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The Catalytic Converter for Automobile Emissions: A Government-Supported Chemical Invention

After World War II, the United States and much of the Western world faced an environmental crisis that needed immediate attention lest contaminated air would soon harm the health of citizens. Harmful emissions from the production of wartime weaponry and supplies had contaminated the air, and innovative action would be needed to combat this environmental health hazard. In the 1950s, the Engelhard Corporation, a former American Fortune-500 company in New Jersey, began development of a catalytic converter that would be able to convert toxic industrial emissions into safe products by oxidation. At the same time, French engineer Eugene Houdry was working on a chemical method to reduce automotive emissions. Unfortunately, it wasn't until the 1970s when automobile emissions of hydrocarbons and carbon monoxide could be curtailed. By then, the United States government, under President Richard Nixon, had created the Environmental Protection Agency (EPA) to subsidize the science that could improve the environment. Production of the catalytic converter on a mass scale was only possible due to societal demand and government response.

In the 1950s to 1970s, concern for air quality was high amongst both scientists/engineers and average citizens. Reports of heavy air pollution from smog in the Los Angeles area caused worry to many, especially Eugene Houdry. In response to increasing air pollution in the U.S., Houdry started his own company, Oxy-Catalyst, to develop converters for smoke stacks and warehouse fork-lifts. The converters on the fork-lifts reduced hydrocarbon emissions from as much as 480 parts per million (ppm) to a much less potent 65 ppm. Even more impressive was the reduction of carbon monoxide emissions from as much as 11,600 to 65 ppm.

Houdry and other scientists/engineers did not rest at just reducing industrial and commercial emissions. They also had to address the ever-pressing issue of emissions from automobiles. The number of vehicles had drastically increased since the end of World War II due to demand for an amplified standard of living. Scientists and engineers had to design a catalytic converter that could be installed in on-road vehicles, as shown in Figure 1. The converter had to and still must oxidize hydrocarbons and carbon monoxide to benign products.

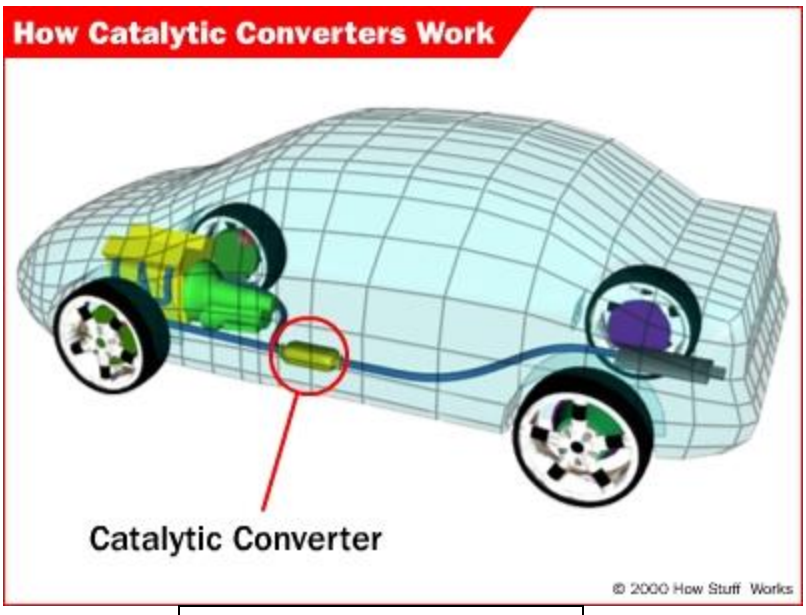

Figure 1: Location of a catalytic converter in an automobile. http://static.ddmcdn.com/gif/catalytic-converter-location.jpg

However, the problem with automotive emissions could not be solely addressed by chemical sciences. The platinum/rhodium catalysts used as oxidizing converters were at risk of being "poisoned" by the widely adopted leaded gasoline (tetraethyl lead) used at the time (~1950s) for fuel in cars and other transportation vehicles. A poisoned catalyst cannot reduce harmful emissions. Tetraethyl lead in gasoline, although capable of increasing octane levels[1] for fuel efficiency and serving as a successful antiknock agent, would have to be drastically decreased and eventually eliminated to achieve cleaner air. In 1973, the EPA passed a reduction standard to slowly phase-out tetraethyl lead in gasoline. By 1986, it was expected to attain only one tenth of a gram per gallon of

[1] Octane level refers to a standard measure of motor performance. A higher octane level/number reflects the highest compression the fuel can withstand before detonating. High compression equates to high performance. For a fuel, octane number 100 means that the fuel performs well as iso-octane.

gasoline of tetraethyl lead, lowered from two to three grams per gallon before legislation was passed. This legislation from the EPA stimulated the first major production of catalytic converters for automobiles.

Although lead was useful for increasing octane levels[2] in gasoline, its negative effect on a catalyst in a converter far outweighed any benefits it could garner toward fuel efficiency. Green technology was becoming a powerful trend in the 1970s for influencing the way chemistry and chemical engineering could and should impact society. Society demanded innovation that would improve air quality. The government responded. By 1995, leaded fuel accounted for only 0.6 percent of total gasoline sales. Effective January 1, 1996, the Clean Air Act banned the sale of the small amount of leaded fuel that was still available for on-road vehicles. In the late 1990s, lead was found only in off-road vehicles like aircraft and racing cars. Science and society were influencing each other to eliminate tetraethyl lead.

