

UNIT V Emission from Automobiles

Introduction to Automobile Emissions

Internal combustion (IC) engines convert chemical energy from fuel into mechanical thermal energy. Ideally, perfect combustion of a hydrocarbon fuel (C_nH_m) with air ($O_2 + N_2$) yields only carbon dioxide (CO_2), water vapor (H_2O), and unreacted nitrogen (N_2).

However, actual combustion inside an engine is imperfect due to transient operations, air-fuel ratio fluctuations, and chemical kinetic limitations. This results in harmful exhaust emissions.

Criteria Pollutants: Formation Mechanisms

A. Carbon Monoxide (CO)

- **Mechanism:** Formed strictly due to incomplete combustion caused by a deficiency of oxygen in the air-fuel mixture.
- **Chemical Nature:** If the mixture is rich (excess fuel), there is insufficient O_2 to convert Carbon (C) fully into CO_2 , halting the reaction midway to CO .
- **Impact:** Toxic gas that binds with blood hemoglobin to form carboxyhemoglobin, reducing oxygen-carrying capacity.

B. Unburnt Hydrocarbons (H_C)

- **Mechanism:** H_C emissions occur due to several distinct engine phenomena:
 1. **Flame Quenching:** As the flame front approaches the cooler metallic cylinder walls, the localized temperature drops, extinguishing the flame before it burns the fuel closest to the wall.
 2. **Crevice Volumes:** Fuel-air mixtures hide in small gaps (like between the piston rings and cylinder wall) where the flame cannot physically propagate.
 3. **Scavenging Loss:** In 2-stroke engines, some fresh air-fuel mixture escapes straight into the exhaust port during the gas exchange phase.

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C. Oxides of Nitrogen (NO_x)

- **Mechanism:** Primarily governed by the **Extended Zeldovich Mechanism**. NO_x (mostly NO and NO_2) is not a byproduct of fuel chemistry, but rather a reaction between atmospheric nitrogen (N_2) and oxygen (O_2).
- **Primary Drivers:**
 1. Extremely high combustion peak temperatures (typically $> 1800 \text{ K}$).
 2. High concentrations of oxygen (lean mixtures).
 3. Adequate residence time at elevated temperatures.

D. Particulate Matter (PM) and Soot

- **Mechanism:** Prevalent in Compression Ignition (CI) engines. Due to heterogeneous combustion, localized pockets within the diesel spray burn with an extremely rich mixture. Liquid fuel drops crack thermally under high temperatures in the absence of oxygen, forming solid carbon spheres (soot nuclei). Polycyclic Aromatic Hydrocarbons (PAHs) agglomerate onto these cores.

Emission & Pollution Standards

Environmental regulatory frameworks force automotive manufacturers to continually innovate to reduce fleet tailpipe emissions.

Indian Standards: Bharat Stage (BS)

India enacted emission norms modeled closely on European guidelines. The timeline shifted dramatically with the leap directly from BS-IV to BS-VI to combat severe urban air quality degradation.

- **BS-IV vs. BS-VI Directives:**
 - **Diesel NO_x Reductions:** BS-VI reduced allowable NO_x emissions for diesel passenger vehicles by nearly 68% (from 250 mg/km to 60 mg/km).
 - **Particulate Matter (PM):** Mandated a drastic reduction in PM mass limits along with the introduction of **PN (Particulate Number)** limits to track ultrafine soot particles.
 - **Fuel Specifications:** Sulfur content was slashed from 50 ppm (BS-IV) down to a maximum of 10 ppm (BS-VI). High sulfur poisons advanced catalytic after-treatment units.

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International Standards: Euro and US EPA

- **Euro Norms (Euro 6 / Euro 7):** Developed by the European Union. Euro 7 focuses heavily on real-world driving emissions (RDE) utilizing Portable Emissions Measurement Systems (PEMS), brake wear particles, and microplastics from tyres.
- **US Standards (EPA & CARB):** The United States Environmental Protection Agency (EPA) along with the California Air Resources Board (CARB) enforce Tier-style regulations. They typically place stricter limits on NO_x emissions for gasoline engines compared to early Euro standards.

