



Encyclopedia

Advanced Petroleum-Based Fuels—
Diesel Emissions Control (APBF-DEC) Project

May 2003

NOTE: This encyclopedia defines the acronyms, words, terms, and phrases used in the APBF-DEC project and its predecessor, the Diesel Emissions Control-Sulfur Effects (DECSE) project. Other entries provide background for the project work. APBF-DEC participants are identified by an asterisk (*). Words in the text that are in *italic/bold* type are further defined elsewhere in the encyclopedia, in alphabetical order. The encyclopedia will be updated at regular intervals. If you have updates, corrections, or additions to this encyclopedia, please send them to Helen Latham, APBF-DEC Communications (lathamh@battelle.org; Battelle, 505 King Ave., Columbus, OH 43201-2693; Phone 614-424-4062; Fax 614-424-5601).

***ACC** – American Chemical Council.

Adsorption – The assimilation of a gas or vapor onto a solid surface.

AFDC – Alternative Fuels Data Center, the U.S. Department of Energy's repository for information about alternative fuels, managed by the National Renewable Energy Laboratory (NREL) in Golden, CO (<http://www.afdc.doe.gov>).

After-treatment devices – Advanced after-treatment technologies that can reduce **CO**, **HC**, **NO_x**, and **PM** emissions from diesel engines. (See also *emission control technologies*.)

AFV – Alternative fuel vehicle.

Aging – The process of intentionally accumulating wear on an emission control technology to simulate in-use operation in preparation for testings, either by physical or chemical means.

Alternative fuels – Fuels that can replace ordinary gasoline or diesel fuel. Alternative fuels include electricity, compressed natural gas (CNG), liquefied natural gas (LNG), hydrogen, methanol, ethanol, propane, and *biodiesel*. Alternative fuels may have energy efficiency and pollution reduction features. The 1990 Clean Air Act encourages the development and use of alternative fuels in vehicles.

APBF-DEC – Advanced Petroleum-Based Fuels—Diesel Emissions Control project. APBF-DEC is an industry/government project to identify and evaluate (1) the optimal combinations of low-sulfur diesel fuels, lubricants, diesel engines, and emission control systems to meet projected emission standards for the 2001 to 2010 time period and (2) properties of fuels and vehicle systems that could lead to even lower emissions beyond 2010.

***API** – American Petroleum Institute.

ASTM – American Society for Testing and Materials.

ATL – Automotive Testing Laboratories, the subcontractor located in East Liberty, OH, that conducted Phase I of the APBF-DEC’s lubricants project, researching the effects of *lubricant* composition on emissions and the performance of advanced emission control technologies.

Base fuel – A base fuel containing 0.6-ppm sulfur is being used in the *APBF-DEC* project. The base fuel is being “doped” (see *doping*) to provide other fuels in the tests (i.e., 8-, 15-, and 30-ppm sulfur).

Biodiesel – An alternative fuel made from non-petroleum feedstocks, such as oil seed crops (e.g., soybeans, canola seeds, or other plant- or animal-derived sources), that can be used as is or blended with conventional diesel fuel to reduce emissions without major modifications or significant effects on engine performance.

BPT – Balance point temperature, commonly used to describe the temperature at which the rate of particulate matter generated is equal to the rate of regeneration in a *diesel particle filter*.

BSCO – Brake-specific carbon monoxide (*CO*).

BSFC – Brake-specific fuel consumption.

BSHC – Brake-specific hydrocarbons (*HC*).

BSNO_x – Brake-specific oxides of nitrogen (*NO_x*).

BSPM – Brake-specific particulate matter (*PM*).

C – Celsius

CAFE – Corporate Average Fuel Economy, which was introduced in 1975 to reduce gasoline consumption by requiring auto manufacturers to meet fuel efficiency targets and to produce and promote more efficient models.

***CARB** – California Air Resources Board.

Catalyst – A substance or device that causes or accelerates a chemical change without itself being changed; in the DECSE program, catalysts intended for diesel exhaust were used in four tests (see *particle trap/filter*, *NO_x adsorber*, *lean NO_x catalyst*, and *oxidation catalyst*).

Cetane number (or cetane rating) – The cetane number or rating is used to measure the quality of a diesel fuel. Cetane represents 100 on the reference scale established to measure the ignition quality of diesel fuel on ignition delay. Using a diesel fuel with a higher cetane number may improve cold starting, ignite more quickly, minimizes engine knock, and reduce engine noise.