From 1975 on, almost all new cars had a built-in catalytic converter. Society and political legislation had stimulated the universal use of the catalytic converter. The EPA was enforcing the installation of catalytic converters through harsh penalties of up to 2500 dollars for not having a converter installed.[3]

By 1981, the older two-way catalytic converter that only oxidized hydrocarbons and carbon monoxide was improved into the currently used three- way catalytic converter, shown in Figure 2. Not only does the three-way catalytic converter perform the two functions of its two-

[2] Without tetraethyl lead, octane levels are still high enough for most automobile engines. Only high compression engines (found in bigger vehicles) will have trouble. Legislation only bans tetraethyl lead in passenger vehicles.
[3] Depending on model, catalytic converters are cheap to replace at around 200-1000 dollars (much less than the EPA fines). Also, converters are small, about 13 inches long and 5 inches wide, allowing easy installation.

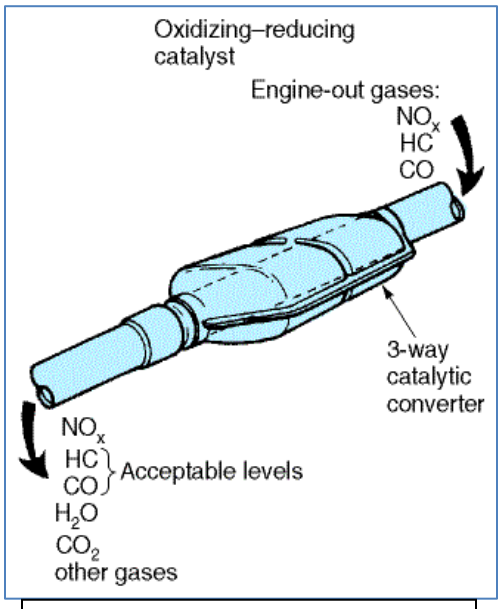

Figure 2: The modern three-way catalytic converter. http://www.enginebasics.com/Engine%20Basics%20Root%20Folder/images/Image12.gif

way counterpart; it can also reduce nitrogen oxides to elemental oxygen and nitrogen.[4] The three-way catalytic converter provided a key advancement for combatting air pollution.

Since the widespread adoption of the three-way catalytic converter, studies have assessed the environmental impacts, both good and bad. Numerous studies ([Sampara et al., 2008], [Wang et al., 2008], and [Zervas, 2008]) show that almost 100% of carbon monoxide is converted to carbon dioxide by a modern catalytic converter, while 90% of hydrocarbons are oxidized to water and carbon dioxide by the same converters. Further, studies ([Johnson, 2008] and [Walker, 2005]) have shown that these converters can reduce nitrogen oxides by 95%. These favorable results assume that the converter is running at optimal temperature 300 – 500 °C[5]. While these temperatures are high and energy-consuming, they give catalytic converters high efficiency.

Without chemical knowledge concerning oxidation and reduction reactions that convert hydrocarbons, carbon monoxide, and nitrogen oxides into benign byproducts, air would be tainted by toxins. Not only would air be smoggy; there would also be serious health repercussions because the air would not be safe to breathe. Bronchitis, asthma and lung cancer result from poor air quality.

[4] Chemical reactions in three-way converter are 1) Reduction of nitrogen oxides to nitrogen and oxygen: $2NO_x \rightarrow xO_2 + N_2$, 2) Oxidation of carbon monoxide to carbon dioxide: $2CO + O_2 \rightarrow 2CO_2$, and 3) Oxidation of hydrocarbons to carbon dioxide and water: $C_xH_{2x+2} + [(3x+1)/2]O_2 \rightarrow xCO_2 + (x+1)H_2O$.

[5] Temperature is maintained by a heating system in the car engine.

Converters must remove the harmful effluent of an engine. Carbon monoxide is an odorless gas that is hard to detect and extremely lethal. Breathing in small amounts can cause death in less than three minutes. Hydrocarbons generate smog in urban areas. They are harmful when breathed in by the lungs. Nitrogen oxides also generate smog, along with acid rain that can damage plants and their ecosystems. Moreover, there are economic gains to catalytic converters: when the air is kept clean, medical expenses decline.

There are some criticisms of the catalytic converter. Oxidation and reduction reactions produce greenhouse gases including carbon dioxide and nitrous oxide (N_2O is formed in a side reaction with nitrogen and oxygen). These gases have been identified by the EPA to accelerate global warming.

Catalytic converters require palladium and platinum. These precious metals, mainly produced in Norilsk, Russia, have led to increases in pollution. Along with pollution, high demand for precious metals is expensive. On balance, the catalytic converter's environmental and health benefits far outweigh any problems it may cause as a side effect. Converters save lives.

The catalytic converter has been a revolutionary invention by chemical technology. While the United States was the first country to embrace cleansing technology, other countries[6] soon followed. Today, most countries use the catalytic converter. Countless lives have been improved while the air has been kept reasonably clean. The catalytic converter's widespread adoption could not have been possible without scientific invention by creative scientists and by

[6] Canada and Chile

society's demand for its application, leading to prompt political action. Clean and healthy air is the result of science coupled with society.

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