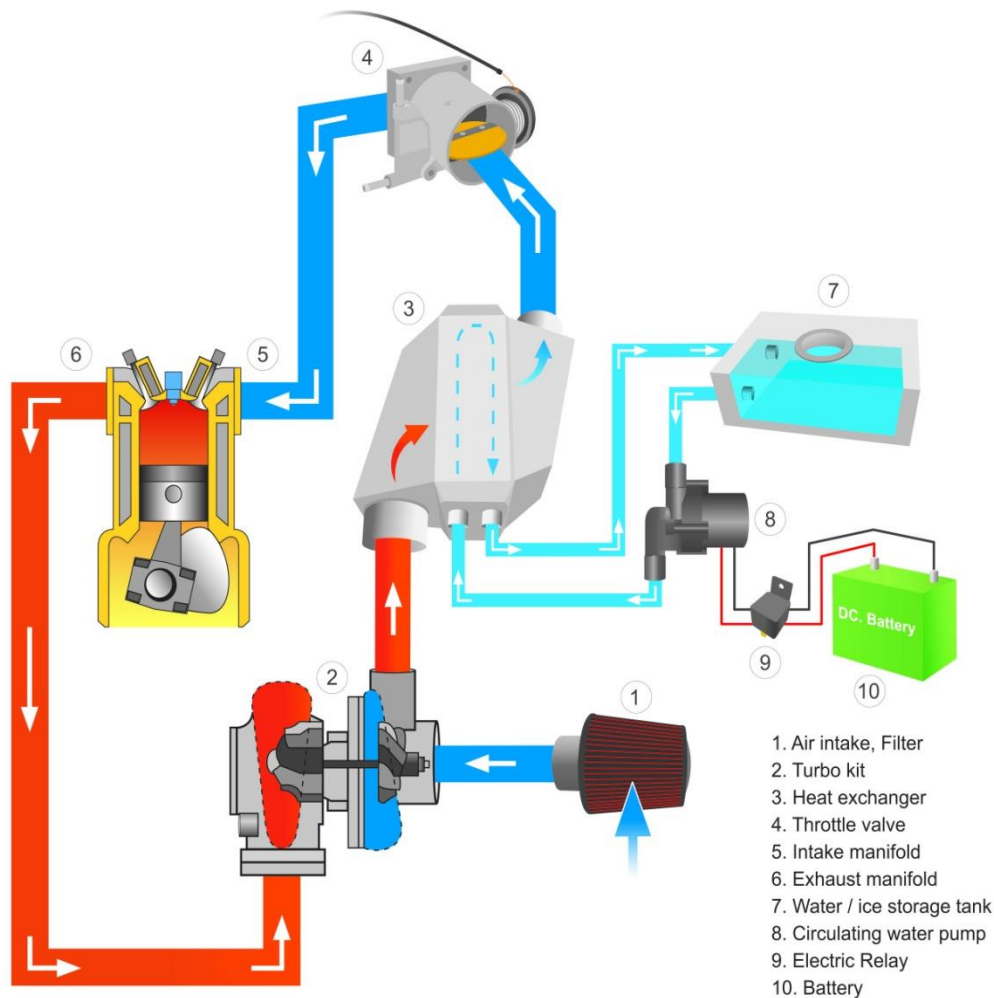
Pollution Control Techniques

To satisfy modern regulatory norms, emission management is broken down into **In-Cylinder Controls** (modifying combustion) and **After-Treatment Systems** (treating exhaust gases).

In-Cylinder Control: Exhaust Gas Recirculation (EGR)

- **Working Principle:** A calibrated fraction of the inert exhaust gas is metered and piped back into the fresh incoming air-to-fuel charge in the intake manifold.
- **Effect on NO_x :** Exhaust gas acts as an inert thermal diluent. It absorbs combustion heat without reacting because it has a high specific heat capacity (due to CO_2 and H_2O content). This directly lowers the peak flame temperature below the threshold of NO_x formation (1800 K).

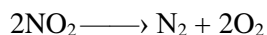
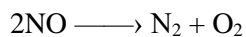
The Air To Water Intercooler System Diagram



After-Treatment: Three-Way Catalytic Converter (TWC)

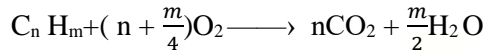
Utilized in Spark Ignition (SI) engines operating strictly at a stoichiometric air-fuel ratio ($\lambda = 1.0$ or $\approx 14.7:1$ by weight for gasoline).

- **Substrate & Materials:** Features a ceramic honeycomb structure coated with an ultra-thin washcoat layer containing precious metals: **Platinum (Pt)**, **Palladium (Pd)**, and **Rhodium (Rh)**.
- **Chemical Reactions:**
 1. **Reduction Catalyst (Rh/Pt):** Converts NO_x into safe nitrogen gas.



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2. **Oxidation Catalyst (Pd/Pt):** Concurrently burns off remaining CO and HC using excess oxygen freed during reduction or residual oxygen.