CI engines – Compression ignition or diesel-cycle engines are used in most heavy vehicles, such as highway trucks, because of their high efficiency and durability compared to spark-ignited gasoline engines. Diesel engines do not use a spark plug to ignite the air-fuel mixture in the combustion chamber.

CIDI – Compression-ignition, direct-injection engines, where fuel is injected directly into each engine cylinder and *NO_x* emissions are reduced. The most efficient CIDI is a diesel engine, which is ignited through the heat of compression. The higher heat resulting from the increased pressure in the combustion chamber makes the air-fuel mixture ignite, thus the *compression-ignition* term. Less fuel is injected into the cylinder, resulting in less throttling losses. (See also *lean burn*.)

CO – Carbon monoxide, a colorless, odorless, poisonous gas produced by the incomplete burning of carbon-based fuels, including gasoline, oil, or wood.

CO₂ – Carbon dioxide, a product of complete combustion of hydrocarbon fuels.

Compression Ignition or CI – A type of ignition that initiates combustion in a diesel engine. The rapid compression of air within the cylinders generates the heat required to ignite the fuel as it is injected.

Control technology/control measures – Systems, equipment, processes or action used to reduce air pollution. The best available control technology/control measure will be required in *nonattainment areas* for **CO**, **NO_x** and **PM**.

CPSI – Cells per square inch.

CRADA – Cooperative Research and Development Agreement, an agreement to conduct research and development activities entered into by a federal agency and a "collaborator," such as a private company, laboratory, or consortium.

CRC – Coordinating Research Council.

Criteria air pollutant – a group of common air pollutants regulated by EPA on the basis of criteria, i.e., information on health and/or environmental effects of pollution. These include CO₂, NO₂, ozone (O₃), lead, PM₁₀, PM_{2.5}, and SO₂.

CVS – Constant volume sampling.

DDC – Detroit Diesel Corporation.

DECSE – Diesel Emissions Control – Sulfur Effects Project. The DECSE project was conducted to determine the impact of fuel sulfur levels on emission control systems, which could be used to lower emissions of NO_x and PM from diesel engines in the years 2002 to 2004. The project was directed by representatives of **DOE**, two of its national laboratories, and manufacturers of diesel engines and exhaust emission control systems. DECSE was the predecessor to the **APBF-DEC** project.

Degreening – Exposing a new emission control device to exhaust gas, to achieve stable operations.

DI – Direct injection engine. (See **CIDI**.)

Diesel engine – An internal-combustion engine that uses the heat of highly compressed air to ignite a spray of fuel introduced after the start of the compression stroke. (Named after Rudolf Diesel [1858-1913], the engine's inventor.)

Diesel fuel – Fuel that can be burned in a *diesel engine*.

Diesel oxidation catalyst (DOC) – Reduces *hydrocarbon*, *carbon monoxide*, and *particulate matter* by oxidation over *catalysts* loaded with precious and base metals.

DME – Dimethyl ether, a derivative of natural gas, is one of the new, synthetic fuels being studied for use in compression ignition engines, such as diesels, to reduce emissions. DME has excellent CIDI fuel characteristics, produces almost no particulates on combustion, and has no offsetting increases in other emissions. But DME is a gas, so there are handling and infrastructure issues. (See also *Fischer-Tropsch fuel* and *new fuels*.)

DOC – See *diesel oxidation catalyst*.

***DOE** – U.S. Department of Energy, the federal agency conducting research on advanced combustion, exhaust after-treatment, and diesel fuel formulations to enable compression ignition or diesel engines to meet emission standards that may be in place beyond 2004. The Advanced Petroleum-Based Fuels project (*APBF-DEC*) is conducted through the DOE Office of FreedomCar and Vehicle Technologies (FCVT). (See the **FreedomCar** listing on page 5.)

Doping – The process of adding to the fuels being tested the proper proportions of other chemicals known to be present in most diesel fuels. For the APBF-DEC and DECSE projects, this process added varying levels of sulfur containing species to the *base fuel*.

DPF – Diesel particle filter, a technology that can remove particulate matter from a diesel engine's exhaust. Using advanced fuel formulations and an **SCR** or a **NO_x adsorber catalyst**, or directly retrofitted to the existing engine, the DPF can reduce regulated, unregulated, and toxic emissions. Several types of DPFs (and SCRs and NO_x adsorbers) are being evaluated in the *APBF-DEC* project.

