carbon monoxide (CO)?
	6. Under what condition will a gasoline engine produce nitrogen oxides?
	7. What does the term “stoichiometrically balanced” mean?
	8. Name the four polluting gases produced in a car’s engine that are treated by a catalytic converter.
	9. Name the cleaner gases that are released from a catalytic converter into the tailpipe.
	10. Describe three ways in which a diesel engine operates differently than a gasoline engine, according to the article.
	11. What was the “defeat device” that Volkswagen installed on its 3.0-L diesel model cars since 2009?
	12. Describe at least two advances that are planned for the cars of the future.

# Answers to Student Questions

**(taken from the article)**

**The Drive for Cleaner Emissions**

1. **Why did Volkswagen tamper with the software in some models of its diesel automobiles?**

*Volkswagen tampered with the software on its diesel cars because they wanted to get away with generating higher exhaust emission on the road than what was allowed by law.*

1. **What are the three fundamental properties that car manufactures need to balance, in order to reduce car emissions?**

*The three fundamental properties are:*

1. *engine power, which affects acceleration and capacity to tow heavy loads,*
2. *engine fuel efficiency, which is the distance traveled for each gallon of fuel consumed, and*
3. *air pollution.*
4. **What are the reactants and products of the most common type of combustion reaction?**

*In the most common type of combustion reaction, gasoline or diesel (the fuel) and oxygen are the reactants, and water and carbon dioxide are the end products.*

1. **What are the two gases that are found in large amounts in air?**

*The two most abundant gases in air are oxygen (O2) and nitrogen (N2).*

1. **Under what condition will a gasoline engine produce carbon monoxide (CO)?**

*Carbon monoxide (CO) and unburned hydrocarbon fuels are produced from incomplete combustion. This occurs when there is too little oxygen available to react with the gasoline.*

1. **Under what condition will a gasoline engine produce nitrogen oxides?**

*Pollutants called nitrogen oxides can from when too much oxygen is present (more than the stoichiometric amount).*

1. **What does the term “stoichiometrically balanced” mean?**

*“Stoichiometrically balanced” means that all reactants are completely used up in a chemical reaction. That is, at the end of the reaction there is no excess of any reactant.*

1. **Name the four polluting gases produced in a car’s engine that are treated by a catalytic converter.**

*The four polluting gases that are treated by a catalytic converter are*

1. *carbon monoxide (CO),*
2. *methane (CH4),*
3. *nitric oxide (NO), and*
4. *nitrogen dioxide (NO2).*
5. **Name the cleaner gases that are released from a catalytic converter into the tailpipe.**

*The cleaner gases that are released from a catalytic converter are carbon dioxide (CO2), nitrogen (N2), and water (H2O).*

1. **Describe three ways in which a diesel engine operates differently than a gasoline engine, according to the article.**

The three ways a diesel engine is different from a gasoline engine are:

1. *The diesel fuel is a more viscous hydrocarbon mixture than gasoline. This makes them more difficult to start in cold weather.*
2. *A diesel engine typically runs ‘fuel lean.” This means that more air is fed into the engine than is necessary to react with the diesel fuel.*
3. *Nitrogen, from the air that is left over, can react with unreacted oxygen to create nitrogen oxide pollutants.*
4. **What was the “defeat device” that Volkswagen installed on its 3.0-L diesel model cars since 2009?**

*The “defeat device” was an additional piece of software that was designed to turn off the function of the NOx adsorption sieve, which resulted in high fuel economy AND high NOx emissions. The software was programmed to reverse the settings to low-emissions and low-fuel economy mode while the car was being tested by regulators. Under normal driving conditions, the emissions exceeded regulations by as much as 40 times. These pollutants cause smog and can harm human health.*

1. **Describe at least two advances that are planned for the cars of the future.**

*The advances mentioned in the article that car manufacturers are working on for the future are:*

1. *developments in the engine’s combustion chambers resulting in more efficient fuel use ,*
2. *research in new lightweight materials, such as aluminum and carbon fiber to improve fuel efficiency,*
3. *improvements in catalytic converters to reduce nitrogen oxide emissions,*
4. *cars that run on natural gas or hydrogen, and*
5. *improvements in battery electrical storage for electric and hybrid vehicles.*

# Anticipation Guide

Anticipation guides help engage students by activating prior knowledge and stimulating student interest before reading. If class time permits, discuss students’ responses to each statement before reading each article. As they read, students should look for evidence supporting or refuting their initial responses.