Diesel After-Treatment: DPF and SCR

Because diesel engines operate with highly lean global mixtures, a standard TWC cannot effectively reduce NO_x. They require dedicated, specialized sub-systems:

- **Diesel Particulate Filter (DPF):** A wall-flow ceramic substrate blocks and traps particulate matter/soot. Over time, soot accumulates and creates exhaust backpressure. The Engine Control Unit (ECU) initiates **Regeneration** by injecting extra fuel post-combustion to elevate exhaust temperatures to $>600^\circ\text{C}$, safely burning off the trapped carbon soot into CO₂.
- **Selective Catalytic Reduction (SCR):** Designed to safely target NO_x in oxygen-rich diesel environments. An aqueous urea solution (commercially branded as **AdBlue**, containing 32.5% chemical urea) is sprayed into the hot exhaust stream ahead of the SCR catalyst block.
 - The heat converts urea into ammonia (NH₃) through pyrolysis and hydrolysis.
 - The ammonia reacts over the catalyst with NO_x to yield pure nitrogen and water:



Advanced Fuel Injection Systems

Optimizing physical fuel droplet size and delivery timing is necessary to minimize engine-out raw emissions before they ever hit the catalytic after-treatment system.

Multi-Point Fuel Injection (MPFI) in SI Engines

Old-style carburetors lacked granular distribution control, sending an uneven air-fuel ratio to different cylinders based on the physical manifold design. MPFI resolves this limitation.

- **System Design:** An electronic fuel injector is positioned inside the intake runner for **each individual cylinder**, targeted directly at the back face of the intake valve.
- **Modes of Operation:**
 - *Sequential MPFI:* Each injector fires independently, timed precisely with its respective cylinder's intake stroke.
 - *Group/Simultaneous MPFI:* Injectors fire in pairs or all at once per crankshaft revolution.
- **Emission Advantages:** By relying on feedback from an exhaust oxygen (λ) sensor, the Engine Control Unit (ECU) dynamically alters the injector pulse width to maintain absolute stoichiometry. This optimization ensures maximum conversion efficiency within the Three-Way Catalytic Converter.

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Common Rail Diesel Injection (CRDI) in CI Engines

Conventional mechanical injection pumps coupled fuel injection pressure directly to engine speed, resulting in poor fuel atomization and high smoke levels at low idle speeds.

- **Working Principle:** A high-pressure fuel radial pump continuously supplies diesel into a heavy-wall central manifold pipe known as the **Common Rail**. This rail acts as a high-pressure accumulator, maintaining diesel under stable pressures ranging from 1500 bar to over 2500 bar regardless of current engine RPM.
- **Component Architecture:** Fast-acting solenoid or **Piezoelectric actuators** control the individual fuel injectors. Because the rail remains continuously pressurized, the ECU can actuate the injector needle multiple times during a single power stroke.
- **Multi-Injection Strategy:**
 1. **Pilot/Pre-injection:** A minuscule fuel volume is introduced just before main ignition. It initiates a soft, controlled flame, preventing a sudden, noisy pressure spike and reducing NO_x creation.
 2. **Main Injection:** Provides the primary fuel volume required to meet torque demands.
 3. **Post-injection:** A tiny burst introduced late in the cycle to raise exhaust gas temperatures for DPF soot regeneration.

Alternative Energy Sources for IC Engines

To break dependence on petroleum oil reserves and minimize carbon footprints, several alternative energy carriers are used or under development.

Gaseous Fuels: CNG and LPG

Compressed Natural Gas (CNG)

Composed predominantly of methane (CH_4). It is compressed to high pressures (200 bar to 250 bar) and stored in heavy structural cylinders.

- **Merits:** High H:C ratio (4:1) results in roughly 25% lower CO_2 greenhouse gas emissions compared to gasoline. It has a high Octane rating (≈ 120), allowing for higher engine compression ratios without knocking.
- **Demerits:** Low volumetric energy density requires bulky, heavy storage onboard, consuming trunk space. It can experience power loss in converted engines due to lower air volume displacement by the gas inside the intake.

Liquefied Petroleum Gas (LPG)

A byproduct of natural gas processing and petroleum refining, consisting of propane (C_3H_8) and butane (C_4H_{10}) mixtures stored under moderate pressures (5 bar to 10 bar).

- **Merits:** Easily liquefied at low pressures, making onboard storage tanks far lighter than CNG cylinders. It mixes thoroughly with air for smooth combustion and lower cold-start emissions.
- **Demerits:** Being heavier than air, leaked LPG pools near the ground or in low structures, presenting a severe fire risk if unvented.