ECU – Electronic control unit. An engine management technology that controls the functions of all vehicle systems.

EGR – Exhaust gas recirculation system. An emission control strategy that redirects some of the cooled exhaust gases back into the engine, replacing some filtered air. The EGR reduces peak combustion temperatures and can reduce **NO_x** emissions. Proper rate settings are necessary to ensure NO_x reductions without significant effects on **PM**, **HC**, or other gaseous pollutants.

***EMA** – Engine Manufacturers Association.

Emissions – Release of pollutants into the air from a mobile or stationary source, i.e., sources emit pollutants. Mobile sources carry sensors that monitor the function of the **emission control systems (ECS)**. Some large stationary sources of pollutants are required to install continuous emission monitoring systems and to continuously measure the pollutants released.

ECS – Emission control system. Systems that significantly reduce tailpipe emissions of one or more pollutants. For the DECSE and APBF-DEC projects, these technologies were called upon to perform reliably, be durable enough to allow degradation testing, and be economically viable both in cost and fuel economy effects. In general, these systems include control devices for particulate matter and **NO_x**. Particulate matter control devices function with two general types of processes. The first involves oxidation of hydrocarbons in the vapor phase that would later condense or adsorb on particles (see *oxidation catalyst*). The second type removes particulate matter through the principle of filtration (see *particle trap/filter*). NO_x control devices include the *lean-NO_x catalyst* and *NO_x adsorber catalyst*.

EO – Engine-out. This generally refers to the exhaust emitted directly from the engine before it passes through the emission control system.

***EPA** – U.S. Environmental Protection Agency.

EPAct – The Energy Policy Act passed by Congress on October 24, 1992, with the goals of enhancing the nation's energy security and improving environmental quality. The act includes provisions addressing all aspects of energy supply and demand, including energy efficiency, alternative fuels, and renewable energy, as well as more traditional forms of emerging, such as coal, oil, and nuclear power. Several part of the act were designed to encourage the use of

alternative fuels, not derived from petroleum, that could help reduce dependence on imported oil for transportation. For further information go to the DOE Web site (<http://www.ott.doe.gov/epact/>).

EPEFE – European Programme on Emissions, Fuels, and Engine Technologies, which conducted a study of both diesel and gasoline. The purpose of the study was to identify the relationships between fuel properties and engine vehicle technologies to determine the effectiveness of various fuel and vehicle strategies to reduce emissions.

Exhaust – The products of combustion. Diesel exhaust is a complex mixture of many constituents and can have a range of temperatures, pollutant concentrations, and particle sizes. Exhaust emissions will be characterized in terms of criteria pollutants [e.g., particulate matter (**PM**), nitrogen oxide (**NO_x**), hydrocarbons (**HC**), carbon monoxide (**CO**)] and other substances [e.g., sulfur dioxide (**SO₂**), carbon dioxide (**CO₂**), soluble fraction of PM].

Feedstocks – Hydrocarbons and oxygenates that can be used/blended to create a fuel.

FEP – Fuel economy penalty.

FEV – FEV Engine Technology, contractor conducting tests of an exhaust aftertreatment system, one of the three **NO_x adsorber/DPF** tests in the APBF-DEC project.

FLRS – Full-load, rated speed.

FreedomCAR – A government-industry program for the advancement of high-efficiency vehicles, focused on fuel cells and hydrogen produced from renewable energy sources. The FreedomCAR program replaced the Partnership for a New Generation of Vehicles in January 2002. The program's long-range goal is to develop technologies for hydrogen-powered fuel cell cars and trucks that will require no foreign oil and emit no harmful pollutants or greenhouse gases. The C-A-R in FreedomCAR stands for Cooperative Automotive Research, which DOE will carry out in partnership with the U.S. Council of Automotive Research, an organization formed by the Ford Motor Company, General Motors Corp., and DaimlerChrysler Corp.

F-T (Fischer-Tropsch) fuels – Diesel fuels can be made from natural gas or any biomass using a method known as the Fischer-Tropsch process. F-T fuels are liquid, not a gas, at ambient conditions. They have a high cetane number and effectively no sulfur content. In the future, F-T fuels may be economically competitive with current “clean” diesel fuels. They can be used in existing diesel engines, and they can be dispensed by existing infrastructure, i.e., pumps and storage systems used for current diesel fuels.