**Directions:**  *Before reading*, in the first column, write “A” or “D,” indicating your agreement or disagreement with each statement. As you read, compare your opinions with information from the article. In the space under each statement, cite information from the article that supports or refutes your original ideas.

|  |  |  |
| --- | --- | --- |
| **Me** | **Text** | **Statement** |
|  |  | 1. The software in Volkswagen’s diesel automobiles was tampered with so that the engines appeared to pollute less than they do.
 |
|  |  | 1. Engineers can simultaneously improve engine power and engine fuel efficiency while reducing air pollution.
 |
|  |  | 1. When gasoline and diesel are burned, the products should be only carbon dioxide and water.
 |
|  |  | 1. Too much oxygen in a fuel mixture can cause nitrogen oxides to form at high temperatures.
 |
|  |  | 1. Catalytic converters in cars change most of the air pollutants created by car engines into less harmful compounds.
 |
|  |  | 1. The catalysts in catalytic converters are made of three different elements,
 |
|  |  | 1. Engineers have not figured out a way to reduce the amount of nitrogen oxides released in diesel exhaust.
 |
|  |  | 1. Lightweight materials would improve fuel economy without increasing air pollution.
 |
|  |  | 1. Engineers are working on cars that use methane or hydrogen gas for fuel because they would be less polluting.
 |
|  |  | 1. At the time the article was written, fully electric and hybrid-electric vehicles made up about 10% of all vehicles sold.
 |

# Reading Strategies

These graphic organizers are provided to help students locate and analyze information from the articles. Student understanding will be enhanced when they explore and evaluate the information themselves, with input from the teacher if students are struggling. Encourage students to use their own words and avoid copying entire sentences from the articles. The use of bullets helps them do this. If you use these reading and writing strategies to evaluate student performance, you may want to develop a grading rubric such as the one below.

|  |  |  |
| --- | --- | --- |
| **Score** | **Description** | **Evidence** |
| 4 | Excellent | Complete; details provided; demonstrates deep understanding. |
| 3 | Good | Complete; few details provided; demonstrates some understanding. |
| 2 | Fair | Incomplete; few details provided; some misconceptions evident. |
| 1 | Poor | Very incomplete; no details provided; many misconceptions evident. |
| 0 | Not acceptable | So incomplete that no judgment can be made about student understanding |

***Teaching Strategies:***

* Links to **Common Core State Standards for Reading**:
	+ ELA-Literacy.RST.9-10.1:Cite specific textual evidence to support analysis of science and technical texts, attending to the precise details of explanations or descriptions.
	+ ELA-Literacy.RST.9-10.5: Analyze the structure of the relationships among concepts in a text, including relationships among key terms (e.g., force, friction, reaction force, energy).
	+ ELA-Literacy.RST.11-12.1:Cite specific textual evidence to support analysis of science and technical texts, attending to important distinctions the author makes and to any gaps or inconsistencies in the account.
	+ ELA-Literacy.RST.11-12.4: Determine the meaning of symbols, key terms, and other domain-specific words and phrases as they are used in a specific scientific or technical context relevant to grades 11-12 texts and topics.
* Links to **Common Core Standards for Writing**:
	+ ELA-Literacy.WHST.9-10.2F: Provide a concluding statement or section that follows from and supports the information or explanation presented (e.g., articulating implications or the significance of the topic).
	+ ELA-Literacy.WHST.11-12.1E: Provide a concluding statement or section that follows from or supports the argument presented.
* **Vocabulary** and **concepts** that are reinforced in this issue:
	+ Chemical and physical properties
	+ Chemical reactions
	+ Viscosity
	+ Personal and community health
	+ Oxidation states
	+ Elements
	+ Conservation of matter
	+ Consumer choices
	+ Recycling
* Most of the articles in this issue provide opportunities for students to consider how understanding chemistry can help them make informed choices as consumers. The articles also connect chemistry and engineering.
* Consider asking students to read “Open for Discussion” on page 4 to extend the information in “The Drive for Cleaner Emissions” on pages 5-7.
* The infographic on page 19 provides more support for the article “Brush Up on Toothpaste!” on pages 14-15.
* To help students engage with the text, ask students which article **engaged** them most and why, or what **questions** they still have about the articles.
* You might also ask them how information in the articles might affect their choices as consumers. Also ask them if they have different ideas to solve some of the problems discussed in the articles.
* The Background Information in the *ChemMatters* Teachers Guide has suggestions for further research and activities.