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Liquid Alternative Fuels: Alcohols and Biomass

Alcohols (Ethanol C_2H_5OH & Methanol CH_3OH)

- **Merits:** High latent heat of vaporization cools the incoming air charge, increasing volumetric efficiency. High octane rating allows advanced spark ignition timing. Ethanol can be distilled from domestic agricultural sources (sugarcane, corn), promoting a closed carbon loop.
- **Demerits:** Highly hygroscopic (absorbs water out of the air), which leads to phase separation in fuel tanks. Highly corrosive to standard fuel system components like copper, brass, and rubber seals, requiring specialized lines and zinc/polymer coatings.

Biomass and Biodiesel

Long-chain fatty acid methyl esters (FAME) produced via the **transesterification** of vegetable oils (e.g., Jatropha, waste cooking oil) reacting with methanol.

- **Merits:** High Cetane number makes it an excellent direct substitute or blending agent for fossil diesel. It contains virtually zero sulfur, preventing SO_x emissions, and offers excellent inherent lubricity.
- **Demerits:** High kinematic viscosity makes it prone to fuel filter plugging and fuel injector gumming in cold weather. It also exhibits slightly higher baseline NO_x emissions due to bound molecular oxygen within the fuel chemistry.

Hydrogen (H_2) as a Fuel for IC Engines (H_2ICE)

Hydrogen can be combusted directly inside a modified internal combustion engine, acting as a transition path toward full fuel-cell electrification.

- **Combustion Characteristics:** Extremely wide flammability limits (equivalence ratio $\phi = 0.1$ to 7.1), allowing engines to run on ultra-lean mixtures. It features an incredibly high flame speed, permitting fast, efficient constant-volume combustion.

Merits of H_2ICE

- **Zero Carbon Footprint:** Tailpipe emissions contain no CO , CO_2 , H_2C , or particulate matter, because there is no carbon in the fuel structure.
- **High Gravimetric Energy Density:** Contains 120 MJ/kg of energy—nearly three times that of conventional gasoline.

Demerits of H_2ICE

- **Backfiring and Pre-ignition:** Because hydrogen requires very little ignition energy and has a tiny quenching distance, hot spots on the exhaust valves or spark plugs can ignite the incoming fuel mixture prematurely, causing backfires into the intake manifold.
- **Storage Challenges:** Must be stored as a highly compressed gas at 700 bar or as a cryogenic liquid at $-253^\circ C$. Both methods require specialized, heavy, and expensive onboard infrastructure.

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- **NO_x Generation:** High flame speeds and high temperatures mean that if the engine is run near stoichiometric conditions, it will produce high levels of thermal NO_x . This requires aggressive lean-burn strategy management or water injection.

Solar and Photo-Voltaic (PV) Energy Integration

- **Mechanism:** Solar cells utilize semiconductor wafers (typically silicon) to absorb photons, releasing electrons to generate a Direct Current (DC).
- **Merits:** Zero operational emissions, silent operation, and complete freedom from grid dependency during sunny periods.
- **Demerits:** Extremely low power density. Solar irradiance maxes out at roughly 1000 W/m^2 under peak conditions. A standard sedan roof provides less than 2 m^2 of usable space, generating under 2 kW of power. This is insufficient to propel a standard vehicle at highway speeds, limiting solar integration to charging auxiliary batteries or running cabin ventilation systems.

Standard Vehicle Maintenance Practices

Adhering to strict, preventive maintenance schedules is necessary to keep automotive emissions within certified limits while ensuring long-term mechanical reliability.

Engine Tuning and Diagnostics

- **Spark Plug Service:** Inspecting for electrode erosion and carbon fouling. Incorrect gaps cause misfires, leading to high raw unburnt hydrocarbon (HC) spikes in the exhaust.
- **Ignition Timing Calibration:** Incorrect timing reduces thermal efficiency and increases combustion temperatures, which drives up NO_x emissions.
- **OBD-II Scanning:** Using On-Board Diagnostics to monitor fuel trim codes, oxygen sensor health, and catalyst efficiency parameters before component failures trigger warning lights.

Fluid and Filter Management

- **Engine Oil Replacement:** As engine oil degrades, its viscosity breaks down, causing increased internal friction. Degraded oil can bypass worn piston rings and burn inside the combustion chamber, causing blue smoke and poisoning the catalytic converter.
- **Air Filter Replacement:** Clogged intake air filters restrict incoming airflow. This causes a rich air-fuel mixture in older carbureted engines, which spikes CO and HC emissions. In modern engines, it restricts total power output.
- **Fuel Filter Service:** Clean fuel filters preserve uniform fuel system line pressure, protecting injectors from abrasive wear and ensuring clean, fine fuel atomization.