FTIR – Fourier Transform Infra-red Spectroscopy. An analytical technique used to identify organic (and in some cases inorganic) materials. The FTIR measures the absorption of various infrared light wave lengths by the material being studied. The infrared absorption bands identify the molecular components and structures.

FTP – Federal test procedure, defined by **EPA** to characterize engine or vehicle emissions during transient operation.

g/bhp-hr – Grams per brake horsepower-hour, a brake-specific unit generally used to characterize emissions from heavy-duty engines.

GHG – Greenhouse gas.

Hazardous air pollutants (HAPs) – Chemicals that cause serious health and environmental effects. Health effects include cancer, birth defects, nervous system problems, and death due to

massive accidental releases such as what occurred at the pesticide plant in Bhopal, India. HAPs are released by sources such as chemical plants, dry cleaners, and motor vehicles.

HDE – Heavy-duty engine.

HFRR – High frequency reciprocating rig (ASTM D6079), a device used to measure the *lubricity* of diesel fuel, in which a hardened steel ball oscillates across a steel plate under a fixed load for 75 minutes. The point of contact between the ball and plate is immersed in the sample. The size of the resulting wear scar on the steel ball is a measure of the sample's lubricity.

HSDI – High speed, direct injection engine.

HT –High-temperature.

Hydrocarbon (HC). Any of many organic compounds containing only carbon and hydrogen, such as benzene and methane.

IDI – Indirect injection engine.

L – Liter.

Lean burn – A more efficient engine (either spark-ignition or diesel) that uses more air than fuel, compared to today's engines. Lean burning engines also use less fuel and have lower HC and CO emissions. But the associated catalytic converters have more difficulty reducing NO_x emissions, especially with high sulfur fuels.

Lean-NO_x catalyst (or trap) – A catalyst capable of chemically reducing NO_x to N₂ in the presence of oxygen is called a lean-NO_x catalyst. Such a catalyst would promote a chemical reaction in which NO forms molecular nitrogen and molecular oxygen. It is difficult to find a catalyst for this reaction that is effective under the conditions present in diesel engine exhaust. Lean-NO_x catalysts can be classified as either a base metal or a precious metal. Base metal catalysts include zeolite-type catalysts. The base metal catalysts operate at “high” temperatures of 300-350°C. They offer selective conversion of NO_x to nitrogen and oxygen. However, stability remains a problem; they are susceptible to hydrothermal deactivation of the zeolite. Precious metal catalysts include platinum-based catalysts. They operate at a lower temperature, i.e., 200-300°C, with effectiveness peaking at about 250°C. They are more stable than base metal catalysts, but they can convert NO_x to nitrous oxide (N₂O) and will oxidize SO₂ to sulfate.

Low-sulfur fuel – This fuel is already available in California and other states—as well as in much of Europe and Japan—but most other states in the U.S. use fuel with higher levels of sulfur. Low-sulfur fuel allows advanced emission control devices, especially lean-burn catalysts, to function more effectively. High sulfur levels in fuels reduce the effectiveness and durability of catalytic converters. The U.S. EPA has mandated that fuel containing <15 parts per million sulfur be used starting in June 2006.

LT – Low-temperature.

Lubricants – Engine oil that reduces friction when applied as a surface coating to moving parts. Lubricants typically contain a mineral or synthetic basestock and a blend of additives that extend the oil's life and enhance performance.

Lubricity – A measure of lubricating quality, typically when referring to a fuel. Certain fuel injection equipment components that are lubricated by the fuel can be damaged when fuels with poor lubricity are used. Lubricity is commonly determined by the **HFRR** or **SBOCLE** tests.

***MECA** – Manufacturers of Emission Controls Association.

MOBILE – A comprehensive mobile source emissions model developed and currently being updated by the U.S. Environmental Protection Agency. The model provides average in-use fleet emissions factors for pollutants for different vehicle categories operated under various conditions as specified by the model user.

Mode – In terms of engine test cycles, a mode is an engine operating condition defined by combination of engine speed (rpm) and load (torque).

MPG – Miles per gallon.

MY – Model year.