***Directions*:** As you read, complete the graphic organizer below to describe the chemistry of reducing car emissions.

|  |  |
| --- | --- |
|  | **Chemistry involved** |
| **Source(s) of nitrogen oxides** |  |
| **Exhaust gas recirculation** |  |
| **Selective catalytic reduction** |  |
| **NOx adsorption** |  |
| **Future developments** | 1.2.3. |

**Summary:** On the bottom or back of this page, write a short email (about 3 sentences) to a friend who wants to know more about how engineers are working to make car emissions cleaner.

# Connections to Chemistry Concepts

**(for correlation to course curriculum)**

1. **Chemical equations**—Discussion about diesel fuel burning in air is an opportunity for students to convert chemical reactions from word equations to chemical equations.
2. **Combustion reactions**—When discussing combustion reactions in class, this article could be used to show how unwanted combustion reactions can produce air pollution involving nitrogen oxides. These unwanted reactions can also include incomplete combustion responsible for producing the deadly poison carbon monoxide.
3. **Stoichiometry**—The stoichiometric balance between fuels and oxygen in an internal combustion engine provides a nice application for the importance of stoichiometric balance and limiting reactants. Burning “fuel lean” and “fuel rich are examples of non-stoichiometric combustion reactions.
4. **Chemical equations**—The generic equation for combustion provided in the article is a good starting point for discussing how to balance chemical equations algebraically.
5. **Precious metals/transition metals**—Metals such as platinum, palladium, and rhodium are used in catalytic converters. Discussion about the periodic table could focus on common properties for these metals (they are stable metals and their d-electrons are easily lost and gained in catalysis reactions).
6. **Catalysis**—By examining how a catalytic converter works, students will better understand that the catalyst is involved in a chemical reaction, but does not show up as an end product in chemical equations.
7. **Adsorption**—Molecular sieves in catalytic converters that filter out toxic emissions by allowing these particles to adhere to the surface of heterogeneous catalysts are great examples of materials that work on the principle of adsorption.
8. **Filtration**—Molecular sieves are great examples of special filtering devices. Porous materials, like sponges, their specific pore sizes only allow smaller molecules to be adsorbed or to adhere to their surface.
9. **Alternative fuels**—“Where do we go from here?”, the last section of the article, introduces students to research with methane and hydrogen as alternate fuels.
10. **Nomenclature**—The common names and systematic names of compounds used in the article could be used as examples of those two different methods of nomenclature in classroom discussion.

# Possible Student Misconceptions

**(to aid teacher in addressing misconceptions)**

1. **“A car that is tuned to burn the exact stoichiometric ratio of fuel to air will produce no pollutants.”** It is true that cars are tuned to burn stoichiometric fuel to air ratios. However, today’s cars have engine control units (ECU) that will adjust this ratio to improve car performance. For example, a cold engine requires a fuel rich mixture because fuel doesn’t vaporize as well when it is cold. This will result in more carbon monoxide and hydrocarbon emissions. A fuel rich mixture is also needed when extra power is needed, such as when accelerating onto a highway. To increase fuel efficiency, cars will run fuel lean. The excess oxygen from the lean burn mixture is available to chemically react with the nitrogen in the air to produce nitrogen oxides, pollutants responsible for smog.
2. **“All the anti-pollution devices cars have nowadays mean that cars don’t pollute anymore.”** The anti-pollutant devices do not function at 100% efficiency and, under certain conditions, do not function at all. For example, the catalytic converter will only function when it reaches temperatures of about 426 °C. So, when you first start your car, the catalytic converter can’t remove any of the pollutants being produced because it hasn’t heated up yet. After about 4,000 miles of operation, a catalytic converter may only be operating at about 98% efficiency. This is due to the loss of active sites on the catalytic surface and may be caused by high temperatures and impurities in the fuel.