Chassis and Emission Checks

- **Tyre Pressure Maintenance:** Under-inflated tyres increase a vehicle's rolling resistance. This forces the engine to burn more fuel per kilometer, directly increasing overall CO_2 emissions.
- **PUC (Pollution Under Control) Certification:** Regular tailpipe exhaust analysis using gas analyzers and opacimeters ensures the vehicle operates within acceptable national limits.

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Natural Gas as a Fuel in Automobile;

A natural gas vehicle (NGV) is an alternative fuel vehicle that uses compressed natural gas (CNG) or liquefied natural gas (LNG) as a cleaner alternative to other fossil fuels. Natural gas vehicles should not be confused with vehicles powered by propane(LPG), which is a fuel with a fundamentally different composition. Worldwide, there were 14.8 million natural gas vehicles by 2011, led by Iran with 2.86 million, Pakistan (2.85 million), Argentina (2.07 million), Brazil (1.70 million), and India (1.10 million).

The Asia-Pacific region leads the world with 6.8 million NGVs, followed by Latin America with 4.2 million vehicles. In the Latin American region almost 90% of NGVs have bi-fuel engines, allowing these vehicles to run on either gasoline or CNG. In Pakistan, almost every vehicle converted to (or manufactured for) alternative fuel use typically retains the capability to run on ordinary gasoline. As of 2009, the U.S. had a fleet of 114,270 compressed natural gas (CNG) vehicles, mostly buses; 147,030 vehicles running on liquefied petroleum gas (LPG); and 3,176 vehicles liquefied natural gas (LNG). Other countries where natural gas-powered buses are popular include India, Australia, Argentina, and Germany. In OECD countries there are around 500,000 CNG vehicles. Pakistan's market share of NGVs was 61.1% in 2010, followed by Armenia with 32%, and Bolivia with 20%. The number of NGV refueling stations has also increased, to 18,202 worldwide as of 2010, up 10.2% from the previous year.

Existing gasoline-powered vehicles may be converted to run on CNG or LNG, and can be dedicated (running only on natural gas) or bi-fuel (running on either gasoline or natural gas). Diesel engines for heavy trucks and busses can also be converted and can be dedicated with the addition of new heads containing spark ignition systems, or can be run on a blend of diesel and natural gas, with the primary fuel being natural gas and a small amount of diesel fuel being used

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Liquefied petroleum gas as a Fuel in Automobile;

Liquefied petroleum gas or liquid petroleum gas (LPG or LP gas), also referred to as simply propane or butane,

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is a flammable mixture of hydrocarbon gases used as a fuel in heating appliances, cooking equipment, and vehicles. It is increasingly used as an aerosol propellant and a refrigerant, replacing chlorofluorocarbons in an effort to reduce damage to the ozone layer. When specifically used as a vehicle fuel it is often referred to as auto gas.

Varieties of LPG bought and sold include mixes that are primarily propane (C_3H_8), primarily butane (C_4H_{10}) and, most commonly, mixes including both propane and butane. In winter, the mixes contain more propane, while in summer, they contain more butane. In the United States, primarily two grades of LPG are sold: commercial propane and HD-5. These specifications are published by the Gas Processors Association (GPA) and the American Society of Testing and Materials (ASTM). Propane/butane blends are also listed in these specifications.

Propylene, butylenes and various other hydrocarbons are usually also present in small concentrations. HD-5 limits the amount of propylene that can be placed in LPG to 5%, and is utilized as an autogas specification. A powerful odorant, ethanethiol, is added so that leaks can be detected easily. The international standard is EN 589. In the United States, tetrahydrothiophene (thiophane) or amyl mercaptan are also approved odorants,[5] although neither is currently being utilized.

LPG is prepared by refining petroleum or "wet" natural gas, and is almost entirely derived from fossil fuel sources, being manufactured during the refining of petroleum (crude oil), or extracted from petroleum or natural gas streams as they emerge from the ground. It was first produced in 1910 by Dr. Walter Snelling, and the first commercial products appeared in 1912. It currently provides about 3% of all energy consumed, and burns relatively cleanly with no soot and very few sulfur emissions.

Bio diesel as a Fuel in Automobile;

Biodiesel and conventional diesel vehicles are one in the same. Although light-, medium-, and heavy-duty diesel vehicles are not technically "alternative fuel" vehicles, many are capable of running on biodiesel.

Biodiesel, which is most often used as a blend with regular diesel fuel, can be used in many diesel vehicles

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without any engine modification. The most common biodiesel blend is B20, which is 20% biodiesel and 80% conventional diesel. B5 (5% biodiesel, 95% diesel) is also commonly used in fleets. Before using biodiesel, be sure to check





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