N₂ – Nitrogen

NAC – See NO_x adsorber catalyst

New fuels – Researchers are developing new fuels and testing ways to adapt existing fuels or chemical compounds for use as fuels to help meet future lower emission standards. An example of an existing fuel being considered is Fischer-Tropsch (**F-T**), named for the two German scientists who invented a method of liquifying natural gas. Examples of chemical compounds that may be adapted for use in engines are biofuels, alcohols, DME (dimethyl ether), DMM (dimethoxymethane), and DOMDME (di-oxymethylene dimethyl ether). Early tests indicate that using these fuels reduces particulates and **NO_x** emissions better than does the reformulated petroleum diesel fuel used in California. One of the issues to be resolved is how to provide the infrastructure so these new fuels can be made available to users. (See also **reformulated fuels**.)

NMHC – Non-methane hydrocarbons. The sum of all hydrocarbon emissions contributing to air pollution except methane.

Noble metal – Any metal or alloy of comparatively high value or relatively superior in certain properties, especially resistance to corrosion or infusibility, such as gold, silver, rhodium, iridium, or platinum.

NO – Nitric oxide. Gas formed by combustion under high temperature and high pressure in an internal combustion engine. NO is a precursor of ground level ozone pollution (O₃), the primary component of smog.

NO₂ – Nitrogen dioxide.

NO_x – Nitrogen oxides. A **criteria air pollutant**. Nitrogen oxide is produced from burning fuels such as gasoline and coal. NO_x along with volatile organic compounds (see VOCs) are the key chemical precursors to the formation of ground-level ozone (O₃), the primary component of smog.

NO_x adsorber catalyst – The NO_x adsorber catalyst is a flow-through exhaust emission control device with the potential to significantly reduce nitrogen oxide (**NO_x**), hydrocarbon (**HC**), and carbon monoxide (**CO**). The adsorber functions by first storing (adsorbing) NO_x and then catalytically reducing the stored NO_x under rich conditions. The NO_x adsorber device does not operate continuously; it cycles between adsorption and reduction. Combined with a **DPF**, the system also can oxidize the diesel particulate matter (**PM**).

***NPRA** –National Petrochemical and Refiners Association.

***NREL** – National Renewable Energy Laboratory in Golden, CO, a DOE national laboratory guiding the APBF-DEC project.

O₂ – Oxygen.

OEM – Original equipment manufacturer.

OICA cycle – Identifier used to designate a test cycle developed during European work. OICA is the acronym for the Organization Internationale des Constructeurs d'Automobiles (International Organization of Motor Vehicle Manufacturers).

ORNL – Oak Ridge National Laboratory, a DOE national laboratory supporting the APBF-DEC project.

Oxidation catalyst – A flow-through emission control device that oxidizes *hydrocarbons*, *carbon monoxide*, and *particulate matter* in a vehicle exhaust over a precious metal catalyst.

OXY or Oxygenates – Oxygen-rich compounds added to vehicle fuels to make them burn more completely, thus significantly reducing unburned *hydrocarbons*, *carbon monoxide*, and other tailpipe emissions. Examples include methyl tertiary butyl ether (MTBE), ethyl tertiary butyl ether (ETBE), ethanol, and biodiesel.

PAH – Polycyclic aromatic hydrocarbons are fine particles often found in engine/vehicle emissions, dust, tobacco smoke, or soil, some of which contain probable human carcinogens.

Particle trap/filter – *Particulate matter* can be removed from exhaust through the use of filters, but to keep the filter operating, it must be “regenerated,” i.e., the particulate matter must be removed from the filter before excessive back-pressure develops. Particle traps include catalyzed soot filters, which contain a filter with a catalyst that promotes oxidation. The catalyst aids in regeneration by lowering the temperature at which ignition of the particulate matter occurs. The catalyst may be applied to the filter, in front of the filter, or it may be applied by adding a substance such as compounds of cerium, platinum, or iron to the fuel. There are also catalyzed soot filters with active generation. These function by adding heat to the filter or changing the operation of the engine to raise the temperature of the exhaust gases.

Particulate matter – Includes dust, soot, and other tiny bits of solid materials that are released into the air. Particulate matter is produced by many sources, including burning hydrocarbon fuels, garbage incinerators, mixing and applying fertilizers and pesticides, steel making, and using fireplaces and woodstoves.