# Anticipating Student Questions

**(answers to questions students might ask in class)**

1. **“The article mentions that when fuel engines are designed to be stoichiometrically balanced, then all reactants would be used up. Then, according to the stoichiometric equation, shouldn’t that prevent the production of the pollutant carbon monoxide (CO)?”** *In theory, yes, this would prevent the production of carbon monoxide. However, the car’s computer does adjust the air/fuel mixture based on driving conditions. For example, when you are driving onto a busy freeway, for safety reasons you will need rapid acceleration causing your engine to respond with a fuel rich burn. During fuel rich burn, there is not enough oxygen present to burn all of the fuel. This results in unburned hydrocarbons and produces carbon monoxide.*
2. **“On the third page of the article, there is a picture of an electric car that is charging. The caption states that the advances in catalytic converters and methods for reducing nitrogen oxide emissions are limiting the pollution that makes it to the tailpipe…. Why would an electric car have a tailpipe if it is not burning fuel?”** *Electric cars don’t have tailpipes because they don’t burn fuel. They would not release water and carbon dioxide.*
3. **“The article mentions that we can expect other fuels to gain a foothold in the car market. But then it states that an idea is to eliminate emissions altogether. Can a car burn fuel without producing emissions?”** *No, all chemical reactions have reactants and end products. So, emissions could not be eliminated.*
4. **“Why would Volkswagen risk an $18 billon fine by tampering with its cars’ exhaust systems?”** To increase sales of their diesel engine cars in the US *Volkswagen was marketing them as low nitrogen oxide emission cars. They tried using selective catalytic reduction technology, but found that expensive because they would have to lease that technology from Mercedes Benz. They also tried using molecular sieves, but found that the filters would clog and considerably decrease fuel economy. They feared the increased costs and decreased fuel economy would reduce sales, so they opted for the defeat device.*

# Activities

**Labs and Demos**

1. **“Ethanol Combustion” demonstration:** While this is written as a student experiment**,** for safety reasons it would be best to do this as a demonstration. It is the basis for the internal combustion engine. The link provides background information, a list of supplies needed, procedure, safety information, and student questions. (<http://dwb5.unl.edu/CHEM/SmallScale/SmallScale-077.html>)
2. **Comparison of heats of combustion of various fuels lab:** Students can do a standard heat of combustion lab to compare different fuels and attempt to relate the heats of combustion to the molecular structure of the fuel. They could use kerosene and butane, for example, or paraffin and ethanol. The American Association of Chemistry Teachers (AACT) has a nice student experiment comparing four different fuels, three alcohols and paraffin, as possible substitutes for gasoline as a fuel for the future. The activity is designed as an inquiry lab for with little actual procedure given. Teams of students must prepare their own method to solve the problem (with teacher supervision, of course). (<https://teachchemistry.org/classroom-resources/evaluating-fuels>; you must be a member of AACT to access the information.)
3. **“Catalytic Oxidation of Acetone by Copper” demonstration:** This demonstration provides visual evidence of what a heterogeneous catalyst does. Directions for performing the demonstration, safety instructions, and the chemical equations are included in the handout. (<https://www.flinnsci.com/globalassets/flinn-scientific/all-free-pdfs/dc91711.pdf>).
4. **“Catalysis of a reaction between sodium thiosulfate and iron(III) nitrate solutions” experiment:** This experiment is from the Royal Society of Chemistry. Students compare the rate of a reaction between sodium thiosulfate and iron(III) nitrate using three transition metal catalysts-copper(II), cobalt(II), or iron(II). Full lab procedure, safety notes, and lab preparation guidelines are provided. (<http://www.rsc.org/learn-chemistry/resource/res00000442/catalysis-of-a-reaction-between-sodium-thiosulfate-and-iron-iii-nitrate-solutions?cmpid=CMP00004764>)
5. **“Lab Problem 2”—“2012 U.S. National Chemistry Olympiad National Exam”:** Students will devise and carry out a method to rank the following substances on their ability to catalyze the decomposition of a 3% hydrogen peroxide solution: iron(III) chloride, yeast and potassium iodide. Students are expected to explain their ranking. A list of materials and chemicals as well as safety guidelines, student answer sheets, notes for preparation of solutions, and targeted student responses are included. (<https://www.acs.org/content/dam/acsorg/education/students/highschool/olympiad/pastexams/2012-usnco-exam-part-iii.pdf?_ga=1.180139556.1010983731.1479489538>)

