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!

Pollutants Produced by a Car Engine

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 (N2)** - Air is 78-percent nitrogen gas, and most of this passes right through the car engine.
- **Carbon dioxide (CO2)** - This is one product of combustion. The carbon in the fuel bonds with the oxygen in the air.
- **Water vapor (H2O)** - This is another product of combustion. The hydrogen in the fuel bonds with the oxygen in the air.

**Directions:** Use the passage below and your knowledge of Chemistry to answer questions 1-5.

**How Catalytic Converters Work**

by Karim Nice from How Stuff Works

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!
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 (O₃), a major component of smog.
- Nitrogen oxides (NO and NO₂, together called NOₓ) - 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.

**How Catalytic Converters Reduce Pollution**

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 NOₓ 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).

There are two main types of structures used in catalytic converters -- honeycomb and ceramic beads. Most cars today use a honeycomb structure.

**The Reduction Catalyst**

The reduction catalyst is the first stage of the catalytic converter. It uses platinum and rhodium to help reduce the NOₓ emissions. When an NO or NO₂ 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 O₂. The nitrogen atoms bond with other nitrogen atoms that are also stuck to the catalyst, forming N₂. For example:

\[ 2\text{NO} \rightarrow \text{N}_2 + \text{O}_2 \]

**The Oxidization Catalyst**

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:

\[ 2\text{CO} + \text{O}_2 \rightarrow 2\text{CO}_2 \]

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.

Other Ways to Reduce Pollution
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.