Plasma assisted exhaust emission control devices – These devices use energy in an electrical plasma to encourage the establishment of a new molecular composition to improve the reduction capabilities of lean exhaust emission control devices. This technology is not fully developed. Early results show that it can have a significant impact on NO_x and PM emissions, but that the fuel economy penalty for the energy necessary to power the after-treatment device may be significant.

PM – See *particulate matter*.

PNGV – Partnership for the Next Generation of Vehicles, which was formed in September 1993 between the U.S. Government and the U.S. Council for Automotive Research (*USCAR*). PNGV's purpose was to develop affordable, midsize, family sedans capable of achieving up to 80 miles per gallon with very low emissions, while providing the performance and safety of today's vehicles. PNGV was discontinued in January 2002 and replaced by a new program, the *FreedomCAR* (see FreedomCar on page 5).

Pollutants – Unwanted chemicals or other materials found in the air. Air pollutants can occur as gases or vapors, dust, smoke or soot. Pollutants can harm health, the environment, and property.

PPM – Parts per million.

R&D – Research and development.

Regeneration – Restoring an emission control device to its original condition. For diesel particle filters, this entails removing collected **PM** by oxidation. For catalysts impaired by sulfur-containing compounds (or other species), this means removing those compounds from the catalyst's surface.

Ricardo, Inc. – Test laboratory in Burr Ridge, IL, that is the subcontractor for the heavy-duty **NO_x adsorber/DPF** project.

RPM – Engine speed in revolutions per minute.

SBOCLE – The Scuffing Load Ball on Cylinder Lubricity Evaluator, a test that measures fuel **lubricity** by determining the maximum load that can be applied without causing scuffing. A ball-on-cylinder apparatus immersed in the sample is run under a series of loads to closely bracket the highest non-scuffing load the sample can tolerate.

***SCAQMD** – The South Coast Air Quality Management District.

SCR – Selective catalytic reduction technology, an emission reduction device that, combined with a diesel particle filter (**DPF**) and advanced fuel formulations, has the potential to reduce regulated, unregulated, and toxic emissions. Two types of SCRs and DPFs are being evaluated in the APBF-DEC project.

SI – Spark-ignition.

SOF – Soluble organic fraction of particulate matter. The quantity and composition of SOF depends upon the solvent used to extract the SOF.

SO₂ – Sulfur dioxide.

SO₄ – Sulfate.

Steering Committee & Working Groups – The **APBF-DEC** technology experts, researchers, and decision-makers who represent federal and state agencies; national laboratories; trade and professional organizations; automobile and engine manufacturers; emission control companies; and energy/additives companies.

Sulfur (S) – A naturally occurring element that can become a contaminant of crude oil, lower the activity of catalytic converters, and increase the pollutants emitted.

SUV – Sport-utility vehicle.

SwRI – Southwest Research Institute, subcontractor in San Antonio, TX, conducting two projects: the **SCR/DPF** technologies test and one of the three **NO_x adsorber/DPF** tests in the APBF-DEC project.

TBN – Total base number, a measure of the alkalinity (acid neutralizing capability) of engine oil.

THC – Total hydrocarbons.

TIAX, L.L.C. – A subcontractor for the APBF-DEC project, assessing the potential to develop a *urea* distribution infrastructure to enable the use of the SCR.

TWC – Three-way catalyst.

ULEV – Ultra-low emissions vehicle.

Urea – An aqueous solution that, when heated, can produce ammonia that can react to reduce NO_x to elemental nitrogen in an SCR device.

USCAR – The United States Council for Automotive Research—the umbrella organization of DaimlerChrysler, Ford, and General Motors—was formed in 1992 to further strengthen the technology base of the domestic auto industry through cooperative, pre-competitive research. In 1993 ongoing government research was aligned with USCAR in the Partnership for the New Generation of Vehicles (see *FreedomCAR* and *PNGV*).

VNT – Variable nozzle turbocharger, which helps to produce better torque characteristics at low engine speed while maintaining power at higher revolutions per minute.

VOCs – Volatile organic compounds include gasoline, industrial chemicals such as benzene, solvents such as toluene, and the common dry cleaning solvent tetrachlorethylene. Many VOCs do not occur in nature but were synthesized by chemists in laboratories. Volatile compounds produce vapors and, at room temperature and pressure, vapors can escape easily. VOCs along with NO_x are the key chemical precursors to the formation of ground level ozone (O₃), the primary component of smog.

WWW – Wide World Web.

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