**Simulations**

1. **“Reactants, Products, and Leftovers”:** This PhET simulation allows students to explore the stoichiometric balance between reactants and identify limiting reactants. Students can also identify the minimum amount of reactants needed for a chemical reaction. There are three chemical reactions to explore: make water, make ammonia, and combust methane. (<https://phet.colorado.edu/en/simulation/reactants-products-and-leftovers>)
2. **“Reactions & Rates”:** This PhET simulation allows students to explore the kinetics of chemical reactions. They can observe reaction rates for both endothermic and exothermic reactions, as well as reactions with different activation energies. They can experiment with how the number of reactant molecules, as well as temperature, affects the rate of a reaction. (<https://phet.colorado.edu/en/simulation/legacy/reactions-and-rates>)

**Media**

1. **Video to explain how a diesel engine works:** This YouTube video (6.19) can be assigned as a homework assignment. It will help students understand how a diesel engine works and describes what happens in each of the four strokes of the internal combustion engine. (<https://www.youtube.com/watch?v=DZt5xU44IfQ>)
2. **Video that compares a diesel engine to a gasoline engine:** This video (4.05) can be assigned after the students view the video on diesel engines. The video compares how the two types of engines work and explains the advantages of each. (<https://www.youtube.com/watch?v=bZUoLo5t7kg>)
3. **An animation—inside a catalytic converter:** This animation (6:16) shows how emission exhaust is converted to water, carbon dioxide and nitrogen inside a catalytic converter. (<https://www.youtube.com/watch?v=W6dIsC_eGBI>)
4. **An animation of BASF’s four way catalytic converter:** This animation (2:53) demonstrates how BASF’s catalytic converter functions. (<https://www.basf.com/en/company/news-and-media/science-around-us/catalytic-converter.html>)

**Lessons and Lesson Plans**

1. **“Particle connections—What’s in a name?”** This POGIL lesson provides the student with a guided inquiry activity using the systematic naming of compounds. This is meant to be a cooperative learning activity. (<http://strippolichemistry.weebly.com/uploads/9/7/8/2/9782140/particle_connections_whats_in_a_name_pogil.pdf>)
2. **“Air Pollution 101”:** At the completion of this cooperative learning activity students will have gained knowledge of the basic sources of air pollution and how it affects health and the environment, and they will be able to form ideas on how the pollutants can be reduced. <http://www.earthday.org/sites/default/files/air_pollution_101_lesson_plan.pdf>

**Projects and Extension Activities**

1. **A debate on new technologies and their environmental impacts:** Student teams research and develop a proposal to decrease the carbon footprint of their city's public transportation system through the use of various new technologies and/or alternative fuels. Students prepare a report that explains why their transportation plan is the best one for their community. Student outcomes are to understand the pros and cons of adopting new technologies to replace existing gasoline-powered vehicles and to describe the environmental impact of alternative fuels. <http://www.pbs.org/wgbh/nova/education/activities/3507_car.html>
2. **A take-home experiment for measuring comparative levels of ozone** <http://www.chemistryland.com/CHM107Lab/Exp03_DetectOzone/OzoneLab/OzoneLab.htm>

# References

**(non-Web-based information sources)**

**The references below can be found on the *ChemMatters* 30-year DVD, which includes all articles
published from the magazine’s inception in October 1983 through April 2013; all available Teacher’s Guides, beginning February 1990; and 12 *ChemMatters* videos. The DVD is available from the American Chemical Society for $42 (or $135 for a site/school license) at this site:** [**http://ww.acs.org/chemmatters**](http://www.acs.org/chemmatters)**. Click on the “Teacher’s Guide” tab to the left, directly under the “*ChemMatters Online"* logo and, on the new page, click on “Get the past 30 Years of *ChemMatters* on DVD!” (the icon on the right of the screen).**

**Selected articles and the complete set of
Teacher’s Guides for all issues from the past three
years are available free online at the same Web site, above. Click on the “Issues” tab just below the logo, *“ChemMatters Online”*.**

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This article discusses the pros and cons of using methanol as a fuel replacement to gasoline, and its potential to reduce air pollution. (Berlfein, J. Alcohol in Your Tank. *ChemMatters*, 1988, *6* (4), pp 10–12)

 There is useful information in this article about how a diesel engine compares to a gasoline engine. (Alper, J. Rudolf’s Diesel Engine. *ChemMatters*, 1990, *8* (4), pp 10–13)

 This article discusses the pollution produced by diesel engines. (Alper, J. Diesel under Pressure. *ChemMatters,* 1991, *9* (1), pp 12–14)

 This 1993 article discusses alternatives to the lead-acid battery needed to produce a practical electric car. (Holtzman, D. Electric Cars. *ChemMatters*, 1993, *11* (2), pp 4–7)

 This experiment allows students to explore how CO2 behaves when released into the atmosphere. (Becker, B. Carbon Dioxide: A Pourable Greenhouse Gas. *ChemMatters*, 2001, *19* (3), pp 10–11)

 This is a nice synopsis on greenhouse gases and global warming. (Herlocker, H. Life in a Greenhouse. *ChemMatters*, 2003, *21* (3), pp 18–21)

 Information about the role of NOx in the production of O3 in the troposphere is included in this article. (Allen, J. Chemistry in Sunlight. *ChemMatters,* 2003, *21* (3), pp 22–24)

The Teacher’s Guide for the October 2003 article above provides much additional information on photochemical smog.

 Read this article to find out how scientists develop mathematical models to predict long term global consequences of air pollutants. (McCue, K. Beefing Up Atmospheric Models. *ChemMatters*, 2003, *21* (3), pp 25–28)

 While this article is about a family that was exposed to high concentrations of carbon monoxide in their home, it describes the blood chemistry of CO poisoning and treatments for CO poisoning. (Graham, T. The Silent Killer. *ChemMatters*, 2005, *23* (1), pp 12–15)

 The Teacher’s Guide for the February 2005 article above provides additional information on the dangers of carbon monoxide poisoning and carbon dioxide in automobile exhaust.

 Biodiesel, an alternative to petroleum diesel, offers safety advantages, is biodegradable and non-toxic, and is renewable. (Kirchhoff, M. Do You Want Biodiesel With That? *ChemMatters*, 2005, *23* (2), pp 7–9)

 The Teacher’s Guide for the February 2005 article above provides additional information on how diesel engines work.

 This article describes the chemical and physical properties of platinum, the precious metal that makes catalytic converters so expensive. (Williard, N. Going for Platinum. *ChemMatters*, 2005, *23* (2), pp 14–16)

 The Teacher’s Guide for the April 2005 article above provides additional information the use of platinum in catalytic converters.

 This article discusses the need for and complexities of global cooperation among scientists, political leaders, diplomats, and industry in solving environmental problems. (Herlocker, H. Clearing the Air: Treaties and Treatments. *ChemMatters*, 2005 *23* (3), pp 14–15)

 While fuel cell technology has improved over the years, this article nicely describes how a fuel cell works and compares hydrogen, methanol, and ethanol as fuels. (Michalovic, M. Beyond Hydrogen: The New Chemistry of Fuel Cells. *ChemMatters*, 2007, *25* (4), pp 17–19)

 For information about a creative and cost effective way to store hydrogen, an alternative fuel to gasoline, read this short article. (Dollemore, D. Atomic Bonding: Energy with Chicken Feathers. *ChemMatters*, 2009, *27* (4), p 4)

 To lessen U.S. dependence on foreign oil and to reduce pollution, American scientists have been researching alternative fuels. One of these new fuels that shows promise is green gasoline. (Schirber, M. Green Gasoline: Fuel from Plants. *ChemMatters*, 2010, *28* (1), pp 13–15)

 This article discusses how capturing CO2 for geological storage may be a way to reduce the concentrations of CO2 in the air. (Vos, S. Cleaning up the Air. *ChemMatters*, 2011, *29* (1), pp 14–15)

 This concise article describes the chemistry of lithium air batteries that are used in electric cars. (Page, P. Electrochemistry: Making Better Electric Cars. *ChemMatters*, 2011, *29* (2), p 4)

 This article discusses the advantages of hydrogen gas over gasoline as an energy source and the problems associated with its production and storage. (Baxter, R. H2GO. *ChemMatters*, 2011, *29* (2), pp 8–9).

 This article describes the chemistry that operates an electric car. (Tinnesand, M. Drivers Start your [Electric] Engines! *ChemMatters*, 2013, *31* (1), pp 14–16)

 This article creatively explains the function of the engine, the catalytic converter, and the exhaust system of a car. (Rohrig, B. Is your car a living thing? *ChemMatters*, 2013, *31* (1), pp 17–19)

 The Teacher’s Guide for the February 2013 article above provides additional information on the chemistry of gasoline, the energy flow in a car, and the oxidation of hydrocarbons.

# Web Sites for Additional Information

**(Web-based information sources)**

**Engine Power**

 This site describes ways to increase the horsepower of a car: <http://www.autoanything.com/performance-parts/increase-horsepower-torque>.

 This site explains the relationship between horsepower and torque: <http://auto.howstuffworks.com/difference-between-torque-and-horsepower.htm>.

**Fuel Economy**

At this government site, you can calculate your car’s total fuel cost during time of ownership: <https://www.fueleconomy.gov/feg/savemoney.shtml>.

 The *New York Times* has current and archived articles and commentaries on automobile fuel efficiency, emission standards, and the latest trends in reducing pollution: <http://www.nytimes.com/topic/subject/fuel-efficiency-gas-mileage>.

The U.S. Department of Energy provides a calculator to compare cars based on MPG, price, body make: <http://www.fueleconomy.gov/feg/findacar.shtml>.

This article describes three problems with fuel economy standards and offers a solution to the problems. (<http://www.economist.com/blogs/freeexchange/2015/07/reducing-carbon-emissions>)

**Pollution**

This tool allows you to compare the CO2 emissions of gasoline, hybrid, and battery powered cars: <http://www.ucsusa.org/clean-vehicles/electric-vehicles/ev-emissions-tool>.

This article highlights factors to consider when comparing electric and gas powered cars. (<https://www.wired.com/2016/03/teslas-electric-cars-might-not-green-think/>)

This article encourages us to consider the full lifecycle analysis of emission when comparing electric vehicles to gasoline powered cars. (<https://www.thezebra.com/insurance-news/2368/why-electric-cars-can-cause-more-pollution-than-gas-cars/>)

The “Tox Town” Web site has information on auto emissions, how the environment can impact human health, and resources for teachers. (<https://toxtown.nlm.nih.gov/>)

**Auto Safety**

This site describes the physics of car crashes: <https://education.ufl.edu/gjones/files/2013/04/teachers_guidePhysics.pdf>.

 This article from *Access Magazine* describes how fuel efficiency regulations can influence safety. (<http://www.accessmagazine.org/articles/fall-2014/fuel-efficiency-standards-greener-cars-safer/>)

 This article mentions the technology used to improve both safety and fuel economy: <http://www.csmonitor.com/2007/0612/p01s04-usgn.html>.

**Catalysis**

This site describes BASF’s 4 way catalytic converter and their ability to reduce NOx and particulate pollution. (<https://www.basf.com/en/company/news-and-media/science-around-us/catalytic-converter.html>)

 This article describes why platinum, palladium, and rhodium are used in catalytic converters. (<http://www.easterncatalytic.com/education/tech-tips/catalyst-basics-platinum-palladium-and-rhodium-%E2%80%93-key-ingredients-that-make-converters-tick/>)

 This site includes a historical overview of catalytic converters, information on current catalytic converters, and future catalytic converter technology. (<http://dev.nsta.org/evwebs/3368/Future%20Breakthroughs/futurebreakthroughs.htm>)

 Because of the high costs of platinum, scientists are researching materials that could replace platinum in catalytic converters. (<http://www.automotive-iq.com/PDFS/Future%20of%20Catalytic%20Converters.pdf>)

 This article explains the theory, operation and testing of catalytic converters. (<http://www.bearriverconverters.com/data/CatOpp.pdf>)

**Defeat Devices**

On January 11, 2017, Volkswagen agreed to pay a $4.3 billion settlement for violating the Clean Air Act and federal prosecutors filed criminal charges against six VW executives. This *New York Times* article describes the charges and explains the software modifications made by VW. (<https://www.nytimes.com/2017/01/11/business/volkswagen-diesel-vw-settlement-charges-criminal.html>)